Simulations of the Radar Cross Section of a Generic Air-to-Air Missile Coated with Radar Absorbing Materials

Mauro A. Alves[1], Guilherme G. Peixoto[1,2] and Mirabel C. Rezende[1]

[1]Instituto de Aeronáutica e Espaço, Divisão de Materiais, [2]Instituto Tecnológico de Aeronáutica,
São José dos Campos, SP, Praça Marechal Eduardo Gomes, 50, CEP 12228-900, Brazil

***Abstract* — Simulations of the radar cross section of a heat-seeking air-to-air missile model were performed using the CADRCS software. In these simulations at a frequency of 10 GHz, the surface of the missile was considered to be a perfect conductor and to be coated with a radar absorbing material (RAM). The comparison of results from the simulations shows how different parts of the missile contribute to the radar cross section (RCS). Also, it is shown how the RCS of the missile is reduced with the use of RAM.**

***Index Terms* — Missiles, modeling, radar cross sections, simulations.**

I. Introduction

Heat-seeking air-to-air missiles (AAMs) are usually carried externally by fighter aircraft mounted on wingtip rails or on hard points under the wings or fuselage. Although their surface area is small compared to the area of the aircraft that carries them, their radar cross section (RCS) can contribute significantly to the total RCS of an aircraft. Flat surfaces such as the flight control fins and wings mounted in cross-like arrangement, and the cylindrical body of the missile can be, depending on the viewing aspect, good radar reflectors.

In order to reduce the RCS contributions from AAMs it would be necessary to carry the missiles inside bays in the fuselage of the aircraft, which is not possible in most of the cases, or to have their surfaces coated with a radar absorbing material (RAM). To understand how the RCS of an AAM can be reduced with the use of RAMs, simulations of the RCS of an AAM model were performed using the CADRCS software [1]. This paper presents the results of the simulations of the RCS of an AAM model with the surface treated as a perfect conductor and partially reflective to radar. These simulations show how the RCS of an AAM can be reduced by the application of RAM to its surface.

II. Radar Cross Section

RCS is a measure of the effectiveness of a target in intercepting and reflecting electromagnetic energy. The RCS of a target is a function of its shape, composition, and frequency and polarization of the incident wave. The RCS is also a function of the position and orientation of the target with respect to the source of the radar wave and radar receiver. If the transmitter and receiver are in the same location, the RCS is referred to as monostatic. The monostatic RCS, in terms of electric field, is defined as [2]:

$$\sigma = \lim_{r \to \infty} 4\pi r^2 \frac{|E_S|^2}{|E_I|^2} , \tag{1}$$

where, r is the distance from object to the observation point, and $\boldsymbol{E}_S$ and $\boldsymbol{E}_I$ are the scattered and incident electric fields at the target, respectively. Equation (1) is valid when the target is illuminated by a plane wave. This is satisfied by the far-field approximation, i.e., when the object is located at a distance at least $r = 2D^2/\lambda$, where D is the largest dimension of the object [3]. Due to the large range of RCS values, a logarithmic power scale is used with the reference value of $\sigma_R = 1\ m^2$ [3]:

$$\sigma_L = 10 \log_{10}\left(\frac{\sigma}{\sigma_R}\right) = 10 \log_{10}\left(\frac{\sigma}{1}\right). \tag{2}$$

Table I lists typical RCS values for several types of objects, ranging in size from insects to a ship, illuminated head-on by the radar [4]. Note that the values listed in this table serve only as a reference since the RCS of an object depends on many parameters, as mentioned above.

TABLE I
TYPICAL RCS VALUES [4].

Target	RCS (m^2)
Large ship	10,000
Bomber	1,000
Fighter	100
Man	1
Birds	0.01
Insects	0.0001

III. Simulation Tool

The RCS of the AAM was simulated using the commercially available simulation software CADRCS. CADRCS combines physical optics with ray tracing techniques to calculate the RCS of a target. This software also treats shadowed ray, which yields very accurate RCS calculations for objects greater than the radar wavelength [5]. CADRCS allows the simulation of the RCS of a target under several different conditions such as wave polarization, aspect angle, distance between target and radar, target reflectivity and surface roughness. CADRCS sale is regulated by the Danish Defense Ministry. Other details about the theory and methods used in CADRCS are considered classified material and are not disclosed to users.

