AIRCRAFT ELECTROMAGNETIC VULNERABILITY OPERATIVE MODEL (MOVEA)

Michel Renard, Christophe Migeon - DGA (1)
Fabrice Tristant, Fabien Terrade, Jean Patrick Moreau - Dassault Aviation (2)
Marc Ponçon, Steven Guillet - Eurocopter (3)
Jean Alain Rouquette - Airbus France (4)
Christophe Girard, Nolwenn Gouedard, Arnaud Guena - Thalès Communications (5)
Philippe Lalande, Pierre Laroche - ONERA/DMPH (6)
Jean-Philippe Parmantier, Isabelle Junqua, François Issac, Laurent Guibert - ONERA/DEMR (7)
Richard Perraud, Ivan Revel, Gilles Peres, Jean-Pierre Estienne, Jesus Aspas-Puertolas - EADS IW (8)
Michael Ridel, Sofiane Houhou - Teuchos France (9)

(1) DGA, 7 rue des Mathurins, 92220, Bagneux, France
(2) Dassault Aviation, 78 Quai Marcel Dassault, 92552 St Cloud, France
(3) Eurocopter, Aéroport International Marseille-Provence, 13725 Marignane, France
(4) Airbus France, 316 route de Bayonne, 31300 Toulouse, France
(5) Thales Communications, 160 Bd de Valmy, 92704 Colombes, France
(6) ONERA DMPH, 29 av de la division Leclerc, 92322 Châtillon, France
(7) ONERA DEMR, 2, Av. Edouard Belin, 31055 Toulouse, France
(8) EADS IW, 12 rue Pasteur 92150 Suresnes, France
(9) Teuchos, sub-contractor for Eurocopter and Airbus, 20 ch Laporte 31300 Toulouse, France

The need for optimization in terms of time and costs in specification, development, qualification and through life processes of Aircraft submitted to various electromagnetic environments has led to classify operational and safety objectives into categories ranging from primordial to desirable. In order to quantify safety objectives, a probability of success is allocated for each of them.

For all aircraft manufacturers the current hardening process of aircrafts mainly relies on development tests, normative equipment qualification tests, and aircraft qualification ground tests, repeated for each category of environmental electromagnetic threat. This procedure has several limitations such as the availability of test setting, aircraft and equipment and implies to deal with extensive tests that imperfectly simulate the real stress.

The purpose of the MOVEA - Aircraft Electromagnetic Vulnerability Operative Model - is to optimize this process by enhancing aircraft manufacturers use of modelling with the help of a computer platform dedicated to the computation of the risk of failure for environmental envelopes enacted by certification or for a specific mission flown by an aircraft under electromagnetic environment conditions.

Indeed, this tool is :

- **complete** : starting from aircraft physical and functional descriptions, mission description, electromagnetic environment, the model provides the probability of success for the mission and allows identifying the weak part of the system.
- **global** : the model, thanks to specific modules brought together in the platform, is able to take into account every electromagnetic aspects : HIRF (High Intensity Radiated Fields - from 10kHz to 40GHz), LEMP (Lightning Electro-Magnetic Pulse), EMC (Electro-Magnetic Compatibility), Radio-Electric Compatibility, ESD (Electro-Static Discharge - both external and internal), NEMP (Nuclear Electro-Magnetic Pulse) and TEMPEST.
- **predictive** : all models used and developed consider all physics mechanisms necessary to determine electromagnetic coupling and susceptibility levels on critical systems.
- **operative** : MOVEA is applicable to any aircraft, allowing parametric studies in a reasonable delay.

As an example, the application of the MOVEA methodology to lightning indirect effects would string together the following modules :

1. Environment module : firstly, an environmental lightning database is being consulted in order to determine, for an in-flight military aircraft, the probability of being struck by lightning in the chosen region of the globe. Then, a zoning module is used to determine the attachment (i.e. the possible initial attachment points of the lightning channels on the fuselage). Finally, a sweeping module is launched to simulate the displacement of the lightning arc root due to the motion of the aircraft.
2. Electromagnetic coupling modules : given an adapted description of the aircraft design in terms of aircraft architecture (skin, apertures, equipment location, etc.) and aircraft wiring (bundles, impedances, cut-off connectors, etc), the EM coupling modules are used to compute currents and voltages induced at the equipment interfaces. For lightning purposes, the first step deals with the computation of common mode source generators (either by an inverse method or by 3D computation). Then those sources are applied to the wiring network models in the second step, to assess the constraint undergone by equipment.
3. Equipment descriptive module : the module computes the probability of failure of the equipment when its interfaces are stressed with the pin-to-case Thevenin generators evaluated by the previous EM computing modules. It hinges on a data base that provides, for the given technology the susceptibility threshold.
4. Final Computation : aircraft manufacturers use their own safety fault tree tool based on FHA (Functional Hazard Assessment) in order to compute the probability of a given event under EM environment. This final probability is then compared to the initial value to quantify the aggravating effect of the encountered environment.

MOVEA is therefore a potential support for all aircraft development and lifetime phases :

- **Specification**, with the customer, of the operational performance required for the aircraft to function within a given and statistically defined electromagnetic environment.
  Specification, with the supplier, of customized levels to be applied to equipments and systems.

- **Conception** by virtual prototyping with the estimation and definition of hardening solutions, before assembly.

- **Qualification and certification** of overall electromagnetic hardening of serial aircraft by combination of ground tests and MOVEA simulations.

- **Configuration management**, based on the MOVEA model validated during qualification/certification phase, with complementary simulations.

- **Through Life Support**, for the establishment of the EMC maintenance and assurance plan and in case of evolution of the flight domain, electromagnetic threats, etc.

MOVEA was a five year project that was launched in 2003 by the « Service des Programmes Aéronautiques (SPAé) »part of the French Defence Agency. To ensure that this project would be addressed with the right level of competence, SPAé placed the order to a consortium made of the major French aeronautics manufacturers and laboratories :

- Airbus, Eurocopter and Dassault-Aviation, as aircraft manufacturers
- Thalès Communications, as equipment manufacturer and platform core designer
- ONERA DMPH, for lightning strike phenomenology, lightning database and zoning computation
- ONERA DEMR and EADS IW, for EMC coupling modules development

The project was managed under the leadership of Dassault-Aviation. CEAT, CELAR and CEG, test and expert centers forming part of the DGA (French Defence Agency), have been designed as advisory organizations by SPAé.

1 Introduction

For a given set of mission data, a typical scenario played by MOVEA hinges on various computation modules and follows a top-down analysis principle.

- Environment modules assess the probability for the aircraft to meet the electromagnetic stress during its mission,
- Electromagnetic coupling modules estimate the transients induced at equipment interface, given the previously computed external stress,
- Equipment descriptive module computes the probability of failure of the equipment, given the previously estimated equipment stress.

A bottom-up analysis is then achieved by inserting the probability of failure due to EM environment in the aircraft fault tree and then by determining the impact on the top probability.

