The Radar Cross Section of Marine Vessels

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Abstract

This paper focuses on the estimation of ship RCS using High-Frequency Structure Simulator (HFSS). The results produced here have been compared to the estimates available in the open literature of a Canadian cargo ship named Teleost and also measured values. In this paper, the RCS of a Canadian marine ship named "Teleost" is presented. RCS depends on various parameters like shape, size, orientation, operating frequency and aspect angle. Simulations using Finite Element Method (FEM) in Ansys HFSS software for monostatic Radar Cross Section were made through 0.1MHz to 8MHz frequency. The results of the proposed method are compared with the existing measured values and simulated values available in open literature. The work is carried out using PEC and steel as the dielectric material to analyse the monostatic RCS values, and a broad comparison is made among previous values and the obtained values. The results of this proposed method are more accurate when compared to the previous works, and are very near to the measured values. The work is carried out using Perfectly Electrical Conductor (PEC) and steel as the materials. The simulations of these two materials are carried out individually, to analyze the Monostatic RCS values.

Keywords: *Radar cross-sections (RCS), High-Frequency, Surface Wave Radar (HFSWR) High-Frequency System Simulation (HFSS), Monostatic RCS, Perfectly Electrical Conductor (PEC)*

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1. Introduction

Radar is the acronym for "RAdio Detection and Ranging". Radar uses radio waves (electro-magnetic waves). These waves have one of the largest wavelengths and smallest frequencies in the EM spectrum. Due to this, radio waves can travel long distances. This property of traveling long distance makes the most basic application of radar, that is ranging and detection. The distance measurement is one of the important applications of radar.

The basic concept of radar is, it transmits a Radio Frequency (RF) signal which is generated by the transmitter, which is radiated by the transmitting antenna and reflected from the reflecting object (target). A small portion of the reflected signal known as 'echo' returns to the radar receiver. Radar uses the 'echo' signal to determine the direction and distance of the reflecting object [1]. Radar can detect targets at near and far distances and it can also measure their range with precision, in all weather conditions, which is a major advantage when compared with other sensors. Usually radar provides exact location of target in range and angle. The change in target location can also be measured from the variation in range and angle with respective to time, by which the 'track' is possible.

Radar operates at different frequencies from a few Megahertz (MHz) to Gigahertz (GHz) within wide range of spectrum, where radar operation principles are the same at any frequency, but the practical implementation is widely different. Electromagnetic waves normally disperse incident energy in all directions when incident on a target. The spatial distribution of energy is called 'scattering', and the object itself is called as 'scatterer'. The energy scattered back to the source of the wave is called 'back-scattering', which mainly

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constitutes the radar echo of the objects. The intensity of the echo is described explicitly by the Radar Cross Section (RCS) of the object.

Therefore, it is critical in design and operation of radars to quantify or describe the echo, in terms of target characteristics as size, shape, and orientation. For this purpose, the target is described as an effective area or echo area terms, still found occasionally in contemporary technical literatures. [2] The Radar Cross Section (RCS) is defined in eq. 1

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \left(\frac{|E_s|}{|E_0|^2} \right)^2 \tag{1}$$

Where

- R is distance between radar and target
- E_0 is electric-field strength of incident wave on target
- Es is electric-field strength of scattered wave at radar.

RCS is also defined as a comparison of the scattered power density at the receiver to the incident power density at the target [3]. This definition also valid for the electric-field strengths and magnetic-field strengths of the incident and scattered. The basic tenets of RCS are as follows

1. RCS can be defined as the ability to reflect the radar electromagnetic waves.
2. RCS value tells how easily an object is detectable by radar.
3. RCS must be as low as possible for the benefit of not being detected.

