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Shape effect on the Radar Cross Section Reduction of complex bodies

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Abstract:

The shape technique is a technique used to rearrange the models proposed for study in a way that reduces their ability to interact with radar waves, thus reducing the RCS value. This can be done by changing the object's shape or modifying it in a certain way. This technology relates to the manufacture and design of targets to avoid detection by radars.

The missile was divided into three parts: the front of the missile, the missile body (cylinder), and the front and rear wings.

The nose of the missile was changed into three shapes: a conical shape, an elliptical shape, and a cone inside the cylinder. It was noted that the cone-shaped nose is the most effective shape in reducing RCS. The missile body (cylinder) was changed into two cylinders separated by a cone, and the shape of the front and rear wings was changed. The effect of each part was studied independently, then the impact of the three parts combined on the RCS was studied, and the value of the reduction in RCS was found for each case of change. Due to the difficulty of analytical methods in dealing with complex bodies, we resorted to using the HFSS simulation program, which is based on the numerical method in its work.

Key word:

Radar cross section (RCS), Radar cross section reduction (RCSR), electromagnetic scattering, shaping technique, High Frequency Structure Simulator (HFSS).

Introduction:

Radar means Radio Detection And Ranging, An electronic system that locates and detects objects .Radars were initially quite huge stations that were fixed on ground, but they were quickly further improved to fit inside various combat platforms like airplanes and ships[1][2].

Radar has many military and civilian applications ,Such as remote sensing, meteorology, radio wave propagation, Marine navigation, Global Positioning System (GPS), mapping, astronomy, precision distance measurement, and imaging [3][4].

The Radar works by sending radio waves in the direction of the targets and afterward analyzing the reflected echoes [5]. Radar cross section (RCS) provides an indicator of the radar signature, and this quantity can be understood as the ratio of the intensity of the reflected signal from a certain target to the power of the reflected signal from a hypothetical perfectly smooth sphere having a cross-sectional area of 1 square meter [6]. The term "RCS" pertains to measuring an object's ability to reflect radar signals to the receiver[5][6].

Electromagnetic problems deal with conductive and dielectric materials, so the boundary conditions for the components of the magnetic and electric fields are mixed, for the tangential electric field compounds vanish on the conductive surfaces. In contrast, the magnetic and electric field compounds are continual on the surface of the dielectric[7].

RCS is affected by a number of factors, including the geometry of the target and the properties of the target material (permeability, permeability, and conductivity), the frequency of the incident wave, the polarization of the incident and scattering wave, and the target direction relative to the radar[8][9][10].

Since the end of World War II, numerous methods have been developed to lessen the RCS. These methods work by simultaneously lowering the radar's capacity to detect the scattering signal emitted by the target and heightening the target's capacity to avoid being detected by the radar. This is accomplished through the utilization of four distinct strategies, any one of which can be utilized on its own or in conjunction with the others: Target shaping, radar-absorbing materials (RAMs), passive cancellation, and Active cancellation[11][12].

Among the most commonly used RCS reduction techniques are shaping and RAMs. A shaping technique involves changing the surface of a target in order to diffract or reflect incident waves away from radar. Aircraft or ships are generally modified according to aerodynamic principles[13].

The first option to consider for RCSR is target shaping. The shape technique essentially involves orienting the surface of a structure in a manner that scatters incident waves away from the radar angle. A good example of target shaping in practice is the F-117 aircraft, which has panels oriented to reduce radar echo contribution [20].

Zaki, Ahmed, Ra'ed Al-Assdi (2009) studied an EM scattering problem from the complicated body of Revolution (BOR) to determine how the BOR shape affects (RCS) for two bodies [14].

A. Motevasselian and B. L. G. Jonsson conducted a 2009 study to reduce the monostatic RCS of aircraft wings in the forward direction .They use these approximations to simplify the problem [15].

In the x-band Hamid Haider and others in 2012, four targets were simulated through target geometry technology. The first target was an unmanned aerial vehicle, the second target was simulating the nose of the aircraft, the third target was simulating the wing by choosing the types of wings, and the fourth target geometry was the tail after choosing three different types of tail[10].

Mehri Hoseini and others, in 2015, optimized the flying object nose (RCS) using a new shaping method. This method allows continuous scatterer shape parameter changes. A mathematical formula with two parameters defined the nose of flying objects with the desired size and sharpness[16].