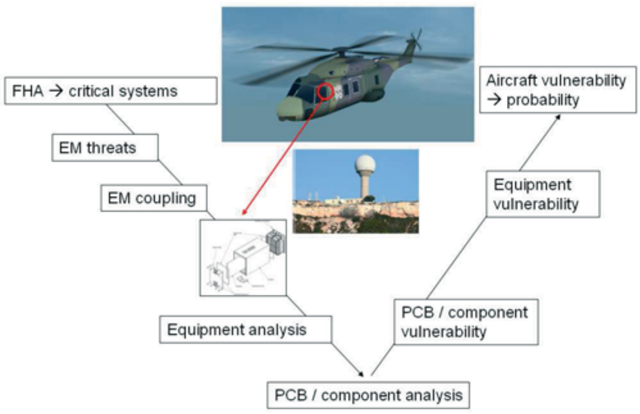

FIG. 1 – Typical scenario played by MOVEA

The demonstration of the predictive and operative characteristics of these modules will be illustrated in the present paper.

2 Environment descriptive modules

2.1 Lightning module

The statistical lightning module developed by ONERA DMPH, hinges on three databases and a probabilistic algorithm :

2.1.1 Lightning environment database

The objective is to compute the probability, for a given mission, to be flying in a zone while a convective cloud reveals an electrical activity. For that purpose, it gathers a database of various satellite measurements achieved over the past 15 years.

As an example, the probability for an aircraft on a Paris-Toulouse flight to meet a storm is displayed below under the shape of a statistical mapping (in red, probability per hour to be stroke by lightning is 5.10^{-4}).

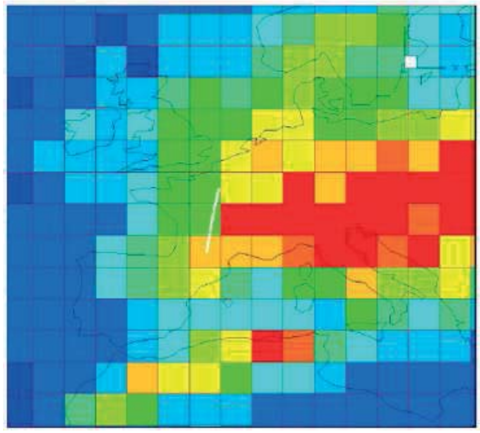

FIG. 2 – Mapping of lightning strike probability in Europe at third semester

A three-month lightning strike statistic is displayed below, for 2500 flight hours.

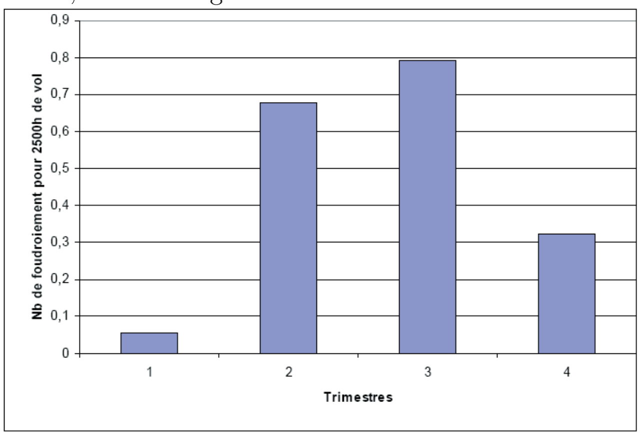

FIG. 3 – Number of lightning strikes for 2500 flight hours - three-monthly representation

2.1.2 Lightning stress database

Transall and Convair flying campaigns measurements have been processed in a database in order to provide a statistical description of lightning strike. MOVEA user selects a given statistical level of protection, for instance 98%. Based on this protection level, the lightning module provides a reference current waveform (burst number and levels, stroke number and peak levels, parameters of waveform, etc.), so that in 98% of cases, the current waveform undergone by the aircraft during its mission remains lower than the reference. Peak current levels extracted from the database turn out comparable to values recommended by certification documents (ED84).

2.1.3 Zoning database

Two models have been developed :

– An attachment model, which describes the lightning initiation phase, and provides in particular input and output points on the aircraft.

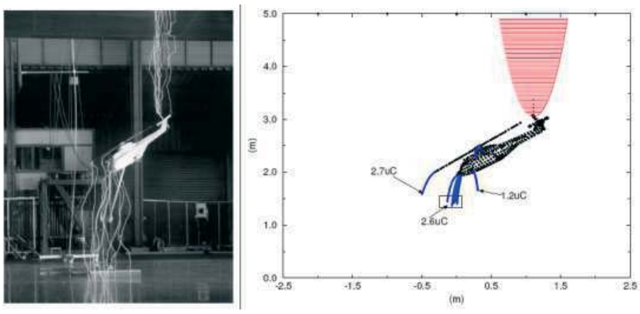

Fig. 4 – Reproduction with Lightning module of empirical attachment achieved on a Super Puma Mock-up in CEAT - FULMEN program

– A sweeping model, which describes, how the discharge foot in contact with the structure moves with the aircraft displacement. In particular, it provides, sweeped points by the arc for each input (output) point.

Both attachment and sweeping modules have been adapted to consider the very particular case of rotary wing, and take into account the successive interceptions of the arc by the blades.

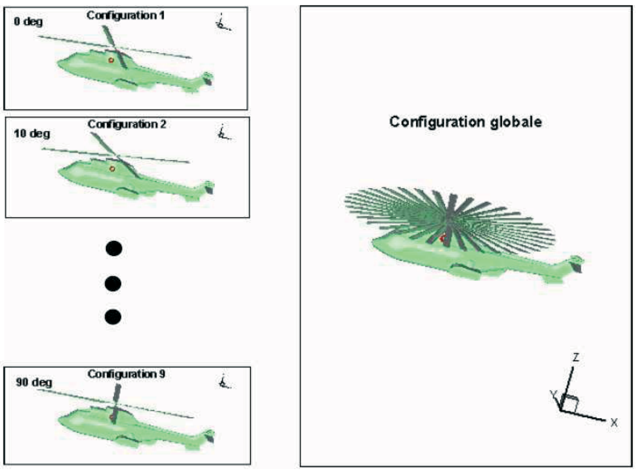

Fig. 5 – Global configuration used for attachment modelling on rotary wing

The Falcon dedicated database generated turns out to include all lightning strikes observed by Dassault Aviation on its Falcon aircrafts family, thus demonstrating the predictive characteristic of the lightning zoning module.

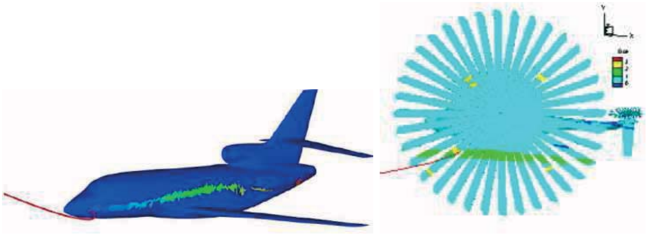

Fig. 6 – Initial attachment of lightning channel and arc displacement on Falcon and Super Puma

2.2 HIRF module

For a given trajectory of the aircraft in an environment comprising one or two high power transmitters, HIRF module developed by EADS IW analyses the electromagnetic threat by :

1. verifying that the aircraft is indeed likely to be lit during its trajectory, considering three-dimensional and kinetic datas (i.e. position and rotation of transmitters, aircraft orientation, speed and trajectory, principal radiating lobe, etc.).
2. for any trajectory segment likely to be stressed, quantifying the field level incident on the aircraft (with application of corrective factor in case of navigation in near field area).

