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Determination of Interrogating Frequencies to Maximize Electromagnetic Backscatter from Objects with Material Coatings

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Abstract. The electromagnetic backscattering of a crosscut of a cruise missile coated by a thin homogeneous layer made of radar absorbent material is modeled using a finite element method. Based on the radar cross section and a reflection coefficient, optimization problems are formulated for evaders and interrogators leading to optimal material parameters for the coating and optimal monostatic radar operating frequencies, respectively. Optimal coating materials are constructed for several radar frequencies. Tuning only dielectric permittivity gives a narrow frequency range of high absorption while also tuning magnetic permeability widens it significantly. However the coating layers considered do not provide substantial reduction of backscattering in the entire frequency range from 0.2 to 1.6 GHz. Computational experiments also demonstrate that the reflection coefficient based on a simple planar geometry can predict well the strength of radar cross section in the sector of interest with a substantially reduced computational burden.

Key words: Radar cross section; radar absorbent material; optimization; finite element model.

1 Introduction

In this paper the determination of interrogating frequencies to maximize electromagnetic backscatter from objects with radar absorbent material (RAM) coatings is considered. Of particular interest are radar cross sections (RCS) of missile like objects using monostatic radars. This is an important class of problems, since the backscattering from missiles is rather faint compared to ones from airplanes. Thus, a RAM coating on a missile might make it very difficult to detect and the proper choice of interrogation frequency can be

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crucial for effective interrogation. A general mathematical formulation for optimizing the frequencies for detection is presented. It is derived under the assumption that the evader also minimizes the backscattering by choosing optimal permittivity and permeability for the coating material. The formulation can be simplified substantially when the material parameters for the coating are known.

Previous scientific literature has considered shape and material optimization for evaders. For example, the papers [10,13,23,24] consider multidisciplinary shape optimization problems for an airfoil where the aim is to minimize the electromagnetic backscattering together with aerodynamical constraints and maximization. In [12,18] an optimization for the shape and material parameters for the coating layer is performed to minimize the RCS in a sector when the shape of outer boundary of the airfoil is fixed. The paper [8] considers the optimization of the material parameters of a coating layer.

In this paper we choose our model geometry as a crosscut of a cruise missile [14] which is coated with a thin homogeneous layer of radar absorbent material. We construct a finite element model for the transverse magnetic polarization in the frequency range from 0.2 GHz to 1.6 GHz. Linear finite elements on triangulation which is locally fitted to the interfaces are used and refined in the coating layer in order to provide sufficient accuracy. Furthermore, the computational domain is truncated to be a rectangular domain and a second-order absorbing boundary condition [1,19] is imposed on the artificial boundary. A more detailed description of the finite element method and the solution of the resulting large linear systems is given in [20]. One of our interests is to compare the use of the reflection coefficients based on a plane wave analysis (resulting in a substantially reduced computational methodology) to predict the strength of the backscattering in the considered frequency ranges.

The outline of the paper is as follows. We begin by defining the geometry of the model cruise missile in Section 2. This section contains also the description of the finite element model and the formula for the reflection coefficient. In Section 3, we consider optimization problems for evaders and interrogators. These are discussed in the context of two player zero sum minmax games in Section 4. We report the results of numerical experiments in Section 5. Our conclusions and some suggestions for further investigations are given in the last section.

2 Model problem

We study the electromagnetic scattering by a perfectly conducting cruise missile coated by a radar absorbent material (RAM) layer of constant thickness. In this investigation we compute the scattering of a crosscut of a missile in two-dimensions. The interrogating electromagnetic incident wave is assumed to be a transverse magnetic and the geometry is simplified by neglecting fins. We remark that this simplification generally reduces the backscattering and, thus, if one can detect a missile without fins then one can certainly detect the same missile with fins. The exhaust nozzle is modeled as a cavity with perfectly