Efficient Ways to Calculate Scattering from Electrically Large Objects: Method of Moments, Physical Optics, and Extrapolation Techniques

Introduction

Calculating bistatic and monostatic scattering from electrically large objects is a challenging task that requires substantial computational resources and careful numerical modeling. Over the years, various simulation techniques have been developed to address this problem effectively.

In this whitepaper, we present and compare several approaches for evaluating bistatic and monostatic scattering, including:

- **Method of Moments (MoM):** a full-wave electromagnetic solver providing accurate results which could serve as a referent data to benchmark the other methods;
- **Extrapolated MoM:** where simulation is performed at lower frequency and the results are extrapolated to the desired higher frequency;
- **Physical Optics (PO):** an asymptotic high-frequency technique used to compute radar cross section (RCS);
- **Extrapolated MoM + PO:** a hybrid approach designed to leverage the strengths of both extrapolation and physical optics methods.

All results are derived from simulations of an electrically large civilian transport aircraft model, performed using WIPL-D Software.

WIPL-D Software is built around a frequency-domain Method of Moments (MoM) kernel, enabling highly accurate electromagnetic (EM) simulations of complex 3D structures. This versatility extends naturally to various scattering problems, making WIPL-D a particularly effective tool for calculating radar cross section (RCS) of diverse targets such as large transport aircraft, fighter jets, helicopters, and unmanned aerial vehicles (UAVs). A key advantage of WIPL-D lies in the efficiency and accuracy of its MoM-based numerical engine. The efficiency is boosted by using quadrilateral mesh elements and higher-order basis functions (HOBFs). Unlike traditional linear (rooftop) basis functions, HOBFs employ higher-order polynomial representations, allowing for a more detailed and dynamic description of surface current distributions over the quadrilateral mesh elements.

As a result, WIPL-D can model significantly larger structures with reduced computational cost and memory requirements, delivering both, fast and precise RCS simulations even on standard, affordable workstation computers.

Electrically Large Civilian Aircraft

The CAD model of the electrically large civilian transport aircraft used in this study is shown in Figure 1. The figure also illustrates the aircraft's orientation relative to the global coordinate system, along with an example of an incident electromagnetic (EM) plane wave excitation and its horizontal polarization.

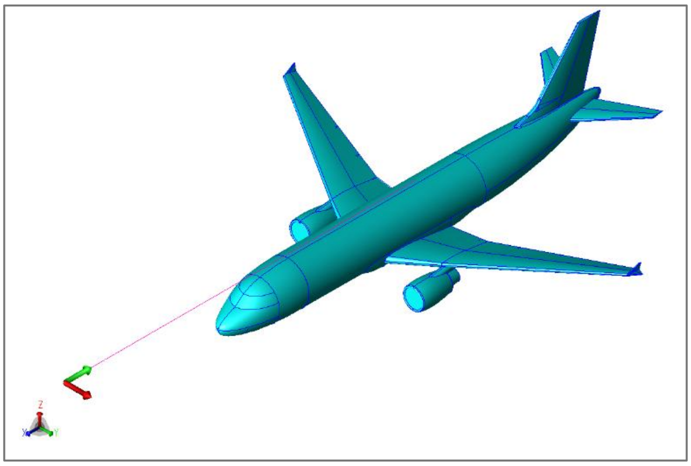

Figure 1. CAD model of the electrically large civilian aircraft.

