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TITLE: Reduction of Time and Costs for Antennas Integration Through Computational Electromagnetism

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Reduction of Time and Costs for Antennas Integration Through Computational Electromagnetism

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1. INTRODUCTION

Modern combat aircraft increasingly incorporate more and more operational functions.

These functions use a wide range of frequencies over the entire electromagnetic spectrum.

They are essentially related to three functions areas, which are :
- Radar function
- Electromagnetic Countermeasures (ECM)
- Communication - Navigation - Identification (CNI).

Each of these functions calls upon a whole suite of equipment units, to ensure the necessary processing, and of antennas, to ensure the associated radio-electric coverage. Each function has its own antenna, or set of antennas, which, more particularly in the case of the ECM and CNI functions, makes it obvious that :
- such antennas form protuberances, becoming less and less compatible with the aircraft's global performance characteristics (drag, RCS,...)
- the great number of them makes installation, more and more costly.

Also, in the case of the Radar function, the antenna, whether of parabolic, mechanical scan or of active, electronic scan type, is generally positioned on the aircraft forebody, with the consequence that the restricts the obtained coverage and furthermore, wastes a "precious" location which could be profitably used for other functions.

To handle this increasing complexity, new technologies and tools are required which reduce time and cost of the system integration on aircrafts

2. WHAT NEW GENERATION ANTENNAS SHOULD BE

When seeking to remedy these impediments on the performance capabilities of the aircraft and its systems (optronics, air data system,...) by use of new solutions, it becomes obvious that our efforts should be directed towards :

- FEWER ANTENNAS, by use of compatible radioelectric grouping methods, so as to satisfy the needs of the growing number of operational functions, whilst maintaining the number of antennas to be fitted within reasonable limits
    - ⇒ this corresponds to concept of multi-function antennas.

To be noted in this context is - taking the example of CNI functions - that if previous generation aircraft (rougly 20 years ago) often followed the "1 function = 1 antenna" principle, nowadays some degree of function grouping, such as in VHF/UHF/MIDS/TACAN antennas has already been achieved, although the involved dimensions of such blade antennas sometimes prove penalizing for their integration with the aircraft (Fig. 2.1).

- ANTENNAS THAT BETTER CONFORM TO THE STRUCTURE, so as to overcome the drawbacks of the protuberances caused by present-day antennas
    - ⇒ this corresponds to concept of conformal antennas, antennas that fit the aerodynamic shape.

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

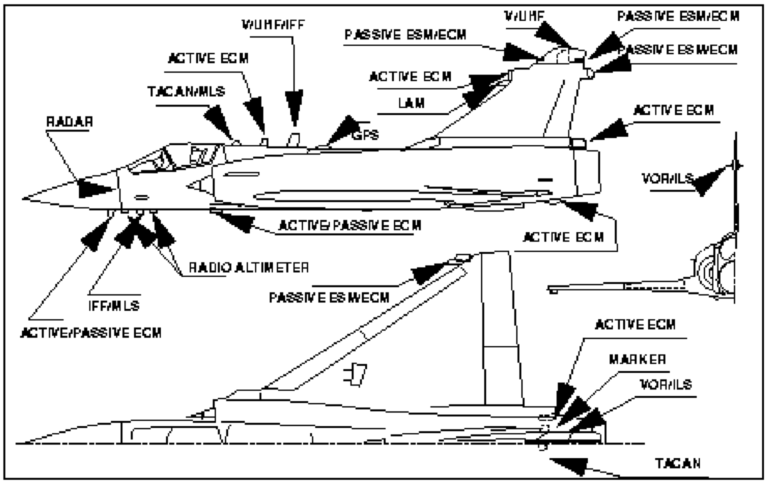

Figure 2.1: Military antennas proliferation

3. OPERATIONAL INTERESTS

Use of such conformal multi-function antennas should contribute towards improving :

- the performance characteristics of the operational functions making use of such antennas
- the global performance capabilities of the aircraft and their systems
- the maintainability/ reliability aspects.

3.1 Operational function-related aspect

Radio-Electric Coverage

Radio-electric coverage improvements may arise from a better distribution of such antennas. The latter are aircraft structure members and, as such, must be able to be fitted to the spine as well as to the leading edge of the wing, to the lower surface of the forward fuselage...