Shichun Chen and others introduced a variable-sweep wing study in 2015 to reduce the aircraft's (RCS) and hostile radar detection probability. A3-D digital model of the variable-sweep wing plane is created using Computer Aided Three-Dimensional Interactive Application (CATIA) to generate digital grids [17].

In the current work, the proposed missile was designed with the help of the HFSS simulation software, this software, which is based on the method of moments (MOM) and finite element method (FEM), is used to solve mathematical physics and engineering problems[18]. The suggested targets' geometric design is developed step by step. The change in shape of the missile was studied in three stages, and the parts that most affected the RCS were identified.

Design and Methodology:

The Piranha missile, which the Brazilian Navy and Air Force jointly produced, is a short-range air-to-air missile[19].The missile parts shown in the Fig. (1), dimensions is shown table (1), the mine aim of the current work is to reduce the RCS of missile by using shaping technique.

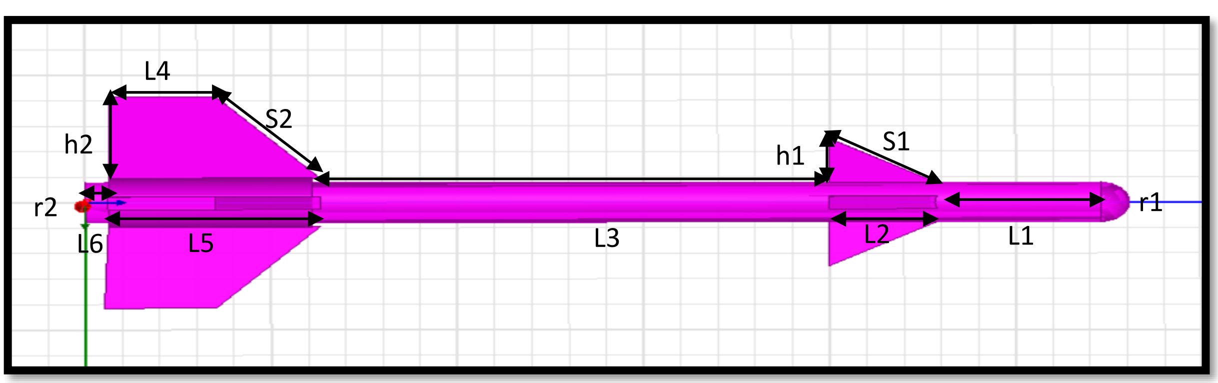


Fig. (1): The Piranha missile with its main dimensions.

symbol	value	symbol	value
r1	1.3 cm	L5	12 cm
r2	1.56 cm	L6	1.2 cm
L1	8.4 cm	h1	4.7 cm
L2	6	h2	4 cm
L3	28 cm	S1	6.8cm
L4	6 cm	S2	8.7 cm

Table (1): dimensions values of proposed model.

Since the target is made of conductive materials, this imposes the existence of boundary conditions that assume that the tangential component of the electric field vanishes on the conductive surfaces[20].

The missile was divided into three parts: the front end (sphere), the missile body (large cylinder), and the rear and front wings. Each part was dealt with independently, and change in (RCS) was noted. Then, note the change that occurred in RCS when collecting the three parts and compare it with the RCS of the original body.

Results and discuss:

The process of scattering in radar pertains to the quantification of the power that is returned by an object. The superposition of the two orthogonal components of the incident wave, E^i_θ, E^i_φ and the far zone scattered wave, E^s_θ, E^s_φ are related by the scattering matrix, according to[21]:

$$\begin{bmatrix} E^s_\theta \\ E^s_\varphi \end{bmatrix} = \frac{e^{-jkr}}{r} \begin{bmatrix} S^{\theta\theta} & S^{\theta\varphi} \\ S^{\varphi\theta} & S^{\varphi\varphi} \end{bmatrix} \begin{bmatrix} E^i_\theta \\ E^i_\varphi \end{bmatrix} \qquad \text{.....................................(1)}$$

The change in the missile structure included the three parts referred to in the previous paragraph. The effect of the three parts and their effect on RCS was studied at frequency Fr=10 GHz, $\varphi = 90$ in the E-plane and the axial incidence of the wave $\theta = 180^{\circ}$.

