Coupling Hierarchical Games with Genetic Algorithms for the solution of mono and bi-static backscattering minimization problems

Mourad Sefrioui — LIP6, Univ. Paris 6

Jacques Periaux — Dassault Aviation

Bertrand Mantel — Dassault Aviation

1. Extended Abstract

Deterministic optimizers are efficient tools for solving optimization problems with unimodal and differentiable objective functions. They require quite few objective function evaluations when compared to stochastic optimization but may easily trapped in local minima and miss global solution.

On the other hand Genetic Algorithms (GAs) are stochastic methods pioneered by J. H. Holland and applied to a wide range of problems ranging in Engineering and Economics. GAs are derivative free search procedures based on the mechanics of natural selection and the so called darwinian principle « survival of the fittest ». A decisive advantage of GAs is its robustness in the search for improvement.

The main goal of this paper is to find solutions of multi objective optimizations of scattered waves CEM problems by active control elements in the two following cases:

case i): combinatorial search of optimal distribution of antennas on the surface of active reflectors minimizing a single mono or bi-static RCS fitness function . The GAs optimization process takes into account the distribution of active elements on different surfacic sites of the obstacle. A candidate solution is then binary encoded with «in » and « off » antennas and cheaply evaluated by its RCS value from a database set up in advance but once for all by a finite element time harmonic Maxwell solver based on exact controllability methods;

case ii): combinatorial search of multi-objective optimization problems by coupling hierarchical games with GAs in the case of two mono or bistatic RCS. This second case corresponds to a physical situation where an aerodynamic shape is illuminated simultaneously by two radars representing a different threat .

Following the game theory approach, the Stackelberg optimization uses a hierarchical strategy which considers two players, one of them stated as the leader with one radar and the second one as the follower with the second radar. The mathematical definition of the Stackelberg game is then implemented with two hierarchical nested Genetic Algorithms.

Stackelberg solutions of the above problems with different angles of illumination and frequencies are compared with both the Nash solution of a competitive symmetric game and also the Pareto Front solutions of a cooperative game in terms of quality and robustness for different choices of mono-static and bi-static RCS fitness functions.

The various results of CEM optimization problems presented in this paper illustrate the robustness of GAs and their emergent information technology potential with different game theory approaches for the future design of low visibility aerospace engineering products of increasing complexity.

2. Numerical experiments for mono or bistatic RCS with active antennas on multi element airfoil

In the present computation we run the Maxwell solver around a three element profile. This profile is in high-lift configuration obtain by GA in an other application (cf. [AIAA] 1998).
In this configuration the moving parts of the profile (slat and flaps) are in an "open position" to insure a maximum of the lift coefficient (see Figure 1) and then the antennas, like panels, are distributed on each profile element.

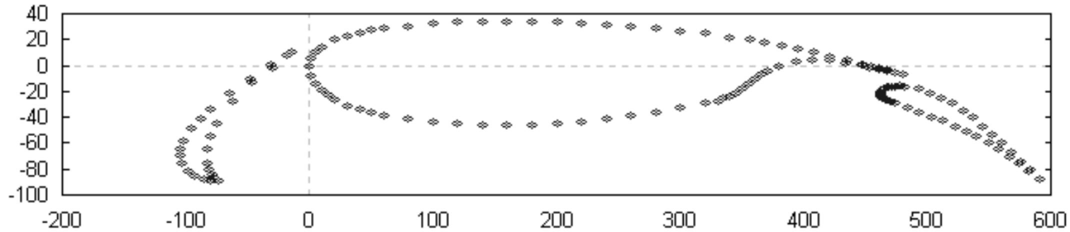

Figure 1

There is 18 (N=18) antennas, 4 on the slat, 10 on the main body and 4 on the flap. Each of them correspond to a smooth shape function with maximum value 1. at the center of the panel and vanishing at the panel boundary (see Figure 2) which may be active or passive. We have almost 6 (k=6) active antennas

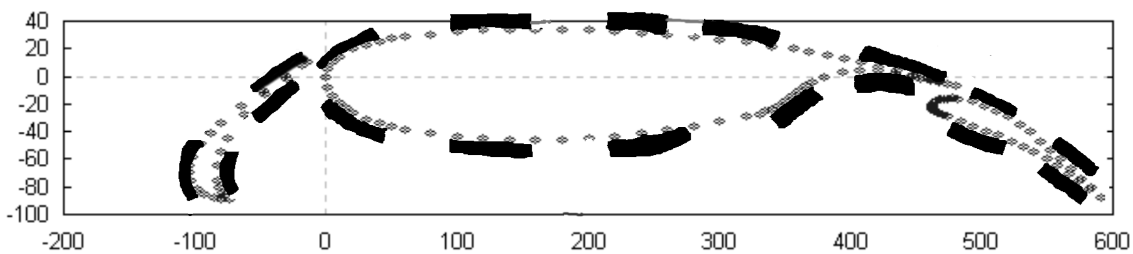

Figure 2. antenna configuration

Each active antenna generates a wave which is likely to minimize the effects of reflection. Due to the linear properties of Maxwell equations, the global electromagnetic field backscattered by the airfoil can be computed by linear combinations of the elementary solutions of Maxwell equations.
The total scattered field can then be expressed as :

$$U = u_{inc} + \sum_{i=1}^{N} z_i * u_{ea_i}(A_i, \theta_i, \varphi_i)$$

In this expression:

