

# Austin RCS Benchmark with WIPL-D Software

## Introduction

Obtaining accurate radar cross section (further, RCS) of an object is an extremely important task in many civilian and military applications. From various techniques for obtaining RCS data, simulation of the object in a software that computes the RCS probably consumes the least resources.

The usage of a software usually requires:

- Importing the model of the object, usually an aircraft, into the software suite
- Adjusting numerical kernel settings in terms of exploiting optimal simulation requirements and focusing on the satisfactory results
- Simulating the object
- Observing and discussing the results

The scattered RCS is evaluated as:

$$\sigma(\phi_i, \theta_i, \phi, \theta) = 4\pi r^2 \frac{|E(r, \phi, \theta)|^2}{|E_i(\phi_i, \theta_i)|^2} = 4\pi \frac{|e(\phi, \theta)|^2}{|E_i(\phi_i, \theta_i)|^2}$$

Where  $E(r, \phi, \theta)$  is a scattered far electric field vector, and  $E_i(\phi_i, \theta_i)$  is the electric field vector of the incident plane wave. In the general case, when the directions of the illuminating wave and of the scattered wave do not coincide, the above expression defines the bistatic RCS. If these two directions coincide, the monostatic RCS is defined. Most often, RCS is divided by the wavelength squared (i.e.,  $\sigma/\lambda^2$  is evaluated) or by a meter squared (i.e.,  $\sigma/m^2$  is evaluated). Such normalized RCS is expressed in unnamed units and thus it can be also expressed in decibels.

This document will outline multiple monostatic RCS results originating from three aircraft models simulated at four different frequencies. The aim of conducting these simulations is a verification of the quality of RCS results obtained using the WIPL-D Software suite [1] by comparing them with the results from “Austin RCS Benchmark” [2]. In fact, The University of Texas Austin has created a computational electromagnetics benchmark suite meant for validating various radar cross-section (RCS) calculation methods.

WIPL-D Software is a full wave 3D electromagnetic Method-of-Moments (MoM) based simulation tool, applying Surface Integral Equations (SIEs) and Higher Order Basis Functions (HOBFs) to ensure better efficiency. It will be shown that the WIPL-D Software can be used to accurately simulate presented aircraft models in reasonable time using an affordable computer workstation.

## Aircraft Models

Relevant models were downloaded from [2]. Aircraft geometries created by University of Texas Austin are displayed in Figure 1 [3].

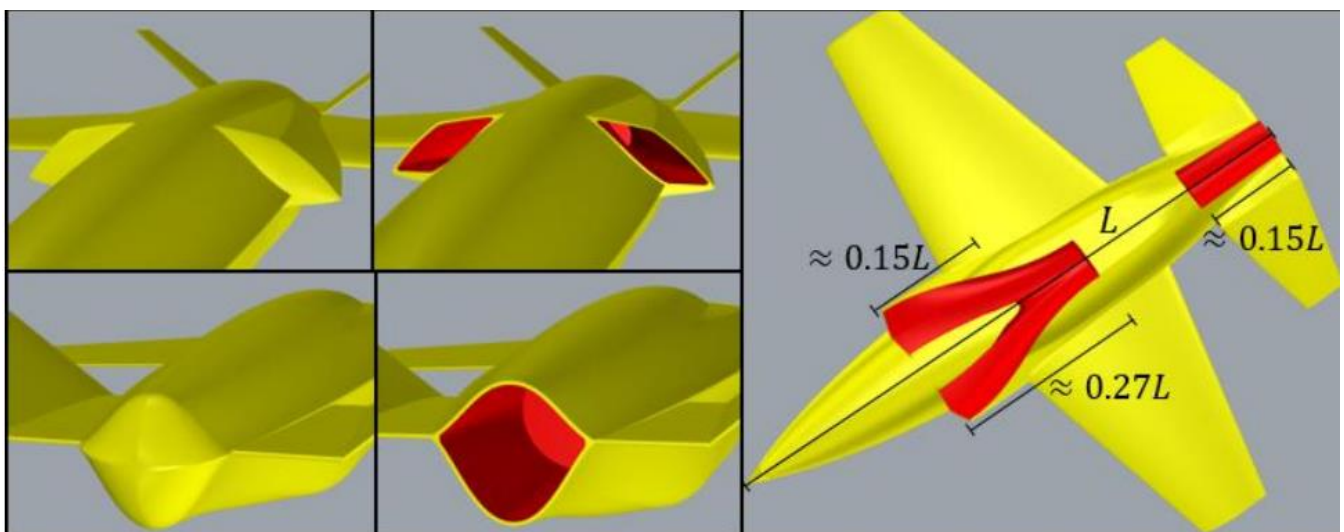
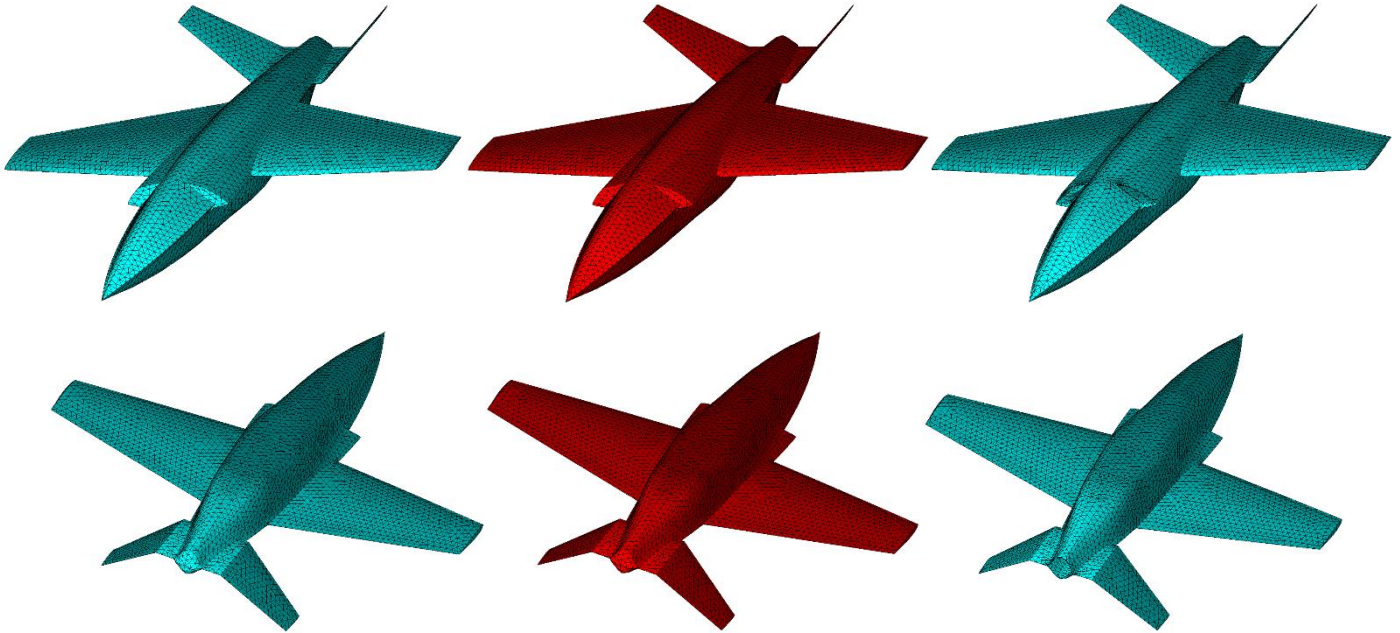