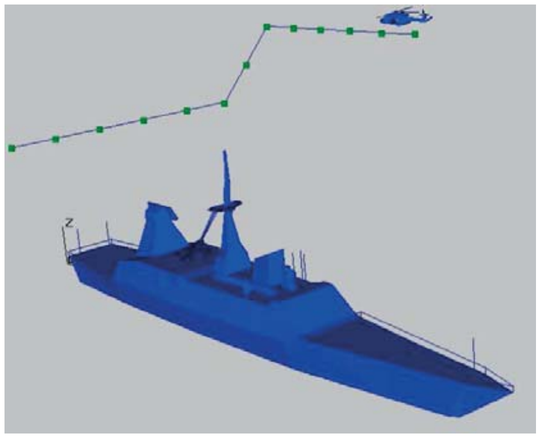

Fig. 7 – Helicopter trajectory segmentation

3. determining the aircraft probability to be lit by transmitters. In case of navigation in a two transmitters environment, the combination of the two stresses is handled at equipment level, where HIRF module provides the probability of combinations (independent stresses, combination based on energy criteria, combination based on amplitude criteria).

Once assessed the aircraft probability to be stressed during its mission, Electromagnetic Modules are used to determine the resulting stress at equipment level.

3 Electromagnetic coupling computational modules

The predictive and operative characteristics of MOVEA electromagnetic coupling modules are hereafter illustrated on the fly-by-wire system of NH90, for low/high frequency stress. Within the frame of a Nuclear Electromagnetic test campaign achieved on NH90 prototype (under a Semi Rhombic Simulator), transients have been measured at the interface of Actuator Control Computer (ACC), on pins which are connected to cables flowing in the cabin (from ACC), in the upperdeck (to main rotor actuators) and in the tail boom (to tail rotor actuator).

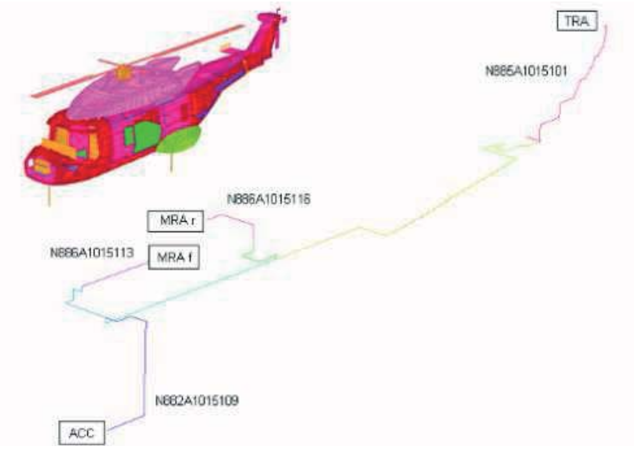

FIG. 8 – Modelling of fly-by-wire harness of NH90

With numerical tools developed by EADS IW (Aseris Software), a predictive analysis of these transients has been carried out. These tools are able to consider all physical mechanisms required for coupling computation on aircraft, i.e. propagation, diffusion (no approximation required on skin depth) and diffraction. This numerical analysis hinges on two steps :

1. Computation of « source terms » : this step consists in computing with Aseris FD (FDTD method), the external stress inside the helicopter and integrating the energy on the overshielded harness. The resulting computed overshielding current flowing on the fly-by-wire harness of interest is used as an input in the second step.
2. Thevenin generators computation : given the source terms and the internal structure of the harness, the resulting Thevenin generators are computed with Aseris 3DNET (transmission line and network method) on the same pins that were measured during test campaign.

3.1 Source terms computation

The test setting used during NH90 test campaign tends to simulate a real NEMP with a grazing planar wave (vertically polarised). In order to dismiss any doubt in relation with the test setting performance (exact reproduction of theoretical NEMP), the whole test setting with helicopter has been modelled with Aseris BE (Boundary Element method).

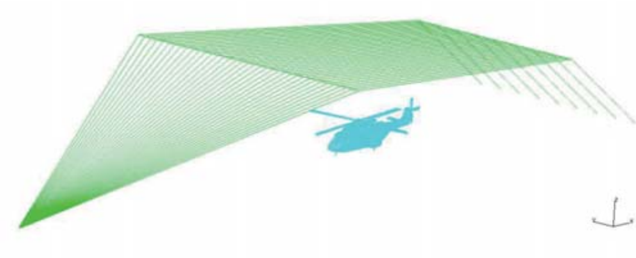

FIG. 9 – Modelling of NH90 and NEMP test setting

Comparison of measured and simulated surfacic fields demonstrate that the test setting is representative of the theoretical planar wave vertically polarised.

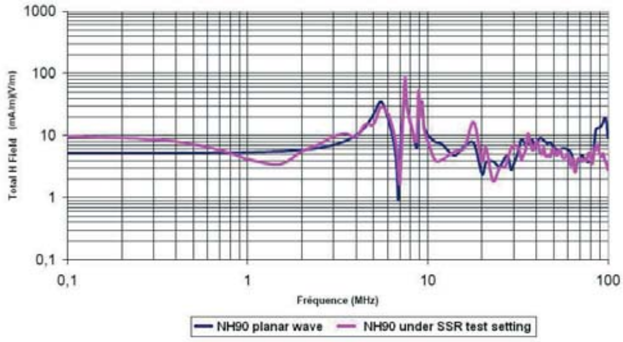

FIG. 10 – Representativeness of test stress to theoretical NEMP

In the following computation steps, the NEMP will then be considered as a planar wave, with no consideration of Semi Rhombic Simulator.
A first estimation of the predictive characteristic of numerical tool is done at the surfacic level of the helicopter.

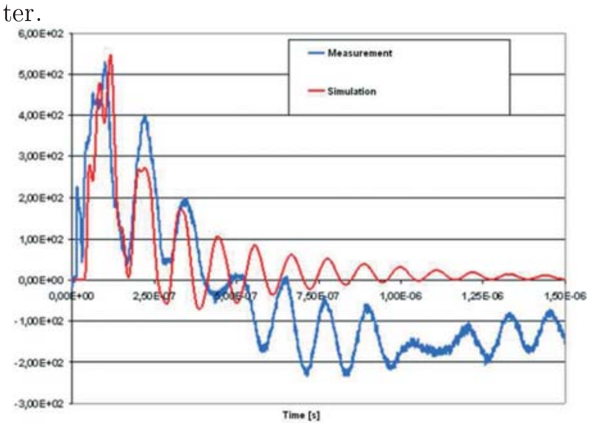

FIG. 11 – Correlation of computed and measured surfacic fields - Tail boom area

Surfacic fields being reproduced with satisfactory accuracy, the source terms are collected all along the discretized overshielded harness.
Local validation is performed by comparison to overshielding current measurements, with probes installed in the cabin and the upperdeck.

