VALIDATION OF AUSTIN RCS BENCHMARKS USING ALTAIR FEKO

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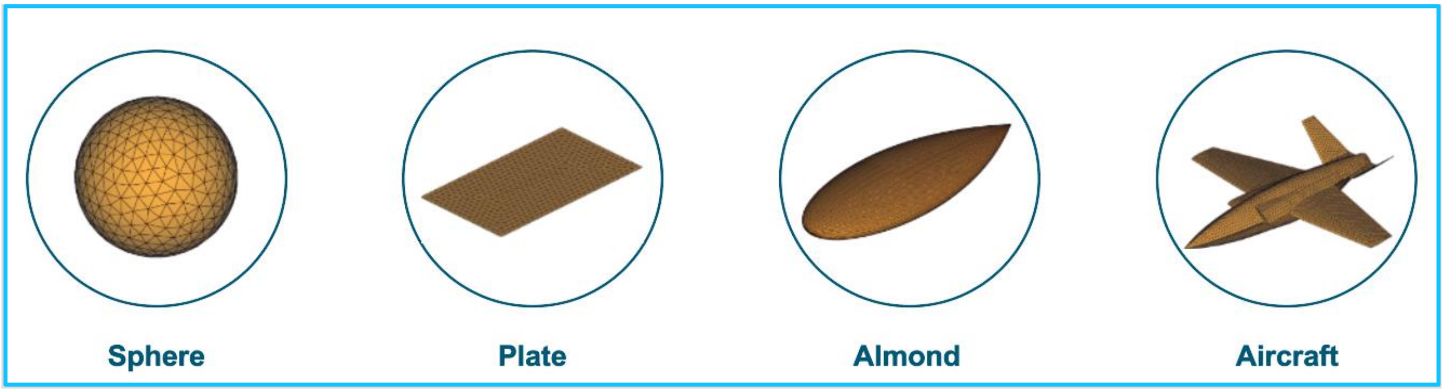


Introduction

Radar Cross Section (RCS) is a measurement that describes an object in terms of its scattering properties when exposed to incident electromagnetic fields. Incident energy from those fields may be reflected, scattered in multiple directions, or absorbed by the object. Altair provides a complete, customizable solution for accurate scattering and RCS analysis that is being used across several industries. Central to this solution is Altair® Feko®[1], Altair's tool for electromagnetic modeling and simulation.

University of Texas (UT) Austin has created a computational electromagnetics (CEM) benchmark suite to validate both current and future electromagnetic radar cross-section (RCS) methods [2]. Austin Benchmark Suite consists of four geometries with various material assignments: sphere, plate, almond, and aircraft. A key benchmark in the suite is aircraft models, one with open ducts and the other closed ducts for the intake/exhaust system. These benchmarks are developed by UT Austin in collaboration with Lockheed Martin Aeronautics' **EXPanded MDO for Effectiveness-based DesIgn TEchnologies (EXPEDITE)** program [3] to create an open-source aircraft model to validate various CEM methods. In this white paper, we present validation of the aircraft models in Austin RCS Benchmark Suite with Altair Feko. We also present the RCS validation of sphere, plate, and almond geometries in the Appendix.

Figure 1(a) shows 3D printed scaled aircraft models with two different sizes (9.1875" and 18.375") [4]. From [2], the closed duct model has a length of 9.1875" and the open duct model has a length of 9.0116". The silver-coated models with closed ducts and open ducts are shown in Figure 1(b) [5].

(a)

(b)

Figure 1 - (a) Two 3D-Printed Aircraft Scale Models (9.1875" and 18.375") [4] (b) Two 3D-Printed Scale Models, One with Open Ducts and Exhaust (left) and One with Closed Ducts and Exhaust (right) with Conductive Coatings [5].

A detailed illustration of the open duct model is shown in Figure 2 [5].

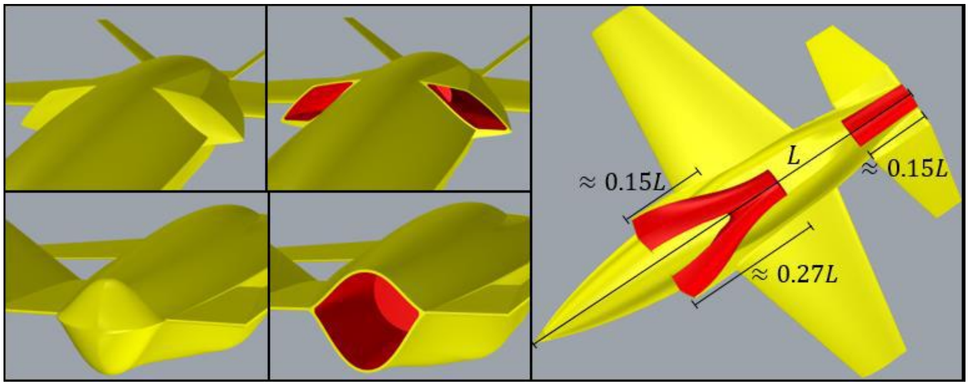


Figure 2 – CAD Model for Aircraft with Intake/Exhaust Ducts Open [5].

This paper presents the performance of Altair Feko's simulations by validating the Austin RCS Benchmark Suite aircraft models with the EXPEDITE measured and UT Austin's ARCHIE-AIM [6] simulation data. All simulations in this paper are performed using Method of Moments (MoM) solver in Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores. Feko includes many other full wave solvers such as ACA (Adaptive Cross Approximation), MLFMM (Multilevel Fast Multipole Method), Finite Element Method (FEM), Finite Difference Time Domain (FDTD) as well as asymptotic solvers such as PO (Physical Optics), LE-PO (Large Element Physical Optics) and RL-GO (Ray Launching Geometrical Optics). All these solvers can be used for RCS simulations based on the electrical size and available computational resources.

Aircraft Models in Austin RCS Benchmark Suite

Three aircraft models from Austin RCS Benchmark Suite are being considered (Figure 3). (a) PEC Aircraft (Closed Ducts), (b) Resin Aircraft (Closed Ducts) with Resin and (c) PEC Aircraft (Open Ducts). Both CAD models (iges format) and mesh models (INP and UNV formats) are provided at Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts [2]. Feko can import both CAD models in iges format as well as mesh files in various formats. In this paper we used the UNV meshes provided at [2].

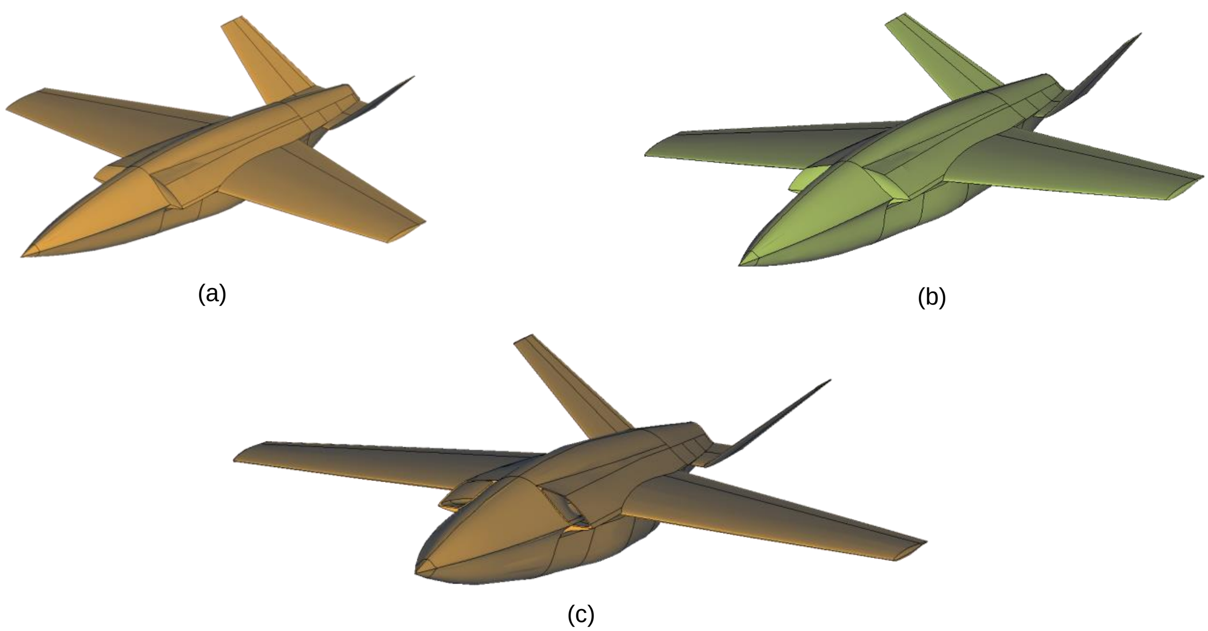


Figure 3 – Aircraft Models from Austin RCS Benchmark Suite Validated with Feko (a) PEC Aircraft (Closed Duct) (b) Resin Aircraft (Closed Duct) (c) PEC Aircraft (Open Duct)

PEC Aircraft (Closed Ducts)

Austin RCS Benchmark Suite [2] includes a data set for measured and simulated RCS data for closed-duct scaled aircraft model with the length of 9.1875” at frequencies 2.58GHz, 5.12GHz, 7GHz and 10.25GHz with incident angles 0º to 180º in the azimuth plane for Vertical and Horizontal polarizations (as given in Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVA-PEC Closed-Duct PRIME Aircrafts/IVA-Reference Data [2]).

The mesh files for the closed duct aircraft are available with various mesh refinements and are available as per the pdf file at Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVB-Resin Closed-Duct PRIME Aircrafts/IVB-Model_mesh_file_descriptor.pdf and are shown in Figure 4.

	Mesh AA	Mesh AB	Mesh BB	Mesh BC	Mesh CC	Mesh CD	Mesh DD
Average Edge Length (m)	2.039×10^{-1}	1.450×10^{-1}	9.903×10^{-2}	7.303×10^{-2}	5.248×10^{-2}	3.644×10^{-2}	2.450×10^{-2}
Maximum Edge Length (m)	3.028×10^{-1}	2.147×10^{-1}	1.517×10^{-1}	1.090×10^{-1}	8.625×10^{-2}	5.353×10^{-2}	3.429×10^{-2}
Minimum Edge Length (m)	1.4461×10^{-2}	1.434×10^{-2}	1.431×10^{-2}	1.243×10^{-2}	2.371×10^{-3}	1.036×10^{-2}	6.502×10^{-3}
	Mesh DE	Mesh EE	Mesh EF	Mesh FF	Mesh FG	Mesh GG	
Average Edge Length (m)	1.825×10^{-2}	1.175×10^{-2}	9.039×10^{-3}	5.984×10^{-3}	4.522×10^{-3}	3.156×10^{-3}	
Maximum Edge Length (m)	2.711×10^{-2}	1.674×10^{-2}	1.325×10^{-2}	9.200×10^{-3}	6.628×10^{-3}	5.093×10^{-3}	
Minimum Edge Length (m)	3.883×10^{-3}	3.063×10^{-3}	2.567×10^{-3}	1.760×10^{-3}	1.858×10^{-3}	8.892×10^{-4}	

Figure 4 – Mesh Model Dimensions for the Closed Duct Aircraft from University of Texas Austin [2]

UNV mesh file was imported into Feko (used the mesh model AA from Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/UNV_Meshes), the length of the imported aircraft mesh model was about 0.5927 meters, or 23.3346 inches, as shown in Figure 5.