Figure 1. The aircraft geometries from Texas University Austin [3]

The aircraft geometries were initially stored in .UNV format files. Then, the files were converted to .STL file format and imported into WIPL-D Pro software. After importing the files into the WIPL-D software, the models are decimated and meshed so that they are represented with bilinear surfaces rather than triangles. Three aircraft models defined using .STL file format are displayed in Figure 2. The first model represents a PEC model of the aircraft with closed duct. The next model is the resin aircraft also with closed duct. Finally, the third model is the PEC model of the aircraft with open duct.



**Figure 2. The aircraft projects in .STL file format. Each aircraft is shown from the front and from behind. From left to right: PEC model of the aircraft with closed duct, the resin aircraft with closed duct, and PEC model of the aircraft with open duct**

Three aircraft models previewed using WIPL-D Software and defined using bilinear surfaces are displayed in Figure 3. Neither reduction nor decimation are applied to any of these models, as the models are obtained through WIPL-D developed triangles to quadrilaterals remeshing procedure.

The overall length of the aircraft is  $\sim 0.23307$  m ( $\sim 9.177$  Inches) for the PEC model of the aircraft with closed duct. The resin aircraft with closed duct is also  $\sim 0.23307$  m ( $\sim 9.177$  Inches) long. The PEC model of the aircraft with open duct is  $\sim 0.2289$  m ( $\sim 9.012$  Inches) long. The difference in lengths appeared due to the differences of the models in the back side of the aircraft (engine exhaust), as displayed in Figure 2.



**Figure 3. Simulated aircraft previewed using WIPL-D Software and defined with bilinear surfaces. From left to right: PEC model of the aircraft with closed duct, the resin aircraft with closed duct, and PEC model of the aircraft with open duct**

The resin used for modelling one of the aircraft is defined with frequency dependent electrical properties, described in [4]. The electrical properties of the resin are outlined in Table 1.

**Table 1. Frequency dependent electrical properties of the resin**

Frequency [MHz]	$\epsilon'$	$\epsilon''$	Frequency [MHz]	$\epsilon'$	$\epsilon''$
10	3.21	$1.29 \cdot 10^{-1}$	2,560	2.96	$9.64 \cdot 10^{-2}$
20	3.21	$1.29 \cdot 10^{-1}$	2,580	2.96	$9.63 \cdot 10^{-2}$
40	3.20	$1.28 \cdot 10^{-1}$	5,120	2.91	$8.60 \cdot 10^{-2}$
80	3.19	$1.28 \cdot 10^{-1}$	5,125	2.91	$8.60 \cdot 10^{-2}$
160	3.17	$1.26 \cdot 10^{-1}$	7,000	2.90	$8.22 \cdot 10^{-2}$
320	3.13	$1.23 \cdot 10^{-1}$	10,240	2.88	$7.85 \cdot 10^{-2}$
640	3.08	$1.18 \cdot 10^{-1}$	10,250	2.88	$7.85 \cdot 10^{-2}$
1,280	3.02	$1.08 \cdot 10^{-1}$	--	--	--

## Simulations Settings and Computer Platform

The next step in simulating the models was setting the numerical kernel and simulation parameters. The models of the aircraft were simulated at 2.58 GHz, 5.12 GHz, 7.00 GHz, and 10.25 GHz (some simulations cover 10.24 GHz, instead). To test accuracy and compare simulation times, some models were decimated while being converted from .STL file to WIPL-D Pro native .IWP file format using five different decimation values. This resulted in five different WIPL-D simulations required for each aircraft model at a selected frequency. The decimation values are: 0.00% (no decimation), 0.01%, 0.03%, 0.10%, and 0.30% of the overall aircraft size. All simulations were performed on full models, without any utilization of the symmetry planes.

To ensure high accuracy, numerical kernel parameter *Integral Accuracy* has been set to *Enhanced 1*. Parameter *Max Patch Size* was modified as well – it was set to 1.67 lambdas instead of being set to 2 lambdas.

Each WIPL-D simulation is performed using pure 3D EM MoM Solver. At all frequencies the RCS is computed with incident wave direction angles defined as  $\theta_i = 0^\circ$  and  $0^\circ \leq \phi_i \leq 180^\circ$ . In WIPL-D, theta angle represents the elevation angle and  $\theta = 0^\circ$  points toward horizon. Besides simulation requirements, each set of results contains, so called, *HH Polarization* and *VV Polarization*. *HH Polarization* represents RCS results in case incident wave contains only  $E_\phi$  component while only scattered  $E_\phi$  component is taken into the account. Similar, *VV Polarization* represents RCS results in case incident wave contains only  $E_\theta$  component while only scattered  $E_\theta$  component is taken into the account.

Table 2 contains data about the computer platform used for the simulations.