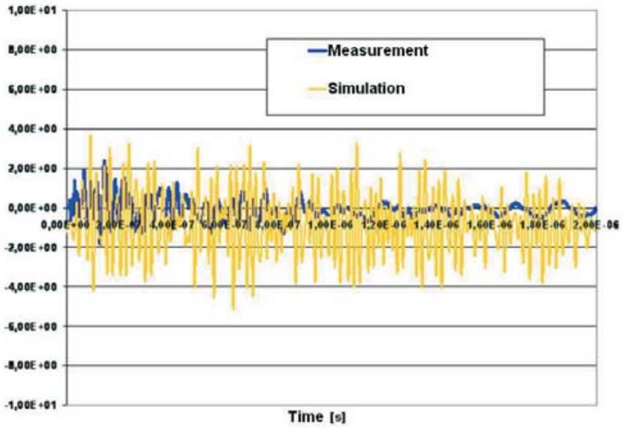

FIG. 12 – Correlation of computed and measured overshielding currents - Cabin area

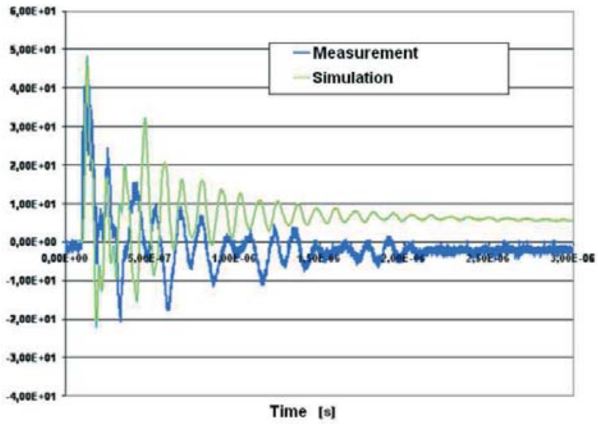

FIG. 13 – Correlation of computed and measured overshielding currents - Upper-deck area

Computed overshielding currents are well correlated to measurements, in both locations of helicopter.

3.2 Thevenin generators computation - comprehensive EADS method

Internal composition of harness (predominantly shielded twisted pairs and a few unshielded pairs and triplets) is then modelled with Aseris NET, taking into account all electrical architecture and physical parameters (transfer impedances of overshielding and shielding, bounding connections, terminal impedances, etc.)
Computed equivalent Thevenin generators at the equipment interface are finally confronted with measurements.

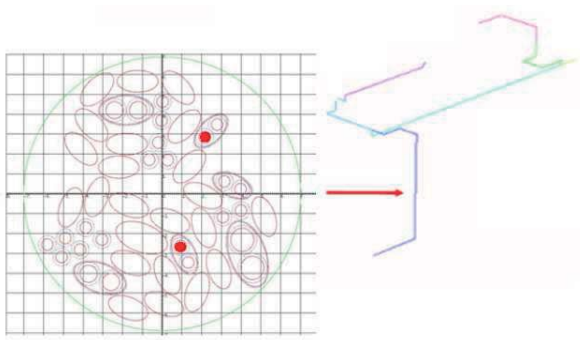

FIG. 14 – Internal harness composition modelling - cabin bundle

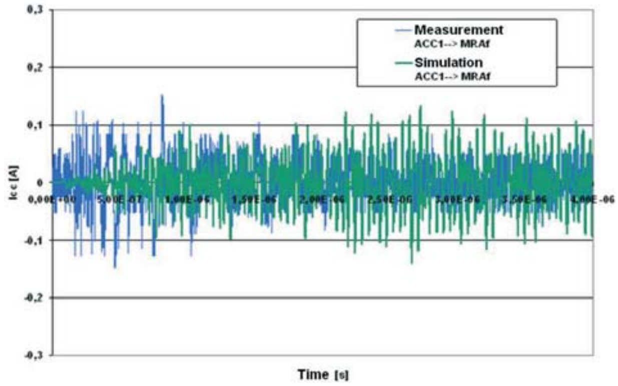

FIG. 15 – Correlation of computed and measured short circuit currents - pin to case (MRAf-ACC)

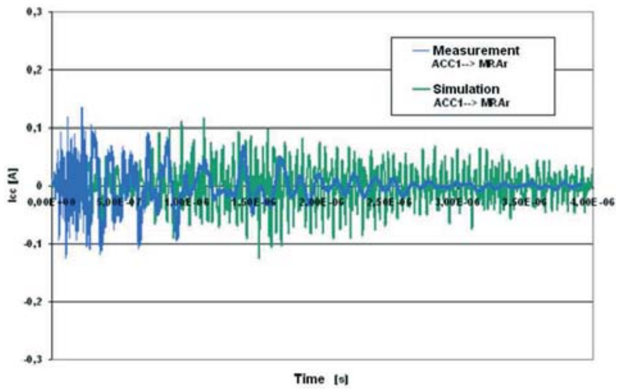

FIG. 16 – Correlation of computed and measured short circuit currents - pin to case (MRAr-ACC)

The displayed short-circuit currents being the outcome of field integration among various and different topological areas of helicopter, the fact that the computed Thevenin generators are well correlated to measurements is an indication of the mastering of overall coupling mechanisms in helicopter. The prediction of constraint at the equipment interface reaches a very satisfactory level of accuracy.
Note : the time lag in displayed curves should not be considered since resulting from a lack of information on time origin measured signal.

On the whole, this correlation to measurement has demonstrated that the EM coupling modules are compliant to MOVEA objectives :

- predictive characteristic : all physical mechanisms are mastered, thus allowing an accurate breakdown of EM constraint (external field, internal field, overshielding current, Thevenin generators) at the entrance of equipment.
- operative characteristic : computing time is consistent with industrial process

3.3 Thevenin generators computation - simplified ONERA method

ONERA DEMR has developed a simplification technique in order to model a complex cable bundle made of a large amount of wires, for instance the NH90 fly-by-wire harness mentioned above. Indeed, the joint combination of a 3D solver and a cable-network solver provides, as demonstrated previously, an effective technique for the assessment of EM coupling on a complex wiring system. However, in several cases (uncertainty of exact position of cables and wires inside the bundle, analysis of former aircrafts deprived of CAD, etc.), the recourse to a simplified technique rather than a deterministic method turns out quite relevant and time-saving in modelling phase. The basic principle of this method (SUITEQ/CRIPTE) consists in the description of the topology of cable bundle in terms of point-to-point cable links and to model these cable-links as equivalent wires in a multiconductor transmission line network model. The simplification technique allows avoiding the following steps :

- deterministic creation of bundle cross section,
- numerical computation of L and C parameters,
- Multiconductor Transmission Line Network,
- distribution of source terms on line, required by MTLN.

On the contrary, it is based on :

- random generation of internal bundle composition thus avoiding any manual operation,
- assessment of primary parameters matrices with help of realistic analytical formulas,
- application of grouping processes and block condensation to reduce networks size,
- coupling estimation on wire of interest based on R, L, C matrices analysis,
- building a single conductor transmission line model for every wire of interest, thus avoiding a network computation on several tubes.

Previous Thevenin generators computed at the interface of NH90 ACC for a NEMP stress with comprehensive method (Aseris software), and compared to measurements, have been generated with ONERA simplification method, provided the same source terms.