1- Changing the front end sphere:

The spherical nose of the missile was changed into three shapes (Cone, elliptical, and Cone inside cylinder) for the purpose of testing the effect of the frontal part of the missile on RCS by changing the length of the Cone (h) in five steps, as shown in the table (2):

case	Body front type	h				
i	cone	5 cm	10 cm	15 cm	20 cm	25 cm
ii	elliptical	5 cm	10 cm	15 cm	20 cm	25 cm
iii	Cone inside cylinder	5 cm	10 cm	15 cm	20 cm	25 cm

Table (2): change the dimensions of missile front (the cone length).

i- Change front end sphere to cone shape:

This paragraph deals with changing the spherical nose of the missile to the shape of a cone as shown in Fig. (2). The length of a cone (h) is changed according to dimensions shown in Table (2).

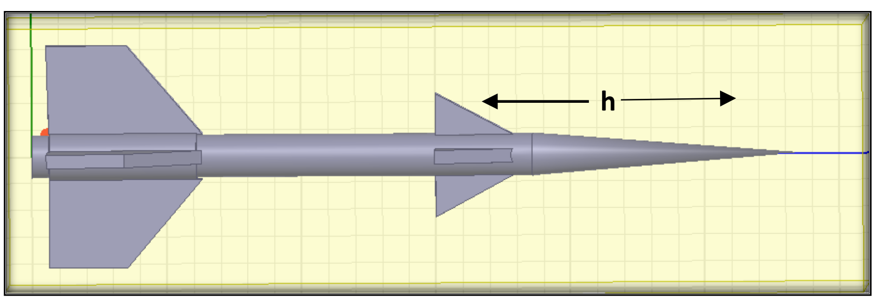


Fig. 2: replace of the missile front from a spherical to a cone front.

After making changes in spherical front of the missile, appeared that the best case in which the length of the cone h=10 cm compared to the spherical front of the missile, the reduction in RCS was about 6.5 dB, as shown in Fig. (3).

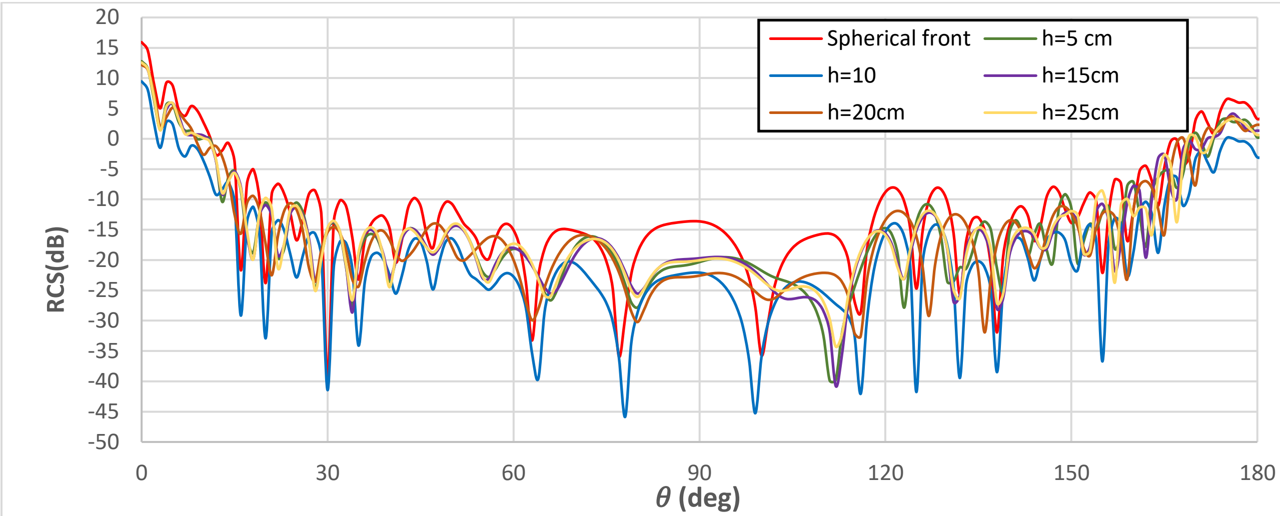


Fig. (3): simulation results of the bistatic RCS of a missile with a spherical nose and a Missile with a cone nose with different vale of h.

In fact, Geometry, or shape and not the target's size, is the most crucial aspect impacting RCS. Shape of the target can significantly influence the RCS value. Some shapes produce greater RCS values, and some forms make lower RCS values. On the other hand, creating objects with rounded edges and smooth curves may help raise RCS levels by reducing diffraction effects and increasing surface area.

