RCS Results for an Electrically Large Realistic Model Airframe

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Abstract **─** The accuracy with which MLFMM, PO and PO with SBR can calculate the RCS of a realistic electrically large model airframe is investigated. The target has a maximum electrical length of 106λ. An accurate 3D numerical model of the target was created using a laser scanner. The numerical results are validated against data measured in a compact range.

Index Terms **─** Method of moments, other asymptotic methods, RCS measurements, scattering/RCS.

I. INTRODUCTION

Validated radar cross section (RCS) data is required for various radar and electronic warfare (EW) applications, viz. detection studies and the development and testing of non-cooperative target recognition (NCTR) techniques. A number of studies have compared measured and simulated RCS of canonical structures or targets constructed of simple canonical structures. A few RCS benchmarking targets have been defined in [1], but almost all of these structures are either electrically simple and/or small. Recently a study compared the measured and simulated data of a relatively electrically large Boeing 777 scale model. This model had a total length of 21λ. A commercially available computer aided design (CAD) model of the Boeing 777 was used with the CADRCS software package, which implements physical optics (PO) combined with ray-tracing and shadowing to calculate the RCS [2]. In [3], three different electrically large targets were analyzed. The computational electromagnetic (CEM) methods that were compared included the multilevel fast multipole method (MLFMM) and PO with shooting and bouncing rays (SBR). The three targets that were analyzed included a trihedral corner reflector, a generic cruise missile and a Cessna 172 model. Only simulated results were considered with MLFMM results used as a reference.

This paper considers the RCS of a realistic 1:25 scale model of a Boeing 707. The model is electrically large with a maximum electrical length of 106λ. The scale model is constructed from thin-walled aluminium. Instead of representing the target as a composition of simple canonical structures or using a commercially available CAD model, a very accurate 3D CAD model was created by laser scanning the scale model. Different CEM methods were used to calculate the RCS of the airframe, using three software packages, viz. MLFMM using FEKO and CST, PO using FEKO, and PO with SBR using SigmaHat (developed by CSIR DPSS, South Africa). The calculated data are validated against RCS data measured in a compact range at the University of Pretoria, South Africa.

II. EXPERIMANTAL SETUP

The VV-polarized monostatic RCS of the model was measured in the compact range (Fig. 1) as a function of frequency and azimuth angle (-180° to 180°) with a typical accuracy of 0.2 dB. The angular increments were 0.2°.

Simulations were performed in the three packages, utilizing different CEM methods, to calculate the VV-polarized monostatic RCS of the target. All the simulations were performed at 10 GHz and 17 GHz over azimuth (0° to 180°) in 0.2° steps, at 0° elevation.

Fig. 1. Boeing 707 scale model in the compact range and laser scanned 3D CAD model in FEKO.

The 3D CAD model used for the simulations is also shown in Fig. 1. The laser scanning was conducted at CSIR Technology for Special Operations (TSO) with

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a hand scanner which generated a 3D point cloud of the model. This point cloud was converted to a mesh model using 3D processing software. The mesh model was imported into FEKO and a simulation mesh was created. The scanned model has an average accuracy of better than 0.2 mm relative to the actual scale model.

FEKO and CST simulations were performed using the MLFMM solver with the combined field integral equation option to increase the computational speed of the simulations [4, 5]. The model was discretized with a mesh size of $\lambda/10$ at 10 GHz, resulting in 570,236 and 570,196 mesh triangles in FEKO and CST, respectively. The full-wave and asymptotic methods compared to the measured data at 10 GHz are provided in Fig. 2 and Fig. 3, respectively. The 17 GHz data is provided in Fig. 4 and Fig. 5, respectively.

III. METRICS AND PERFORMANCE

In general, the results show good agreement between the overall shape of the measured and simulated data over the entire azimuth range for all four CEM techniques considered. The two asymptotic techniques differ from the measured data over small angular regions, where the RCS values are low. There are some distinct characteristic returns in the angular RCS response, the first being at port side broadside, between 89º to 91º (10 GHz) and 89.4º to 91.8º (17 GHz), when the fuselage of the aircraft is perpendicular to the incident field. Here, the RCS values are the largest and have narrow beam-widths. The second characteristic return is the flash produced by the leading edge of the port side wing, between 38º to 41.2º (10 GHz) and 38.2º to 40.4º (17 GHz).