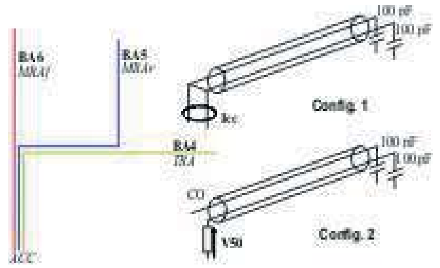

FIG. 17 – The three cable-links of interest of NH90 fly-by-wire harness, and the two configurations of twisted pair cable measurements inside the 3 CLs

The ONERA simplification and EADS comprehensive approaches provide quite similar results in frequency domain but the differences observed logically have some influence on the time domain responses. A satisfactory degree of accuracy is achieved considering that the tests, performed in year 2000, were not fully dedicated to such validation assessments.

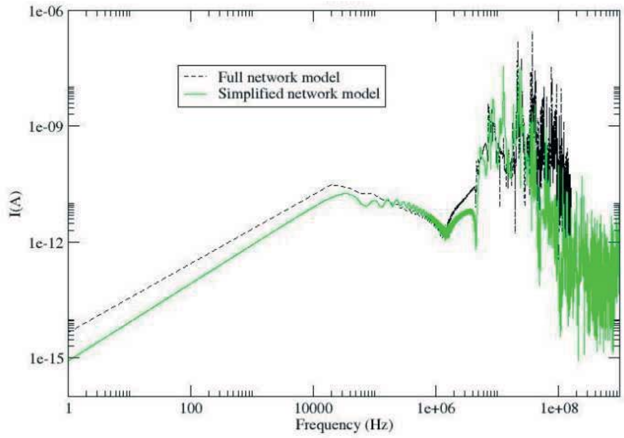

FIG. 18 – Current frequency spectra obtained with the simplification and deterministic approaches - pin to case

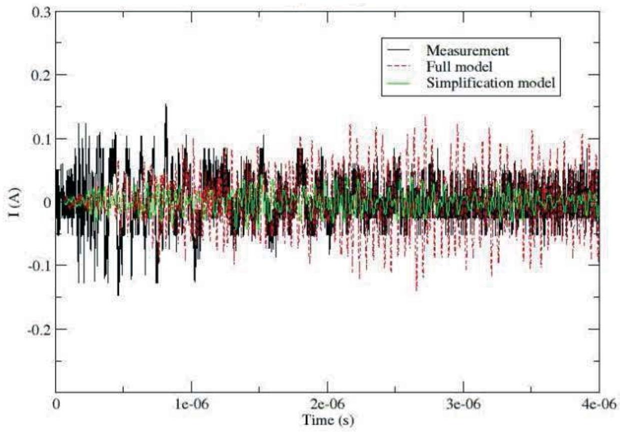

FIG. 19 – Current time domain responses obtained with the simplification and deterministic approaches, compared to measurement - pin to case

For a given external electromagnetic threat, whether having recourse to EADS Aseris comprehensive method or ONERA simplification technique for Low/High Frequency stresses, or using ONERA Power Balance tool (c.f. 4.2.1) for Hyper Frequency stress, MOVEA is able to provide the resulting constraints at the equipment interface with a satisfactory degree of accuracy.

4 Equipment vulnerability module

4.1 Equipment vulnerability model

The Equipment descriptive module, developed by Thalès Communications, provides the probability of failure of the equipment for a given constraint on its interface (electrical field incident on cards, or pin-to-case Thevenin generators evaluated by the previously described EM coupling method). As a result, the methodology of the equipment module is adapted to conducted and/or radiated environments.
As an example, the procedure for a conducted stress is the following :

1. I/O data : pin to case EM coupling data (I and V)
2. a first comparison is performed between Input data and usual norm values applied in equipment test. If the aircraft transient levels are much below the levels applied on equipment, a simplification considers a nil probability of event.
3. the protection assessment models evaluate the perturbation evolution between the connector and the interface of the active components.
4. the failure assessment module at component level : all interfaces are described by a generic electrical schematic. This approach permits to adapt the protection model to the actual design with a possible modification of all components (type and values) and to take into account the impedance of the active component for the failure evaluation. The generic notion of interface lightens the electronic data collection phases performed by the equipment or aircraft manufacturer.
5. the failure assessment model at equipment level : the estimated malfunctions are combined with the fault tree in order to provide the output data : the probability of event at equipment level.

Experimental validations are achieved at different levels (protection, component and equipment failure modes) to demonstrate the capability of the equipment model.

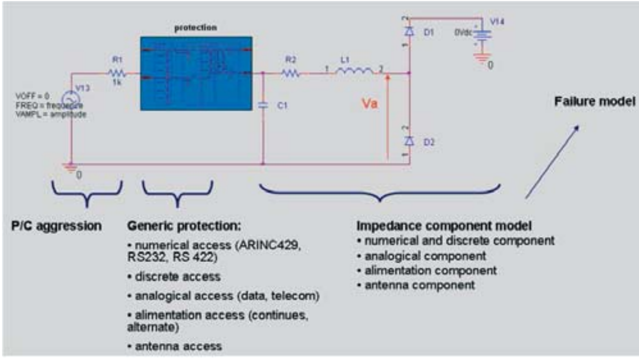

FIG. 20 – Equipment descriptive module

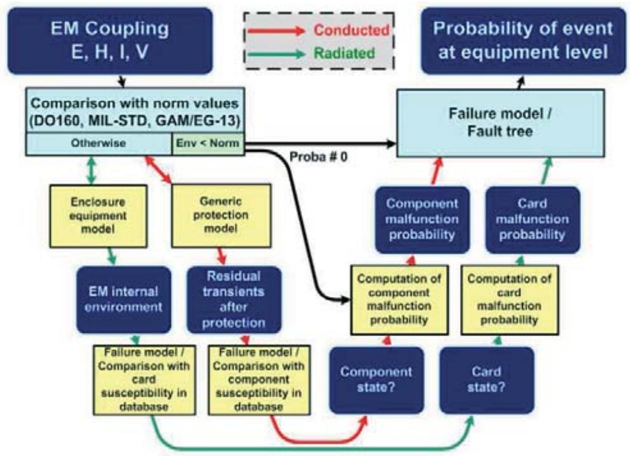

FIG. 21 – Equipment descriptive module principle

4.2 Illustration of equipment vulnerability prediction

A system validation has been achieved to illustrate the predictive characteristic of the MOVEA, by reproducing functional tests results recorded during NH90 HIRF test campaign on NH90 Multi Function Display (MFD). Functional tests have been performed beyond required qualification levels, in fact up to test setting limits, in view of assessing hardening margins. External HIRF stress of cockpit, where are located four MFDs, has led to the following behaviour :

- In CW mode, no malfunction was noticed even until maximum field level applicable,
- In PM mode, few non critical susceptibilities have been recorded for much higher levels than required qualification levels : among the four MFD installed in NH90 cockpit, two first suffered from disturbances (flickering) for the external level « L-2.5 dB », then display loss (extinction) for the external level that we will name « L ».

One asset of MOVEA is precisely the ability to predict the behaviour of such equipment under this type of electromagnetic stress.

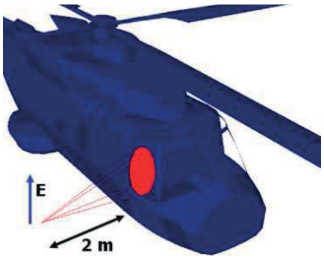

Fig. 22 – HIRF stress of MFD at system level

The principle of the vulnerability analysis achieved hinges on three steps :

1. breakdown of EM constraint until equipment interface (in this specific case, only radiated constraint on cards has been computed, since predominant to conducted constraint),
2. stress of MFD cards model with computed fields, for different levels and frequencies,
3. prediction of unwanted event, depending on external stress level and frequency.