The designers tried to minimize the presence of surfaces or edges that could align their normal vectors with the direction where an enemy radar could be located, particularly with the frontal aspect. Hence, avoiding curves or bumps within the context of reducing radar cross-section (RCS) is imperative[22].

ii- Change front end sphere to elliptical shape:

The missile's spherical nose was changed to an elliptical shape, as shown in Fig 4.

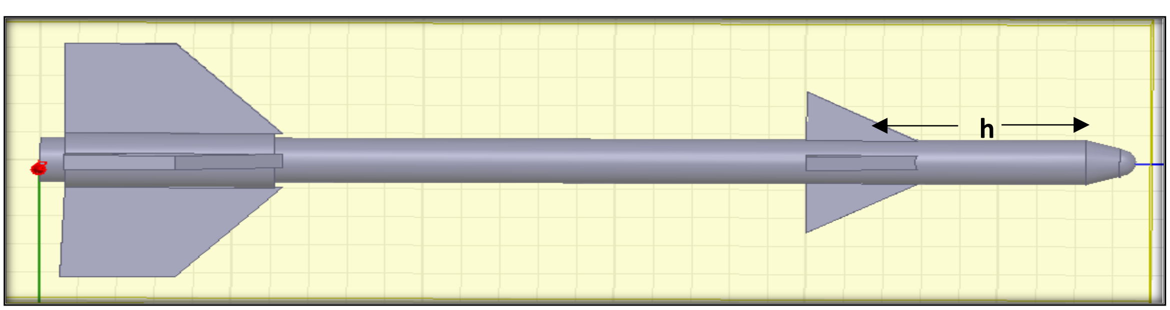


Fig. (4): the missile of elliptical nose shape.

The best results were obtained in the axial incident for the bistatic RCS case when h=15 cm, as shown in Fig. (5), and the RCSR for this case is about 4.3 dB.

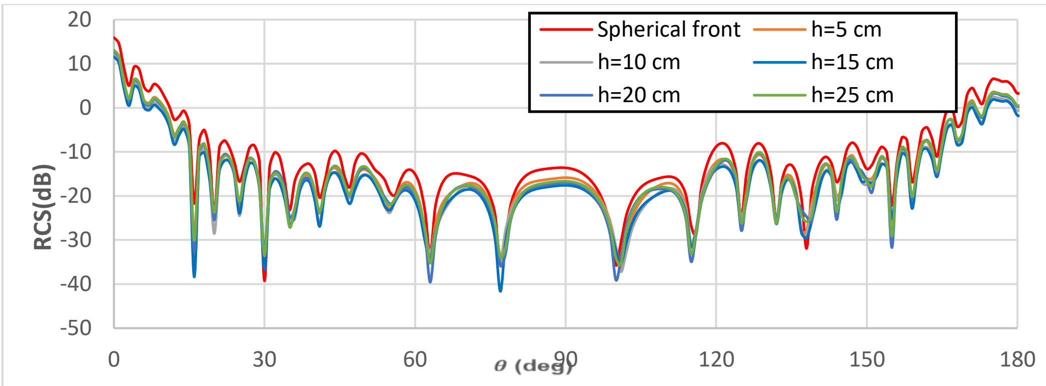


Fig. (5): Comparison between the bistatic RCS of a missile with a spherical nose and a Missile with an elliptical front of length h.

iii- Change front end sphere to cone inside cylinder:

In this test, the spherical front of the missile was transformed into a cone inside cylinder as fig. (6). the length of the cone (h) changed according to the dimensions shown in Table (2).

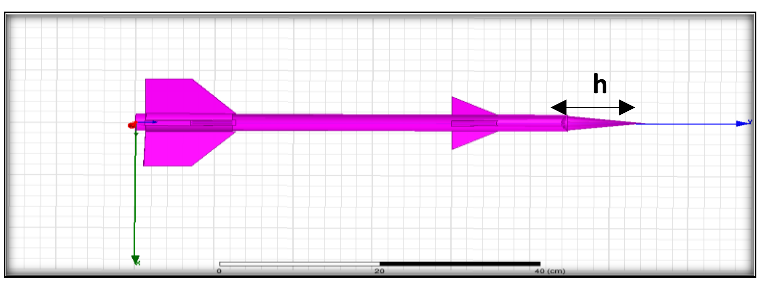


Fig. (6): Transform of the missile's spherical nose to cone inside cylinder shape.