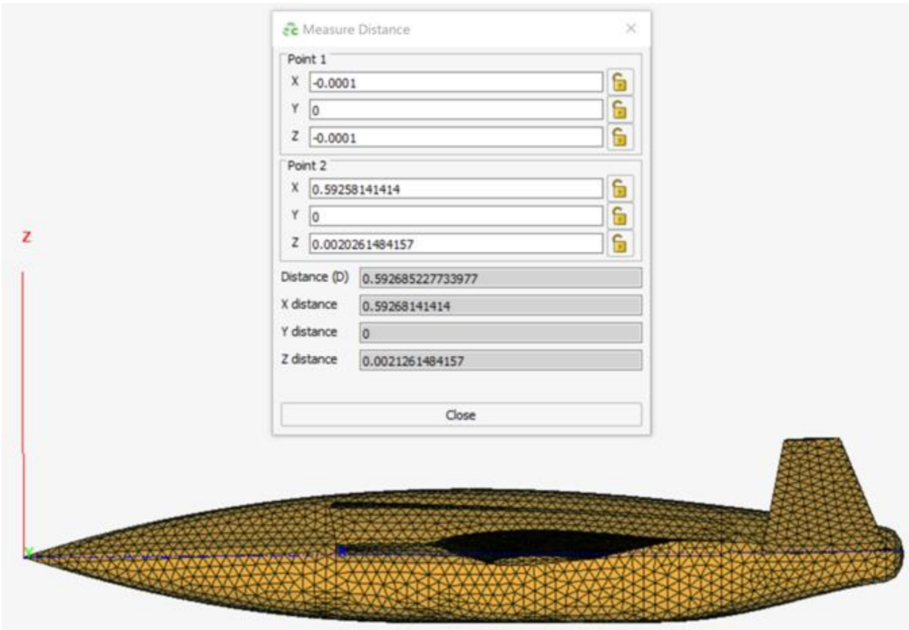


Figure 5 – Imported Closed Duct Aircraft UNV Mesh AA Model [2]

Average Mesh triangle edge length of the imported mesh is 0.008028m (Figure 6(a)) and does not match with the edge length 0.2039m for AA mesh (Figure 4). The model needed to be scaled up to the full aircraft length of about 15 meters, or 49.4 feet [4] with a scale factor of 25.40157 to match with Mesh AA edge length of 0.2039m. The mesh triangle results at the full-scale dimensions are shown in Figure 6(b), matching the mesh AA in Figure 4. The aircraft mesh model is then scaled down to the analyzed length of 9.1875 inches [4] with a scaling factor of 0.015484. Scaling down to 9.1875 inches makes the average mesh size to be 0.003157876 meters (Figure 6(c)), which is smaller than one eighth of the wavelength at the highest frequency 10.25GHz. Additionally, the aircraft was rotated 180 degrees around the z-axis to match the problem description in [4].

Triangles	
Count	10 404
Average edge length	0.00802790695167657
Minimum edge length	0.000569107756784332
Maximum edge length	0.0119203357185983
Edge standard deviation	0.00109571799289026

(a)

Triangles	
Count	10 404
Average edge length	0.203921440386499
Minimum edge length	0.0144562305215002
Maximum edge length	0.302795242179476
Edge standard deviation	0.0278329572966616

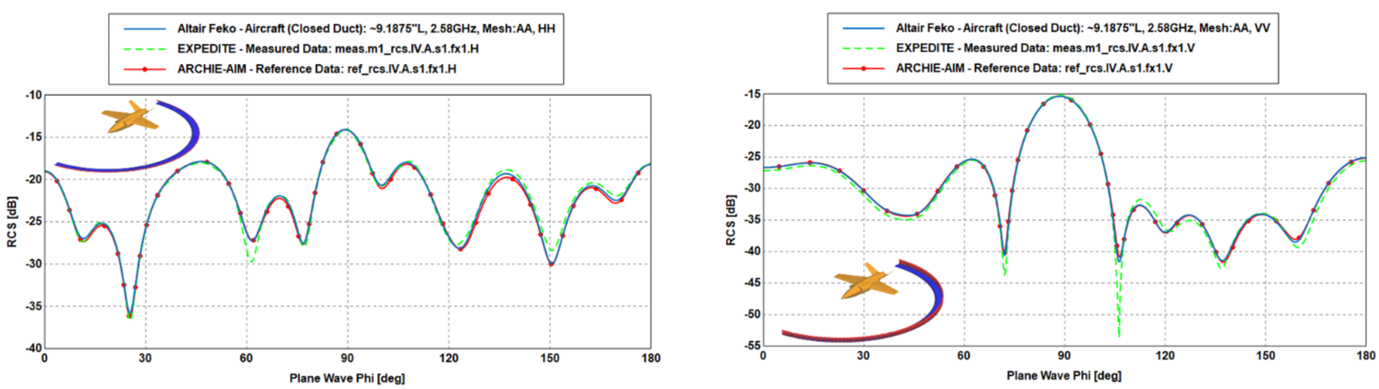
(b)

Triangles	
Count	10 404
Average edge length	0.00315751958294455
Minimum edge length	0.000223840273394909
Maximum edge length	0.00468848152990701
Edge standard deviation	0.000430965510781506

(c)

Figure 6 – Feko Mesh Triangle Edge Lengths (a) Average Edge Length of Mesh AA as Imported from the UNV File (b) Average Edge Length after Scaling Up by a Factor of 25.40157 and (c) Average Edge Length after Scaling Down the Mesh (b) by a Factor of 0.015484.

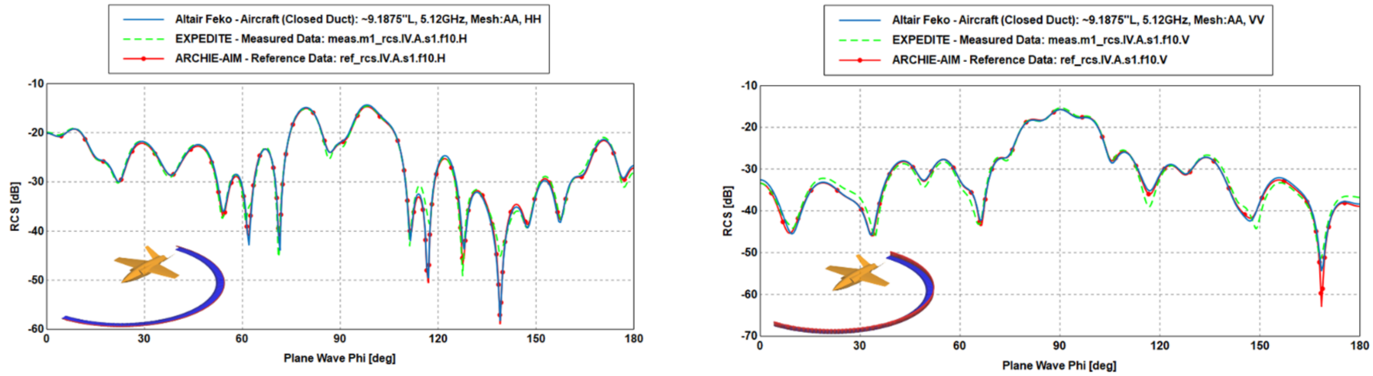
The aircraft is simulated at frequencies of 2.58GHz, 5.12GHz, 7GHz, and 10.25GHz. At all frequencies, monostatic RCS is computed with the incident wave was set at angles of $\theta_i = 90\,°$ and $0\,° \leq \phi_i \leq 180\,°$ for both VV and HH polarizations. Results of Feko using MoM solver, ARCHIE-AIM simulation data, and EXPEDITE measured data are shown in Figure 7 for 2.58GHz, Figure 8 for 5.12GHz, Figure 9 for 7GHz and Figure 10 for 10.25GHz. Feko simulations agree well with ARCHIE-AIM simulation data as well as EXPEDITE measurement data.



(a) HH Polarization

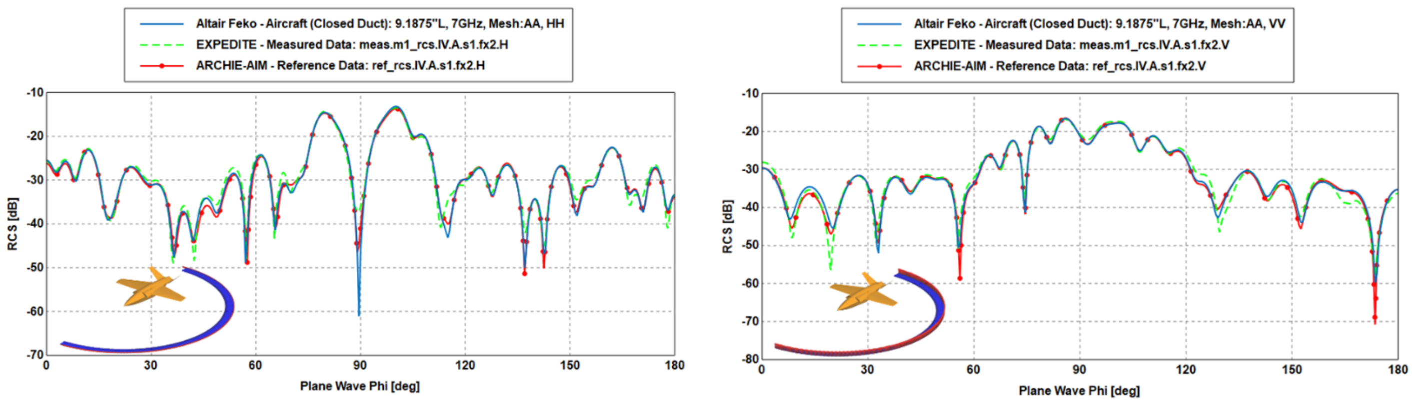
(b) VV Polarization

Figure 7 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Closed Duct Aircraft at 2.58GHz



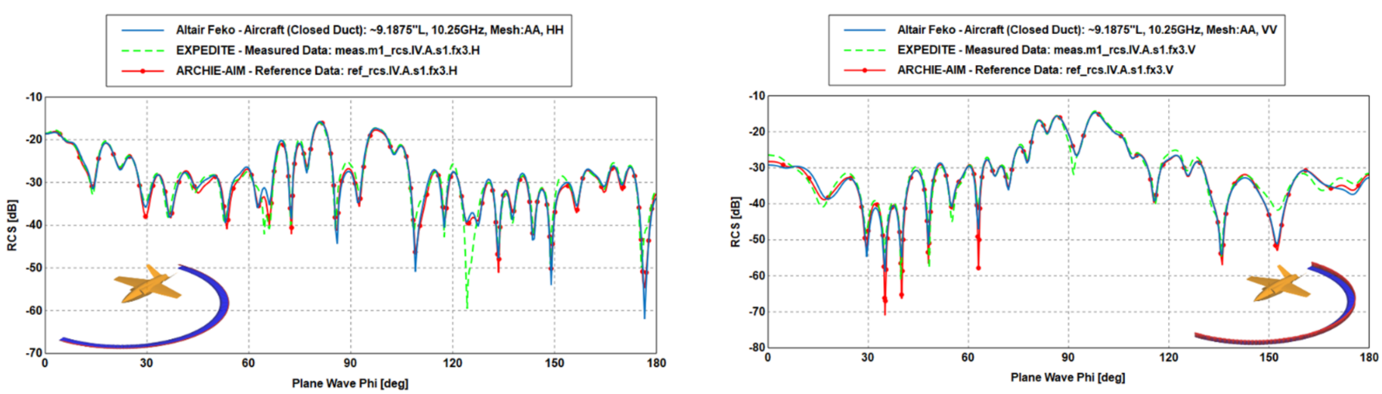
(a) HH Polarization (b) VV Polarization

Figure 8 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Closed Duct Aircraft at 5.12GHz



(a) HH Polarization (b) VV Polarization

Figure 9 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Closed Duct Aircraft at 7GHz



(a) HH Polarization (b) VV Polarization

Figure 10 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Closed Duct Aircraft at 10.25GHz

Resin Aircraft (Closed Duct)

The dimensions of the resin aircraft with closed duct were the same as the PEC closed duct aircraft model. The mesh model used to simulate the resin aircraft was the same mesh model (Mesh AA) used for the PEC closed duct aircraft along with the necessary transformations to scale the mesh to 9.1875 inches in length. Measured RCS data is available at frequencies 2.58GHz, 5.12GHz, 7GHz and 10.25GHz with incident angles 0º to 180º in the azimuth plane for Vertical and Horizontal polarizations (as given in Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVB-Resin Closed-Duct PRIME Aircrafts/IVB-Reference Data [2]). The dielectric properties for the resin used for simulations are given in Table 1 over the frequencies of interest [7]. To apply the dielectric to the mesh model, the triangle label properties were changed with the front medium as the resin dielectric and the back medium as free space shown in Figure 11. Geometric symmetry was applied to the mesh model to ensure uniform mesh normals over the entire aircraft. Additionally, the aircraft was rotated 180 degrees around the z-axis to match the problem description in [4].