Three aspects amongst these needs for improvement are currently clearly identified :

- coverage of the radar surveillance and IFF interrogation function, to provide for surveillance of an area of a surface larger than what is currently possible
- possibility to ensure, for firing control purposes, radar target tracking and aircraft/ missile links over larger sectors and not, as currently feasible, exclusively limited to the aircraft front sector
- possibility to have larger antenna bases so as to increase the ESM functions accuracy.

Emission control

For most operational functions, it is furthermore desirable to endow such antenna types with a coverage, and hence, scanning adaptativity function which will provide for improvement of discretion during transmission (via direction, beam provision), or even, for protection against jamming during reception (implying, in this case, via antenna milling provision).

Inter-function compatibility

The problems relative to the compatibility between the different operational functions have to be resolved by use of communal, elementary antennas in conjunction with the necessary components, whether radio-electric (multiplexers, filters,... or processing) sequencing (temporal comparability) units.

Here again, two examples may be given ; the compatibilities between radar/ ECM-jammer and IFF interrogator - responder/ MIDS Data Link.

3.2 Aircraft and Systems Global Performance Characteristic Aspect

Aerodynamic Characteristics

Elimination of the current antenna-generated protuberances (essentially in the ECM and CNI function case) will result in less aircraft drag.

Electromagnetic Signature

Use of conformal, multi-function elements, since this would mean fewer antennas, is expected to result in less global aircraft RCS. This will however, require particular care with such new antenna installations. The apparent RCS reduction that would result from the absence of protuberances, must not be cancelled out by new problems which are bound to arise : gaps, impedance disruption at the aircraft/ antenna interface,...

Global Aircraft System Aspect Integration Constraints

Use of conformal antennas spread over the whole aircraft surface is expected to contribute to global improvement of the airborne system.

As an example and as already mentioned, the benefits of replacing the current antennas ensuring the radar function on the aircraft forebody by conformal antennas spread over the aircraft surface would be :

- liberation of installation areas, thus making them available for accommodation of other sensors (optronics, for example)
- new possibilities to improve the aircraft's air data system performance capabilities (today we remove the pitot tube so as not to interfere with the radar performance capabilities).

Maintainability/ Reliability Aspects

Potential benefits for these aspects would be :

- the need of fewer antennae to be integrated with the aircraft and hence, ultimately, of fewer associated maintenance action. To be noted also is that the conformal antenna aspect will also improve their erosion resistance, which again concurs towards reducing maintenance
- to offer the possibility of using the operational functions in degraded modes without, however, in the case of active antennas, complete loss of the involved function. This would arise from the adaptativity notion which would imply the use of a great number of active modules. Failure of the modules may tolerate progressive, although not necessarily total, function degradation.

4. ROLE OF MODELLING TOOLS

Significant progress has been yielded over recent years by both the processors and the software used for electromagnetism modeling numerical simulation plays an increasingly important role which is complementary to that of test means. Measurements are a pre-requisite for identification of the elementary constituents' characteristics, for analyses and for validation of electromagnetic systems. Computations offer essential additional functionality for designing antennas that fit the aircraft.

4.1 Hybrid Methods

The DASSAULT AVIATION developed computation code SPECTRE gathers numerical and asymptotical electromagnetic computation methods. The numerical methods use finite-element field modeling. The latter offer great accuracy and robustness for computations on complex structures composed of different dielectric materials which may be prone to attenuation losses. These methods are, however, limited by the size of the matrix problems that can be handled by the processors. On current computers, it is challenging to conduct numerical method computations on the whole aircraft that exceed the Giga Hertz range.

Asymptotical methods are the numerical methods' natural complement to conduct higher frequency computations. These methods describe the electromagnetic field propagation along the ray traces, by use of analytical reference solutions Fig. 4.1 shows the ray tracing taken into account for the computation of a fraction of the antenna pattern. As asymptotical formulations show serial $1/K^{\alpha+N}$ developments, their validity rather applies to the higher frequencies, but is not suited for geometrical parts which are of small-size, compared to the wavelength.