In order to run the simulations with CADRCS, a computer-aided design (CAD) model of the target is needed. For this study, a CAD model of the AAM was created using AutoCad software. This model was imported into the Rhinoceros software and its surface was discretized into triangular elements by an automatic mesh generator. The only parameter used in the generation of the mesh was the maximum allowable dimension of the triangular elements. The mesh was then imported into CADRCS for the simulations. A Pentium 4 3.2 GHz PC with 3.0 GB RAM memory was used in this work. The typical run time for the simulations was about 60 h.

Fig. 1 shows the model of the AAM used in the simulations. The surface of the model was discretized into 377,540 triangular elements. The largest dimension of these triangular elements was 2 mm. The design and dimensions of this model are similar to those of a generic AAM; there was no intent to reproduce exactly the design of any particular missile. Note that a mirror, which is part of the heat-seeking system, is located on the nose of the missile. The mirror is mounted on a gimbal system and can move in yaw and pitch. In the simulations, the mirror remained stationary and facing forward.

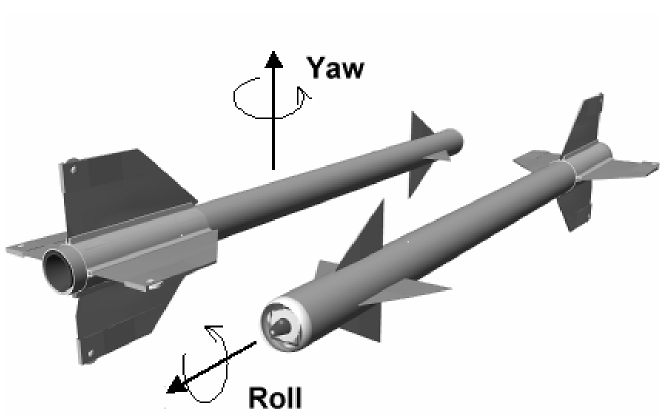

Fig. 1. CAD model of an AAM. The overall length of the missile is 2.65 m, the diameter of the cylindrical body is 0.18 m, the wingspan is 0.58 m and the finspan is 0.47 m. The mirror in the nose of the missile is protected by a transparent dome. The axes of rotation, yaw and roll, used in the simulations are shown.

IV. Results

A monostatic radar configuration at a frequency of 10 GHz (X Band) with vertical polarization was used in the simulations. RCS values were simulated for the AAM rotating in yaw and roll, and calculated at intervals of 0.5°. The model was rotated 360° in yaw and 90° in roll. Simulations were made assuming that the surface of the missile was a perfect conductor and partially coated with RAM. In order to simulate a surface coated with RAM, the values of reflectivity (r) of the elements that constitute the surface of the model can be chosen between 0 and 1. Fig. 2 shows the RCS of the AAM as a function of the aspect angle, with the model rotating in yaw, for a model whose surface is reflective to radar waves.

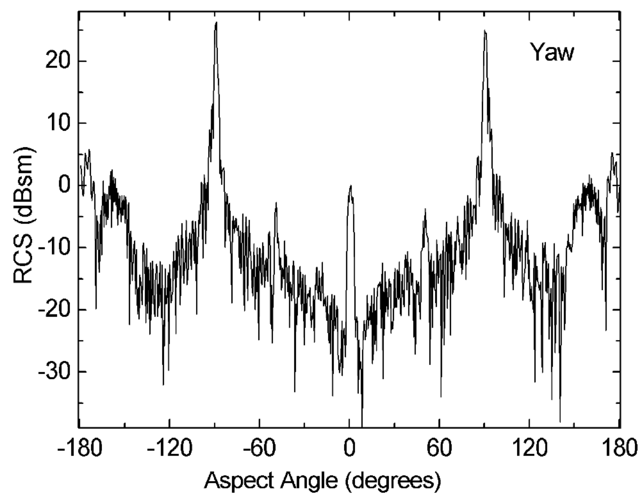

Fig. 2. Simulated RCS of a model of an air-to-air missile at 10 GHz. Rotation in yaw. The angular positions of 0°, -90° and 90°, and -180° and 180° correspond to the front, side and rear views of the model, respectively.

The main peaks in the RCS pattern, shown in Fig. 1, correspond to the mirror of the heat-seeking device at 0°, lateral sides of the missile at about -90° and 90°, and nozzle cavity at about -180° and 180°. The peaks at -50° and 50° are created by the leading edges of the wings. It is interesting to observe the range of variation of the RCS as a function of the aspect angle. For this model, the RCS varies by more than 50 dBsm. Also, the RCS of the model is at its highest value when its lateral sides are illuminated, and in this situation, the fins, wings and the cylindrical body are perpendicular to the incident radiation.

