Modelling of Electromagnetic Scattering from Large and General Intakes on Complex Platforms

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Abstract ─ In the framework of the design of low observable aircraft, one of the most difficult problem is the numerical modelling of aeronautical air intakes with an – usually complex – arbitrary shape. Also the presence of radio absorbing material demands for accurate methods in evaluating the low level scattering for real life problems. This paper addresses the use of a full wave approach, based on the Multilevel Fast Multipole Approach (MLFMA), for a high fidelity modelling both of the whole (real life) aircraft, and of the intake scattering contribution, useful in the design and optimization stage of the intake itself.

Index Terms ─ Fast methods, Method of Moments (MoM), MLFMA, radar signature, scattering.

I. INTRODUCTION

One of the most demanding problems in computational electromagnetics is given by the low observable design of a modern aeronautical platform. This is due to the different scattering phenomena contributing to the global scattered field as well as to the electrical size of the platform at the typical impinging radar wave frequencies. The stealthness requirement in real life industrial problems requires computationally efficient and accurate electromagnetic computational tools able to assess low Radar Signatures.

In the nose on aspect angles, the jet intake is one of the major hot spots generating high level of radar signature for a large set of aspect angles. Particular design techniques are used to reduce the intakes' signature. For instance, line-of-sight blockage of the engine and usage of radar absorbing material / structure installation [1]. These techniques make usually intakes a complex – and electrically large – structure to be analyzed. In the design phase the capability to assess the scattering contribution of the only intake is a key point in order to optimize it in terms of shaping, materials, engine fan and air flow control structures. Other than the capability to aggregate the signature of the intake with the scattering contribution of the whole aeronautical platform it is also mandatory since the electrical size of the EM problem makes a brute force application of a full wave approach strongly inefficient.

Several works have been published for the solution of the intake scattering, resorting to asymptotic [2] and hybrid numerical techniques [3-5]. In this contribution, we address the use of a frequency domain full wave (MoM) method for a high fidelity modelling of intakes and aircraft structures, with MLFMA to allow the analysis of the electrically large problems arising in real life cases. The used formulation and the main characteristics of the numerical solver are summarized in Section II, while Section III describes the evaluation of the scattering contribution of intake alone to the overall radar signature. Some results are described in Section IV and some conclusions are drawn in Section V.

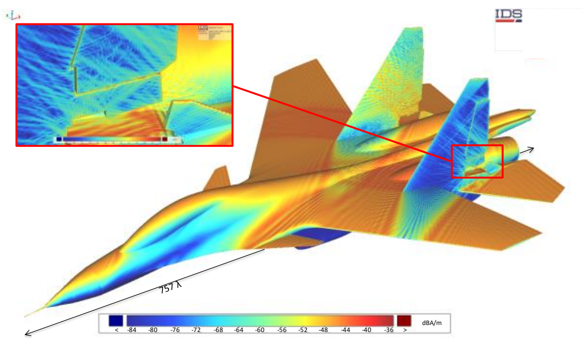
II. HIGH FIDELITY AIRCRAFT SCATTERING MODEL

Real life aircrafts are very complicated structures. In order to accurately estimate their electromagnetic behavior, it is needed to finely model their geometry and structures (high fidelity modelling). This leads to a multi-scale object, composed by different materials (conducting, dielectric, radio absorbing). The Method of Moments is able to give very accurate results on an arbitrary geometry at the expenses of a high numerical complexity. Acceleration methods, like the MLFMA give the possibility to analyze electrically large structures.

The used electromagnetic solver is a Frequency Domain Method of Moments with Galerkin's discretization on a triangular mesh. It implements the Poggio-Miller-Chang-Harrington-Wu-Tsai (PMCHWT) formulation [6], and any combination and arrangement of lossy and lossless materials can be considered. In particular, such formulation is applied on the dielectric interfaces separating homogeneous dielectric materials; while the Electric Field Integral Equation (EFIE) and the Combined Field Integral Equation (CFIE) are applied on open

Submitted On: June 28, 2017
Accepted On: March 26, 2018

and closed conducting surfaces, respectively. The Multilevel Fast Multipole Approach (MLFMA) [7] is used to efficiently solve electrically large models. In such a case an iterative solver has to be employed (BiCGStab, GMRESR, etc.) and the MoM linear system has to be effectively preconditioned. Due to the multi-scale nature of the model (also determined by meshing the surface of dense materials), a MultiResolution (MR) preconditioning is adopted [8] to obtain a solver with high computational efficiency. By using such solver, it is possible to consider real life structures (Fig. 1, Fig. 2).