- A_j denotes the amplitude coefficient,
- $\theta_j(x)$ $,0 \le \theta(x) \le 1$ a shape function equal to 0 outside of the panel

and φ_j the phase angles,

- u_{inc} the backscattered wave of the incident wave and
- u_{ea_j} the backscattered wave of the elementary antenna corresponding to the boundary condition :

$$\mathrm{A}_{\mathrm{j}} * \theta(x) * \exp(i\omega t + \varphi_j)\,, \omega = 2\pi / T \text{ with } T \text{ the period of the impinging radar wave.}$$

$z_j = 0$ or 1 depending on active (1) or passive (0) element, $\sum_{\mathrm{j=1,N}} z_j = k$

for more details on the Maxwell solver we can refer to [Miech].

As starting point we run Maxwell solver for 3 incident waves, 0 degree, +45 degrees and -45 degrees and we compute once for all and store the 18 elementary solutions.
Using one of this incident wave plus the elementary solution we minimize the radar cross section of the profile in an angular sector of space corresponding to the incident wave (standard optimization) or in a different angular sector: bi-static optimization. Any combination of objective function standard or bi-static optimization allows us to define cooperative, non cooperative or hierarchical optimization connected to Pareto, Nash or Stackelberg game theory.

At present time we are able to present standard optimization (Figure 3 and 4) and bi-static optimization (Figure 5 and 6). We present also comparison between both (Figure 7).