Such methods require continuous validation efforts. The used validation cases are generic cases.
In order to associate the different methods' respective contributions, the SPECTRE code uses hybrid methods. By combining numerical methods, by means of which are computed the fields in small-size complex areas, with asymptotical methods, which take into account larger areas, a great variety of problems can be solved. An example of the use of these methods is given in Fig 4.2. The computation of a blade antenna placed on a circular plate breaks down into 2 parts :

1. Numerical method modeling of a blade antenna placed on a plane gives the field in even point of its surface of allows definition of electric and magnetic currents equivalent to those of an antenna with respect to electromagnetic emission,
2. Asymptotical method modeling of the equivalent current distribution radiation gives the reflections on the plate ant the scattering by the circular rim, to determine the far field pattern.

These methods although very attractive by their potential capabilities require fully mastery in their employment. The choice of how a problem is to be broken down into different sub-domains according to the different associated computation methods calls upon a physical sense of apprehension of the encountered phenomena.

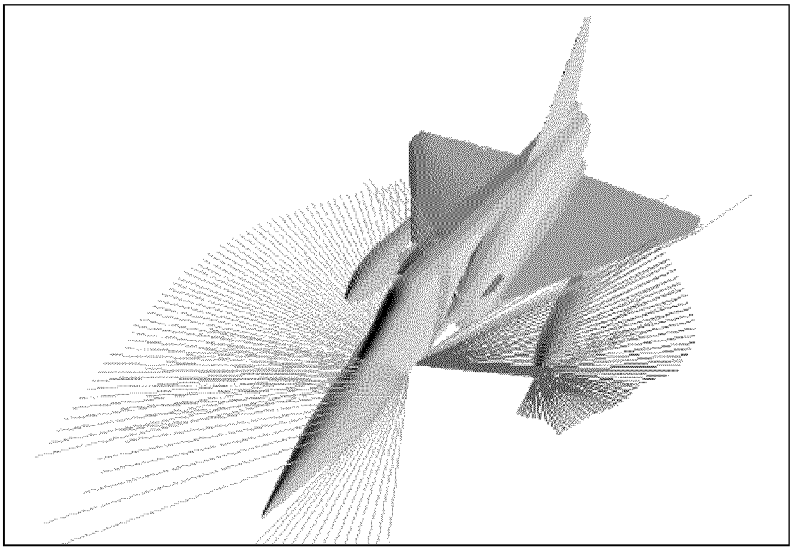

Figure 4.1: Ray Tracing for antenna pattern computation

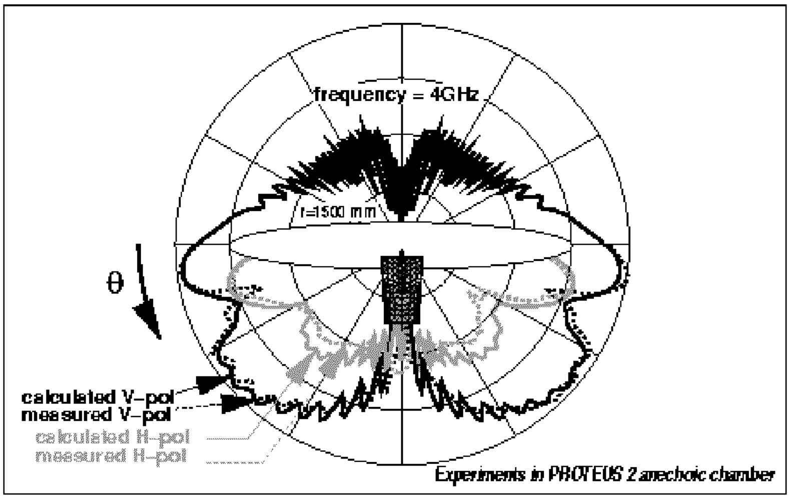

Figure 4.2: Blade antenna on a circular plate, comparison of numerical and experimental patterns,

4.2 Optimization of Antenna Locations

Determining preferred antenna locations is a task becoming increasingly complex on account of the number of antennas and the number of constraints that come into play. From the radioelectrical point of view, such optimization must take into account the sought coverage pattern, as well as the compatibility between the different equipment such optimization must also account for the thermal and chemical aeromechanical environment constraints, notably with respect to structure deflections liable to reach amplitudes that risk jeopardizing the systems' performance capabilities.