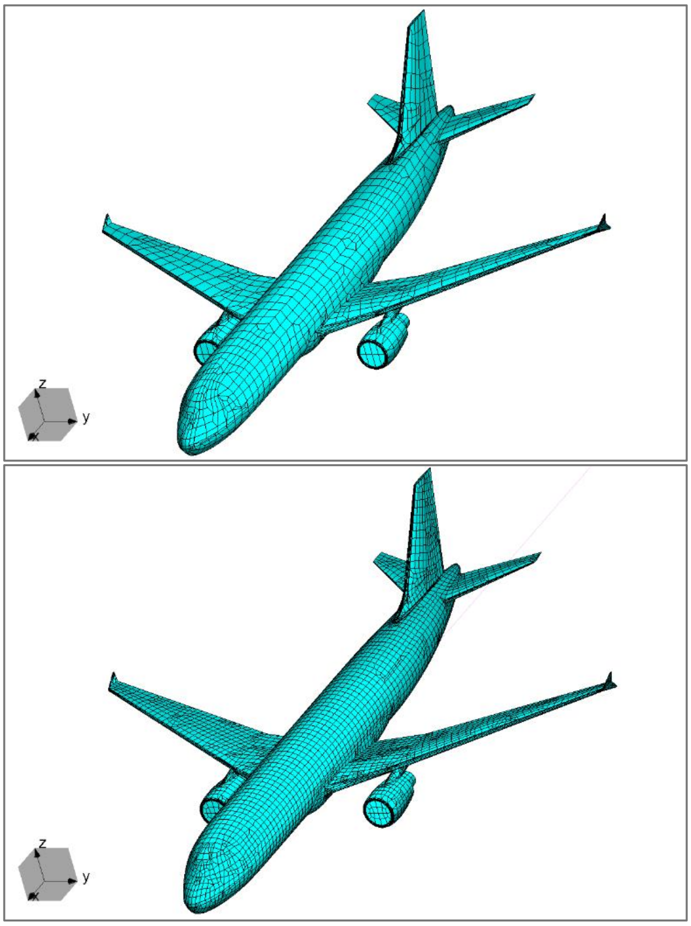

Figure 2. Models of the electrically large civilian aircraft meshed at 0.5 GHz (top) and 1.0 GHz (bottom).

To enable efficient numerical analysis, the model was meshed at two frequencies, 0.5 GHz and 1.0 GHz. The corresponding meshed geometries, highlighting the quadrilateral surface discretization, are presented in Figure 2.

The approximate physical dimensions of the aircraft are 40 m in length, 36 m in wingspan, and 12 m in height, making it a representative case of an electrically large structure for RCS simulations.

Simulations at 0.5 GHz

At 0.5 GHz, the aircraft model was simulated using the Method of Moments (MoM) solver in both monostatic and bistatic configurations. The excitation source was a horizontally polarized electromagnetic (EM) plane wave, as illustrated in Figure 1 for the bistatic case. The resulting total radar cross section (RCS) was computed and expressed in decibels (dB). Simulations were performed in the x0y and x0z planes, with the output calculated over 3,601 angular directions in each case.

In WIPL-D's convention, the θ angle represents the elevation, where 0° corresponds to the horizontal direction (toward the horizon) and 90° points upward (toward the sky). The corresponding scattering results are presented in Figure 3.

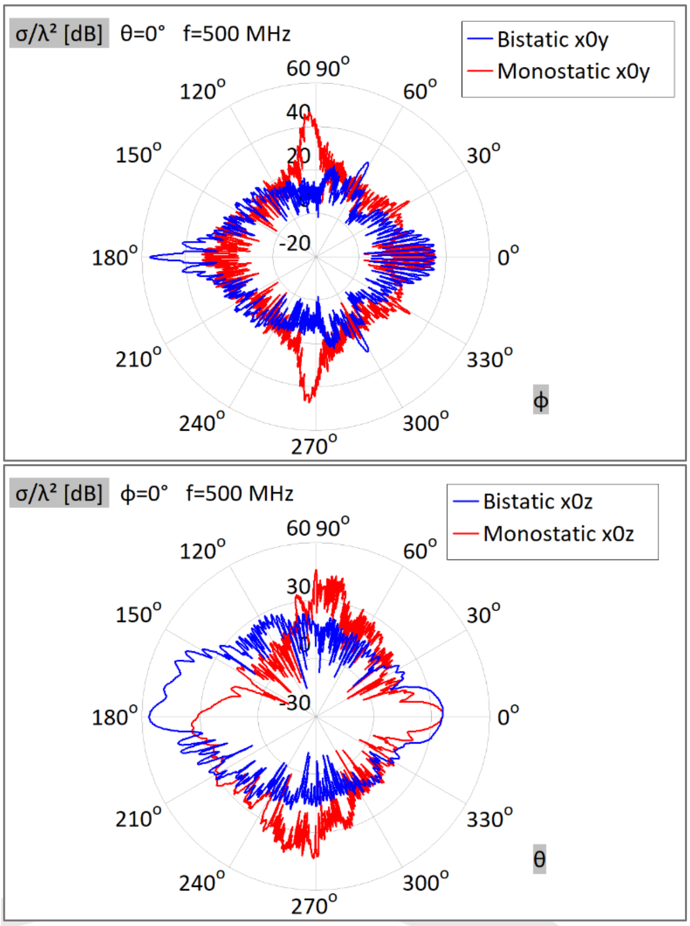

Figure 3. Monostatic and bistatic scattering at 0.5 GHz in x0y plane (top) and x0z plane (bottom).

The current distribution computed at 0.5 GHz serves as the foundation for extrapolation, allowing prediction of RCS results at higher frequencies, specifically 1.0 GHz, for the selected test case.

Simulations at 1.0 GHz

At 1.0 GHz, the aircraft model was analyzed in both monostatic and bistatic configurations using the following simulation approaches:

- **Method-of-Moments (MoM)** solution;
- **Extrapolated MoM**, derived from lower-frequency data;
- **Physical Optics (PO)** solution;
- **Extrapolated MoM + PO** approach.