Mesh cells: 50,078,830 triangles (on closed surfaces)
Unknowns: ***78,023,802*** *(RWG), Boundary condition: CFIE*
Plane Wave from phi=30°/theta=60°
*Hardware: 2*Xeon E5-2660v3 @ 2.6GHz, 512GByte RAM DDR4*
N° threads: 20, N° of iterations: 47 (res. 8.66E-03)
RAM: 350 GB, Elapsed time: 7h 12min

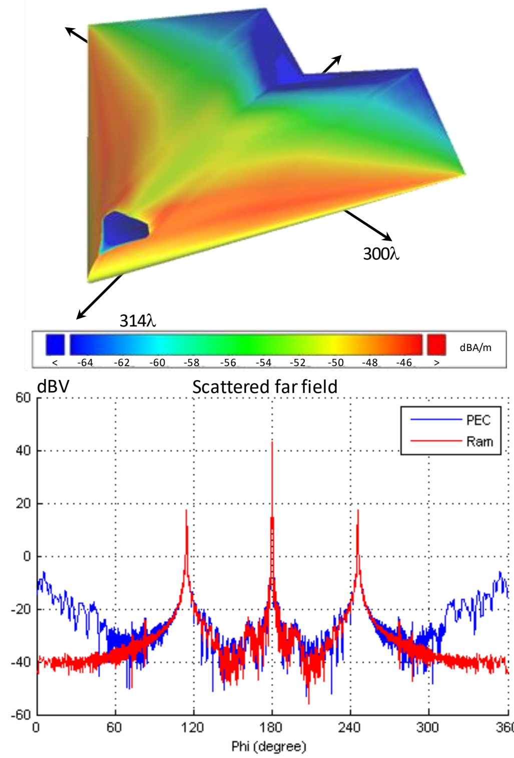
Fig. 1. Equivalent electric current on a Sukhoi, induced by an impinging plane wave @ 10 GHz.

Particular materials can be characterized by means of a general anisotropic Impedance Boundary Condition (IBC) [9], relating the tangential electric and magnetic field through a local Surface Impedance $\underline{\underline{Z}}_S$ described by a 3 × 3 dyad:

$$\vec{E} - (\hat{n} \cdot \vec{E})\hat{n} = \underline{Z_S}\hat{n} \times \vec{H} \rightarrow \vec{M} = -\hat{n} \times \underline{Z_S}\vec{J}, \qquad (1)$$

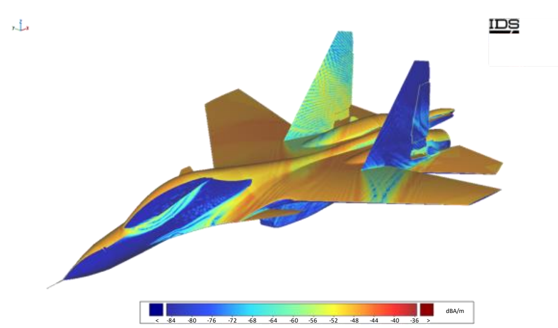
where $\hat{n}$ is the conducting surface normal. Equation (1) establishes a relation between the equivalent surface magnetic ($\vec{M}$) and electric ($\vec{J}$) currents on IBC surfaces (1, right). This allows to avoid magnetic unknowns on surface of IBC materials, but this has to be included carefully in the formulation, due to the fact that it defines a discontinuous distribution when RWG are used to expand the electric current $\vec{J}$.

Even if we can efficiently model whole aircrafts, it is important to consider the possibility of modelling the contribution of single parts (the intake in our case) for design and optimization purposes. A designer can model the aircraft platform once – also with techniques other than MoM (modelling the structure in Fig. 1 with the Iterative Physical Optics [10] we obtain the result shown in Fig. 3) – to be combined to the contribution of the intake, the last modelled every time a change is made by designers. The next section considers the evaluation of the intakes contribution. All the results were obtained with the numerical code of IDS (IDS Method of Moment Multi-Port, IDS IPO), integrated in the Galileo-EME framework [11].



Mesh cells: 28,396,720 triangles (on closed surfaces)
Unknowns: ***42,595,080*** *(RWG), Boundary condition: CFIE+IBC*
PW from phi=0°/theta=90°, V pol.
*Hardware: 2*Xeon E5-2660v3 @ 2.6GHz, 512GByte*
N° threads: 20
RAM: 247 GB, Elapsed time: 5h 43min Total

Fig. 2. Equivalent electric current (top) and scattered field (bottom) for a UCAV, induced by an impinging plane wave @ 10 GHz. Pec labels refers to an intake without a RAM covering.



*Unknowns: 14**,278,340***
Plane Wave from phi=30°/theta=60°
Hardware: 2 GPU Kepler
RAM: 12 GB, Elapsed time: 2h 50min

Fig. 3. Equivalent electric current on a Sukhoi, induced by an impinging plane wave @ 10 GHz, evaluated by using a fast IPO formulation.