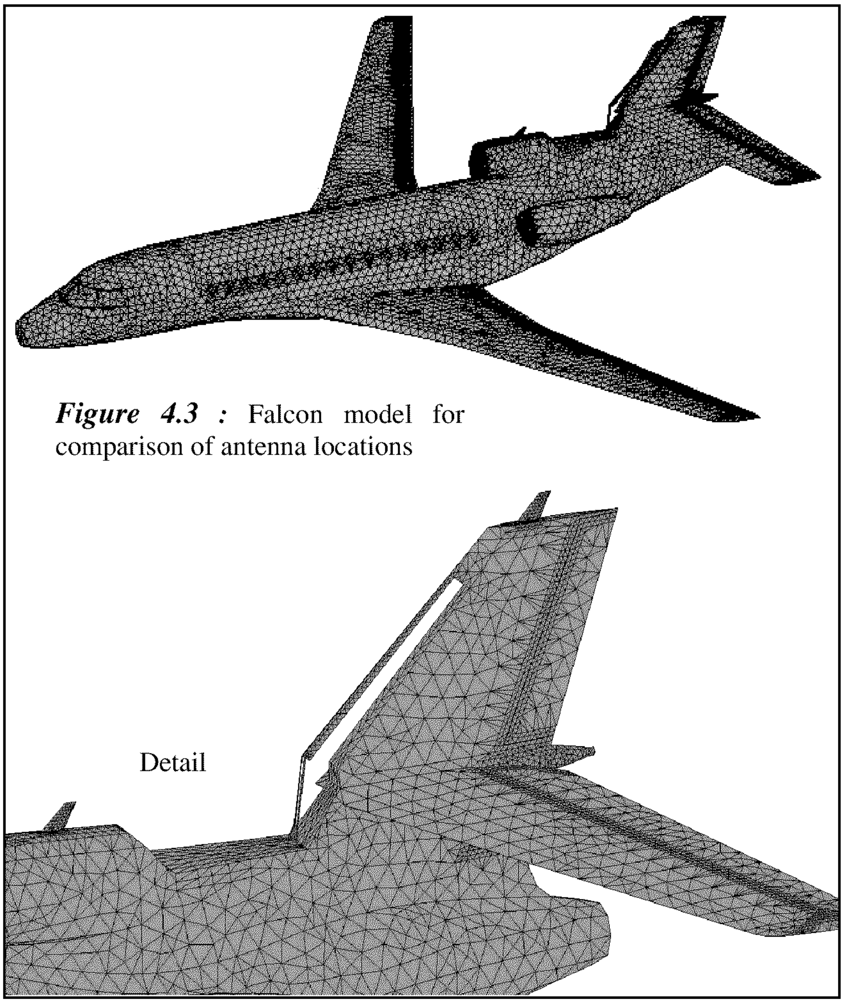

Figure 4.3 : Falcon model for comparison of antenna locations

4.3 Antenna Field Isolation

With the near field computations can be obtained the impedance inputs and the mutual impedance between antennas. The computations require detailed modeling of the geometry around the excitation accesses, together with a precise description of the dielectric materials.

The elementary result leads to the coupling power between 2 antennas. For more global analysis can be represented in each point of the surface, the coupling level vis-à-vis one antenna of a given type. A presentation example is given in Fig. 4.4, showing the coupling vis-à-vis an antenna fitted to the fuselage upper surface.