Since, RCS is important factor to achieve stealth of an object, prediction and reduction of RCS become an important aspect while the vehicle is being built. Where prediction is defined as finding the RCS of an object, while reduction is a process of reducing the value of RCS. Prediction can be done in two ways, one being the conventional way, using the mathematical formulas and techniques available in the open literature and other way is the usage of simulation software's available. There are many commercially available software's that can predict the RCS value with high accuracy. Even there are many ways that focus on the reduction of RCS value. Some of them are the application of Radio Absorbing Materials (RAM), changing the dimensions of the vehicle, etc. RCS plays an important role in the understanding of the EM phenomenon of radar. The following methods are used for determining the RCS

- Geometrical Optics (GO)
- Physical Optics (PO)
- Geometrical Theory of Diffraction (GTD)
- Physical Theory of Diffraction (PTD).

The following techniques are used by commercial software's for the prediction of RCS are:

1. Methods of Moments (MoM): This type is used for linear and partial differential equations.
2. Finite Element Method (FEM): It is used for complex geometric shapes. In this method, the complex object is divided into smaller parts and the RCS of each smaller part is calculated and then added to get the RCS of the complex shape.
3. Finite Distance Time Domain (FDTD): It is the simplest and easiest to implement [4].

The main objective of this paper is to find or predict the RCS of the objects by deploying a 3D model in ANSYS HFSS software and evaluating the performance by comparative study obtained from achieved results to results available in open literature. One of the oldest methods of finding the RCS value of any object in the lab is 'MACROSCOPE'.
There are many other software's that can be used to predict the RCS value of any object by simulating the conditions, which can be set by the user.

Here in this paper, ANSYS HFSS software is used for the prediction of the RCS value along with the shape and size of the object, which play a major role in predicting value of RCS. Factors like wind and water reflections (for naval applications) will affect the value of RCS (when measured physically).

Figure 1: Teleost Ship

2. Literature Survey

The initial works on radar started in 1962, the authors discussed about the basics of the radar and its uses in [2]. One of the usages is to find RCS of an object. Taking a clue from research [2], the first major work on RCS and importance of RCS were discussed and published in the year 1978 by [5]. This discussion has led to the increase in attention towards RCS [6]. In [7], the author discusses a laboratory method to find (predict) the RCS using a software, which can be used to predict the RCS of any object. In the year 2006, work on 2 Canadian cargo ships was carried out to simulate the RCS values, using the HFSWR method and comparing the values with the originally measured value [8]. Taking a clue from the previous research of [8], authors discussed the effect of oceanic environment, and conducted a work in 2009, to calculate the practical effect of the oceanic environment on the value of RCS of any object in atmosphere. In 2012, one of the major researches was conducted on the prediction and the reduction of the RCS value for naval ships [9]. In [10], the authors have presented the different methods of predicting the RCS of ships and different parameters which will affect the value of RCS are presented.

In 2013, the authors have presented research on the (RAM) Radar Absorbing Material [11], they have di-electric properties. They are used to reduce the value of RCS of any ship or aircraft. RAM works on the principle of the object absorbing the electromagnetic wave energy to minimize the intensity of the reflected signal. The imaginary part in the dielectric constant leads to a reduction or decrease in the value of RCS.

In 2015, two major research works in the field of RCS are conducted. One research has worked on a combination of Frequency and Material Independent Reactions - Methods of moments 'FMIR-MoM' with the 'barycentric sub-division' to analyze the wide-band RCS of objects with 'PEC' material was discussed in [12]. Another research has worked on the different ways to calculate the RCS. Mainly techniques like Physical Optics (PO) and

Geometrical Optics (GO) are used to calculate the RCS. In [13] authors utilized software mechanism for the prediction of RCS. In 2017, for the first time, High-Frequency Ground Wave Radar (HFGWR) was used to predict the RCS of ships. With the use of HFGWR, the RCS value is significantly improved [14].

In 2018, RCS was used to calculate the dynamic human motions by virtual reality [15]. Authors used the Shooting and Bouncing Ray (SBR) technique. In this work, the human body was converted into a poly mesh and the SBR technique was used.