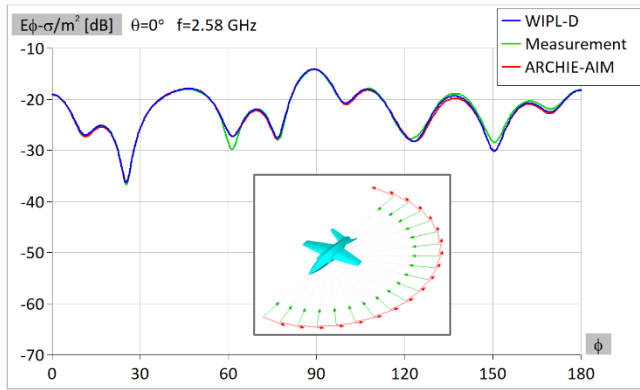
**Table 2. Computer platform used for the simulations**

Hardware	Description
Processor	Intel® Xeon® Gold 6342 CPU @ 2.80GHz 3.50 GHz (2 processors)
RAM	256 GB

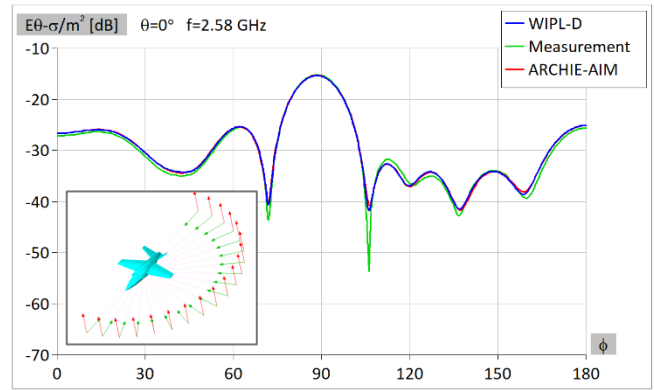
## RCS Results – PEC Aircraft with Closed Duct

Calculated RCS results and simulations requirements for the PEC aircraft with closed duct are displayed in Figures 4-7. Simulations results\requirements at 2.58 GHz, 5.12 GHz, 7.00 GHz, and 10.25 GHz are also outlined in Figures 4-7, respectively. Each figure contains:

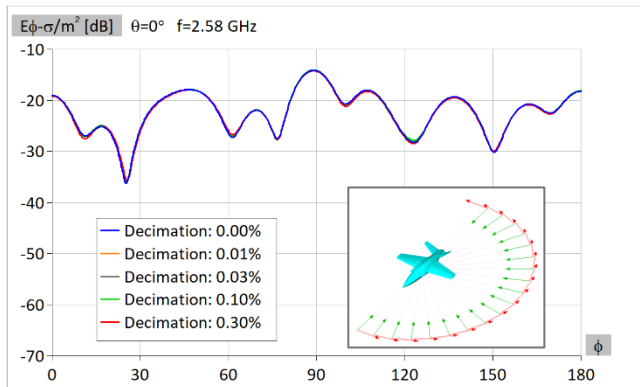
- RCS monostatic results for *HH Polarizations* compared between WIPL-D simulation data (when no decimation was applied), ARCHIE-AIM [5] simulation data, and EXPEDITE measured data (top left)
- RCS monostatic results for *VV Polarizations* compared between WIPL-D simulation data, ARCHIE-AIM simulation data, and EXPEDITE measured data (top right)
- RCS monostatic results for *HH Polarizations* compared between WIPL-D results with different decimation settings (bottom left)
- A table with WIPL-D simulation requirements (bottom right).



HH Polarization



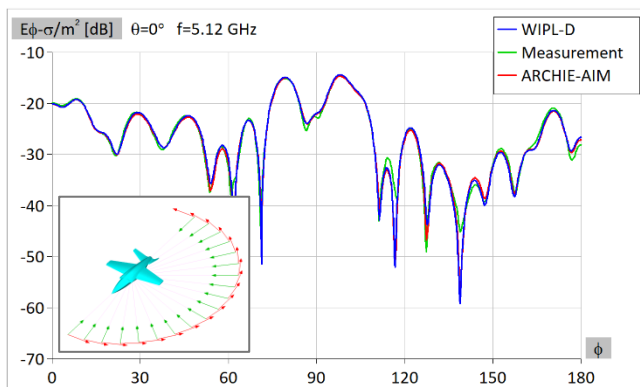
VV Polarization



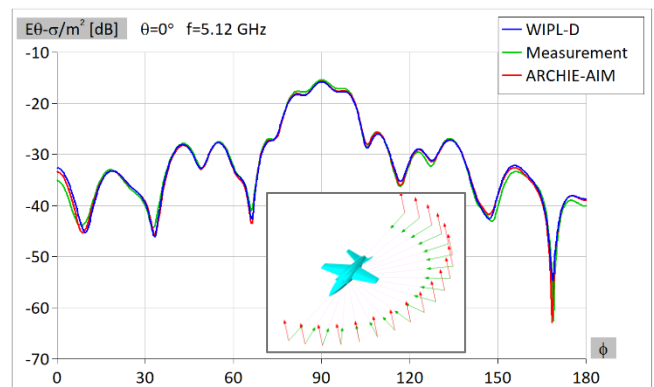
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	43,452	243.97
0.01%	13,400	26,800	105.78
0.03%	7,920	15,840	48.38
0.10%	3,242	6,650	16.52
0.30%	1,234	2,888	6.72

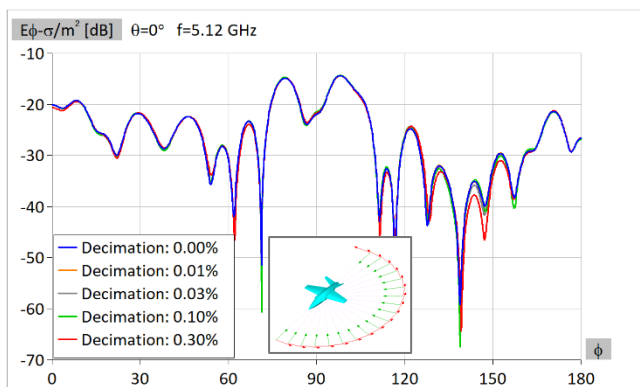
Figure 4. Outlined data for frequency of 2.58 GHz