A. Accuracy metrics

The critical ranges in the accuracy analysis were chosen to be the azimuth ranges which included the characteristic returns, namely the broadside return and wing flash. Four accuracy metrics were defined to compare the measured and simulated RCS results, and to quantify the accuracy of the various methods.

The first metric is the difference between the measured and simulated peak RCS values, in the critical azimuth ranges. The absolute values of the deep nulls were disregarded as they may have led to misleadingly large RCS differences. These large differences could be due to the miss sampling of nulls or slight misalignment between the geometrical shape of the physical and numerical models. The second metric is the azimuth angle ranges, in the critical regions, over which the difference between the measured and simulated RCS remained less than 5 dB. The angular accuracy of the side lobes near the characteristic returns is chosen as the third metric. The fourth metric is the peak RCS differences and the side lobe accuracies of the methods over an azimuth range where the RCS values are lower (i.e., below -5 dBsm). This range is chosen from 41.2º to 60º for the 10 GHz data and 40.4º to 64º for the 17 GHz data, and will be referred to as the lower RCS range.

Expanded views of the angular ranges surrounding the port broadside and wing flash of the 17 GHz data are provided for easier visual comparison in Fig. 6 and Fig. 7. Figure 7 also includes an expanded view of the lower RCS azimuth range from 40.4º to 64º.

B. Numerical performance

A summary of the evaluated accuracy metrics for all four methods at 10 GHz is provided in Table 1.

MLFMM (FEKO) results at 17 GHz of the broadside return are accurate to within 5 dB and the wing flash to within 4.0 dB. The azimuth ranges over which the simulated RCS remains within 5 dB of the measured RCS is 43.6º and 29.4º, respectively. The angular accuracy of the side lobes near the characteristic returns are 0.2º and 0.4º, respectively. This method's RCS results are accurate over 40.4º to 64º (the lower RCS range). Here, the maximum difference between the calculated and measured data is 7.3 dB and the side lobes are accurate to within 0.4º.

The MLFMM (CST) results at 17 GHz of the broadside return are accurate to within 5 dB and the wing flash to within 4.2 dB. The azimuth ranges over which the simulated RCS remains within 5 dB of the measured RCS is 44.8º and 30.4º, respectively. The angular accuracy of the side lobes near the characteristic returns are 0.2º and 0.4º, respectively. This method's RCS results are accurate over the lower RCS range. Here, the maximum difference between the calculated and measured RCS data is 8.0 dB and the side lobes are accurate to within 0.4º.

With PO (FEKO) at 17 GHz some ranges are slightly inaccurate, but there is overall good agreement at the characteristic returns. The broadside return and wing flash is accurate to within 2.5 dB and 3.5 dB, respectively. The azimuth range over which the simulated RCS remains within 5 dB of the measured RCS is 29.8º and only 8º, respectively. The angular accuracy of the side lobes near the characteristic returns is 0.2º. The maximum RCS difference in the lower RCS range is 11.7 dB and there is almost no correlation between the simulated PO and measured side lobes in this range. Larger errors are produced by the PO method, between 43.4º and 59.6º compared to the MLFMM method.

PO with SBR (SigmaHat) results for the broadside return and wing flash are accurate to within 3.3 dB and 3.7 dB, respectively at 17 GHz. The azimuth ranges over which the simulated RCS remains within 5 dB of the measured RCS is 24.8º and only 9.6º, respectively. The angular accuracy of the side lobes near the characteristic returns is 0.2º. The maximum difference in the lower RCS range is 10.1 dB and although the RCS trends are similar in this azimuth region, there is almost no correlation between the simulated PO with SBR and measured side lobes. This method produced larger errors between 43.4º and 59.6º compared to the MLFMM method.

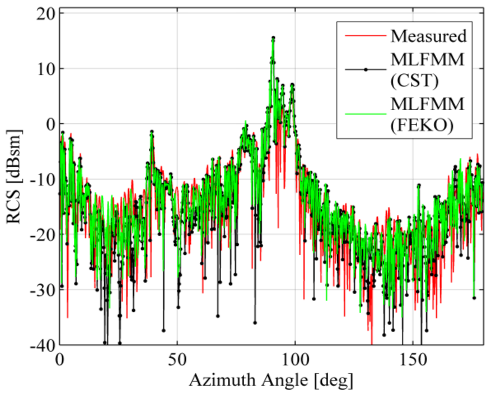

Fig. 2. RCS measured at 10 GHz compared to RCS calculated with MLFMM in FEKO and in CST.