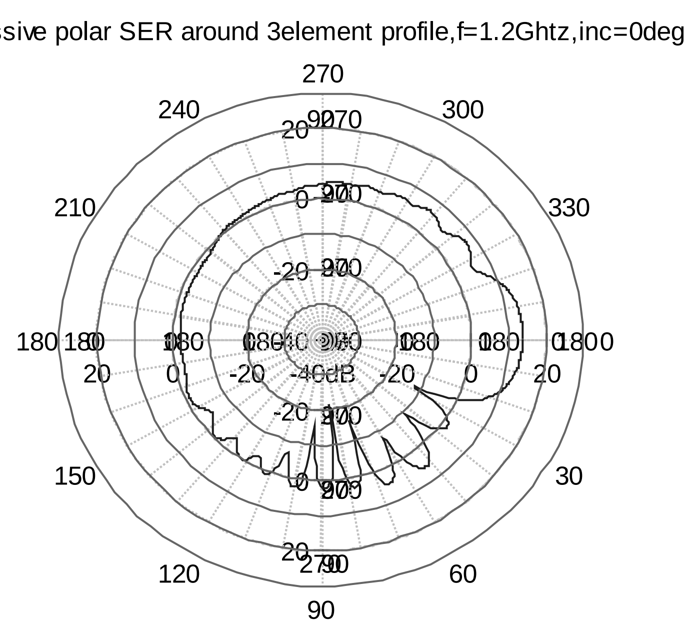

Figure 3: RCS of passive initial situation

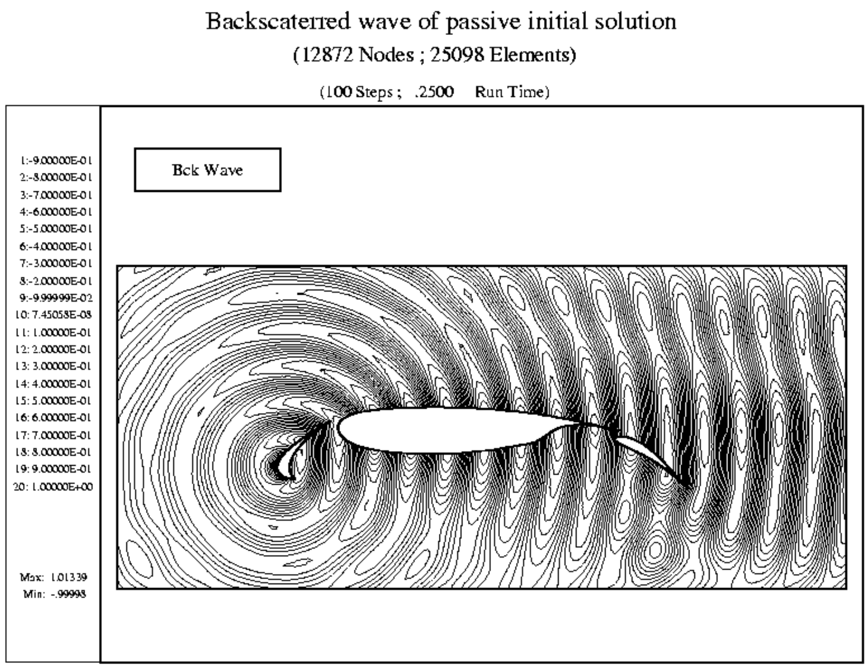

Figure 4: Initial solution

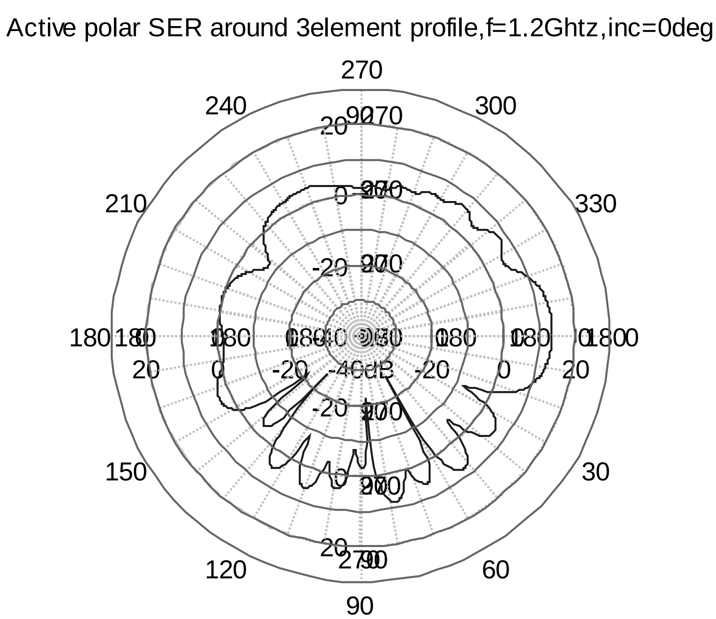

Figure 5: RCS after bi-static minimization

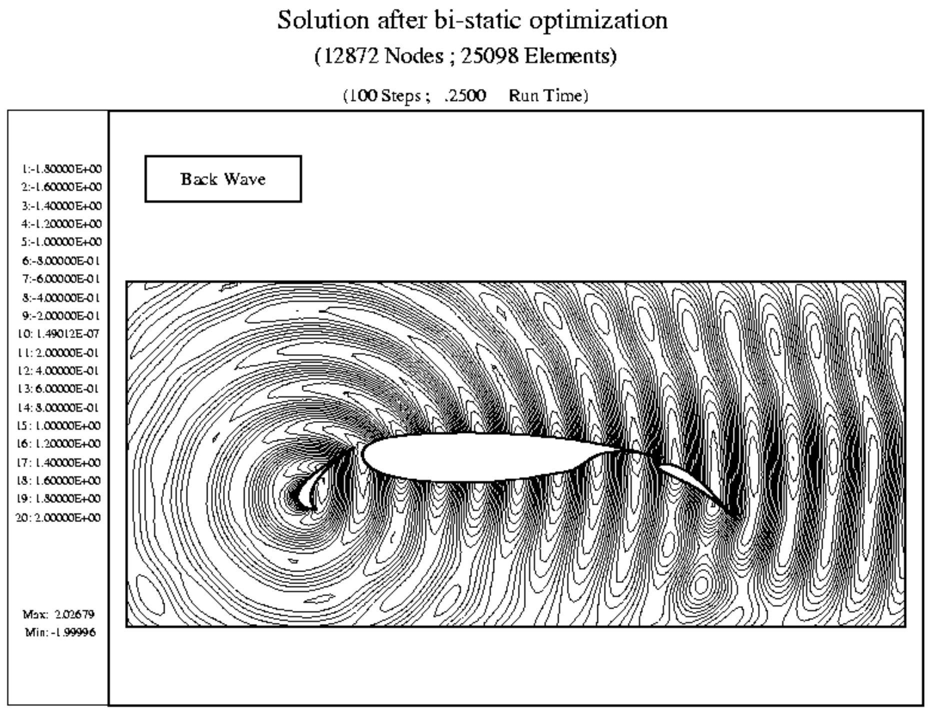

Figure 6: Backscattered solution after bi-static optimization

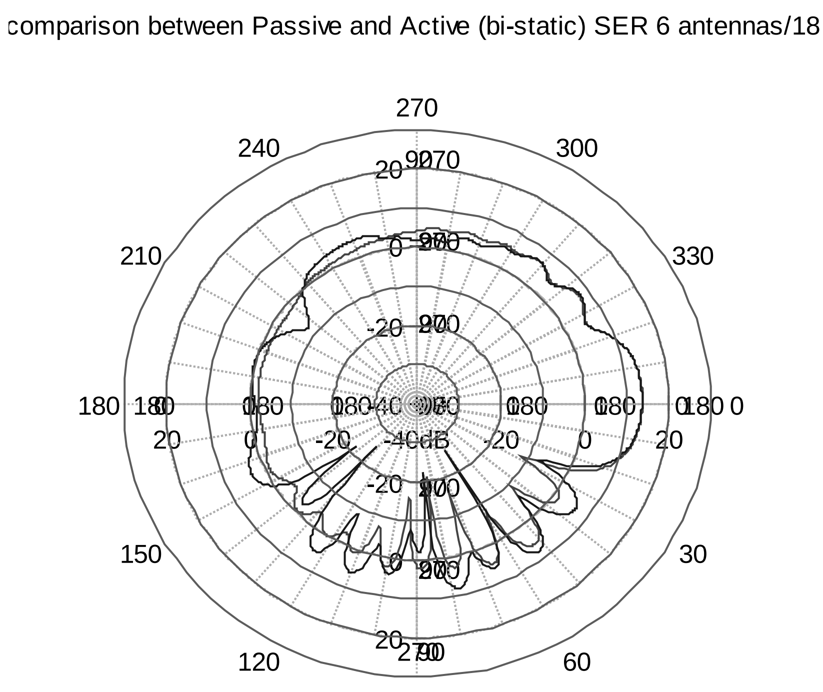

Figure 7 Comparison between initial RCS and bi-static RCS minimization

Red line corresponds to the initial passive backscattered wave and blue line to the bi-static minimization in the angular sector between 125 and 155 degrees. Two peaks are clearly visible in that direction and the fitness value is 3814.724365 compared to the initial value 4009.09350

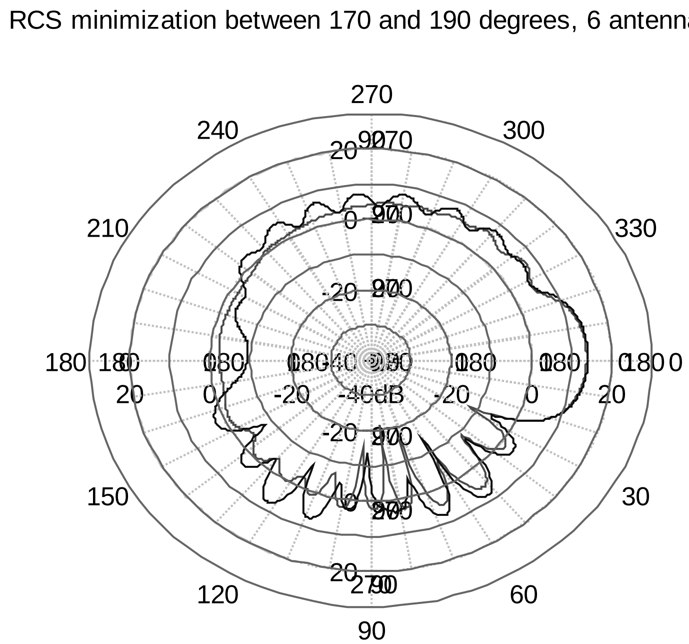

Figure 8 Comparison between initial RCS and standard RCS minimization

Red line corresponds to the passive initial RCS with fitness value 4009.09350 and dark-blue line to the RCS minimization between 170 and 190 degrees with fitnees value 3744.983398

3. Numerical experiments for multi RCS minimization with active antennas on multi element airfoils

To be presented at the conference.

4. Acknowledgments

The authors would like to thank J-.L. Lions and R. Glowinski for fruitful discussions on exact controllability methods and cooperative and non-cooperative strategies. The present work has been achieved through a close collaboration with M.-O. Bristeau, INRIA-Rocquencourt, for the numerical solution of the Maxwell equations.

5. References

[AIAA] B. Mantel, J. Périaux, M. Sefrioui, B. Stoufflet, J.-A. Désidéri, S. Lanteri and N. Marco, Evolutionary computational methods for complex design in aerodynamics, Proceedings of the AIAA Aerospace Sciences Conference, 12-15 January 1998, Reno, Nevada (USA), Paper AIAA-98-0222.

[Miech] M.O. Bristeau, R. Glowinski, B. Mantel, J. Périaux, and M. Sefrioui, Genetic Algorithms for Electromagnetic Backscattering Multiobjective Optimization, E. Miechelssen, Ed., John Wiley, 1999