4.2.1 Breakdown of EM radiated constraint with Power Balance

A predictive assessment of the electrical field undergone by MFD cards is carried out with Power Balance.

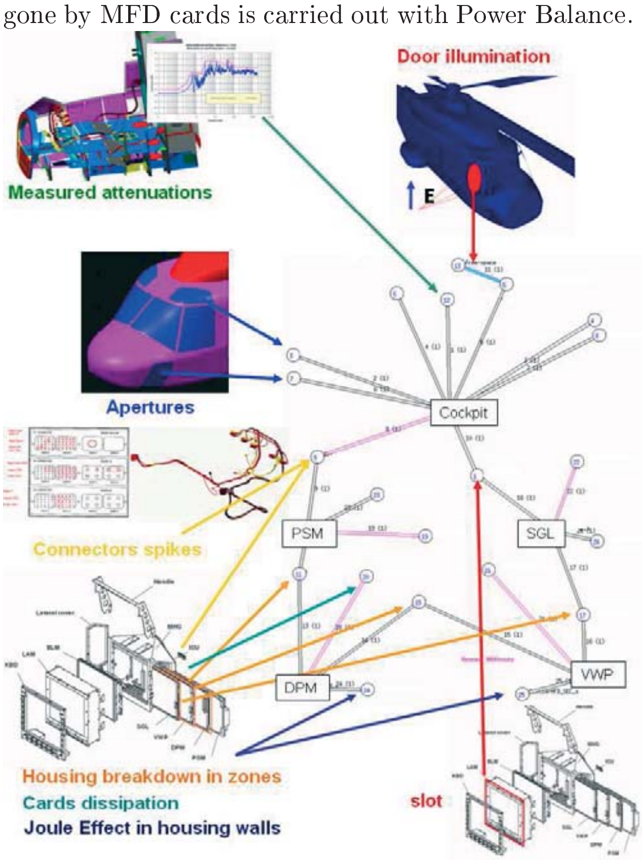

Fig. 23 – Power Balance modelling of MFD HIRF stress

This numerical tool, developed by ONERA DEMR, is based on a statistical approach which allows to compute power density in a given system cavity (tree nodes), provided all energy dissipation and transfer mechanisms (tubes). In particular, the external field applied to the helicopter cockpit can be declined down to the equipment housing in terms of electrical field stressing the cards. These fields are developed inside the housing due to the radiation of backshelf conductors as well as a front slot inherent to the display system.

4.2.2 Vulnerability prediction of MFD equipment card model

Provided the electrical fields in which are immersed each equipment card, as well as their characteristics (type of signal processed, ground plane, max and mean track lengths, etc.), the vulnerability module computes the residual voltage which is then compared to a data base of susceptibility voltage levels. Depending on this confrontation, a failure probability of the equipment for the given stress and frequency is computed.

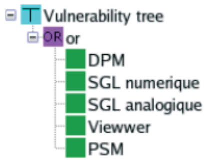

Fig. 24 – Vulnerability tree at equipment level

In CW mode, the vulnerability model has proven to be conservative compared to qualification results and margins assessment. Indeed, for the maximum level applicable, far beyond required qualification level, the model has predicted a failure probability of 30%, when experimentally, no susceptibility has been noticed.

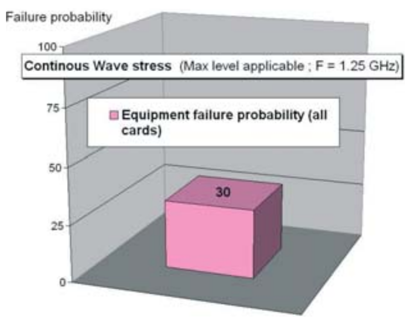

Fig. 25 – Vulnerability prediction for CW HIRF stress

In pulsed mode, the vulnerability model predicts 54% of chance to be subjected to a failure, for a level which is 2dB higher than the experimental susceptibility threshold.

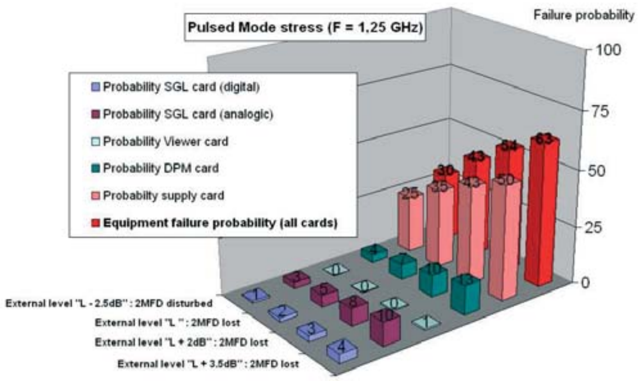

FIG. 26 – Vulnerability prediction for PM HIRF stress

In addition to this satisfactory accuracy, the model points out that the card which prevails in the equipment susceptibility is the power supply card with 43% of failure probability, thus indicating the weakest part of design.

For equipments that, unlike MFD, would turn out susceptible below required qualification level, a hardening indication is provided by model.

In the end, vulnerability model predictions are consistent with qualification demonstration (no failure for required qualification levels) as well as experimental margins (susceptibility thresholds reproduced with acceptable accuracy).

5 Internal Electromagnetic Compatibility Module

As an alternative option to 3D coupling modules which require significant efforts in terms of modelling and computation time, the Internal EMC module developed by EADS IW permits to estimate the order of magnitude of the radiated emission of aircraft cables provided a modest set of information.

Indeed, based on normative CE/RE data or bundle current measurements and a simplified modelling of equipment harness in aircraft, the module successively computes bundle current, then radiation of this bundle current in the desired aircraft location.

A system validation has been carried out on NH90, intending to predict the pollution of a VHF-FM antenna, by the Multi Function Display number 1.

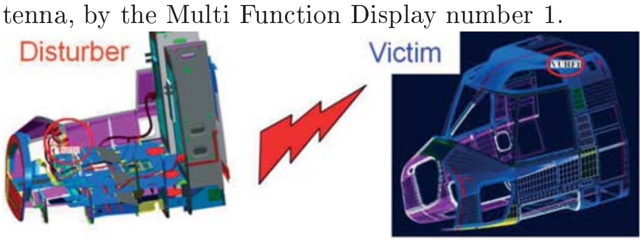

FIG. 27 – Prediction of MFD pollution of VHF/FM antenna on NH90

The MFD cable network flowing in the cockpit floor is made up with three unshielded bundles.

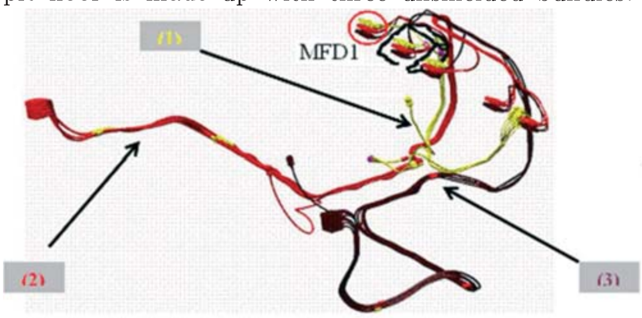

FIG. 28 – MFD harness installation on NH90 cockpit

In perspective of a telegraphist method computation (Aseris NET), the network has been flattened with simplification hypothesis (floor considered as an infinite ground plane, constant height, bundle is modelled by an equivalent cable, etc.)