III. INTAKE CONTRIBUTION TO RADAR SIGNATURE

In evaluation of the contribution of an air intake to the overall scattered field (obtained through a coherent sum of the different contributions), we could neglect some interactions (with the rest of the structure), and we could add other interactions (with the outer surface of the intake). We have different possibilities (Fig. 4):

- To model the intake walls as a thin surface. The walls contribute to the scattered field;
- To model the intake with both sides of the walls. Then, discard the scattering contribution of basis functions on the exterior side;
- To insert a dummy interface on the mouth. Then, discard the scattering contribution of basis functions on the exterior wall side. Only the mouth contributes to the scattered field, giving good results in the half space the mouth is looking to.
- To insert a dummy interface on the mouth and don't generate basis functions on the exterior wall side (halving the unknowns). Only the mouth contributes to the scattered field, giving good results in the half space the mouth is looking to.

The first choice can lead to inaccurate results. The other methods give almost the same results, but the last choice allows the halving the unknowns on the intake. This is the method we have adopted in this paper. In every case, the inclusion of a small part of the aircraft structure near the mouth (discarded in the evaluation of the overall scattered field) helps to increase the accuracy of the simulation.

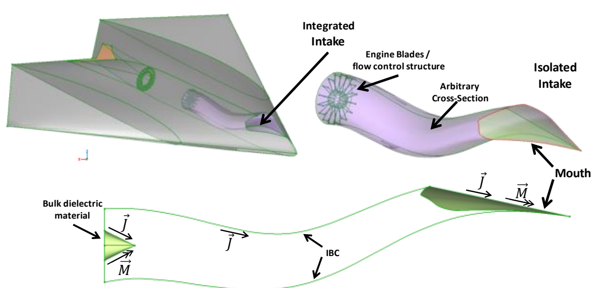


Fig. 4. Typical Air intake isolated problem.

IV. VALIDATION AND EXAMPLE OF APPLICATION

In this Section we report some validation data obtained on the 9 m × 9 m perfectly conducting UCAV shown in Fig. 4. The structure (60 λ × 60 λ @ 2 GHz) is discretized with 712365 triangles, and the validation is carried out in terms of monostatic scattered field on the +10 degrees elevation plane. The nose is heading 180 degrees azimuth. Figure 5 shows the Radar Cross Section of the Intake in Fig. 4, modelled with thin walls and with the proposed method. The scattered field from the walls causes the beat visible at high angles. The platform contribution shows that the intake contributes significantly on the scattered field. The combination of intake and platform scattered field is compared to a simulation of the complete UCAV in Fig. 6. To the purpose of air intakes design, this result represents a good agreement, and by considering a small part of the fuselage in solving the intake allows to obtain a more accurate result (Fig. 6).

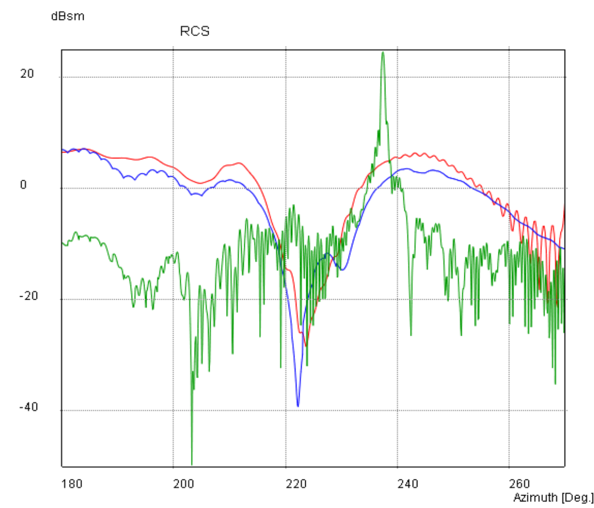


Fig. 5. VV monostatic scattered field of the intake in Fig. 4, modelled with thin walls (red) and with the proposed method (blue). The platform contribution (green) is also shown.

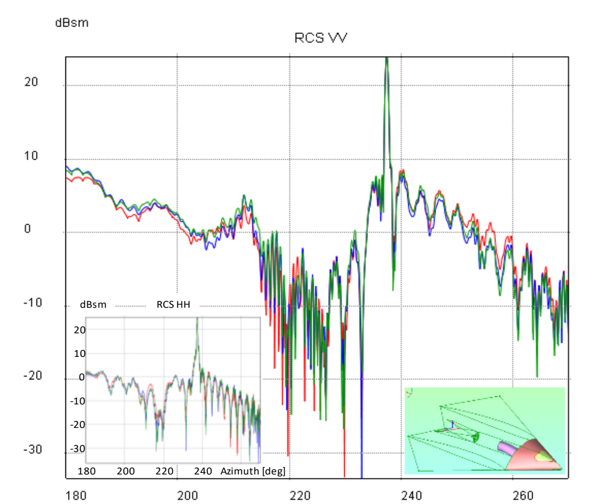


Fig. 6. VV monostatic scattered field of the UCAV in Fig. 4, considering the complete structure (blue), or combining separate contribution from the intake and the platform (red). Inclusion of a small part of the fuselage (inset) in solving the intake allows to obtain a more accurate result (green). Similar results are obtained for the HH polarization (inset).