The results obtained in the axial incident for the Bistatic RCS case, is shown in Fig. (7), and the RCSR value for this test is 3.5 dB when the length of cone equal to h=10 cm.

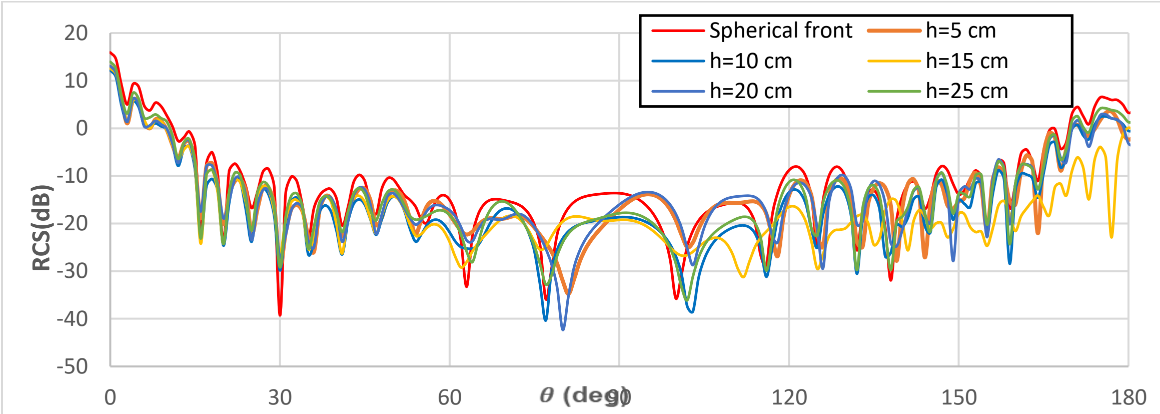


Fig. (7): simulation result the bistatic RCS of a missile with a spherical nose and a Missile with cone inside cylinder of length h.

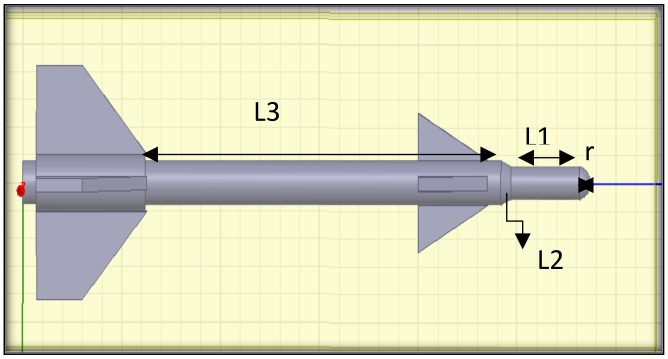
Comparing the three case above with the missile's RCS with a spherical nose, a cone nose has the most impact on RCS. Because body form impacts RCS, missiles with spherical noses have a high surface area in front of the incoming radar wave. The missile's cone-shaped nose reduces radar wave exposure, lowering RCS.

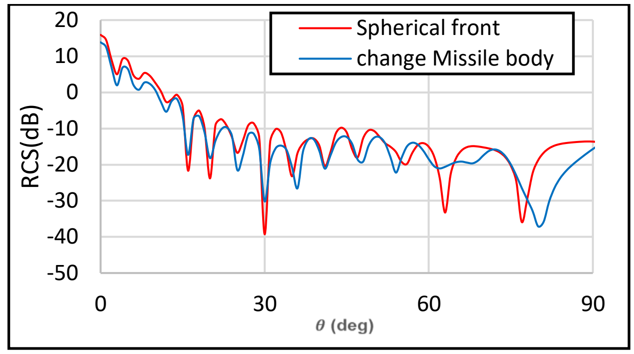
2- Body of the Missile (cylinder):

Some simple changes were made to the missile body, and the best case was chosen to obtain a reduction in the RCS.

Changes made during design in the shape of the missile body affect the (RCS), and therefore the ability of the Radar to detect and track the target, and this can further RCSR by 50% of the chance Missiles and targets that can avoid detection by Radar.

The missile body was changed from a cylinder into two cylinders separated by a cone, as Shown in Fig. (8) And dimension of Body Missile arranged as: r=1.2 cm, L1=7 cm, L2=1 cm, L3=36 cm.