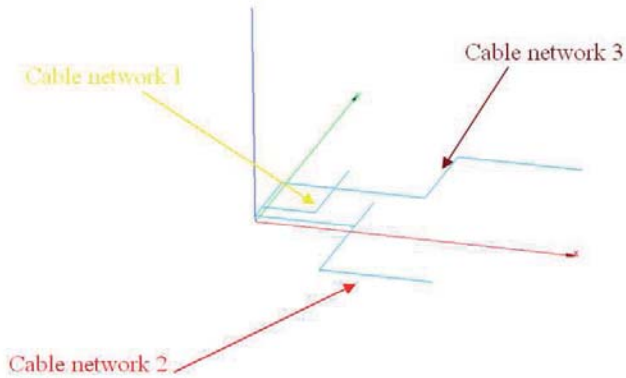

FIG. 29 – Simplified modelling of MFD harness helicopter configuration

The bundle currents measurements are processed in order to determine an equivalent voltage generator, which then allows computing with Aseris NET the current distribution in any location of the bundle. Common mode bundle currents are then radiated to the antenna location (through the near field module of Aseris BE), and compared to measurements (voltage measurements converted in electric field through the antenna factor).

Note : measurements of bundle currents and voltage at antenna foot, achieved in an imperfectly faradized hangar of Eurocopter, have been carried out with equipment ON and OFF to assess the external noise coupling on cable. Current and voltage converted in electric field that are due to noise and not to MFD cable radiation are blackened on graphs. A current resonance is noticeable slightly above 150 MHz.

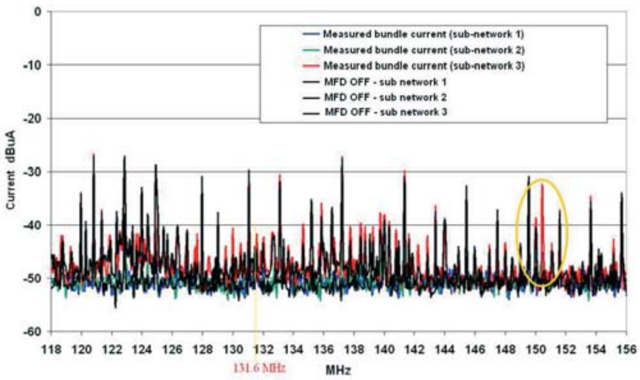

FIG. 30 – Measured currents on three MFD bundles (equipment ON and OFF)

MIL STD 461 standard requirement for equipment radiated emissions is displayed in green. The order of magnitude of the MFD cable network radiation predicted by the MFD cable network is quite well in accordance to the measurement displayed in red.
The latter is characterized by two resonances that are not attributable to environmental noise at 131MHz and 150MHz. If second resonance is clearly a consequence of MFD bundle current radiation, as noticed on previous figure, the model trends to clear the MFD cable network responsibility for the first resonance.
In fact, it is the aperture at screen level of MFD which turns out to be the origin of the disturbance, as illustrated by affixing an aluminium sheet on the front face.

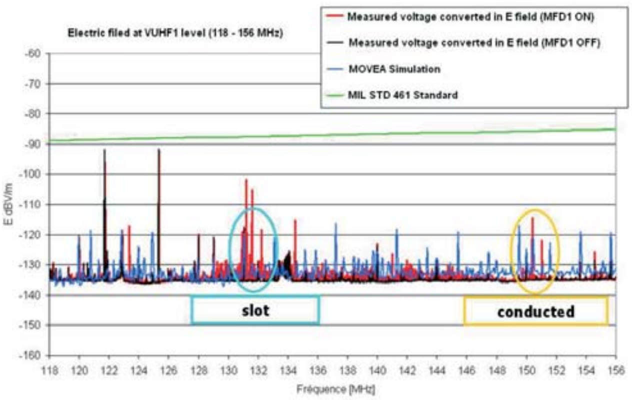

FIG. 31 – Computed and measured (equipment ON and OFF) fields at VHF-FM antenna location

6 MOVEA application - NH90 landing scenario on aircraft carrier

As an illustration of MOVEA approach and the set of modules described above, a realistic scenario is played of an NH90 landing on aircraft carrier involving different HIRF transmitters.

Functional analysis carried out deals with functions in relation with the Actuator Control Computer, which is a sub-system of NH90 fly-by-wire. It is a redundant sub-system, ensuring a quadruple electric control of the three main rotor actuators (MRAf, MRAr, MRAl), as well as the tail rotor actuator (TRA).
Top unwanted event is therefore the failure of the ACC channel A.

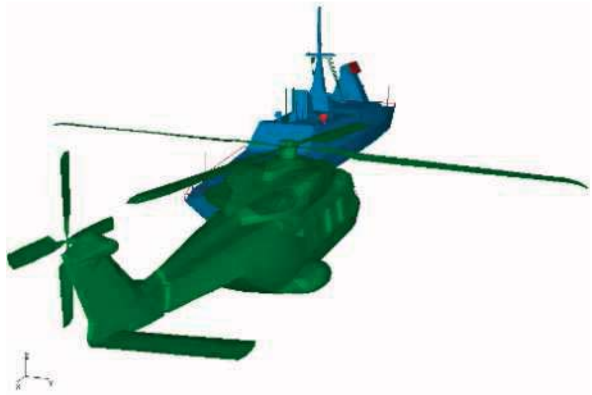

FIG. 32 – NH90 landing on aircraft carrier

6.1 Environment analysis

Two landing phases are considered, each exposing the aircraft to different HIRF threats.
During the crossing phase, the trajectory of the helicopter is such that the system is submitted to a fixed data link beam, and potentially to a rotary surveillance radar beam.
Both transmitters function in Hyper frequency range. HIRF module determines the electric fields level undergone by the aircraft as well as the probability to be submitted to the rotary beam, given 3D and kinetic datas.

FIG. 33 – Crossing phase - influence of rotary surveillance radar and data link transmitter

During landing phase, helicopter is still under the influence of the rotary surveillance radar, but also the omni-directional HF antenna. HIRF module provides the electric field levels applied on NH90, as well as the probability to meet the rotary beam.

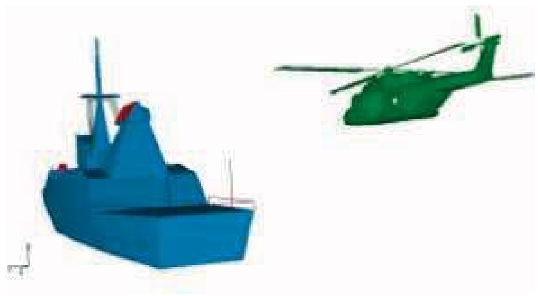

FIG. 34 – Landing phase - influence of rotary surveillance radar and HF antenna

6.2 Electromagnetic coupling

6.2.1 High frequencies stress

EADS comprehensive approach (Aseris FD - 3DNET) is applied to determine the Thevenin generators developed at the interface of ACC due to HF monopole radiation assessed previously at helicopter level.