Table 1: Dielectric Relative Permittivity Values of Resin for Frequencies of Interest

Frequency	ε′	ε’’
2.58 GHz	2.96	0.0963
5.125 GHz	2.91	0.086
7 GHz	2.90	0.0822
10.25 GHz	2.88	0.0785

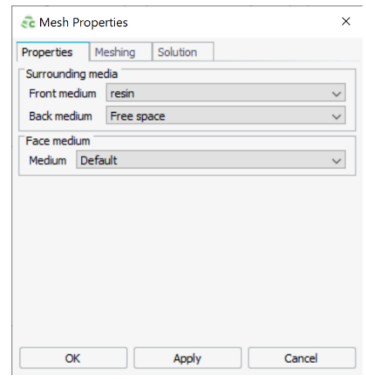
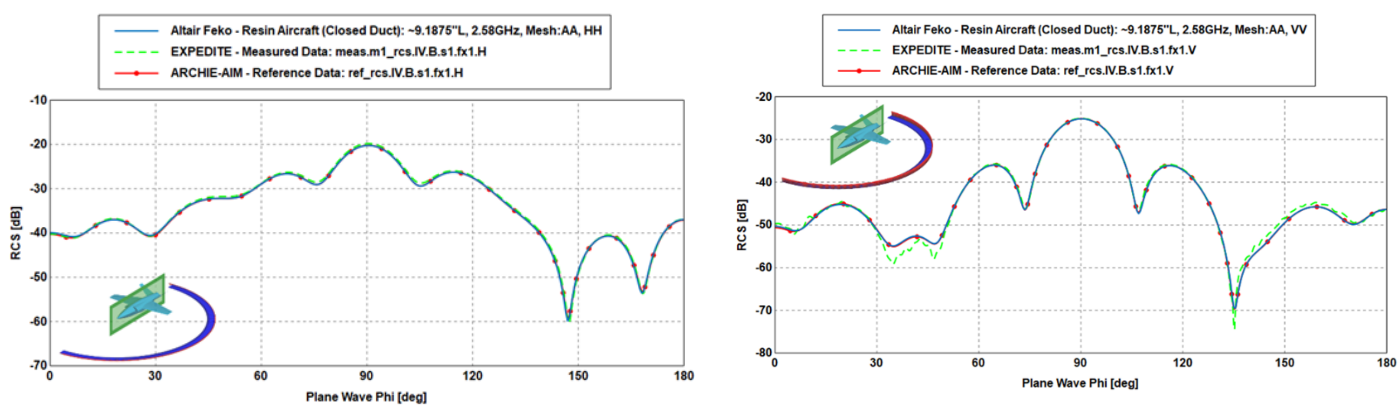


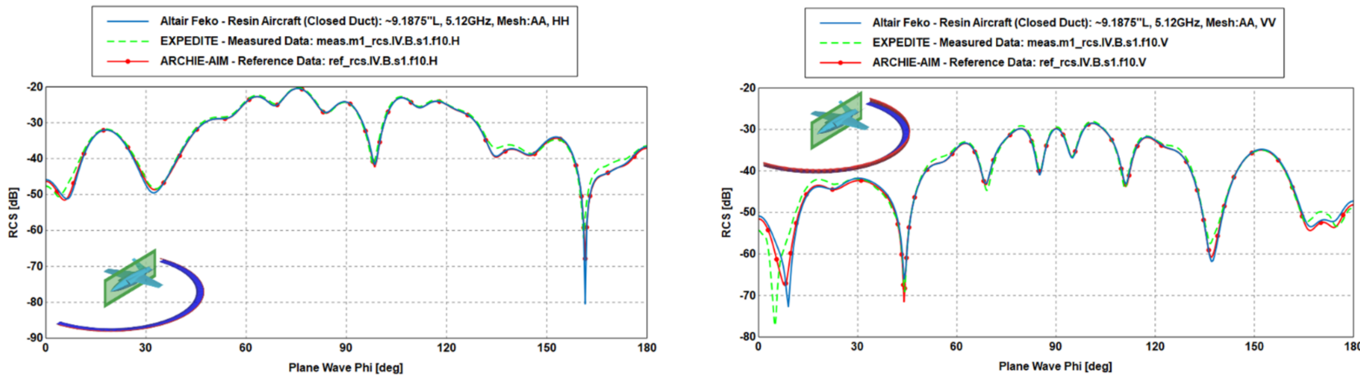
Figure 11 – Assignment of Mesh Properties for the Resin Aircraft

The aircraft is simulated at frequencies of 2.58GHz, 5.12GHz, 7GHz, and 10.25GHz. At all frequencies, monostatic RCS is computed with the incident wave was set at angles of $\theta_i = 90\,°$ and $0\,° \leq \phi_i \leq 180\,°$ for both VV and HH polarizations. Results of Feko using MoM solver, ARCHIE-AIM simulation data, and EXPEDITE measured data are shown in Figure 12 for 2.58GHz, Figure 13 for 5.12GHz, Figure 14 for 7GHz and Figure 15 for 10.25GHz. Feko simulations agree well with ARCHIE-AIM simulation data as well as EXPEDITE measurement data.



(a) HH Polarization (b) VV Polarization

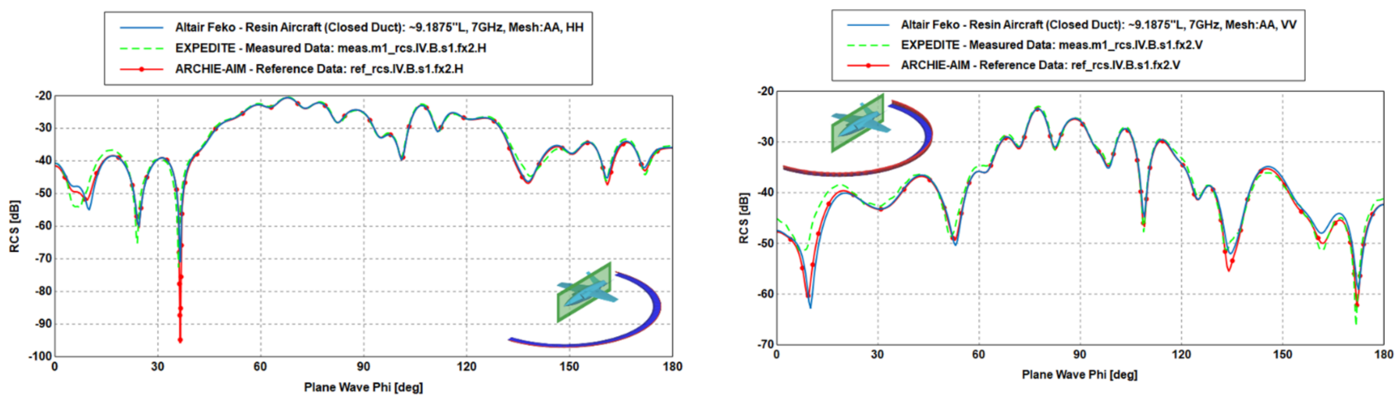
Figure 12 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Resin Closed Duct Aircraft at 2.58GHz



(a) HH Polarization

(b) VV Polarization

Figure 13 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Resin Closed Duct Aircraft at 5.12GHz



(a) Horizonal Polarization

(b) Vertical Polarization

Figure 14 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Resin Closed Duct Aircraft at 7GHz

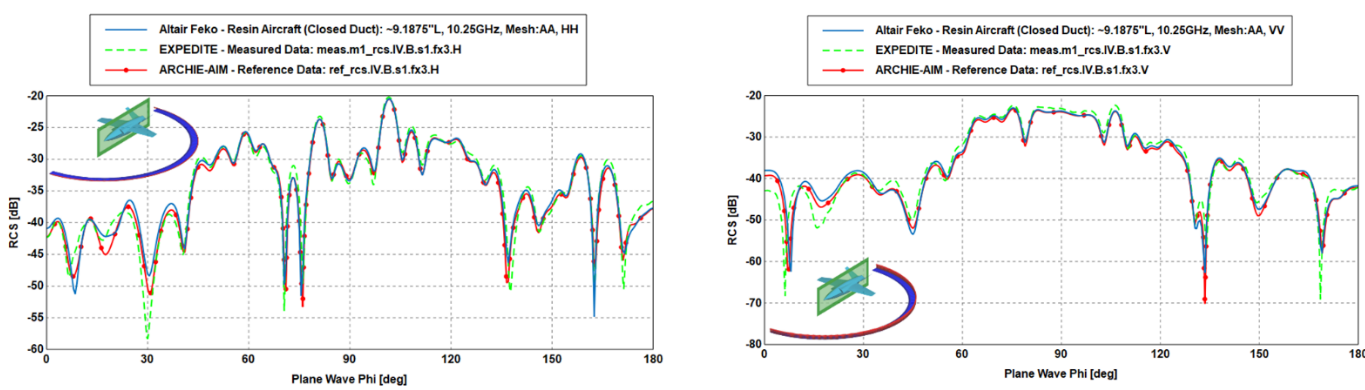


Figure 15 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for the Resin Closed Duct Aircraft at 10.25GHz

PEC Aircraft (Open Duct)

Austin RCS Benchmark Suite [2] includes data set for measured and simulated RCS data for open-duct scaled aircraft model with the length of roughly 9.0116 inches at frequencies 2.56 GHz, 2.58GHz, 5.12GHz, 7GHz and 10.25GHz with incident angles 0º to 180º in the azimuth plane for Vertical and Horizontal polarizations (as given in Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVC-PEC Open-Duct PRIME Aircrafts/IVC-Reference Data [2]).

The mesh files for the open duct aircraft are available with various mesh refinements are available as per the pdf file at Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/Problem IVC-PEC Open-Duct PRIME Aircrafts/IVC-Model_mesh_file_descriptor.pdf and are shown in Figure 16.

Mesh Files: File Names

	Mesh AA	Mesh AB	Mesh BB	Mesh BC	Mesh CC	Mesh CD	Mesh DD
Average Edge Length (m)	2.010×10^{-1}	1.451×10^{-1}	1.011×10^{-1}	7.302×10^{-2}	5.076×10^{-2}	3.645×10^{-2}	2.549×10^{-2}
Maximum Edge Length (m)	3.011×10^{-1}	2.151×10^{-1}	1.523×10^{-1}	1.090×10^{-1}	7.593×10^{-2}	5.353×10^{-2}	3.808×10^{-2}
Minimum Edge Length (m)	1.431×10^{-2}	1.210×10^{-2}	1.083×10^{-2}	1.210×10^{-2}	9.580×10^{-3}	9.957×10^{-3}	5.787×10^{-3}
	Mesh DE	Mesh EE	Mesh EF	Mesh FF	Mesh FG	Mesh GG	
Average Edge Length (m)	1.824×10^{-2}	1.271×10^{-2}	9.038×10^{-3}	6.475×10^{-3}	4.521×10^{-3}	3.160×10^{-3}	
Maximum Edge Length (m)	2.696×10^{-2}	1.903×10^{-2}	1.325×10^{-2}	9.512×10^{-3}	6.603×10^{-3}	5.087×10^{-3}	
Minimum Edge Length (m)	5.095×10^{-3}	2.952×10^{-3}	2.304×10^{-3}	1.815×10^{-3}	1.277×10^{-3}	8.892×10^{-4}	

Figure 16 – Mesh Model Dimensions for the Open Duct Aircraft from University of Texas Austin [2]

UNV mesh file was imported into Feko (used the mesh model AA from Austin-RCS-Benchmarks/Problem IV-PRIME Aircrafts/UNV_Meshes), the length of the imported aircraft mesh model was about 0.58139 meters, or about 22.89", as shown in Figure 17.