HH Polarization



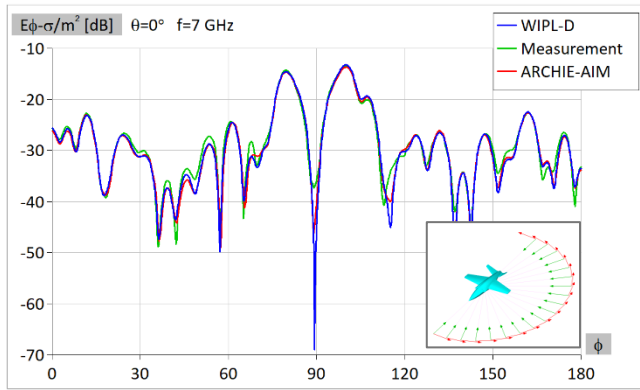
VV Polarization



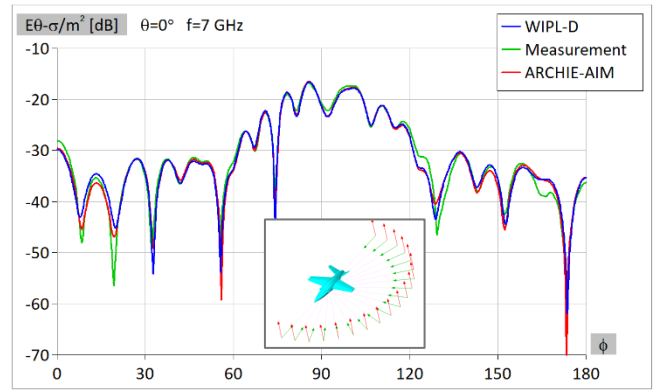
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	43,452	246.45
0.01%	13,400	26,800	105.77
0.03%	7,920	16,120	48.34
0.10%	3,242	7,487	17.83
0.30%	1,234	3,925	7.78

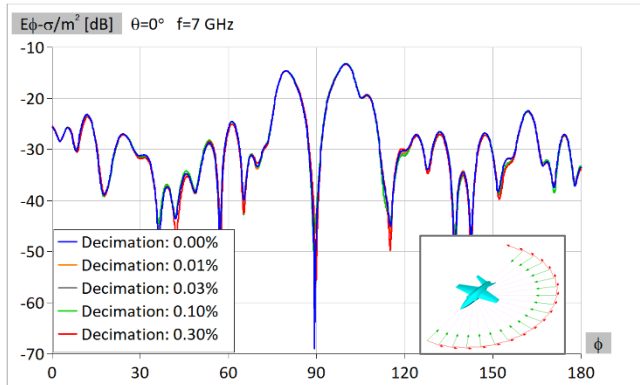
Figure 5. Outlined data for frequency of 5.12 GHz



HH Polarization



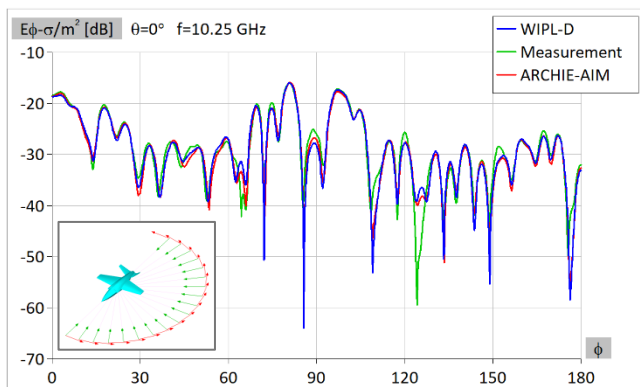
VV Polarization



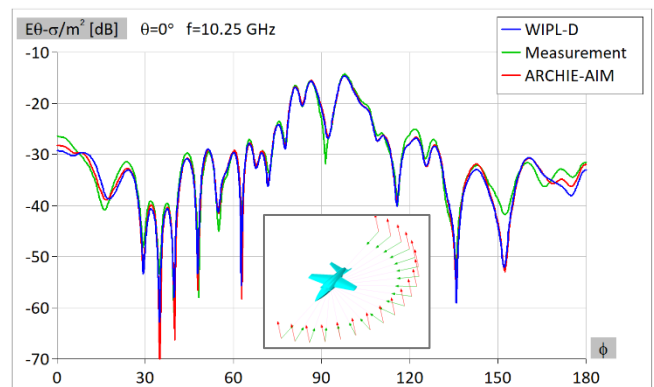
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	43,452	248.69
0.01%	13,400	27,138	107.38
0.03%	7,920	17,139	51.03
0.10%	3,242	8,572	19.16
0.30%	1,234	5,555	9.28

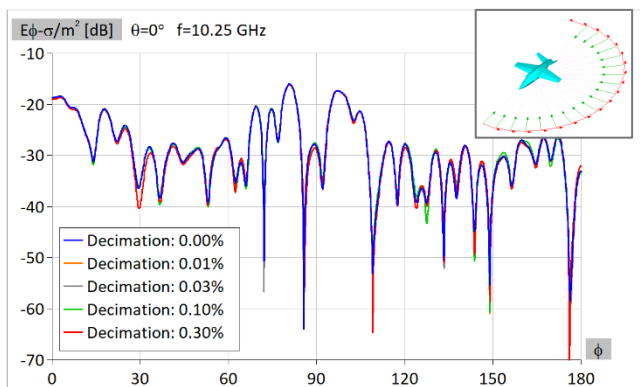
Figure 6. Outlined data for frequency of 7.00 GHz



HH Polarization



VV Polarization



HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	43,452	248.05
0.01%	13,400	28,370	112.30
0.03%	7,920	19,360	55.69
0.10%	3,242	11,625	22.89
0.30%	1,266	8,317	12.31

Figure 7. Outlined data for frequency of 10.25 GHz



## RCS Results – Resin Aircraft with Closed Duct

Calculated RCS results and simulations requirements for the resin aircraft with closed duct are displayed in Figures 8-11. Simulations results/requirements at 2.58 GHz, 5.12 GHz, 7.00 GHz, and 10.25 GHz are also outlined in Figures 8-11, respectively. Each figure contains:

- RCS monostatic results for *HH Polarizations* compared between WIPL-D simulation data (when no decimation was applied), ARCHIE-AIM simulation data, and EXPEDITE measured data (top left)
- RCS monostatic results for *VV Polarizations* compared between WIPL-D simulation data, ARCHIE-AIM simulation data, and EXPEDITE measured data (top right)
- RCS monostatic results for *HH Polarizations* compared between WIPL-D results with different decimation settings (bottom left)
- A table with WIPL-D simulation requirements (bottom right).