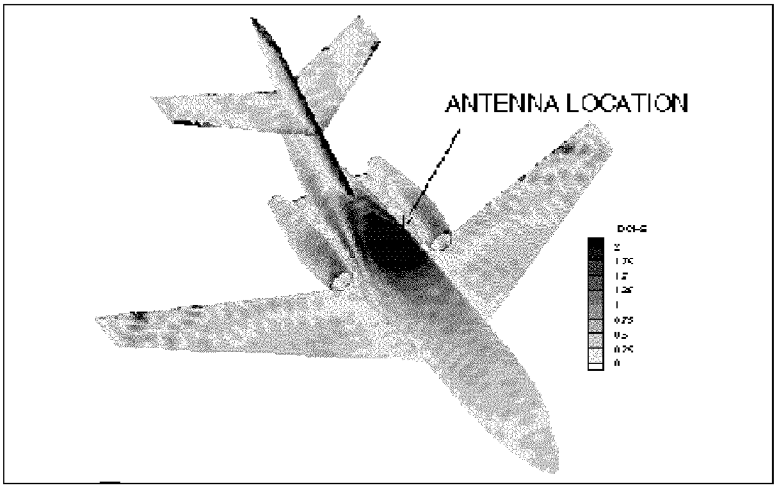

Figure 4.4: Mutual coupling with an antenna in a dorsal location

4.4 Designing Electromagnetic Windows

Radome designing has to take into account a great number of constraints :

- aeromechanical environment (vibrations, deflections)
- thermal and chemical environment
- low observability (radar and improved)
- radioelectric transparency in the used frequency bandwidths.

Electromagnetic computations are used to determine the geometry and materials that offer on acceptable compromise. Fig. 4.5 shows an S-band transparent leading edge structure that allows integration of radiating elements.

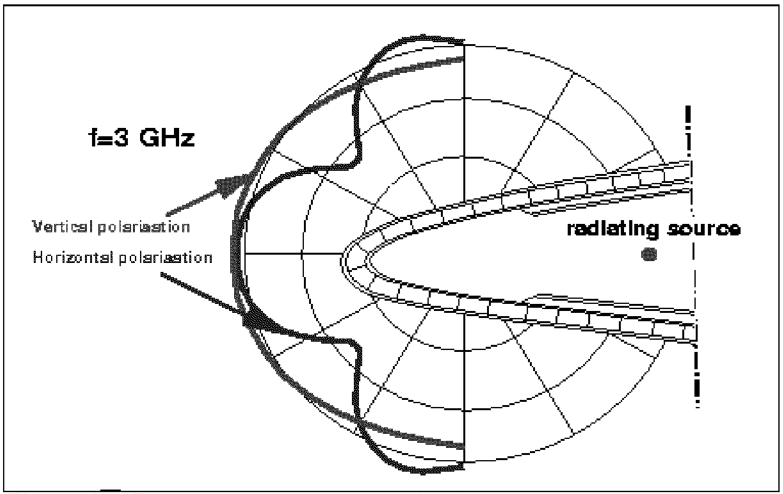

Figure 4.5: Radiation pattern across a leading edge radome

On account of the discretion related constraints, the radom transmission bandwidths have to be limited to those of the used frequencies V/UHF antennas, for example, have RCS of considerable levels. One solution consists in using a radome whose transmission bandwidth is limited to frequencies of less than 1 GHz, with low transmission above such levels.

This characteristic property can be achieved by certain frequency-selective surfaces (FSS) Fig. 4.6 shows the transmission factor, via FSS composed of 3, very dense, cross dipole or tripole type layers. This allows to achieve low transmission factors between 5 and 20 GHz.

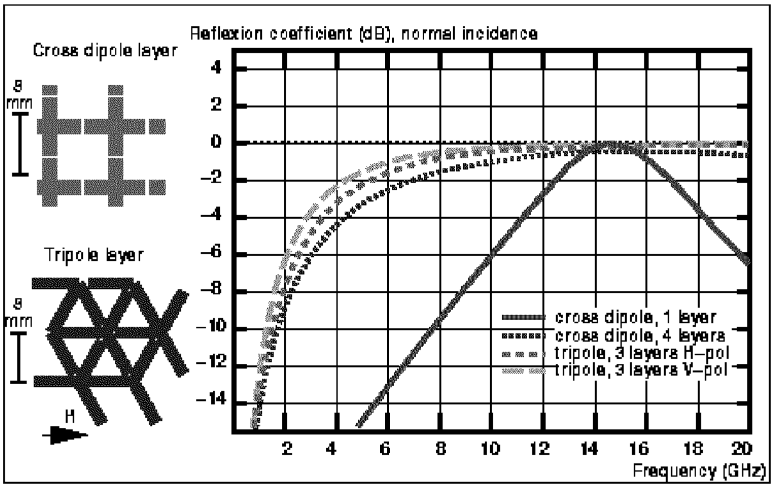

Figure 4.6: Reflectivity of frequency selective surfaces, normal incidence comparison of three different configurations.