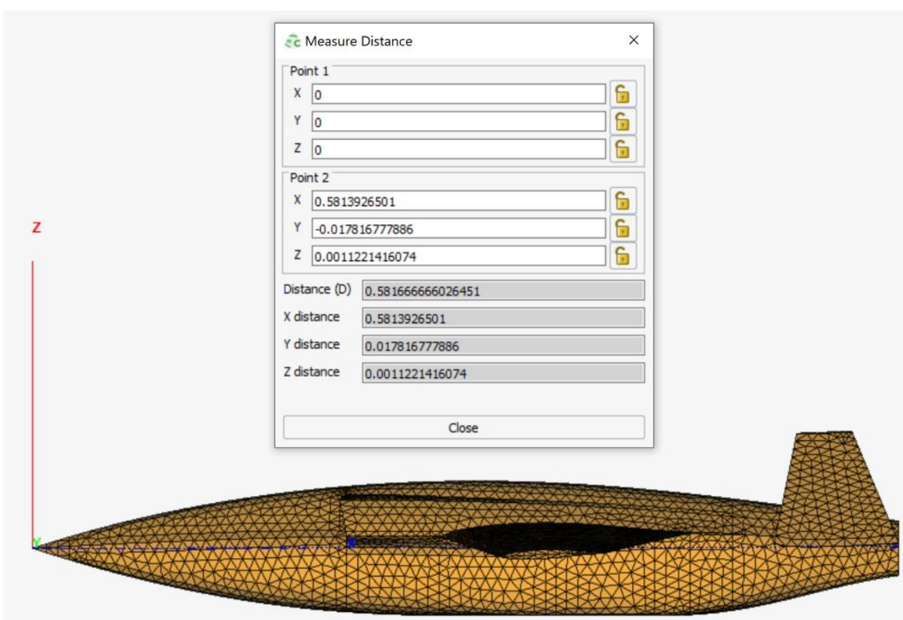


Figure 17 – Imported Open Duct Aircraft Mesh AA Model

Average Mesh triangle edge length of the imported mesh is 0.007915m (Figure 18(a)) and does not match with the edge length 0.2039m for AA mesh (Figure 4). The model needed to be scaled up to the full aircraft length of about 14.48 meters, or 48.56 feet [4] with a scale factor of 25.4561182 to match with Mesh AA edge length close to 0.2010m. The mesh triangle results at the full-scale dimensions are shown in Figure 18(b), matching the mesh AA in Figure 16. The aircraft mesh model is then scaled down to the analyzed length of 9.0116 inches [4] with a scaling factor of 0.0154658531. Scaling down to 9.0116 inches makes the average mesh size to be 0.0031162 meters (Figure 18(c)), which is smaller than one eighth of the wavelength at the highest frequency 10.25GHz. Additionally, the aircraft was rotated 180 degrees around the z-axis in order to match the problem description in [4].

Triangles	
Count	12 236
Average edge length	0.00791516258591207
Minimum edge length	0.000563263774626103
Maximum edge length	0.0118562834689993
Edge standard deviation	0.00149908548042572

(a)

Triangles	
Count	12 236
Average edge length	0.201489314359195
Minimum edge length	0.0143385092246602
Maximum edge length	0.301814953399553
Edge standard deviation	0.038160897181621

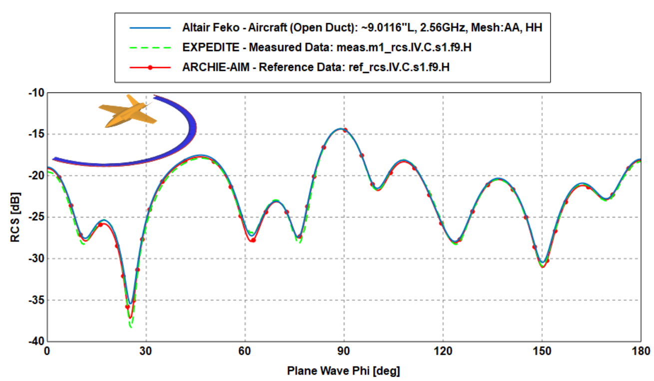
(b)

Triangles	
Count	12 236
Average edge length	0.00311620413709904
Minimum edge length	0.00022175727734159
Maximum edge length	0.00466782573266083
Edge standard deviation	0.000590190829975151

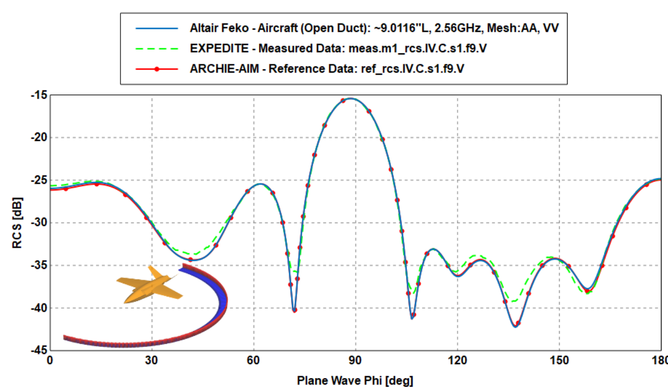
(c)

Figure 18 – Feko Mesh Triangle Edge Lengths (a) Average Edge Length of Mesh AA as Imported from the UNV File (b) Average Edge Length after Scaling Up by a Factor of 25.4561182 and (c) Average Edge Length after Scaling Down the Mesh (b) by a Factor of 0.0154658531.

The aircraft is simulated at frequencies of 2.56GHz, 2.58GHz, 5.12GHz, 7GHz, and 10.25GHz. At all frequencies, monostatic RCS is computed with the incident wave was set at angles of $\theta_i = 90°$ and $0° \leq \phi_i \leq 180°$ for both VV and HH polarizations. Results of Feko using MoM solver, ARCHIE-AIM simulation data, and EXPEDITE measured data are shown in Figure 19 for 2.56GHz, Figure 20 for 2.58GHz, Figure 21 for 5.12GHz, Figure 22 for 7GHz and Figure 23 for 10.25GHz. Feko simulations agree well with ARCHIE-AIM simulation data as well as EXPEDITE measurement data.

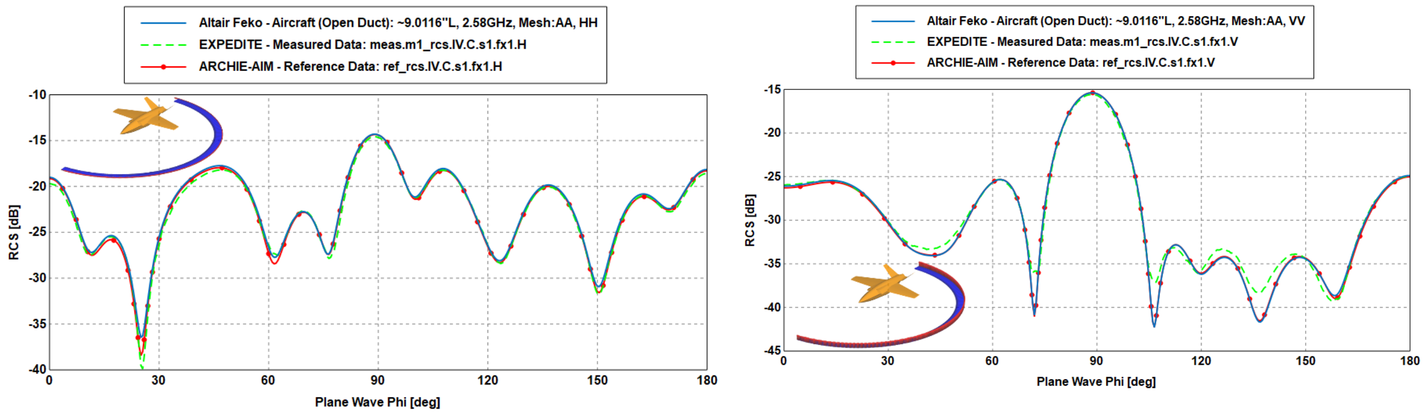


(a) HH Polarization



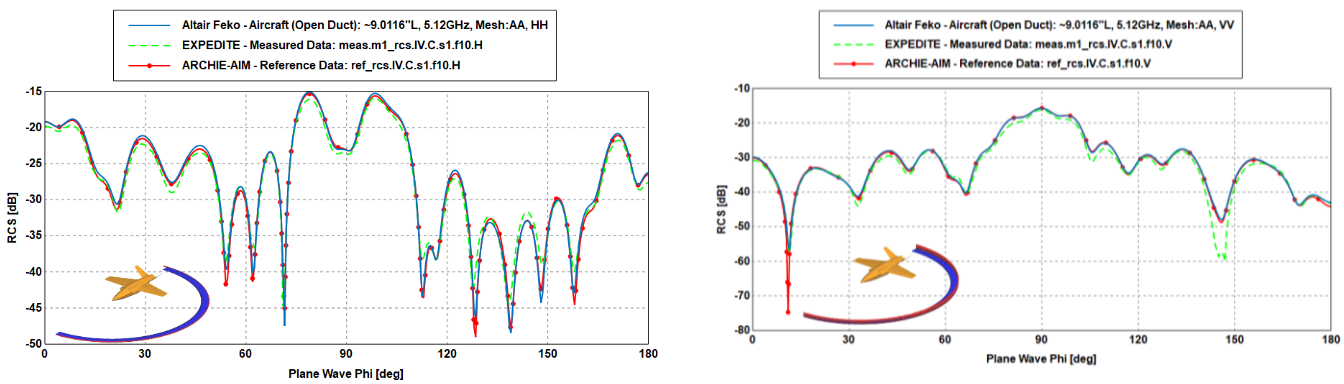
(b) VV Polarization

Figure 19 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for PEC Open Duct Aircraft at 2.56GHz



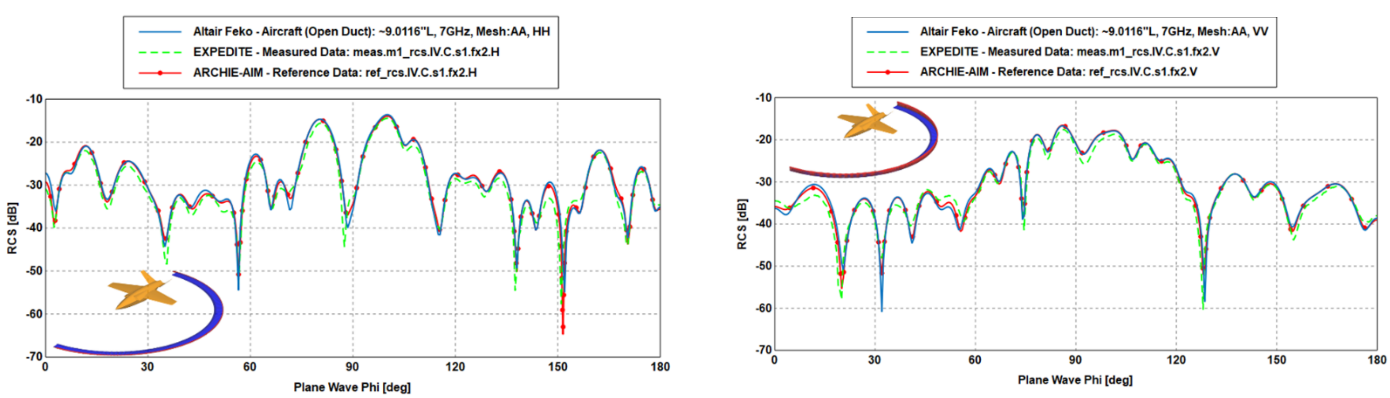
(a) HH Polarization (b) VV Polarization

Figure 20 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for PEC Open Duct Aircraft at 2.58GHz