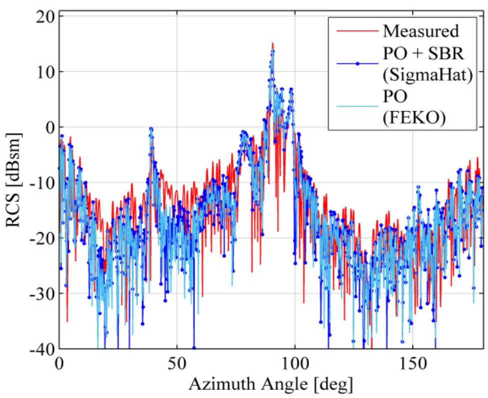

Fig. 3. RCS measured at 10 GHz compared to RCS simulated via PO in FEKO; PO with SBR in SigmaHat.

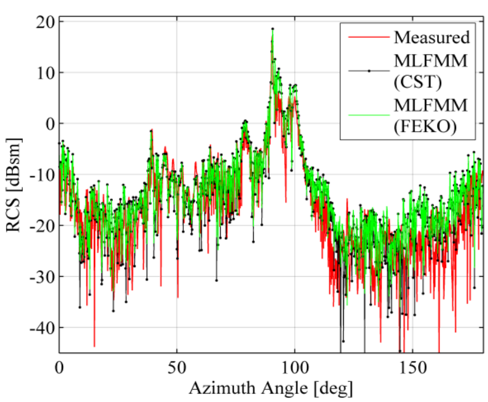

Fig. 4. RCS measured at 17 GHz compared to RCS calculated with MLFMM in FEKO and in CST.

A summary of the evaluated accuracy metrics for all four methods at 17 GHz is provided in Table 2. Key specifications of the computers that were used for the simulations, as well as the computing resources required by each method, are summarized in Table 3.

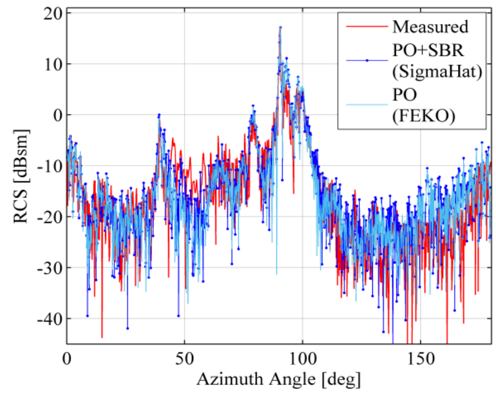

Fig. 5. RCS measured at 17 GHz compared to RCS simulated via PO in FEKO; PO with SBR in SigmaHat.

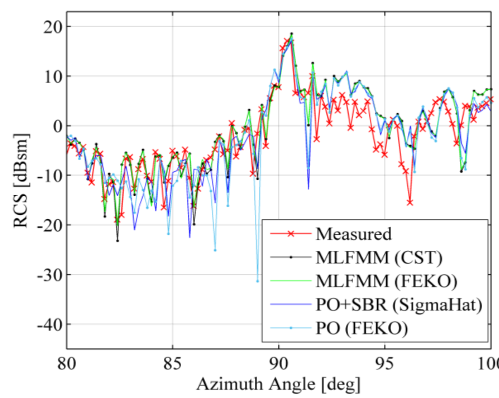

Fig. 6. RCS measured and simulated with the different methods, at 17 GHz for the port side broadside.

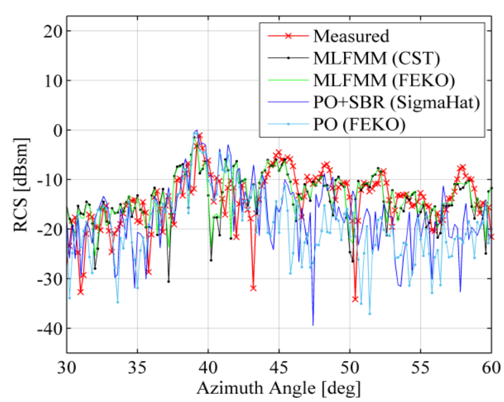

Fig. 7. RCS measured and simulated at 17 GHz at the port side wing flash and the lower RCS range.