5. AEROELASTICITY

Some sensor which are sensitive to phase shift are affected by deflections of the aircraft structure. The analysis of this aerodynamic – structure – electromagnetism coupling is not tractable by ground tests. Multi physics simulations are used to rank the main parameters affecting the system performance, and to develop sensor algorithms robust to these deflections. Fig 5.1 shows the synoptic of such a coupled simulation

Such simulation requires a electromagnetic computation at each time step, on the deflected geometry of the aircraft. Asymptotical methods are well suited because they model accurately the main electromagnetic effects, and their computational time is not affected by the geometrical deflections.

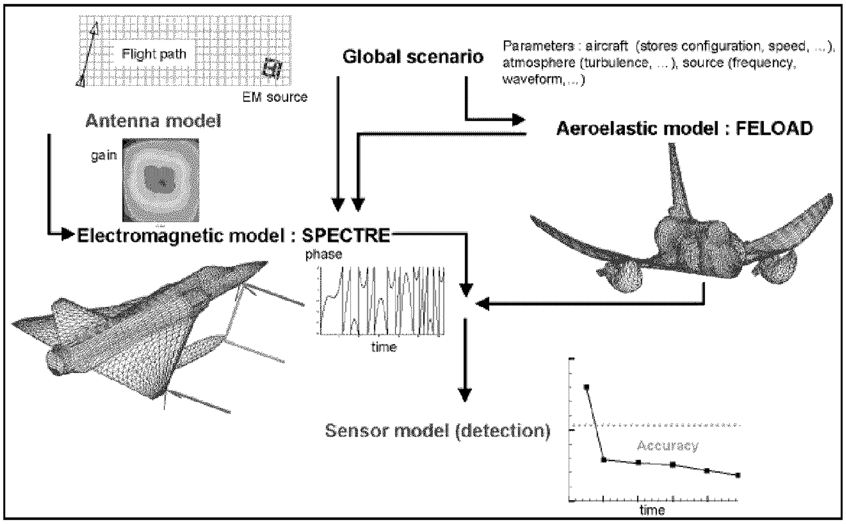

Figure 5.1 : Multi-physics simulation for a wing mounted antenna

6. NEW TRENDS (1) : COLLABORATIVE SIMULATIONS

The before mentioned modeling tools provide for the use of new methodologies to determine the locations of antennas aboard the aircraft the object is to bring into play an equipment model and an aircraft model so as to derive, as early as possible, the behavior of antennas that are to be integrated with the aircraft.

The **equipment model** accurately represents the antenna (power supply, shapes, material...) and gives the radiated fields on a fictitious surface area around the antenna, the lather being fitted to a locally representative surface of the aircraft shape (typically, over a few tens of centimeters).

The aircraft model gives a fine-grid representation of what is fictitious interface surface-external and indicates the electric currents on this electrically bonded surface for each incidence direction.

The reciprocity principle, the date of the two models (fields and currents) can be simply connected on the interface surface and thus give the radiated far field, where :

- $E^{\alpha}(x)$ is the equipment model's electric fields on the interface surface, antenna emitting
- $J^{s}(x)$ is the aircraft model's electric courant on the bonded interface surface, the aircraft being exposed to a unitary plat wave in $\hat{\imath}$-direction
- $G(\hat{\imath})$ is the antenna gain in $\hat{\imath}$-direction.

$$\sqrt{G}(\hat{\imath}) = \frac{j\omega\mu}{4\pi} \int_{\mathrm{Sint}} E^{\alpha}(x) \,.\, J^{s}(x)dS(x)$$

This principle is classically used for the hybridization methods presented hereabove. There are several variants to this principle, which, allow adaptations to the cases under study in accordance with the used computation methods.