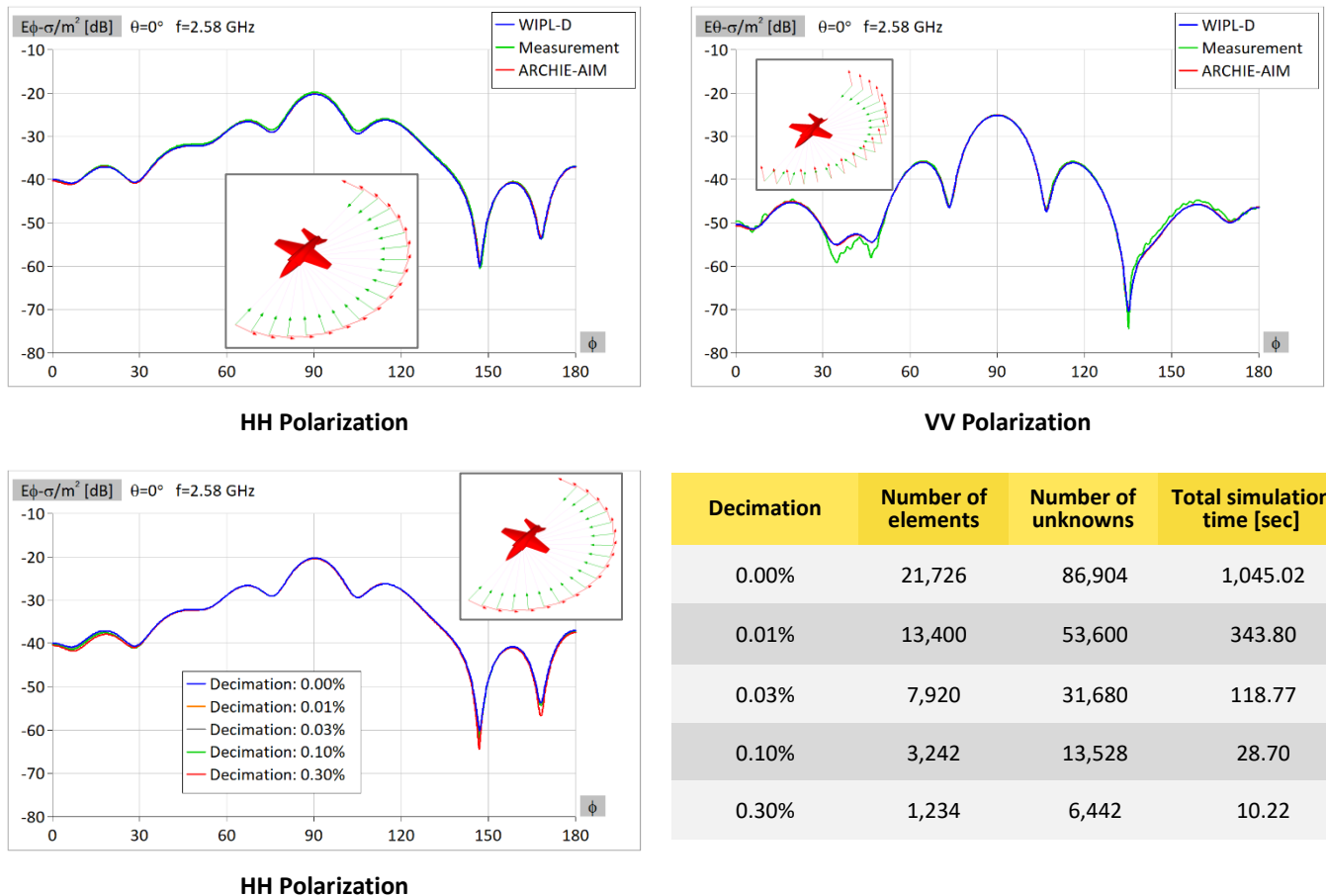
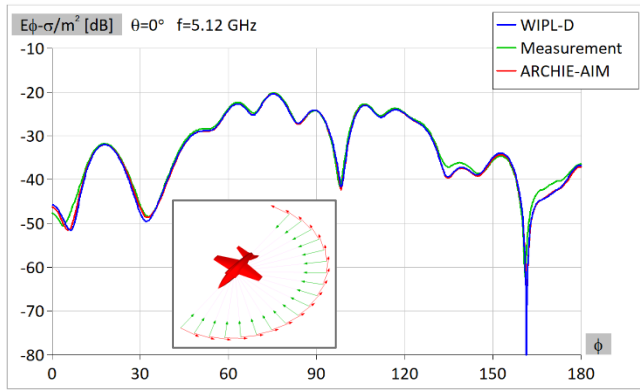
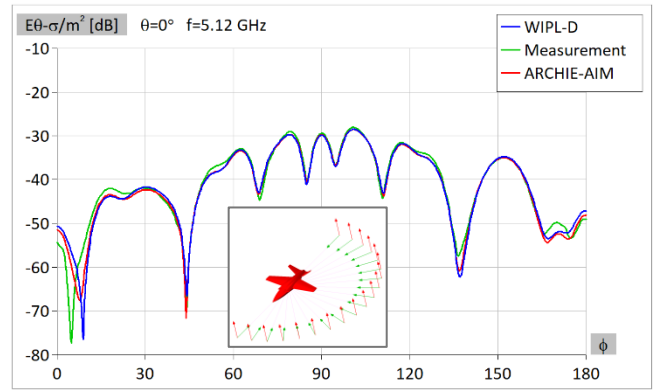


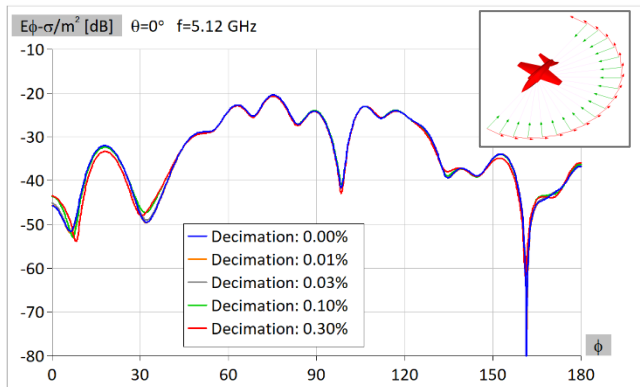
Figure 8. Outlined data for frequency of 2.58 GHz