The **MoM** solution was obtained through a standard WIPL-D solver run. The **Extrapolated MoM** results were derived from the previously computed 0.5 GHz data, where the current distribution at 0.5 GHz was extrapolated to predict the corresponding RCS at 1.0 GHz. The **PO** solution was produced using the **Physical Optics solver** integrated within WIPL-D Software, which is designed for efficient scattering simulations. The **Extrapolated MoM + PO** approach combines the extrapolated 0.5 GHz MoM results with PO-based computations, effectively leveraging the advantages of both methods.

As in the 0.5 GHz case, the excitation was a horizontally polarized EM plane wave (the bistatic configuration is illustrated in Figure 1). The total RCS, including both θ (theta) and ϕ (phi) components in decibels (dB), was computed in the x0y and x0z planes over 3,601 angular directions in each case.

The resulting scattering patterns at 1.0 GHz are presented and compared in Figures 4-7.

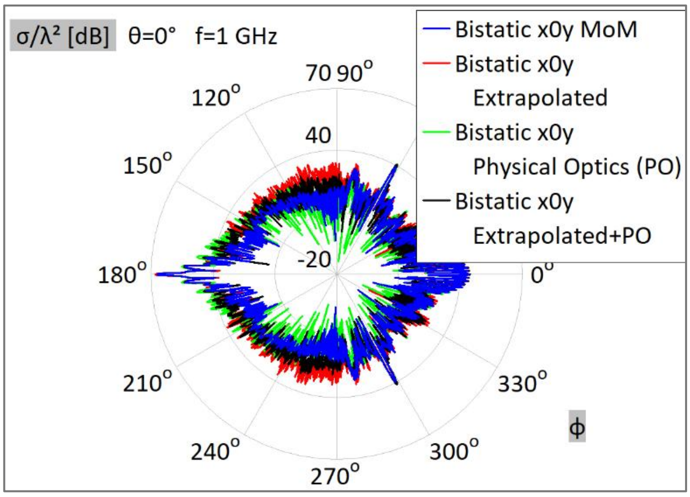

Figure 4. Bistatic scattering at 1.0 GHz in x0y plane.

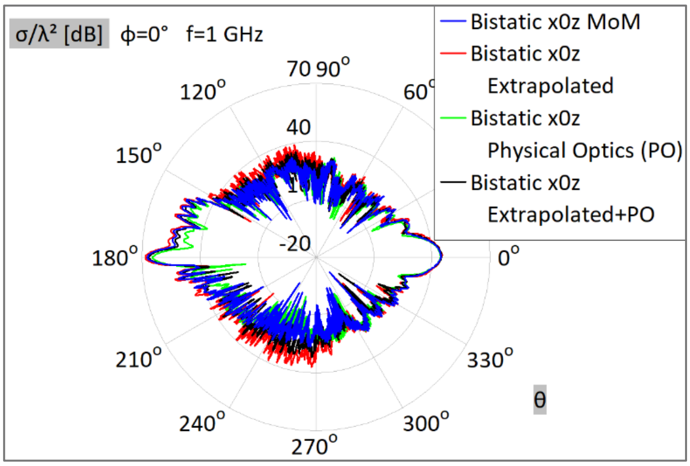

Figure 5. Bistatic scattering at 1.0 GHz in x0z plane.

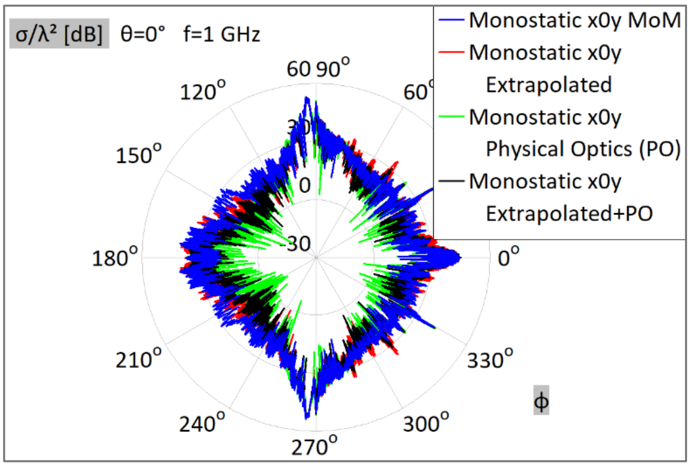

Figure 6. Monostatic scattering at 1.0 GHz in x0y plane.