A validation of a simple case consisting in a monopole antenna mounted on a parallelepiped box is shown in Fig. 6.1, 6.2 and 6.3. The validity of the approach is demonstrated by the compared results of the models coupled with direct computations and a measurement.

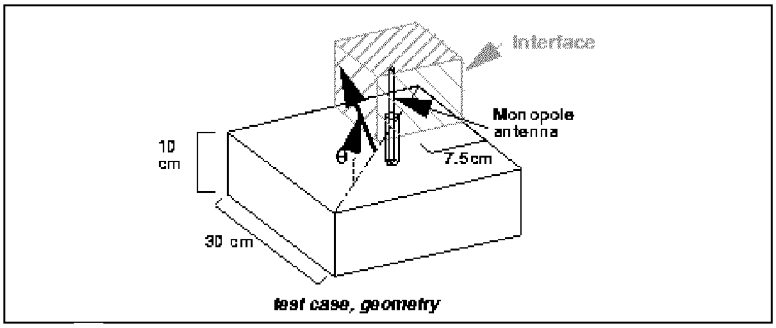

Figure** 6 **1: Monopole mounted on a box

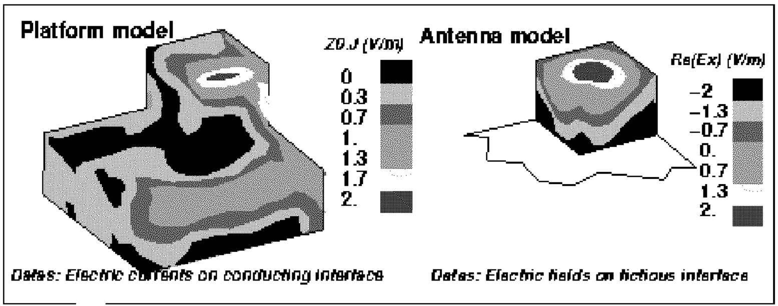

Figure** 6 **2: Illustration of the platform and antenna models

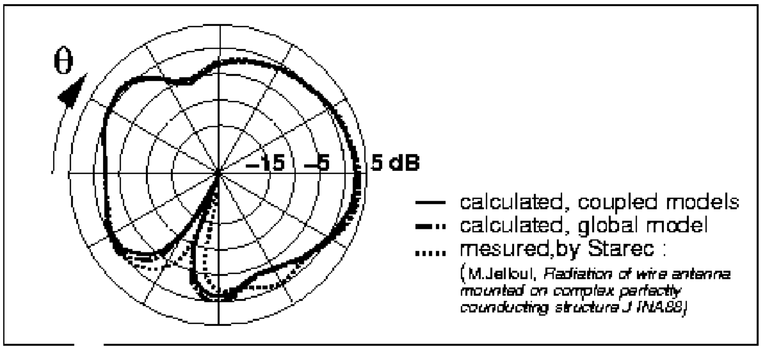

Figure** 6 **3: Radiation pattern

7. NEW TRENDS (2) : SHARING APERTURES

- It is at present obviously not conceivable to have, for the envisaged applications, wide band antennas that can globally cover the entire electromagnetic spectrum used on combat aircraft. This hence means that choices have to be made.
- Also, given that, for certain functions, radiation pattern adaptativity is wanted (the lather, here again, depending on the covered spectrum), the possibilities for achieving such adaptativity within one single unique radiation element must not result in elementary antenna sizes that are too big and hence, difficult to integrate.
- Lastly, the functions to be integrated in these new multi-function antennas must be compatible amongst themselves, as regards the performance characteristics to be ensured.

A first line of thought thus could lead to :

7.1 Grouping of the CNI functions, from the IFF to the GPS band within one and the same elementary antenna

A first analysis, essentially focused on printed circuit or wave guide-type antennas, has, indeed, shown that the required sizes of a radiating surface covering the considered bandwidth (200 to 1500 MHz) and providing a potential antenna pattern modulation minimum are in the order of the 700 mm diameter and 100 mm depth.

Given such sizes and the difficulty to integrate them with the aircraft, designing conformal antennas of lower bandwidth (for a civil non-crypted voice transmission VHF function, for example) and of the same performance level as current solutions (faired printed circuit-type antenna in fin tip) cannot be envisaged.