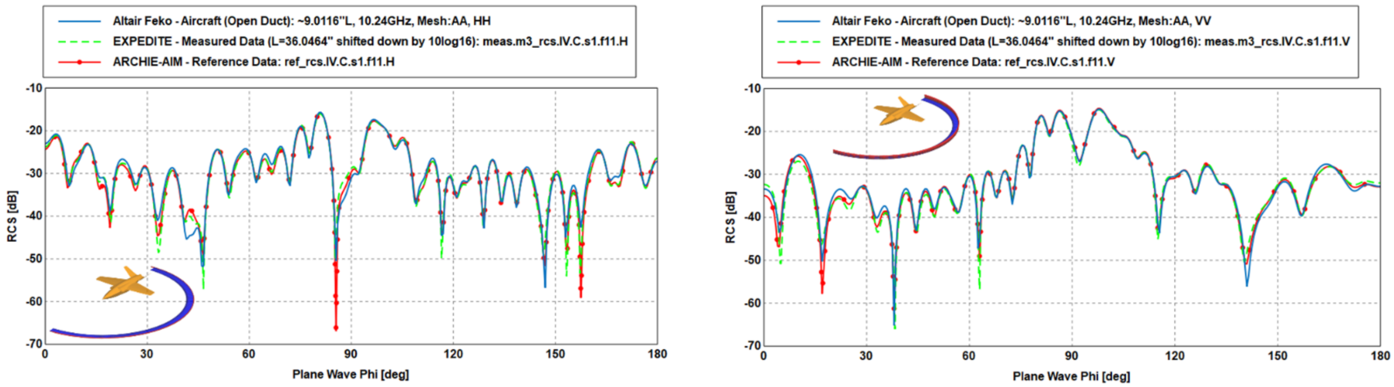
(a) HH Polarization (b) VV Polarization

Figure 21 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results for PEC Open Duct Aircraft at 5.12GHz



(a) HH Polarization (b) VV Polarization

Figure 22 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results PEC Open Duct Aircraft at 7GHz



(a) HH Polarization (b) VV Polarization

Figure 23 – Feko, ARCHIE-AIM, and EXPEDITE RCS Results PEC Open Duct Aircraft at 10.24GHz

Conclusion

Performing Feko RCS analysis of the models and materials provided by University of Texas Austin's Benchmark Suite [2] resulted in accurate RCS simulation and validation of Feko performance. Specifically, Feko has simulated accurate RCS results for the open and closed duct aircraft models through comparison between the provided EXPEDITE measured and ARCHIE-AIM simulated data. Now that Feko simulations have been validated, further investigation can be performed such as simulations at higher frequencies, using Feko's additional solvers to minimize runtime and memory, and using additional CPU cores to utilize the parallel processes of Feko's solvers to minimize runtime.

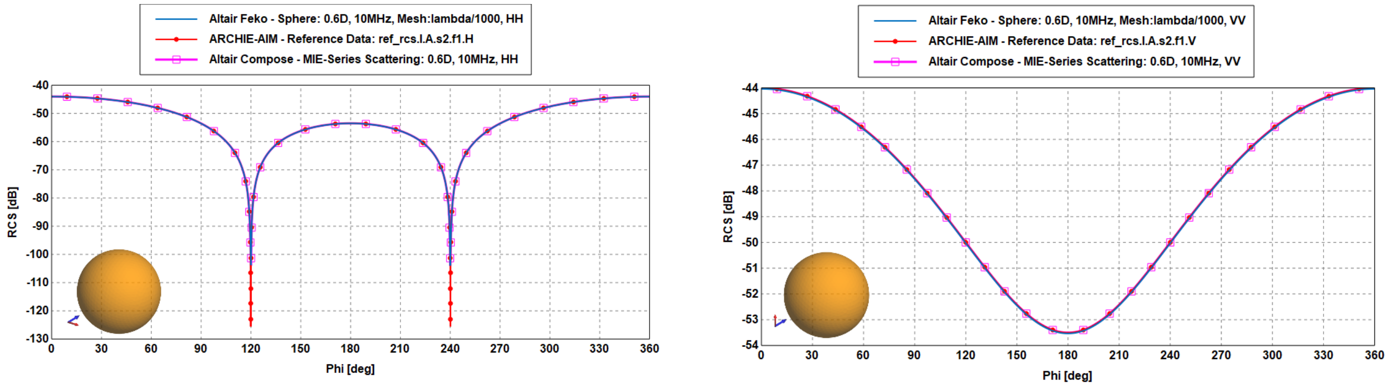
APPENDIX

In addition to the aircraft models presented, Austin RCS Benchmark Suite also consists of four generic geometries with various material assignments: sphere, plate, almond, and aircraft. In this Appendix we present the validation Feko RCS simulations of sphere, plate, and almond geometries.

PEC Sphere

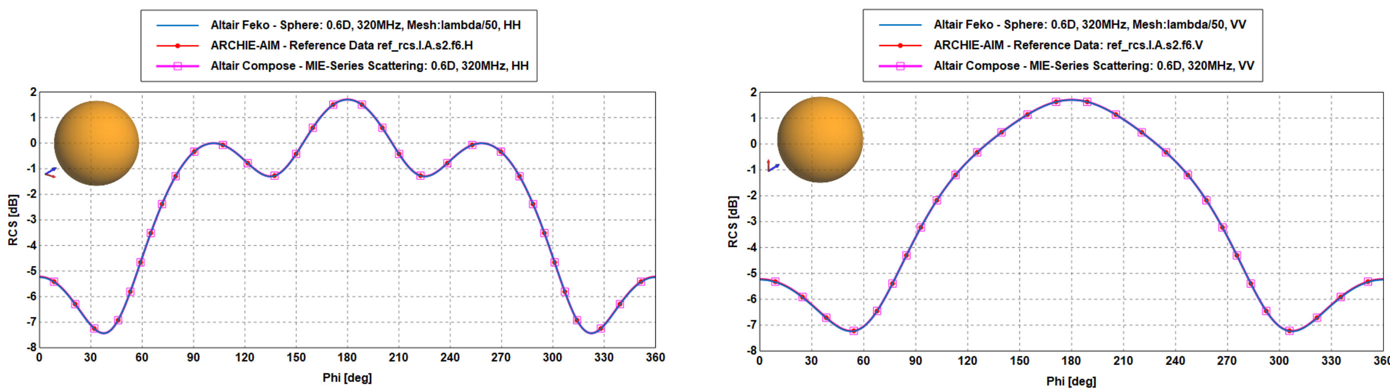
The PEC sphere problem set varies the diameter of the sphere and the frequency of the incident wave to compute RCS. The diameters of the sphere are defined in the Benchmark Suite to be 0.6m and 19.2m and they are analyzed at 10MHz and 320MHz. The incident wave was set at angle of $\boldsymbol{\theta_i} = \mathbf{90}°$ and $\boldsymbol{\phi_i} = \mathbf{0}°$. RCS was computed as bistatic RCS at the angles $\boldsymbol{\theta_s} = \mathbf{90}°$ and $\mathbf{0}° \leq \boldsymbol{\phi_s} \leq \mathbf{360}°$. At all frequencies, the polarization analyzed were VV and HH polarizations. In addition to Feko simulations, we also carried out MIE-Series [8] simulations modified from the MIE-Series code from [9] which were performed using Altair Compose [10] to validate both Feko and ARCHIE-AIM simulations. All simulations are performed in Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores using MoM Solver in Feko, except for the case of 19.2m diameter sphere at 320MHz, which is simulated using MLFMM solver in Feko.

Feko simulations of RCS of Spheres are shown for 0.6m Diameter at 10MHz (Figure A.1), 0.6m Diameter at 320MHz (Figure A.2), 19.2m Diameter at 10MHz (Figure A.3) and 19.2m Diameter at 320MHz (Figure A.4) and compared with MIE-Sphere code as well as ARCHIE-AIM [6] simulation data. All three simulations agree very well.



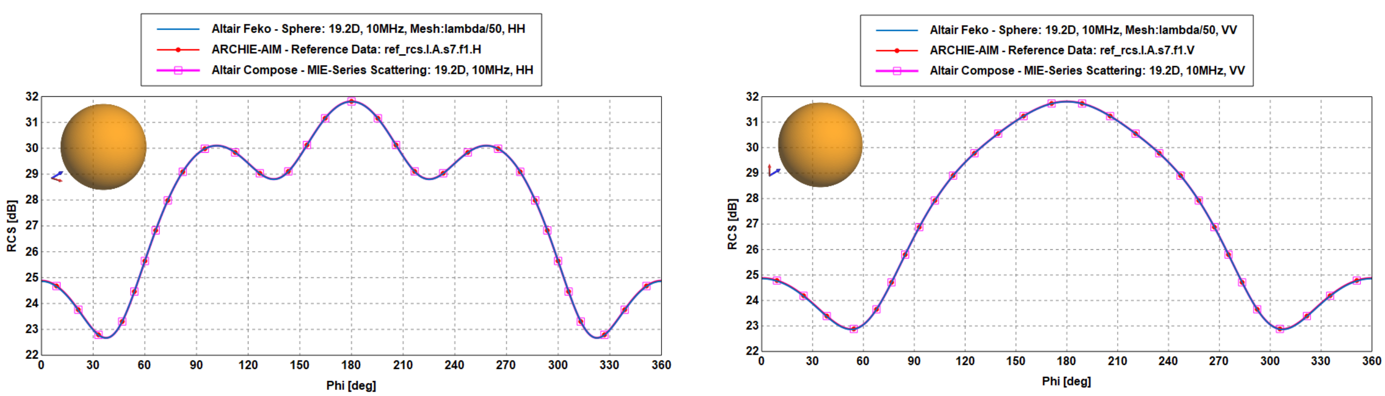
(a) Horizontal Polarization (b) Vertical Polarization

Figure A.1 – Feko, ARCHIE-AIM, and MIE-Sphere RCS Simulations for 0.6m Diameter PEC Sphere at 10MHz



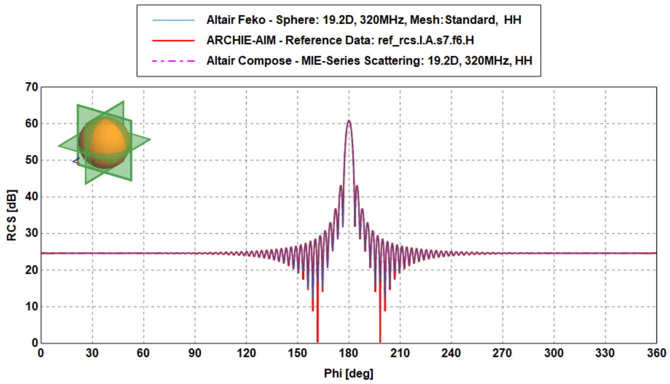
(a) Horizontal Polarization (b) Vertical Polarization

Figure A.2 – Feko, ARCHIE-AIM, and MIE-Sphere RCS Simulations for 0.6m Diameter PEC Sphere at 320MHz