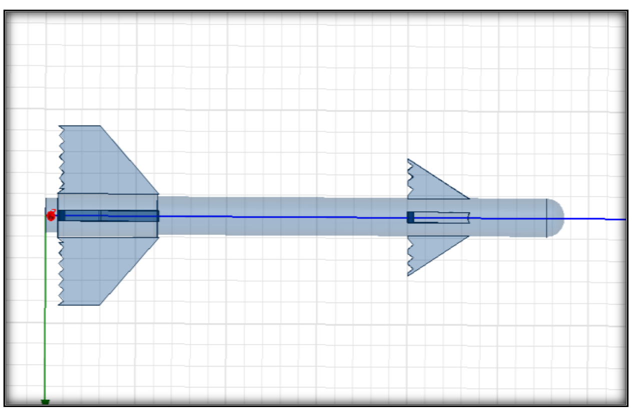
(a) (b)

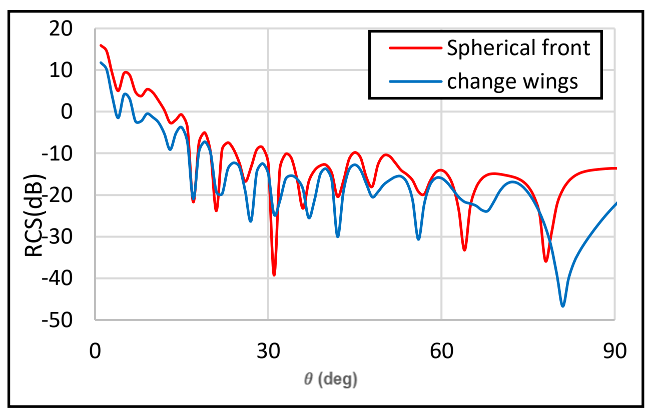
Fig.(8): (a): Modulation second part of missile and (b): compared RCS between Spherical Front and change missile body.

From fig.(8-b), we notice that the reduction value in RCS is 2 dB, which is less than that in the first part.

3- Change Wings of the missile:

The missile dimensions in Fig. (9-a) are the same as those in table (1), with the wings changed. From observing Fig. (9-b), we notice that the reduction in RCS is 4 dB.



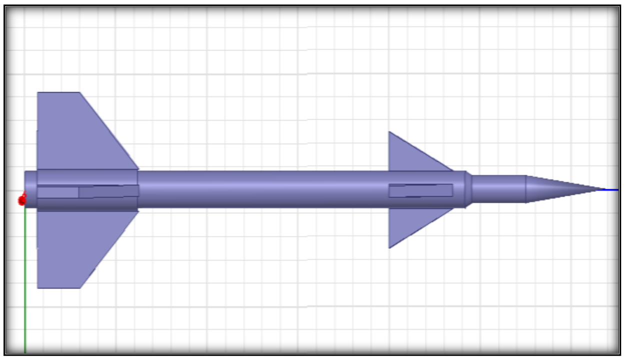


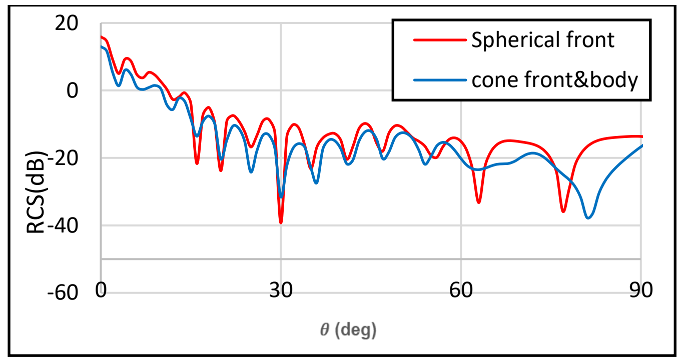
(a) (b)

Fig.(9):(a) Conversion third part of missile and (b): comparison RCS between Spherical Front and change of wings missile.

Changing the three parts of the missile, we find that changing the spherical nose of the missile to a cone shape is the most influential case on the RCS value, as the RCSR value in the case of the cone is the highest value among the other values.

If we take the change of the missile's spherical nose into a cone with the change of the missile's body (cylinder), we notice that the reduction in RCS is 2.9 dB, as shown in the fig.(10-b).