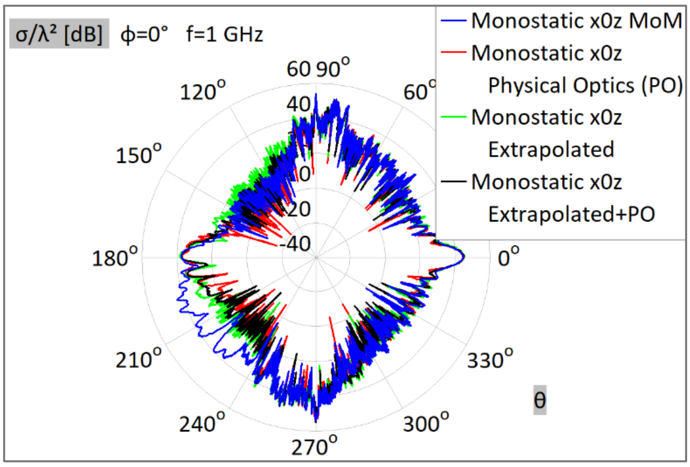

Figure 7. Monostatic scattering at 1.0 GHz in x0z plane.

Analysis of Efficiency and Accuracy

Analysis of the results presented in Figures 4-7 shows that all methods produce comparable scattering patterns, with only minor deviations between them. While none of the alternative methods exactly replicate the Method of Moments (MoM) reference solution, the differences are expected.

The Extrapolated MoM, Physical Optics (PO), and Extrapolated MoM + PO approaches are inherently approximate techniques, designed primarily to reduce computational cost and simulation time. These methods enable the analysis of higher-frequency scenarios by introducing a controlled trade-off between accuracy and efficiency compared to the full-wave MoM solution.

All simulations were executed on a desktop workstation, whose hardware configuration is summarized in Table 1.

Table 1. Exploited PC desktop workstation.

Hardware	Description
Processor	Intel(R) Core(TM) i9-14900K (3.20 GHz)
RAM	128 GB
GPU	NVIDIA GeForce RTX 4090

The corresponding model parameters, including the number of mesh elements, number of unknowns, and total simulation time for each project, are listed in Table 2.

Table 2. Number of elements, number of unknowns and simulation times.

Project	Number of elements	Number of unknowns	Total simulation time
0.5 GHz Bistatic (MoM)	4,818	131,170	10 mins
0.5 GHz Monostatic (MoM)	4,818	131,170	11 mins
1.0 GHz Bistatic (MoM)	9,838	400,778	2 hours 51 minutes
1.0 GHz Monostatic (MoM)	9,838	400,778	3 hours 6 minutes
1.0 GHz Bistatic (Extrapolation)	(*)4,818	(*)131,170	5 secs
1.0 GHz Monostatic (Extrapolation)	(*)4,818	(*)131,170	25 mins
1.0 GHz Bistatic (PO)	9,838	400,778	2 secs
1.0 GHz Monostatic (PO)	9,838	400,778	11 mins
1.0 GHz Bistatic (Extrapolation+PO)	---	---	5 secs
1.0 GHz Monostatic (Extrapolation+PO)	---	---	37 min

During computation, the GPU was utilized for matrix inversion, while the CPU handled all other stages of the simulation process.

Regarding the data summarized in Table 2, it is assumed that simulation times are identical whether results are computed in the x0y or x0z planes (e.g., monostatic MoM simulations in both planes require the same computational time). When two results differ slightly, the longer (worst-case) time is reported. For extrapolated simulations, the number of elements and unknowns required at 1.0 GHz is copied from the 0.5 GHz case, denoted with an (*) in Table 2. For models combining extrapolation and PO, the number of elements and unknowns are omitted from the table, as they are not directly relevant.

Table 2 clearly illustrates a reduction in computational effort achieved with these methods. For instance, the most demanding simulations, MoM ran at 1.0 GHz, require approximately three hours, whereas 0.5 GHz MoM simulations, which serve as the basis for extrapolated results, take no more than 15 minutes. Simulations using the PO method are completed in under 15 minutes, and even the longest approximative simulations take less than 40 minutes.

When combining a base MoM simulation with any approximative method, for instance, a 0.5 GHz monostatic MoM simulation followed by a 1.0 GHz monostatic extrapolated result, the total computation time remains under one hour, demonstrating the significant efficiency gain of these approaches.

Conclusion

This paper demonstrates that WIPL-D Software can be employed efficiently for a wide range of realistic scattering simulations whether combining the MoM solver with approximative methods, or using the approximative methods alone.

A comparison of simulation times and results quality shows that a significant reduction in computational resources is achievable without compromising the accuracy. Remarkably, all simulations were performed on an affordable desktop workstation, highlighting the merit of these methods for complex, electrically large structures.