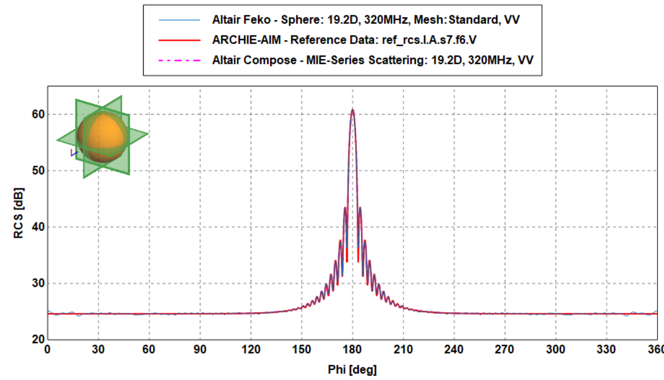


(a) Horizontal Polarization (b) Vertical Polarization

Figure A.3 – Feko, ARCHIE-AIM, and MIE-Sphere RCS Simulations for 19.2m Diameter PEC Sphere at 10MHz



(a) Horizontal Polarization

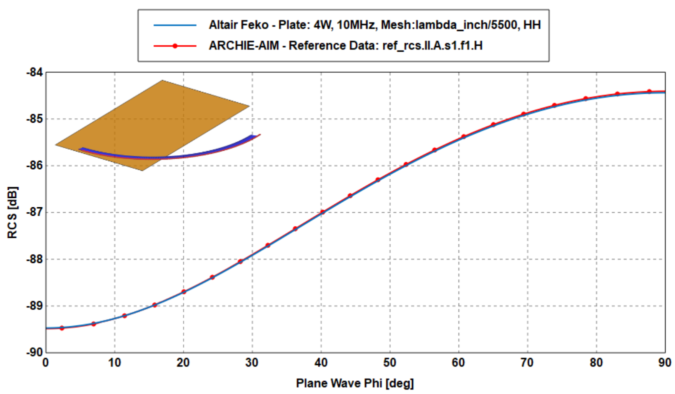


(b) Vertical Polarization

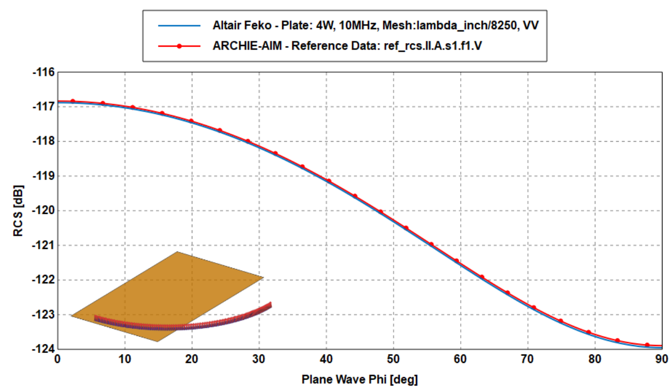
Figure A.4 – Feko, ARCHIE-AIM, and MIE-Sphere RCS Results for the HH Polarized 19.2m Diameter PEC Sphere at 320MHz

PEC Plate (No Thickness)

The no thickness PEC plate problem set varies the size dimensions of the plate and the frequency of the incident wave for simulating RCS. The dimensions of the no thickness plate are W x 7W/4, where W is either 4 inches or 128 inches. The 4-inch width plate is simulated at frequencies 10MHz and 5.12GHz and the 128-inch plate is simulated at 10MHz and 320MHz. The incident wave was set at angles of $\theta_i = 80°$ and $0° \leq \phi_i \leq 90°$. RCS was computed as monostatic RCS with VV and HH polarizations of the incident plane waves. The 4-inch width plate is simulated at frequencies 10MHz (Figure A.5) and 5.12GHz (Figure A.6) and the 128-inch plate is simulated at 10MHz (Figure A.7) and 320MHz (Figure A.8). Feko simulations agree well with ARCHIE-AIM [6] simulation data. All simulations are performed in Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores using MoM Solver in Feko**.**

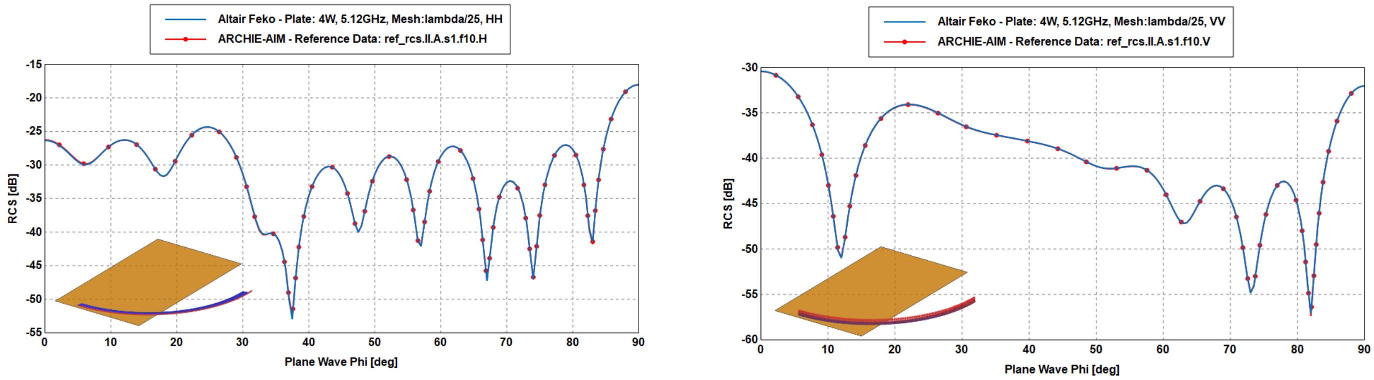


(a) Horizontal Polarization



(b) Vertical Polarization

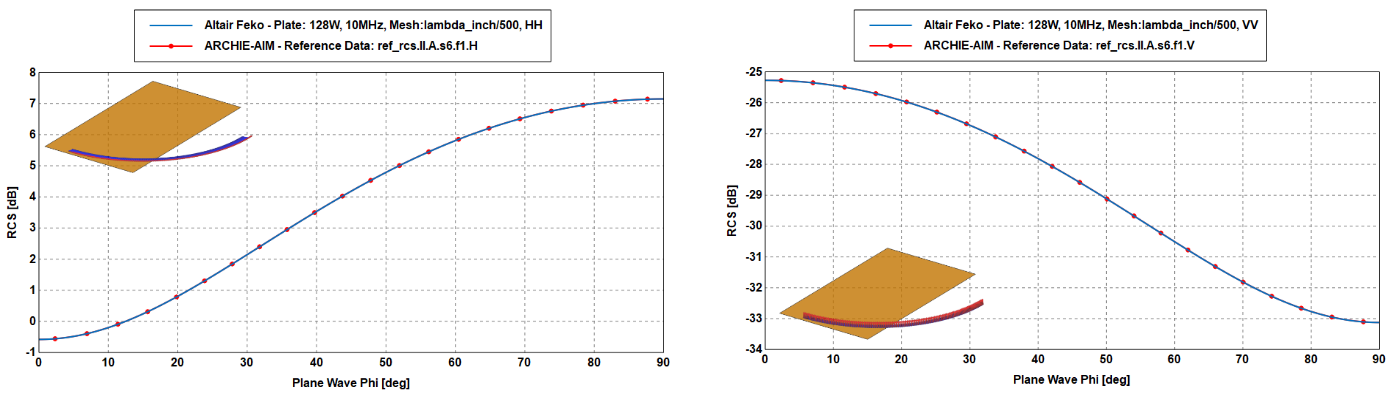
Figure A.5 – Feko and ARCHIE-AIM RCS Results for 4-inch Width PEC Plate at 10MHz



(a) Horizontal Polarization

(b) Vertical Polarization

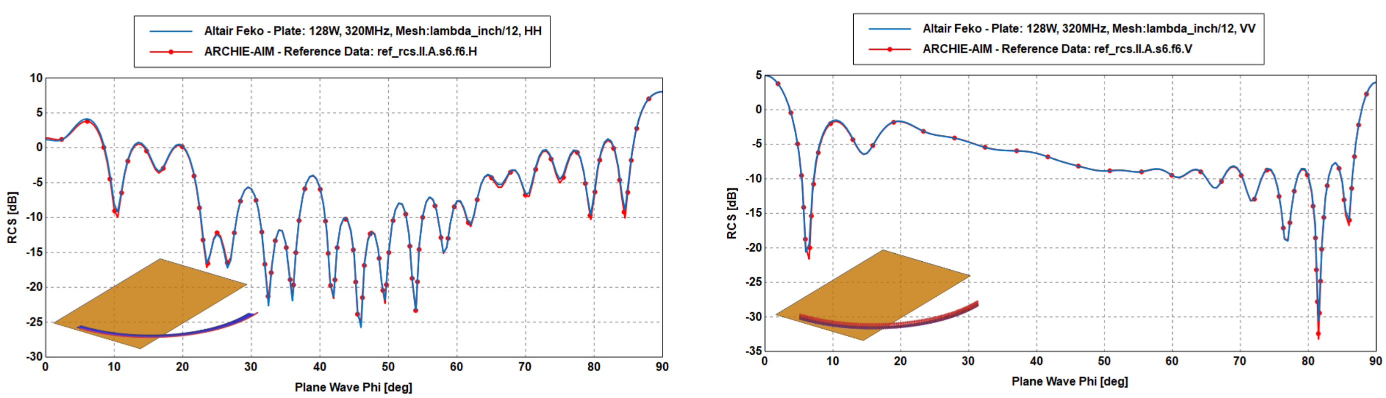
Figure A.6 – Feko and ARCHIE-AIM RCS Results for 4-inch Width PEC Plate at 5.12GHz



(a) Horizontal Polarization

(b) Vertical Polarization

Figure A.7 – Feko and ARCHIE-AIM RCS Results for 128-inch Width PEC Plate at 10MHz



(a) Horizontal Polarization

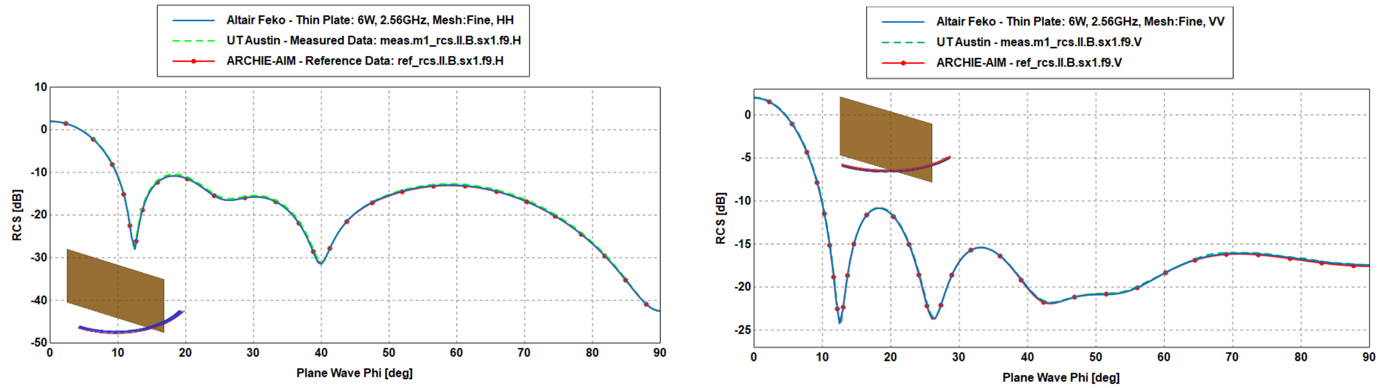
(b) Vertical Polarization

Figure A.8 – Feko and ARCHIE-AIM RCS Results for 128-inch Width PEC Plate at 320MHz

PEC Plate (64mil Thickness)