HH Polarization



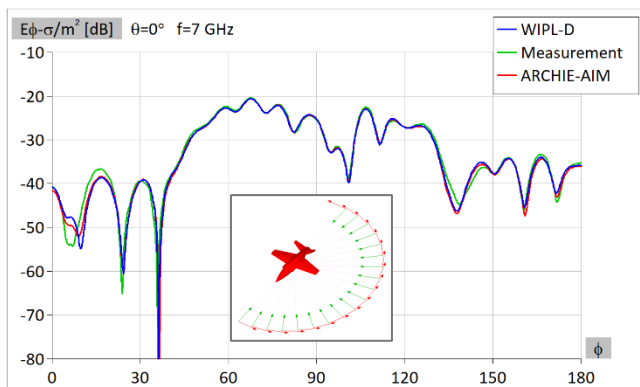
VV Polarization



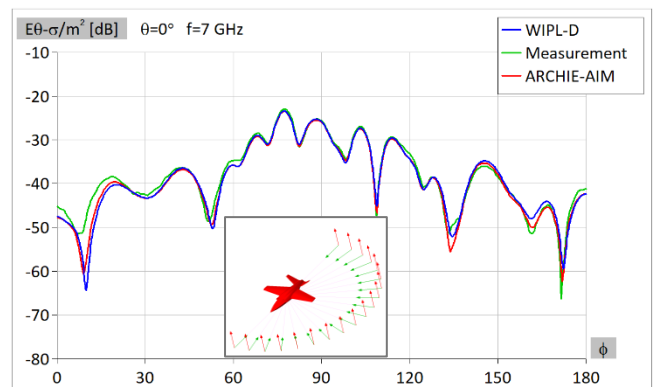
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	86,904	1,040.36
0.01%	13,400	54,164	349.91
0.03%	7,920	33,750	128.11
0.10%	3,242	16,550	34.09
0.30%	1,234	10,378	14.28

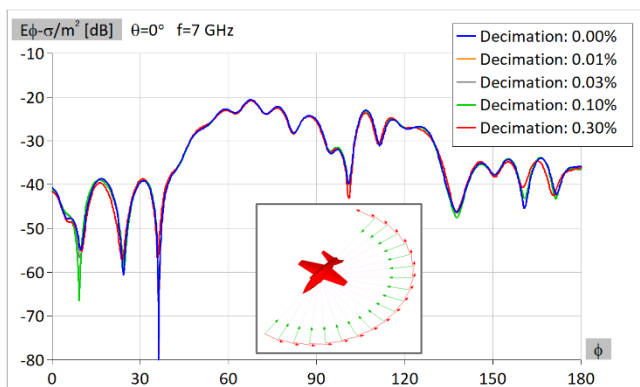
Figure 9. Outlined data for frequency of 5.12 GHz



HH Polarization



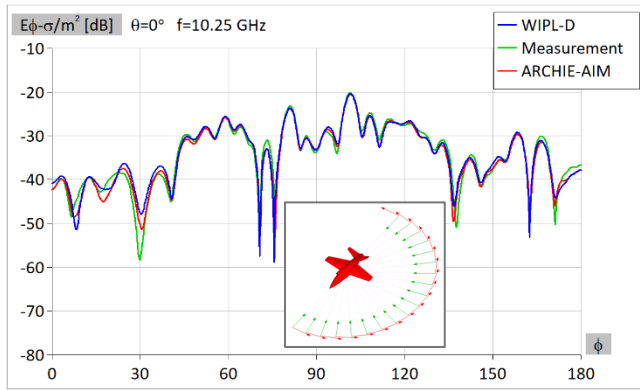
VV Polarization



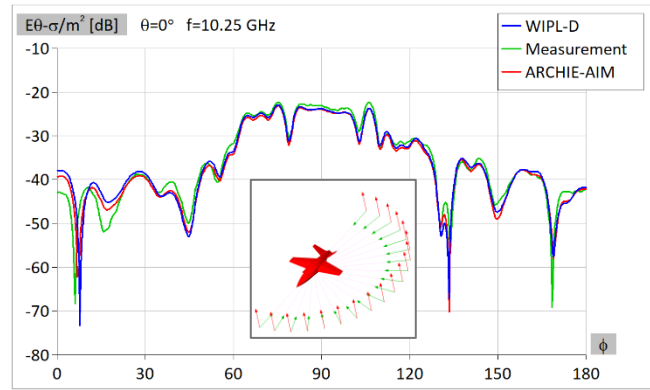
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	86,904	1,038.98
0.01%	13,400	56,158	369.03
0.03%	7,920	37,494	145.11
0.10%	3,242	20,886	42.86
0.30%	1,234	14,130	19.22

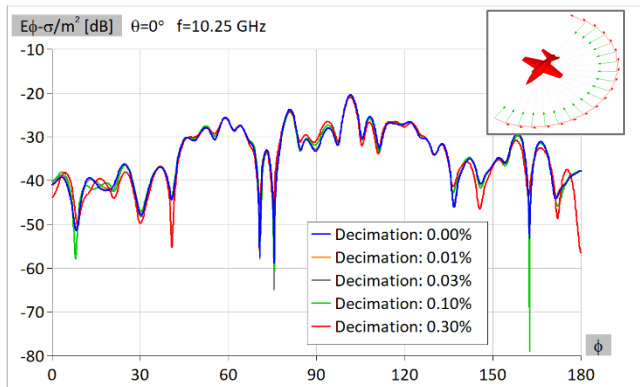
Figure 10. Outlined data for frequency of 7.00 GHz



HH Polarization



VV Polarization



HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	21,726	86,904	1,054.39
0.01%	13,400	60,648	423.23
0.03%	7,920	45,114	190.84
0.10%	3,242	30,412	70.86
0.30%	1,350	22,908	37.58

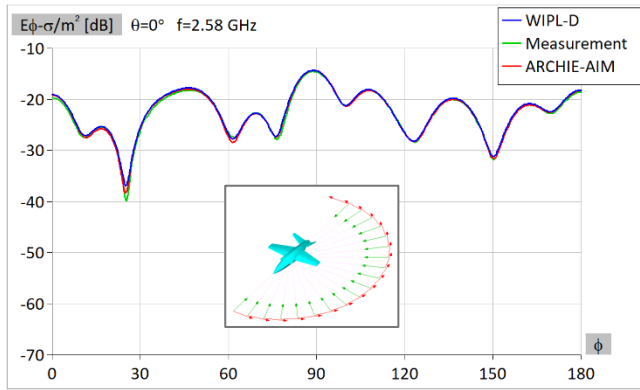
Figure 11. Outlined data for frequency of 10.25 GHz