3. Experiment Analysis

In this work, experimental analysis is carried out using ANSYS High Frequency System Simulation (HFSS). The Canadian marine vessel named 'Teleost' is illustrated fig. 1, and 3D models of side view and top view of the 'Teleost' ship are shown in fig. 3 and fig. 4. In addition, to this fig. II shows top view of a ship with respective to angles of incident fields referred to Port, Starboard, Bow and Stern. Here ship is modeled using Perfectly Electrical Conductor (PEC) material.

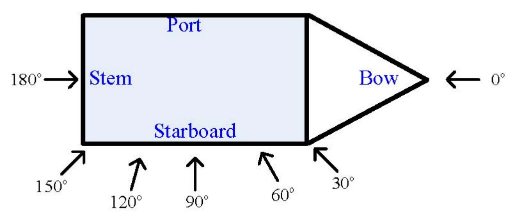

Figure 2: Teleost Ship Top View w.r.to incident angles

The Monostatic RCS values of the ship is obtained by taking the reference of the top view of the ship fig. 2.

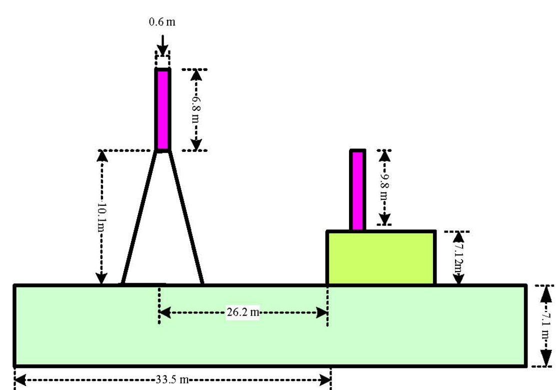

Figure 3: Ship Side View

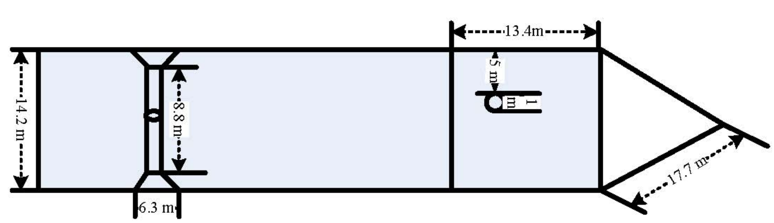

Figure 4: Ship Top View

Analysis are carried out using a frequency sweep ranging from 0.1 MHz to 8.0 MHz. Excitations are set up at the starboard angle of the ship. Boundaries are set up at the corners of the ship. The simulations are carried out using ANSYS HFSS 2019 software tool.

4. FEM Analysis

Finite Element Method (FEM) subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object.

The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then approximates a solution by minimizing an associated error function via the calculus of variations. The Finite element breaking of the Teleost Ship is shown in fig. 5.