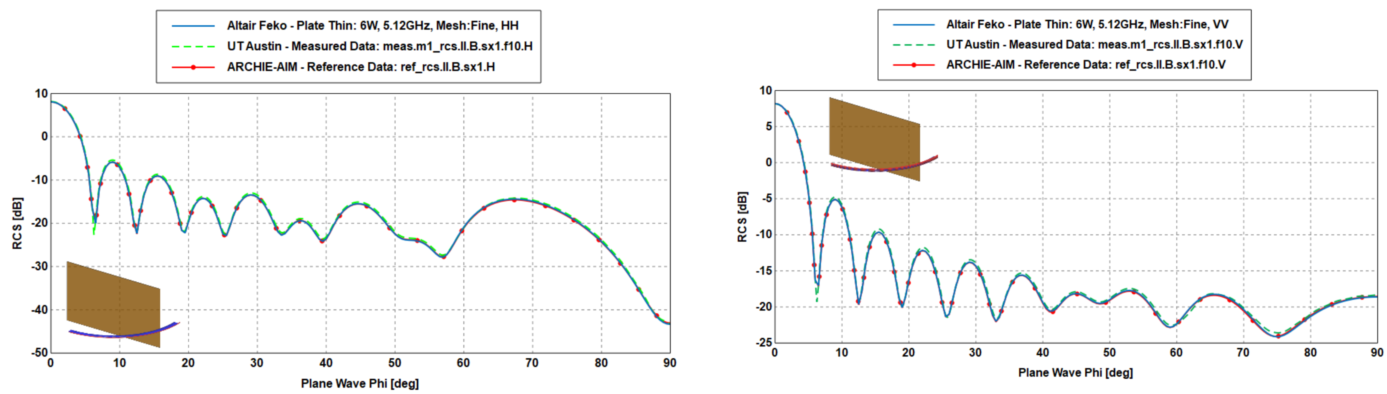
The 64mil thickness PEC plate problem set varies the size dimensions of the plate and the frequency of the incident wave for simulating RCS. The dimensions of the plate are W x 7W/4 x 64mil, where W is 6 inches. The plate is simulated at frequencies 2.56GHz, 5.12GHz, 7GHz, and 10.24GHz. The incident wave was set at angles of $\theta_i = 90\,°$ and $0\,° \le \phi_i \le 90\,°$. RCS was computed as monostatic

RCS with VV and HH polarizations of the incident plane waves. RCS simulations are shown in Figures A.9 (2.56GHz), A.10 (5.12GHz), A.11 (7GHz), A.12 (10.24GHz). Feko simulations agree well with ARCHIE-AIM simulation and measured data [2]. All simulations are performed with Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores using MoM solver in Feko.



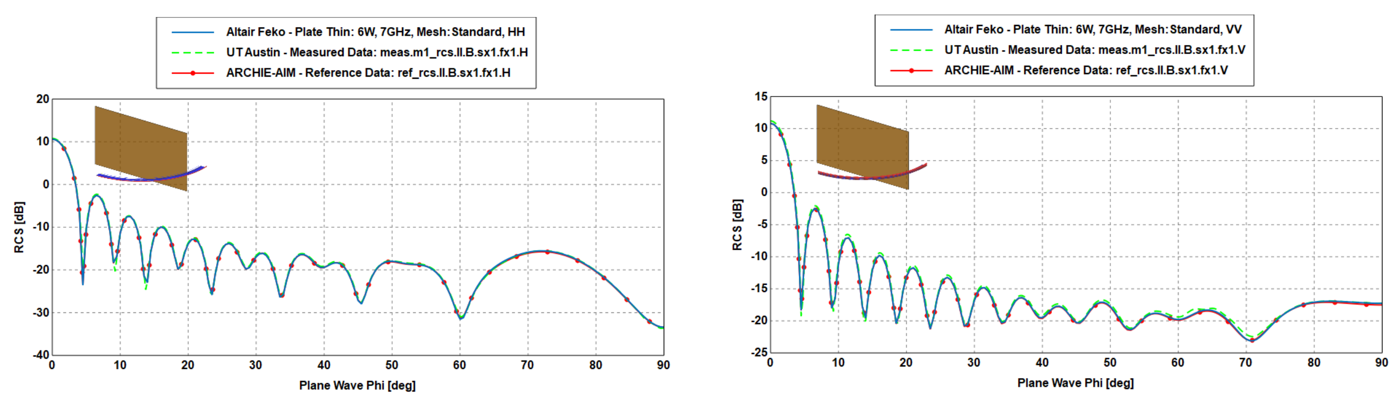
(a) Horizontal Polarization (b) Vertical Polarization

Figure A.9 – Feko, ARCHIE-AIM, and Measured RCS Results for 64mil thick PEC Plate at 2.56GHz



(a) Horizontal Polarization (b) Vertical Polarization

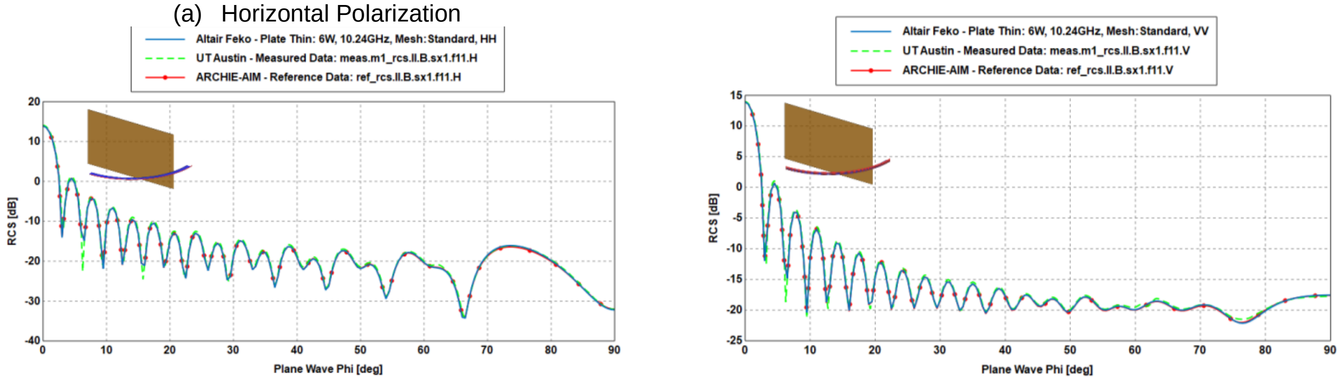
Figure A.10 – Feko, ARCHIE-AIM, and Measured RCS Results for 64mil thick PEC Plate at 5.12GHz



(a) Horizontal Polarization (b) Vertical Polarization

Figure A.11 – Feko, ARCHIE-AIM, and Measured RCS Results for 64mil PEC Plate at 7GHz

(a) Horizontal Polarization



(b) Vertical Polarization

Figure A.12 – Feko, ARCHIE-AIM, and Measured RCS Results for 64mil PEC Plate at 10.24GHz

PEC Almond

The PEC Almond problem set varies the frequency of the incident wave for simulating RCS at frequencies 3.5GHz, 5.125GHz, 7GHz, and 10.25GHz. The dimensions of the almond were derived from [11], where the length of the almond is about 9.936 inches. The incident wave was set at angles of $\theta_i = 90\,°$ and $0\,° \leq \phi_i \leq 180\,°$. RCS was computed as monostatic RCS with VV and HH polarizations of the incident plane waves. All simulations are performed with Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores using MoM Solver. RCS simulations are shown in Figures A.13 (3.5GHz), A.14 (5.125GHz), A.15 (7GHz), and A.16 (10.24GHz). Feko simulations agree well with ARCHIE-AIM simulation [6] and measured data [12].

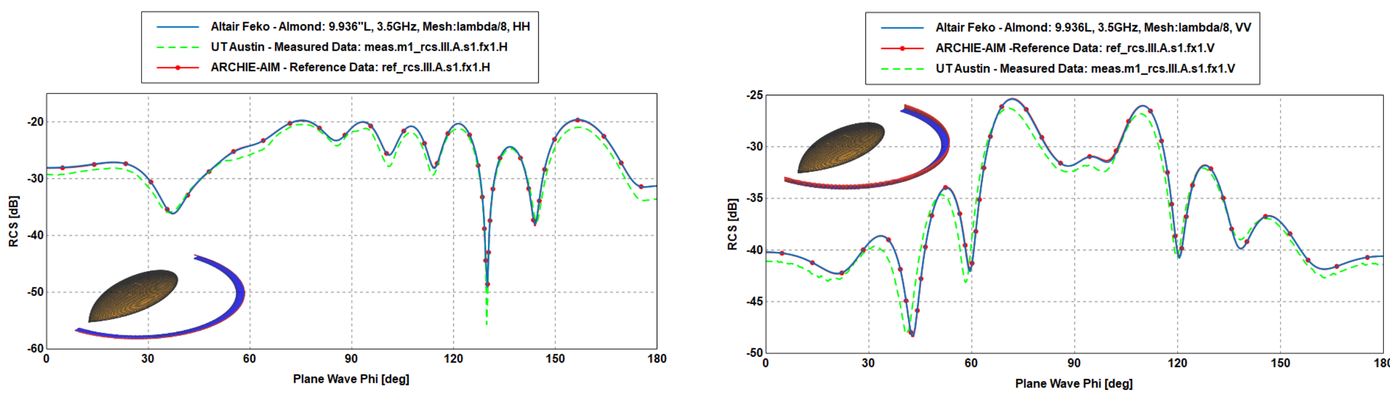
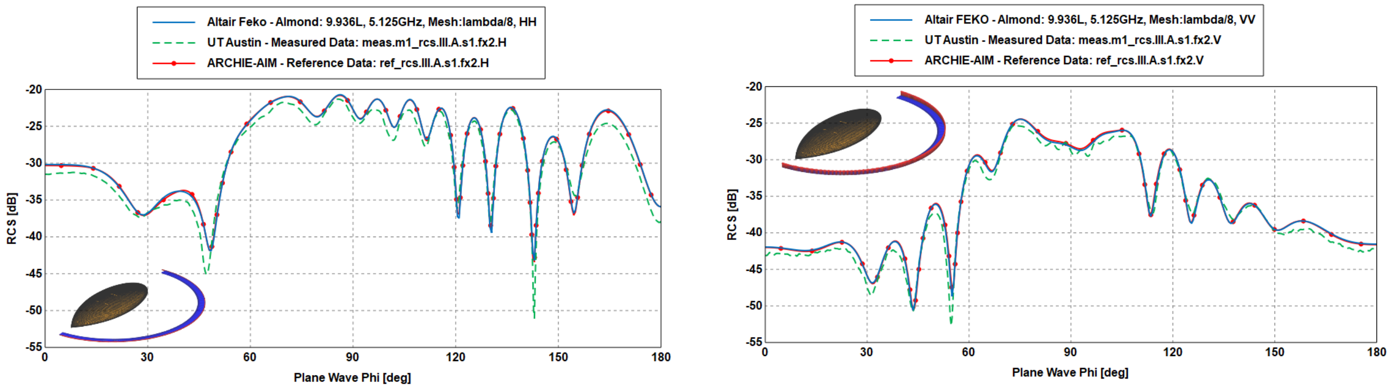
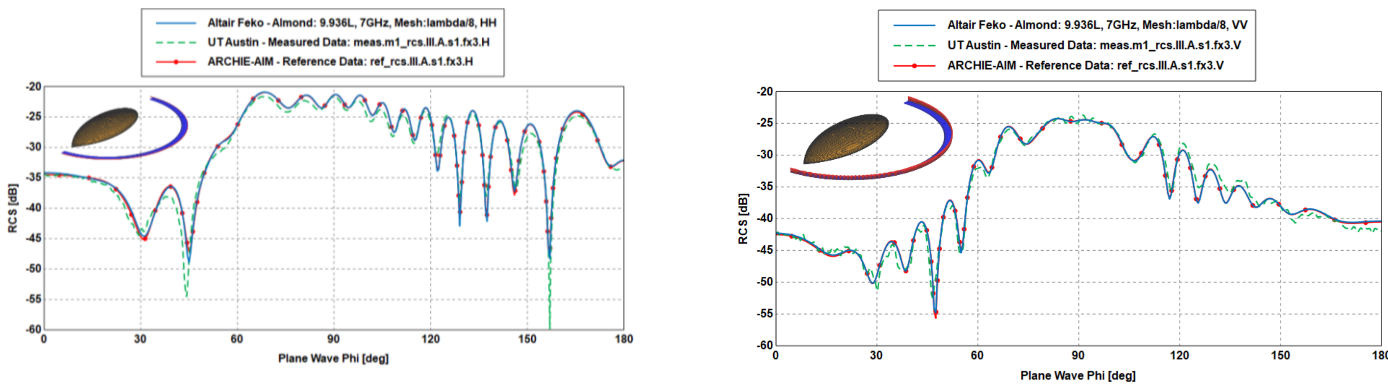