Fig. 3 shows the RCS of the model rotating in roll as a function of the aspect angle. The surface of the model was assumed to be a perfect conductor. The RCS pattern in Fig. 3 is similar to the RCS pattern created by a 90° dihedral [3]. This was expected due to the cross-like arrangement of the fins and wings. At 0° and 90°, two of the wings and fins are perpendicular to the incident radiation and the reflection was at a maximum. The RCS at these aspect angles correspond to the RCS values at +90° and –90° in Fig. 2. For different angles, interactions between multiple reflections from the surfaces of the fins and wings create the oscillatory behavior observed in Fig. 3. Note that for the simulation with the model rotating in roll the rocket nozzle is hidden from the radar view, since it is located inside the body of the missile.

The result of the simulation, shown in Fig. 2, can serve as guidelines on how to proceed in order to reduce the cross section of the missile. One interesting aspect of the simulations is the relatively high RCS values when the missile is illuminated head-on by the radar. The metallic mirror of the heat-seeking detector is a good radar reflector, though in a narrow angle. Since it is not possible to coat the dome of the missile with RAM, as these materials are opaque to infrared radiation, the dome could be coated with a film that reflects radar waves [6]. This would help reduce the RCS of the missile since the hemispherical shape of the dome is a good scatterer of radar waves compared to the mirror.

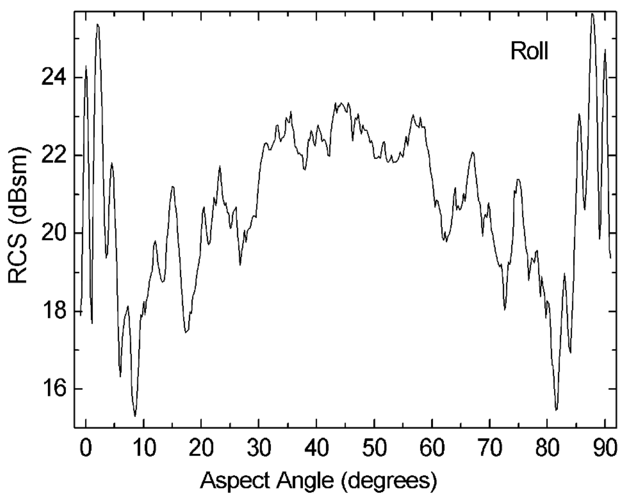

Fig. 3. Simulated RCS of the model of an air-to-air missile at 10 GHz. Rotation in roll. The angular positions of 0° and 90° correspond to the situation when fins and wings are perpendicular to the incident radiation.

In Figs. 4 and 5 are shown simulations where the dome and the rocket nozzle behave as perfect conductors, and the fins, wings and cylindrical body are coated with RAM. In these simulations, it was assumed that the reflectivity (*r*) of the parts of the missile coated with RAM was r = 0.001. In Fig. 4 (model rotating in yaw), it can be seen how the application of a reflective coating to the dome is effective in reducing the missile RCS; the RCS peak observed in Fig. 2 at 0° is reduced significantly, by as much as 20 dBsm. Also, the comparison of both RCS patterns in Fig. 4 shows that to reduce significantly the RCS of the missile, its external surface needs to be completely coated with RAM. The top panel of this figure shows that when only the surfaces of the wings and fins are coated with RAM, the contribution of the cylindrical body to the RCS of the missile is still very important, especially when the radar illuminates its lateral side. In the bottom panel, it can be seen how the application of RAM to the cylindrical body, fins and wings reduces the RCS significantly. In both cases, an important contribution to the RCS, at about 180° and –180°, is generated by the rocket nozzle, which is not coated with RAM in the simulations.

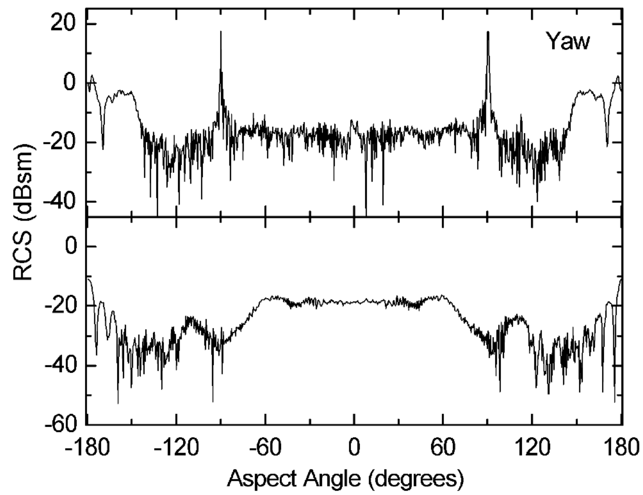

Fig. 4. Simulated RCS of the model of an air-to-air missile at 10 GHz. Rotation in yaw. The angular positions of 0°, -90° and 90°, and -180° and 180° correspond to the front, side and rear views of the model, respectively. In these simulations, the nose dome and the rocket nozzle of the model are perfect conductors. In the top panel, the simulations were performed with fins and wings coated with RAM with r = 0.001. In the bottom panel, the fins, wings and cylindrical body were coated with RAM with r = 0.001.