## RCS Results – PEC Aircraft with Open Duct

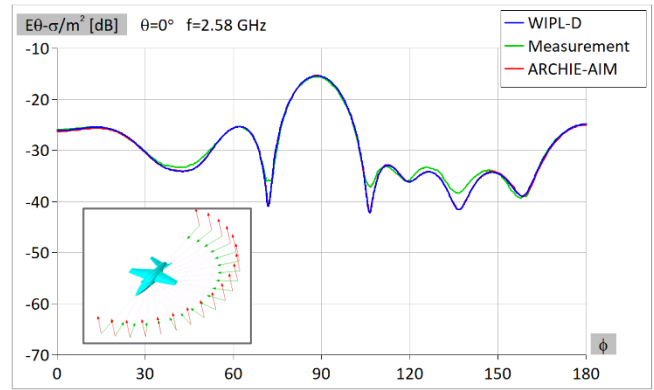
Calculated RCS results and simulations requirements for the PEC aircraft with open duct are displayed in Figures 12-15. Simulations results\requirements at 2.58 GHz, 5.12 GHz, 7.00 GHz, and 10.25 GHz are also outlined in Figures 12-15, respectively. Each figure contains:

- RCS monostatic results for *HH Polarizations* compared between WIPL-D simulation data (when no decimation was applied), ARCHIE-AIM simulation data, and EXPEDITE measured data (top left)
- RCS monostatic results for *VV Polarizations* compared between WIPL-D simulation data, ARCHIE-AIM simulation data, and EXPEDITE measured data (top right)
- RCS monostatic results for *HH Polarizations* compared between WIPL-D results with different decimation settings (bottom left)
- A table with WIPL-D simulation requirements (bottom right).

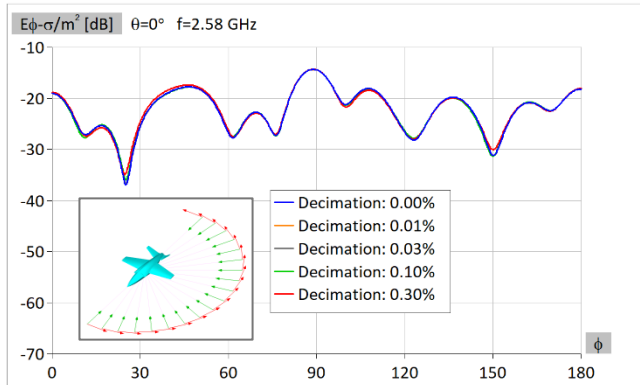




HH Polarization



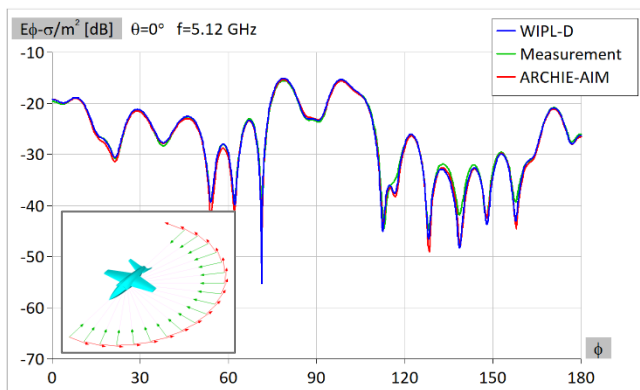
VV Polarization



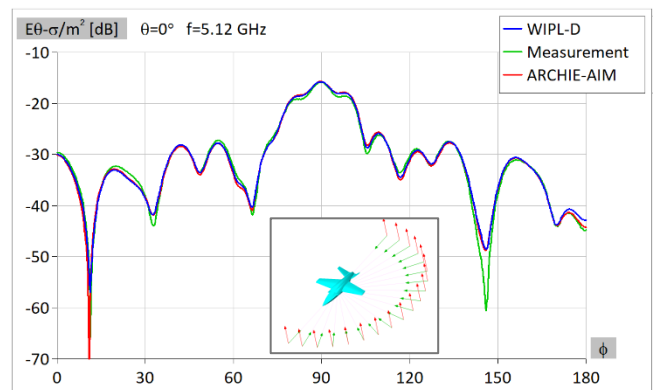
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	25,888	51,776	345.55
0.01%	16,970	33,940	155.91
0.03%	10,188	20,490	70.33
0.10%	5,050	10,314	27.78
0.30%	2,330	4,985	11.98

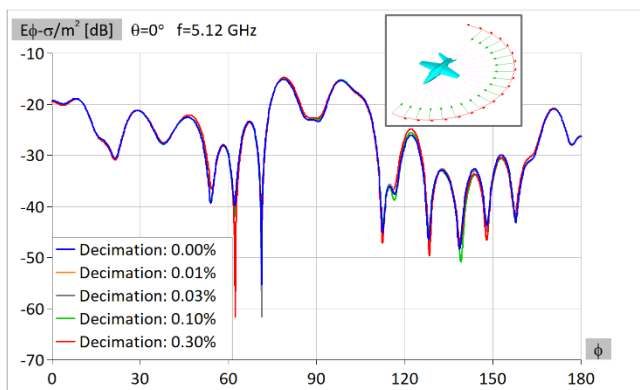
Figure 12. Outlined data for frequency of 2.58 GHz



HH Polarization



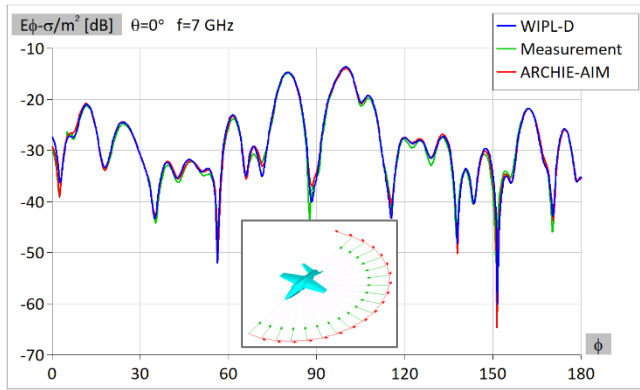
VV Polarization



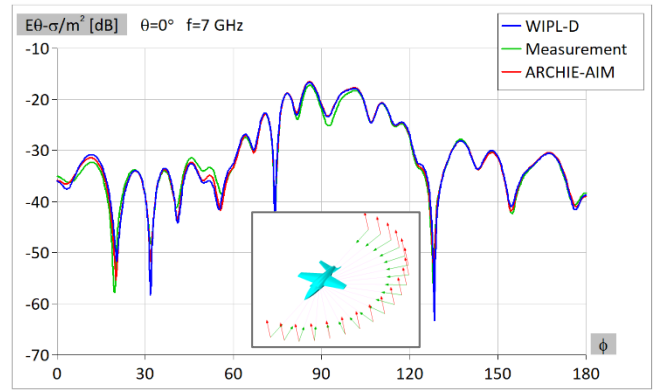
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	25,888	51,776	351.38
0.01%	16,970	33,940	159.62
0.03%	10,188	21,113	70.50
0.10%	5,050	11,292	29.41
0.30%	2,330	6,077	13.16