Figure A.13 – Feko, ARCHIE-AIM, and Measured RCS Results for PEC Almond at 3.5GHz



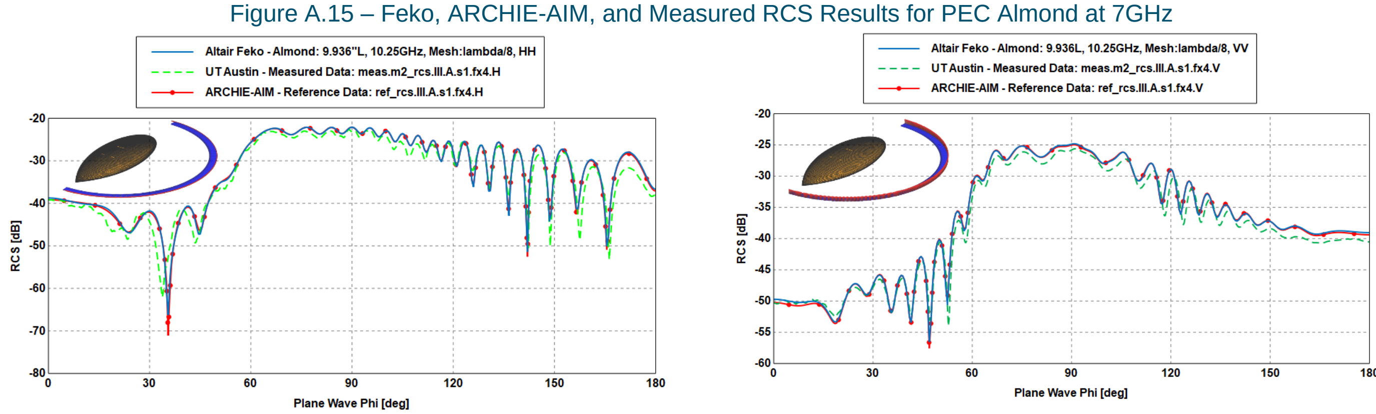
(a) Horizontal Polarization (b) Vertical Polarization

Figure A.14 – Feko, ARCHIE-AIM, and Measured RCS Results for PEC Almond at 5.125GHz



(a) Horizontal Polarization (b) Vertical Polarization

Figure A.15 – Feko, ARCHIE-AIM, and Measured RCS Results for PEC Almond at 7GHz

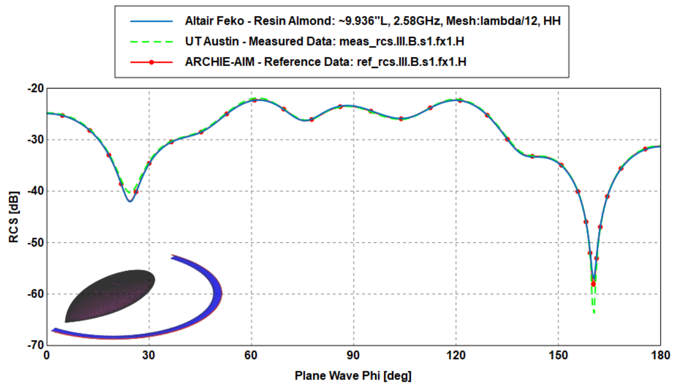


(a) Horizontal Polarization (b) Vertical Polarization

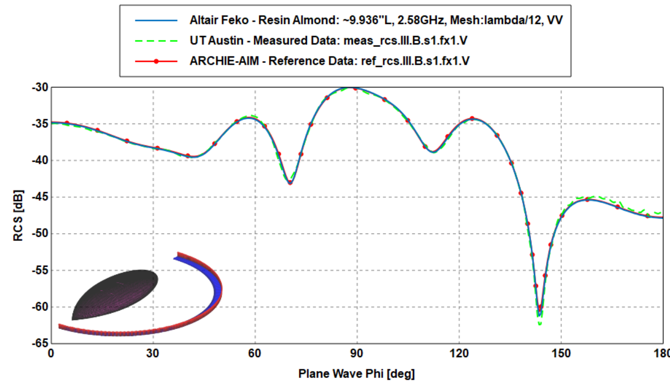
Figure A.16 – Feko, ARCHIE-AIM, and Measured RCS Results for PEC Almond at 10.25GHz

Resin Almond

The resin Almond problem set uses the same geometry as the PEC almond and varies the frequency of the incident wave for simulating RCS at frequencies 2.58GHz, 5.125GHz, 7GHz, and 10.25GHz. The dielectric used for the resin is defined in [13] and the dielectric's complex relative permittivity is shown in Table 1 over the frequencies of interest. Properties of resin are applied to the mesh triangles by editing the triangle properties, as shown in Figure 11 for the resin aircraft model. The front medium is defined as the resin dielectric and the back medium as free space. The incident wave was set at angles of $\theta_i = 90°$ and $0° \le \phi_i \le 180°$. RCS was computed as monostatic RCS with VV and HH polarizations of the incident plane waves. All simulations are performed with Feko version 2022.3 on Intel® Core™ i7-8850H CPU @ 2.60 GHz with 32 GBs of RAM with 6 physical cores using MoM solver. RCS simulations are shown in Figures A.17 (2.58GHz), A.18 (5.125GHz), A.19 (7GHz), and A.20 (10.25GHz). Feko simulations agree well with ARCHIE-AIM simulation [6] and measured data [2].

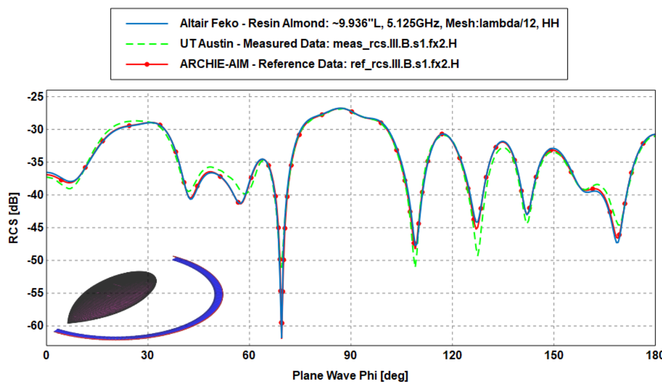


(a) Horizontal Polarization

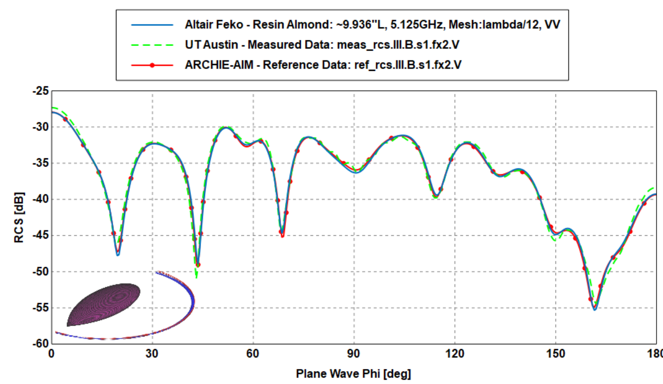


(b) Vertical Polarization

Figure A.17 – Feko, ARCHIE-AIM, and Measured RCS Results for Resin Almond at 2.58GHz

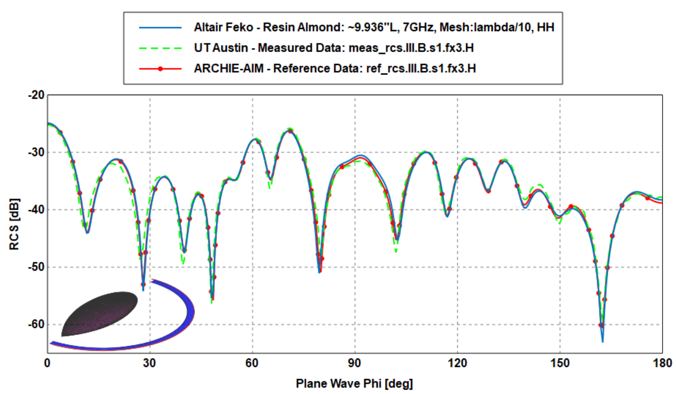


(a) Horizontal Polarization

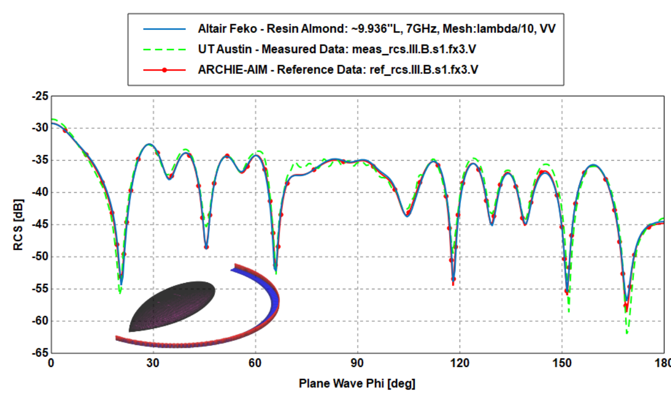


(b) Vertical Polarization

Figure A.18 – Feko, ARCHIE-AIM, and Measured RCS Results for Resin Almond at 5.125GHz

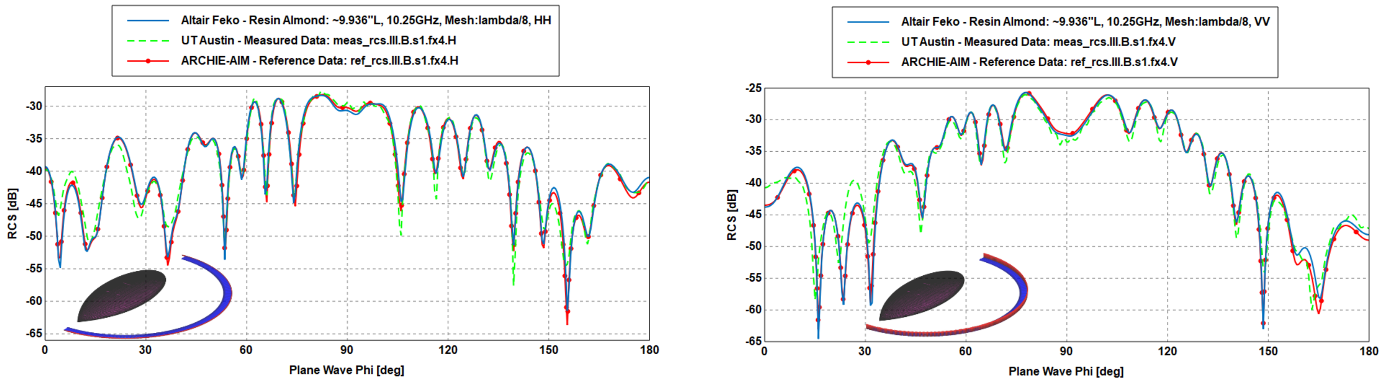


(a) Horizonal Polarization



(b) Vertical Polarization

Figure A.19 – Feko, ARCHIE-AIM, and Measured RCS Results for Resin Almond at 7GHz



(a) Horizontal Polarization (b) Vertical Polarization

Figure A.20 – Feko, ARCHIE-AIM, and Measured RCS Results for Resin Almond at 10.25GHz

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