In Fig. 5 (model rotating in roll), it can be observed that to reduce the RCS of the model, it is required that most of its surface be coated with RAM. The top panel of this figure shows the simulated RCS of the model when only its fins and wings are coated with RAM, and the bottom panel shows the RCS when fins, wings and cylindrical body are coated with RAM; the difference in RCS values between these two situations are of about 50~60 dBsm.

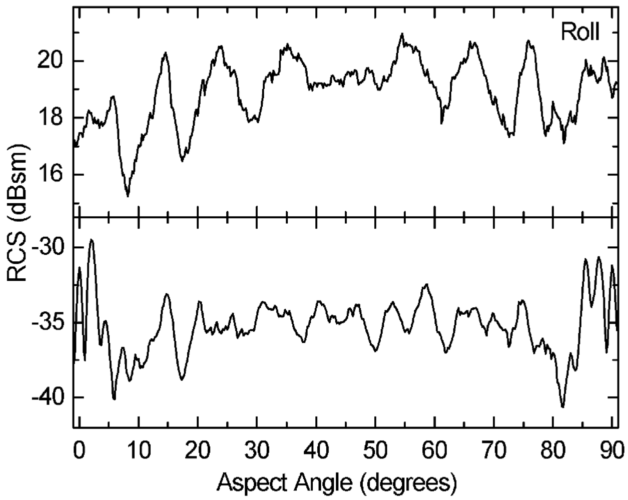

Fig. 5. Simulated RCS of an air-to-air missile model at 10 GHz. Rotation in roll. In these simulations, the nose dome is a perfect conductor. In the top panel, the simulations were performed with fins and wings coated with RAM with r = 0.001. In the bottom panel, the fins, wings and cylindrical body are coated with RAM with r = 0.001. The angular positions of 0° and 90° correspond to the situation where fins and wings are perpendicular to the incident radiation.

V. Conclusions

The RCS of an AAM was simulated using the CADRS software. Depending on the aspect angle, the cylindrical body and the flat surfaces of the wings and fins are the main contributors to the total RCS of the AAM. It is interesting to observe that the mirror of the heat-seeking device can also be an important source of radar signal returns. When only parts of the surface of the AAM are coated with RAM, the resulting RCS is well within the detectability limit of modern radars, indicating that in order to obtain a significant reduction of the RCS it is necessary to essentially coat most of the external surfaces of the AAM with RAM. It is also important to mention that the application of a radar reflective material to the nose dome, which protects the mirror of the heat-seeking system, has the effect of reducing the RCS of the missile when it is illuminated head-on by the radar. These results show the importance of simulation tools in the analysis of targets, for they can help estimate the RCS pattern of the target, identifying the main contributors to the RCS and suggesting approaches to reduce the RCS of the target.

Acknowledgments

The authors wish to thank the Brazilian funding agencies CNPq and FINEP, and also the Brazilian Ministry of Defense for the financial support.

References

[1] G. A. Lindqvist, *CADRCS Simulation Tool*. CSS, Copenhagen, 2005.
[2] "IEEE Standard Definitions for Terms for Antennas," IEEE Trans. on Antennas and Propagation, vol. AP-37, pp. 956-966, June 1989.
[3] E.F Knott, J.F. Schaeffer and M.T. Tuley, *Radar Cross Section*, Norwood, Artech House Inc., USA, 1993.
[4] J. A. Adam, "How to design an `invisible aircraft," *Spectrum IEEE*, vol. 25, no.4, pp. 26-31, April 1988.
[5] H. Essen, S. Boehmsdorff, G. Briegel and A. Wahlen,"On the Scattering Mechanism of Power Lines at Millimeter-Waves", *IEEE Trans. on Geoscience and Remote Sensing*, vol. 40, no. 9, pp. 1895-1903, September 2002.
[6] B. Sweetman. *Stealth Aircraft*. Osceola, Motorbooks International, 1986.