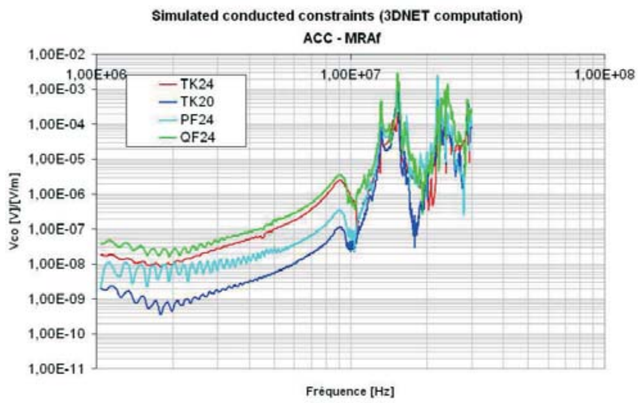

FIG. 35 – Aseris computation of Thevenin generators developed on ACC channel A - pin-to-case level

6.2.2 Hyper frequencies stress

Regarding Hyper frequencies radiations, Onera Power Balance estimates the resulting electric field on the ACC channel A cards, provided the external level at helicopter level. As an example, the constraint breakdown is, for crossing phase, achieved starting from cabin, to cockpit, then backshelf, dirty area of equipment housing and finally clean area of channel A.

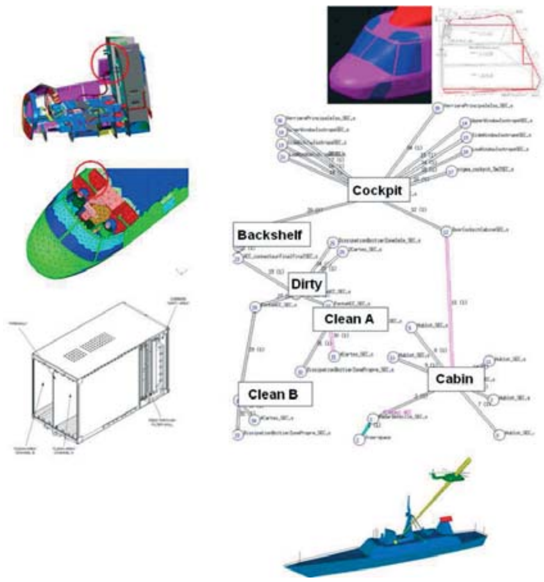

FIG. 36 – Power Balance modelling of scenario

6.3 Equipment modelling

As far as radiated emissions are concerned, other than housing data which processed directly in Power Balance modelling, equipment model is provided with cards data (technology, ground plane, min/max track lengths) . With regard to conducted emissions, computed transients coming from actuators cope with a protection circuit that is described in a Netlist in the equipment descriptive model; grounding and first active component are also inputted. Equipment module suggests a verification criteria based on the observation of several voltage levels. Depending on these comparisons, the model is considered disrupted.

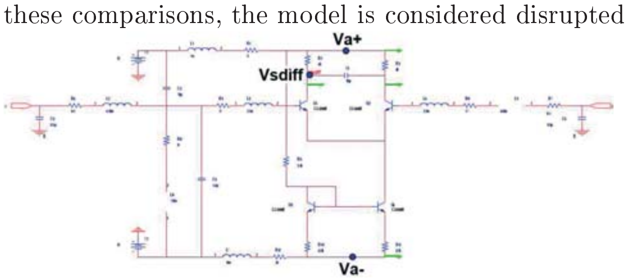

FIG. 37 – Active component and disrupt criteria

6.4 Equipment and aircraft vulnerability prediction

Considering hardening level of fly-by-wire system (fully overshielded bundles, high attenuations attributable to backshelf and excellent ACC housing), the ACC channel A failure probability predicted by MOVEA is 0.

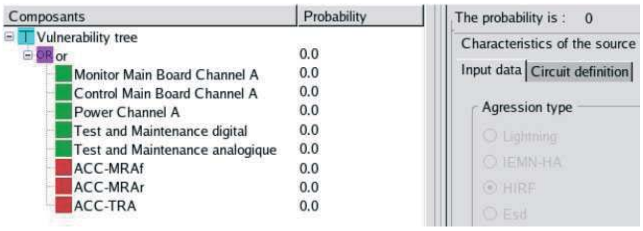

FIG. 38 – Equipment failure probability computation

Consequently, the introduction of this EM failure probability in classical aircraft fault tree is effectless.

7 Additional developments and analysis

All modules developed within the frame of MOVEA project are not recalled in the present paper.
As an evidence of the global and complete characteristics of MOVEA, it is necessary to mention :

7.1 Material Architecture module

Developed by Dassault Aviation, the aim of this module is to provide all EM coupling modules with an adapted description of the aircraft design, with a particular effort focused on wiring data processing.

7.2 IEMN High Altitude Module

This module developed by Thalès Com, defines the electromagnetic parameters (normative waveform, polarization, incidence) of the impulsion with respect to the aircraft orientation and location.

7.3 Electrostatic Discharge module

7.3.1 External ESD module

Developed by EADS IW, this module is based on a global comprehension of charge and discharge mechanisms occurring on aircrafts. It provides a probability of external ESD occurrence in a given area of aircraft, with its electrical characteristics in terms of wave form and level. A satisfactory validation to return on experience has been achieved on an Airbus A320 flight scenario.

7.3.2 Internal ESD module

Developed by Dassault Aviation, this module provides a probability to undergo an internal ESD, given aircraft pipe architecture (section, bounding nature, etc.), flow characterization (pollution and speed) and environment data (pressure, temperature, relative humidity).

7.4 Radio Electric Compatibility Module

Developed by Dassault Aviation, ARTEMIS module allows estimating static and dynamic perturbations of transmitters and receivers via their antennas.

7.5 System test settings

A detailed analysis of aeronautical test settings used by worldwide aircraft manufacturers has been carried out, and points out settings that should be favoured. For small and medium aircrafts (helicopters, offensive and business aircrafts) : coaxial return injection (LEMP, low frequencies HIRF, NEMP) and Reverberation Chamber method for high frequencies HIRF.
For large aircrafts (Airbus family) : ground return injection (LEMP, HIRF low frequency and NEMP) and planar wave illumination for high frequencies HIRF.

8 Conclusion

MOVEA undoubtedly modified the aircraft manufacturers perspective on the possibilities to model electromagnetic hardening. Indeed, if the idea to resort to a virtual aircraft for conception and justification is a long-term will that is shared by most of industrials, the possibility to efficiently introduce EMC has always seemed to be a distant perspective. In five years, MOVEA, by gathering various competences, has brought back this perspective to a much shorter term. Thus, different new programs, as well as revaluation of current ones, will benefit from all or part of achieved advances, and will lie in the scope of a qualifying modelling logic, which feasibility has been demonstrated by the MOVEA project. Moreover, it is needless to say that improvements remain necessary on several aspects, for which it was acknowledged since the very beginning that they made up a major technical challenge. We mainly allude to processes and MOVEA tools harmonization with those of system analysis, equipment vulnerability modelling, and consideration of statistical aspect of handled data.
The authors want to thank all their MOVEA partners, DGA and in particular Mr. Michel Renard for having made possible this publication.

9 References

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