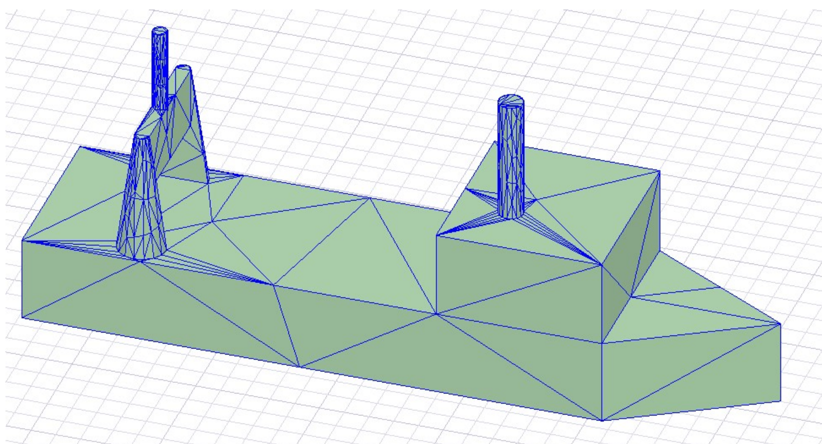

Figure 5: Finite Element breakdown

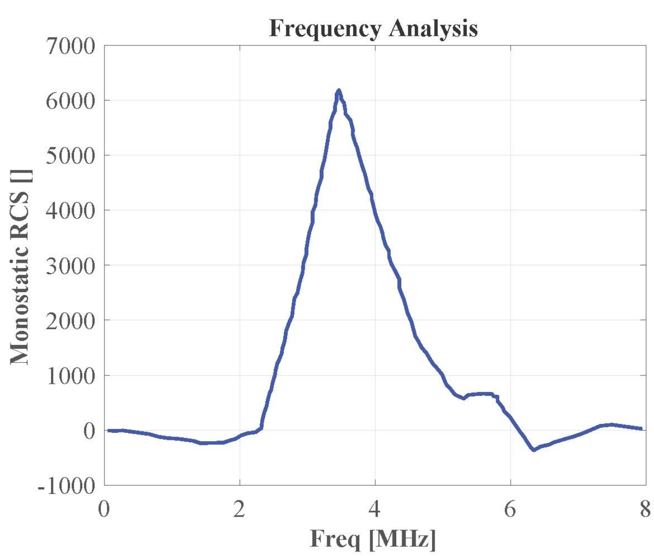

Figure 6: Frequency Analysis

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4.1 Results, Discussions and Observation

Analysis were carried out using FEM method on PEC material of 'Teleost' ship, and the observations are presented below in fig. 6. It is observed that a dip in the value of RCS at 6.5 MHz. One major reason behind that dip is the A-Frame mast in the Teleost ship (which can be observed in the fig 1). Where a mast is a spar, or arrangement of spars, which is erected more or less vertically on the center-line of a ship used for carrying sails, and derricks, which gives necessary aid to a navigation, for look-out position, signal yard, control position, radio aerial, or signal lamp.

From the simulations, fig. 6 shows a dip value at 6.5MHz and the Monostatic RCS value has a peak at 4 MHz. From this analysis, authors used only 4MHz frequency and tested at different parts of the ship. At the bow part of ship, the Monostatic RCS is 41.5dB, for starboard it is 42dB, and for stern it is 42dB, and whereas for port 39.5dB values are obtained for the PEC material. Table I shows the comparison of simulation values achieved and observed from previous literature [8], [16], for PEC material.

From the above values it can be noted that, for PEC material, the Monostatic returns obtained in this study have good gain, when compared with the values in [8], [16]. Here, authors not only considered PEC as a material, also considered Steel as another material and carried out for analysis. Simulation shows the observed values are 42.5dBat bow, 35dB for starboard, 32dB at the stern, and 41dB at the port.

Table 1: Comparison of the RCS Values of 2 different Papers to the Simulated Values

S.No.	Position of Consideration	Simulated values from [8]	Simulated values from [16]	Measured values from [16]	Simulated Values
1	Bow	41.9	38.4	40	41.5
2	StarBoard	42.2	34.4	42	42
3	Stern	40	36.4	40	42
4	Port	NA	32.5	43	39.5