Table 1: Summary of the accuracy metrics at 10 GHz

Metric	MLFMM (FEKO)	MLFMM (CST)	PO (FEKO)	PO+SBR (SigmaHat)
Broadside				
Max. Δ_{RCS} [a]	2.3 dB	4.1 dB	3.8 dB	1.8 dB
Range [b] ↔ $\Delta_{RCS} \leq 5$ dB	26.5°	39.0°	19.5°	24.2°
Side lobe accuracy	0.2°	0.3°	0.3°	0.6°
Wing Flash				
Max. Δ_{RCS}	2.7 dB	3.1 dB	4.1 dB	3.7 dB
Range ↔ $\Delta_{RCS} \leq 5$ dB	24°	29.2°	4.7°	7.6°
Side lobe accuracy	0.4°	0.4°	0.5°	0.6°
Lower RCS Range				
Max. Δ_{RCS}	4.7 dB	4.9 dB	10.5 dB	10.8 dB
Side lobe accuracy	0.6°	0.4°	0.6° (41°- 43°)	0.6° (41°- 43°)

[a]The difference between the peak RCS values.
[b]The azimuth angle range where Δ_{RCS} is equal to or less than 5 dB.

Table 2: Summary of the accuracy metrics at 17 GHz

Metric	MLFMM (FEKO)	MLFMM (CST)	PO (FEKO)	PO+SBR (SigmaHat)
Broadside				
Max. Δ_{RCS}	5.0 dB	5.0 dB	2.5 dB	3.3 dB
Range ↔ $\Delta_{RCS} \leq 5$ dB	43.6°	44.8°	29.8°	24.8°
Side lobe accuracy	0.2°	0.2°	0.2°	0.2°
Wing Flash				
Max. Δ_{RCS}	4.0 dB	4.2 dB	3.5 dB	3.7 dB
Range ↔ $\Delta_{RCS} \leq 5$ dB	29.4°	30.4°	8°	9.6°
Side lobes accuracy	0.4°	0.4°	0.2°	0.2°
Lower RCS Range				
Max. Δ_{RCS}	7.3 dB	8.0 dB	11.7 dB	10.1 dB
Side lobe accuracy	0.4°	0.4°	None	None

Table 3: Computational resources (Intel Xeon) for 17 GHz

	MLFMM	MLFMM	PO	PO+SBR
Software	FEKO	CST	FEKO	SigmaHat
N_{Cores}	12	12	12	16
CPU	2.3 GHz			2.7 GHz
RAM	32 GB			48 GB
Processes / Threads	12	12	12	1
Resources Required				
Memory	23.7 GB	8.0 GB	4.2 GB	0.66 GB
CPU-time per sample + mesh and matrix setup	33.7 min + 2.1 h	26.9 min + 6.9 h	52.5 s + 1.9 min	13.2 s

IV. CONCLUSION

An electrically large conducting 1:25 scale model of a Boeing 707 with a maximum electrical length of 106λ was analyzed. Instead of representing the target as a composition of simple canonical structures or using a commercially available CAD model, a very accurate 3D CAD model was created by laser scanning the model. Different CEM methods and three software packages were used to predict the RCS of the target, viz., MLFMM using CST and FEKO, PO using FEKO and PO with SBR using SigmaHat. The simulated data was validated against measured RCS data of the scale model, obtained in a compact range. All the methods showed good agreement with the measured data over the important azimuth ranges at 10 GHz and 17 GHz. The accuracies of the asymptotic methods increased as the frequency did. The accuracies with which the asymptotic methods calculated the larger RCS values (above -5 dBsm) compared well to the more rigorous full-wave methods. The lower RCS values calculated with the PO with SBR method was a slightly better approximation of the measured data compared to the PO method, at 17 GHz. In this lower RCS range the accuracies of the full-wave methods were much better than the asymptotic methods. MLFMM was the most accurate method at both frequencies, and the FEKO implementation thereof was the most accurate for the lower RCS values at 10 GHz. The most efficient in terms of computational time, memory requirements and accuracy was the PO with SBR method.

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