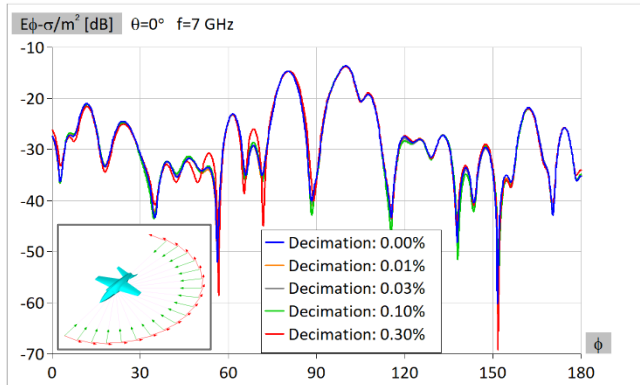
Figure 13. Outlined data for frequency of 5.12 GHz



HH Polarization



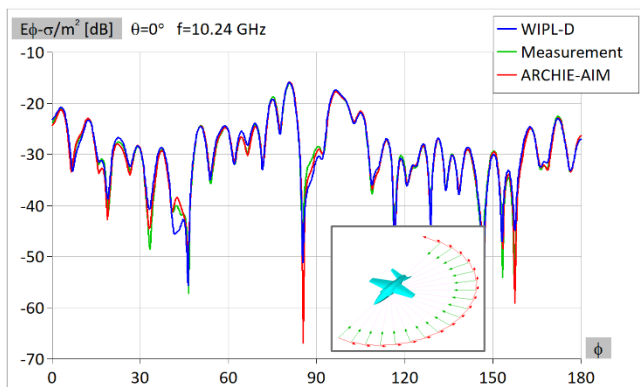
VV Polarization



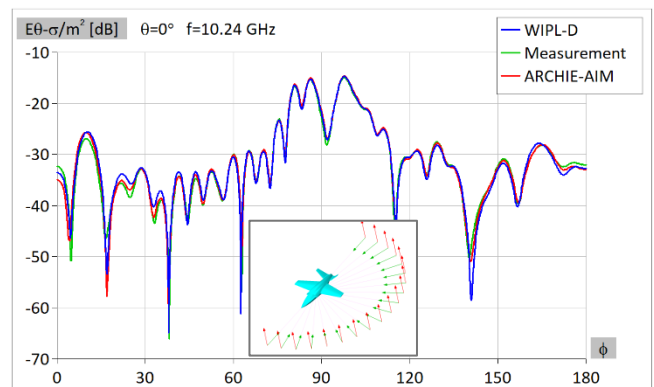
HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	25,888	51,776	351.34
0.01%	16,970	34,213	162.42
0.03%	10,188	22,196	73.89
0.10%	5,050	12,400	30.78
0.30%	2,330	7,523	14.67

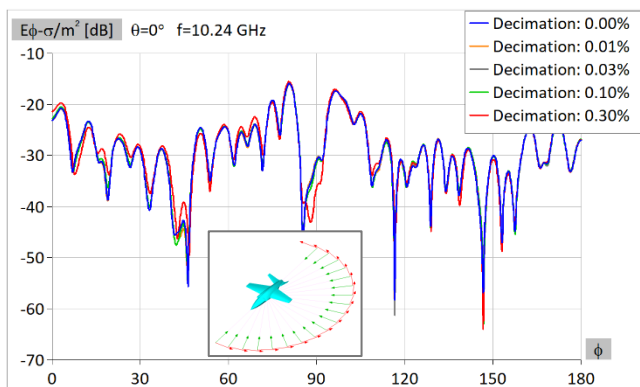
Figure 14. Outlined data for frequency of 7.00 GHz



HH Polarization



VV Polarization



HH Polarization

Decimation	Number of elements	Number of unknowns	Total simulation time [sec]
0.00%	25,888	51,776	346.33
0.01%	16,970	35,545	166.06
0.03%	10,188	24,273	81.30
0.10%	5,050	15,736	36.08
0.30%	2,362	10,771	18.23

Figure 15. Outlined data for frequency of 10.24 GHz

## Conclusion

This document outlined multiple RCS results originating from three aircraft models simulated at four different frequencies. The aim of conducting these simulations is the verification of the quality of RCS results obtained using WIPL-D Software by comparing them with the results from “*Austin RCS Benchmark*”.

It was demonstrated that WIPL-D results are in great agreement with measurement/simulation results provided by “*Austin RCS Benchmark*”. It was then shown that different decimations applied to original model can reduce the simulation time while still providing accurate simulation results.

## References

- [1] WIPL-D Software - [Electromagnetic Simulation and EM Modeling Software | WIPL-D](#)
- [2] University of Texas Austin CEM Benchmarks - [AustinCEMBenchmarks/Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts at master · UTAustinCEMGroup/AustinCEMBenchmarks · GitHub](#)
- [3] A. Maicke *et al.*, "A Benchmark Airplane Model with Ducts," *2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)*, Denver, CO, USA, 2022, pp. 657-658, doi: 10.1109/AP-S/USNC-URSI47032.2022.9887354.
- [4] Resin electrical properties - [AustinCEMBenchmarks/Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVB-Resin Closed-Duct PRIME Aircrafts/IVB-ProblemDescription.pdf at master · UTAustinCEMGroup/AustinCEMBenchmarks · GitHub](#)
- [5] F. Wei and A. E. Yilmaz, "A More Scalable and Efficient Parallelization of the Adaptive Integral Method—Part I: Algorithm," in *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 2, pp. 714-726, Feb. 2014, doi: 10.1109/TAP.2013.2291559.