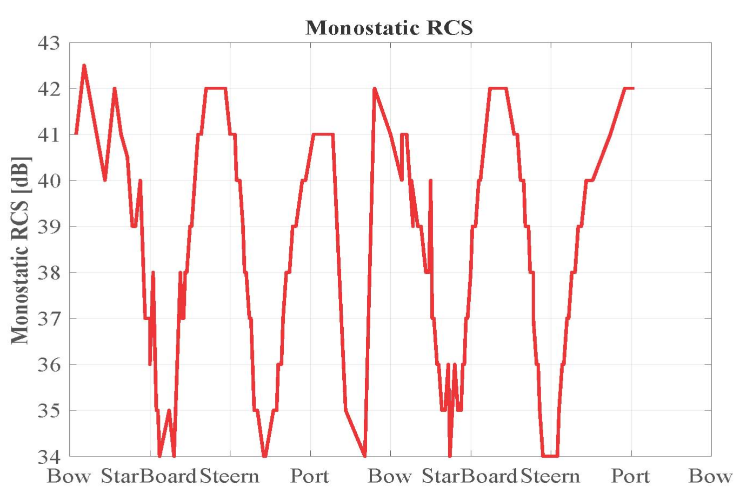

Figure 7: Monostatic RCS

Figure 7 shows Monostatic RCS values for various azimuth angles from (-180 to +180 or 0 to 360) of incident fields referred as the different parts of the ship mainly port, starboard, bow and stern.

Whereas fig. 8 shows the comparison of simulation values achieved and observed from previous literature [8], [16], shows the measured values and respective simulation values for PEC material. In fig. 8 'blue line' depicts the simulated RCS values, and 'Red Stars' shows physically measured values from [16]. The 'purple line' shows are the simulated values used by [8]. The 'yellow line' represents the RCS values obtained from simulation using ANSYS HFSS software for PEC material. The fig. 9 illustrates the comparison between PEC and steel as material with respective to various angles of incident fields.