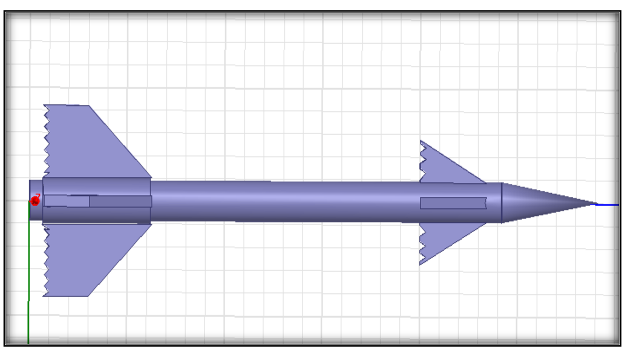


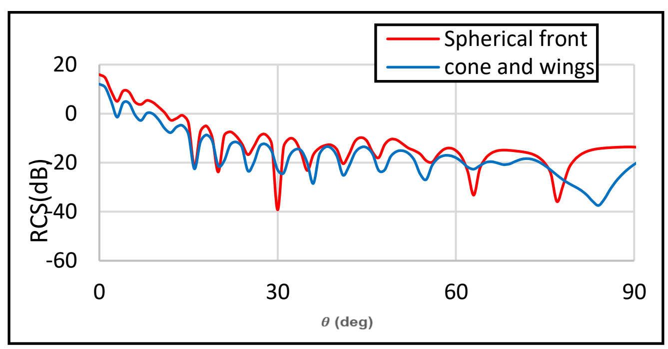


(a) (b)

Fig.(10):(a) Altering first and second parts of missile and (b): comparison RCS Between Spherical front and first and second parts of missile.

On the other hand, the convert the missile from spherical nose to a cone with the change of wings, the results RCSR is about 3.8 dB, as shown in the fig.(11-b).

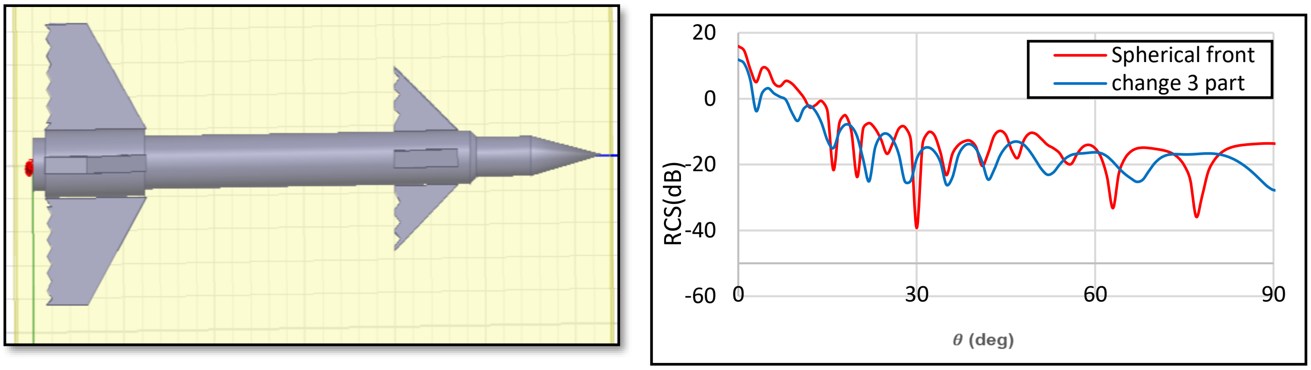




(a) (b)

Fig.(11):(a) changed first and third parts of missile and (b) comparison RCS between Spherical front and first and third parts of missile.

Finally, the effect of changing the three parts (spherical front, body, wings) together and comparing them with a missile with original case, we notice that the reduction in RCS is 4 dB.



(a) (b)

Fig.(12):(a) Remodel three parts of missile , Fig.(b): comparison RCS Between Spherical front and change three parts of missile.

Conclusion:

Utilize geometric design principles to shape the target in a way that minimizes radar reflection. Shaping technique aims to make the target's surface deflect the reflected radar waves in many directions without returning to the radar. There are many areas in the target's body, such as the front and wings, that have a significant role in RCS, and changing the shape of these areas reduces the RCS, Therefore, the research does not focus on the impact on aerodynamic properties or the combat missions for which the target is designed. The reduction came in varying proportions depending on the selected sections of the missile. In the case of changing the nose 6.5dB, the body 2 dB and the wings were reduced 4 dB.

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