Figure 7 shows some results on a more realistic case. Some details are given in the figure. The beat on the scattered field due to the walls is again visible in the graphs.

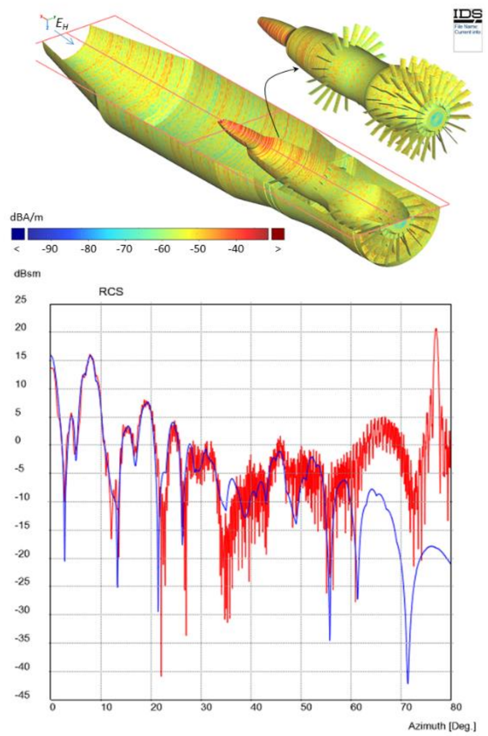


Fig. 7. Equivalent electric current (top) and monostatic Scattered field (bottom) for a 5.17 m × 1.19 m × 1.19 m Intake @ 10 GHz (10,824,636 unknowns and CFIE+IBC formulation), modelled with thin walls (red) and with the proposed method (blue).

V. CONCLUSIONS

In this paper the modelling of real life, aeronautical air intakes with an arbitrary shape is addressed, with reference to the modeling of the intake alone and the combination of its response with the platform one to obtain the scattered field of the complete aircraft. Being able to maintain a sufficient accuracy, this allows an easier design and optimization of the intakes. Different ways to decouple intake and aircraft scattering contribution was analysed, and the most efficient method is validated on a test case.

REFERENCES

[1] B. S. Haisty, "Lockeed Martin's - Affordable Stealth," National Press Club, Washington DC, 15 Nov. 2000.

[2] P. H. Pathak and R. J. Burkholder, "Modal, ray, and beam techniques for analyzing the EM scattering by open-ended waveguide cavities," *IEEE Trans. Antenna Propagat.*, vol. 37, pp. 635-647, May 1989.

[3] P. R. Rousseau and R. J. Burkholder, "A hybrid approach for calculating the scattering from obstacles within large open cavities," *IEEE Trans. Antenna Propagat.*, vol. 43, pp. 1068-1075, Oct. 1995.

[4] A. Barka, P. Soudais, and D. Volpert, "Scattering from 3-D cavities with a plug and play numerical scheme combining IE, PDE, and modal techniques," *IEEE Trans. Antenna Propagat.*, vol. 48, pp. 704-712, May 2000.

[5] F. Hu, C. Wang, and Y. Gan, "Efficient calculation of interior scattering from large three-dimensional PEC cavities," *IEEE Trans. Antenna Propagat.*, vol. 55, pp. 167-177, Jan. 2007.

[6] P. Yla-Oijala, M. Taskinen, and J. Sarvas, "Surface integral equation method for general composite metallic and dielectric structures with junctions," *Prog. Electromagn. Res.*, vol. 52, pp. 81-108, 2005.

[7] W. C. Chew, J. Song, et al., *Fast and Efficient Algorithms in Computational Electromagnetics*. Boston, MA: Artech House, 2001.

[8] F. Vipiana, G. Vecchi, and D. R. Wilton, "A multi-resolution moment method for wire-surface objects," *IEEE Trans. Antenna Propagat.*, vol. 58, no. 5, pp. 1807-1813, May 2010.

[9] A. W. Glisson, et al., "Electromagnetic scattering by an arbitrarily shaped surface with an anisotropic impedance boundary condition," *App. Comp. Elec. Soc. Jour.*, vol. 10, no. 3, pp. 93-106, 1995.

[10] P. De Vita, A. Mori, L. Pandolfo, M. Bercigli, M. Bandinelli, G. Carluccio, M. Albani, et al., "Analysis of scattering from electrically large objects using fast far field iterative physical optics," *2017 11th Euro. Conf. on Ant. and Prop. (EUCAP)*, Paris, pp. 509-512, 2017.

[11] https://www.idscorporation.com/pf/galileo-suite/