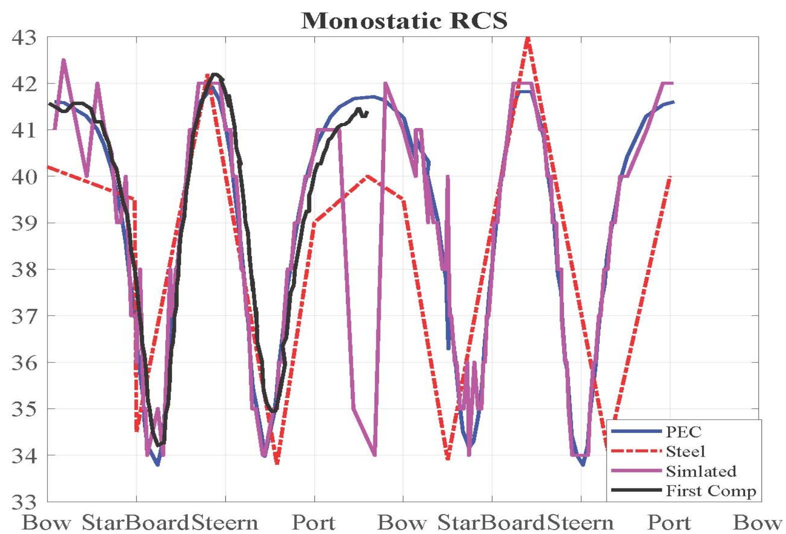

Figure 8: Comparison plot

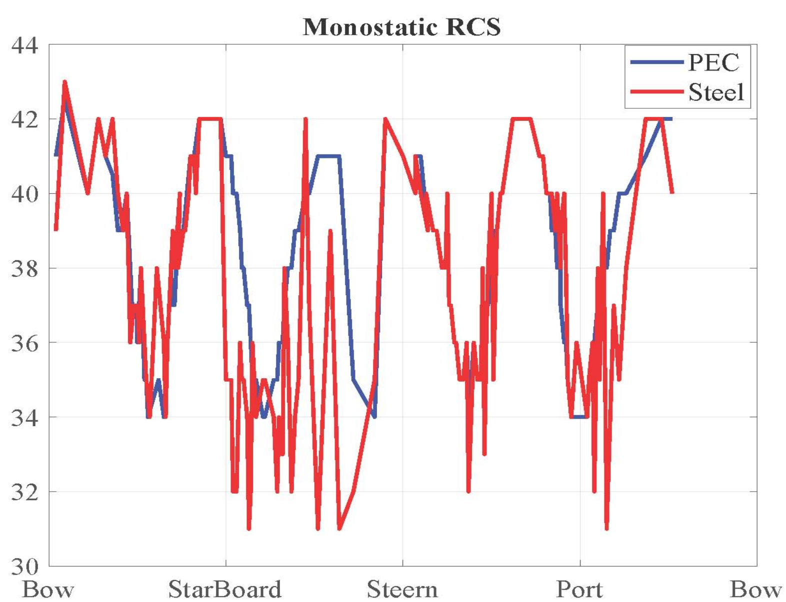

Figure 9: Steel vs PEC

5. CONCLUSION

In this paper the value of RCS of a Canadian ship "Teleost" which is modeled by PEC and steel materials is successfully predicted using HFSS and the Finite Element Method, the produced results prove to be better than the results in the existing literature. In future the effect of the environment on the value of RCS can also be studied.

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REFERENCES

1. G Richard Curry, Radar System Performance Modeling. Artech House, BOSTON LONDON, second edition ed., 2000.
2. M. I. Skolnik, "Introduction to radar," Radar handbook, vol. 2, p. 21, 1962.
3. MERRILL I. SKOLNIK, Radar Handbook. McGraw-Hill, Inc., second edition ed., 1992.
4. E. F. Knott, J. F. Schaeffer, and M. T. Tulley, Radar cross section. SciTech Publishing, 2004.
5. F. Paddison, C. Shipley, A. Maffett, and M. Dawson, "Radar cross section of ships," IEEE Transactions on Aerospace and Electronic Systems, no. 1, pp. 27–34, 1978.
6. D. W. Hess, "Introduction to rcs measurements," in 2008 Loughborough Antennas and Propagation Conference, pp. 37–44, 2008.
7. M. B. Heydari, M. Asgari, M. Zolfaghari, and N. Jafari, "Comparison of various full-wave softwares in calculating the rcs of simple objects," International Journal of Mechatronics, Electrical and Computer Technology (IJMEC), vol. 8, pp. 4002–4008, 2018.
8. H. Leong and H. Wilson, "An estimation and verification of vessel radar cross sections for high-frequency surface-wave radar," IEEE Antennas and Propagation Magazine, vol. 48, no. 2, pp. 11–16, 2006.
9. J. Khan, W. Duan, and S. Sherbaz, "Radar cross section prediction and reduction for naval ships," Journal of Marine science and application, vol. 11, no. 2, pp. 191–199, 2012.
10. V. D. Charris and J. M. G. Torres, "Analysis of radar cross section assessment methods and parameters affecting it for surface ships," Ciencia y tecnolog´ıa de buques, vol. 6, no. 11, pp. 91–106, 2012.
11. I. M. Jaber and H. I. Hammed, "Radar absorbing material (ram) and its effects on the radar detection range," Journal of Madenat Alelem University College, vol. 5, no. 2, pp. 6–15, 2013.
12. P. Du, Y. Shao, and J. J. Zhang, "Wideband rcs analysis of pec objects by combining fmir-mom with barycentric subdivision-based quadrature technique," in 2015 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz. Applications (IMWS-AMP), pp. 1–3, IEEE, 2015.
13. J.-T. Hwang et al., "Radar cross section analysis using physical optics and its applications to marine targets," Journal of Applied Mathematics and Physics, vol. 3, no. 02, p. 166, 2015.
14. K. Sun, B. Wen, and R. Wang, "Analysis of ship rcs detected by multifrequency hfgwr," International Journal of Antennas and Propagation, vol. 2017, 2017.
15. A. D. Singh, S. S. Ram, and S. Vishwakarma, "Simulation of the radar cross-section of dynamic human motions using virtual reality data and ray tracing," in 2018 IEEE Radar Conference (RadarConf18), pp. 1555–1560, IEEE, 2018.
16. S. K. Podilchak, H. Leong, R. Solomon, and Y. M. Antar, "Radar crosssection modeling of marine vessels in practical oceanic environments for high-frequency surface-wave radar," in 2009 IEEE Radar Conference, pp. 1–6, IEEE, 2009.