Also, the vast majority of CNI functions require omnidirectional coverage types (voice, IFF response, date transmission... which must be compatible amongst themselves.

7.2 Grouping the Radar/ESM/ECM/IFF Interrogation functions, in conjunction with using a lower radar band

These three functions must, indeed, have common coverage areas and common scanning domains, especially if the lather are to be more extensive than in current practice.

Furthermore, the use of common radioelectric scanning axes (in surveillance areas will, operationally, lead to a better association of the tracks provided by these different sensors.

Also, in the case of the radar function, the fact of distributing several (conformal) antennas over a greater aircraft surface than in current practice, will provide for lowering the working frequency (> = L band) and thus, improve the detection of stealthy targets and enhance anti-jammer protection, both currently inexistant in such frequency domains.

As a conclusion, for future aircraft which should be endowed with conformal multi-function antennas, there are two such-type equipment families that appear to emerge :

- one "low band" family (essentially grouping the CNI functions)
- one "high band" family (countermeasures and radar, amongst others).

An industrial example of a coupled simulation illustrates those recommended solutions. The previously described methodology was successfully applied between DASSAULT AVIATION and THALES Airborne Systems during a feasibility study to install CNI conformal and multi-function antennas on Rafale.

The GPS, IFF, MIDS and TACAN functions were grouped within the same antennas block, located on the Rafale spine behind the canopy. This development was performed to achieve the following specifications :

- conformal antennas
- adaptative patterns for MIDS and GPS to ensure resistance to jamming.

Fig. 7.1 shows the magnetic currents, induced by the radiation of a MIDS element, on the fictitious interface, computed by THALES AS.
Fig 7.2 shows the Rafale fine grid mesh used by DASSAULT AVIATION to compute the radiated pattern of this element, installed on the aircraft.

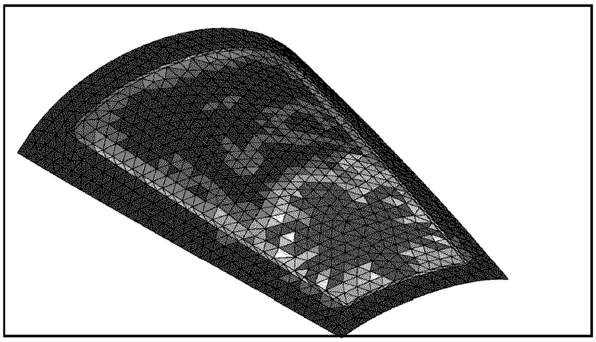

Figure 7.1 : magnetic field on fictitious interface

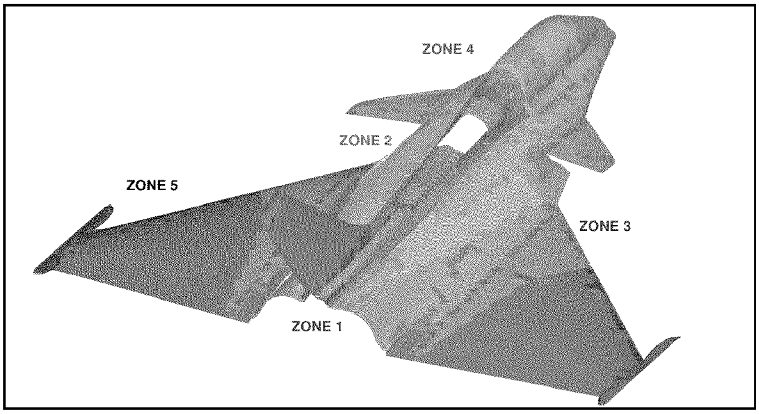

Figure 7.2 : Rafale fine-grid mesh

Improved antenna integration with the aircraft may furthermore arise from exchanges with partner contractors involved in such new design methodologies.

Paper #59
Discussor's Name: David McInroy
Author's Name: Gerard LeFlour

Q: Do you use spectre code for analysis on interference between the radar and an on-board jammer?

A: This will be more easily achieved in the next 5 years or so with modeling. Sodelobe predictions are currently difficult.