Monostatic RCS of Fighter Aircraft

WIPL-D Software suite offers a great set of tools for full wave electromagnetic (EM) simulation of real life geometries at high frequencies. WIPL-D Pro CAD enables import of extremely complex geometries from all popular CAD files (this allows using models created in tools specialized for mechanical engineering), validation of models, and easy simplification of details obsolete for EM simulation itself (typical example are metallic screws). This product also includes in-house developed mesher which performs subdivision of complex geometries into generalized quadrilaterals which serve as input for numerical kernel. The meshing is automated and extremely efficient to allow precise modeling of details, curvatures and small features while the requirements for EM simulation are kept as minimal as possible.

After a proper quad mesh is created, WIPL-D Pro allows EM simulation in most efficient manner available among commercial tools. WIPL-D kernel supports mesh elements (quads) of size 2 wavelengths by 2 wavelengths due to unique higher order basis functions (current expansion on mesh elements is a polynomial of 8^{th} degree for 2 wavelengths edge). The number of unknown coefficients to be stored in Method of Moments (MoM) matrix is minimal and it can be estimated as 30 unknown coefficients per lambda square for metallic surfaces. The tool encompasses many features to further decrease number of unknowns but preserve the accuracy, which leads to even less demanding EM simulation. WIPL-D also offers very efficient CPU and GPU simulation on inexpensive hardware platforms. WIPL-D support team has years of experience in simulation of complex EM problems and it offers it services to users as part of regular technical support process.

F16 Simulation

One of the most complex applications of EM codes for RCS are fighter airplanes because of their size, complexity and high frequencies used for manufacturing of devices in this field.

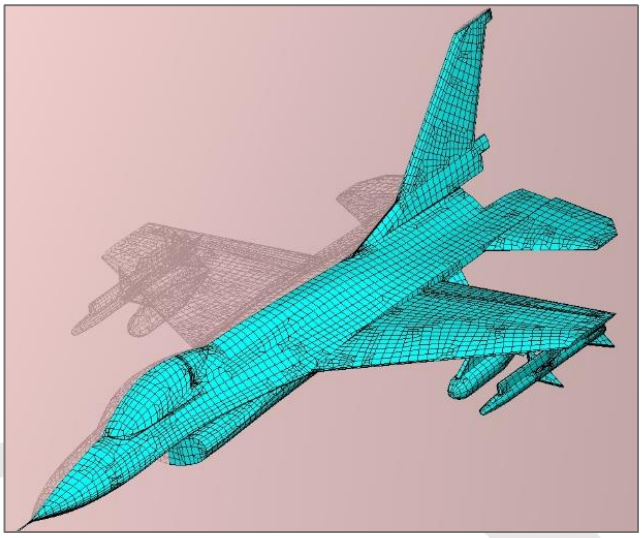

Figure 1. F16 fighter airplane (meshed at 3 GHz)

We will illustrate the efficiency of WIPL-D code by using simulation of monostatic RCS of F16 fighter.

Fighter length is 15.97 m, wing span is 10.73 m. The simulation is performed at several frequency, of which the highest is 3.0 GHz which makes airplane ~160 wavelengths long. Without any reduction for the number of unknowns, simulation requires 320,822 unknown coefficients.

The most efficient manner to simulate extremely large EM models is to use hardware platforms enhanced with GPU cards. This simulation was performed on the following workstation:

Intel® Xeon® CPU E5-2650 v4 @ 2.20 GHz (2 processors) with 256 GB RAM and four GPU cards NVIDIA GeForce GTX 1080 Ti

RCS was performed as monostatic. Symmetry of the structure was used to half the number of unknowns. Incident wave lies in the symmetry plane and number of directions for the entire span of angles in this plane is 1800. Simulation time is 9863 seconds (2.7 hours).

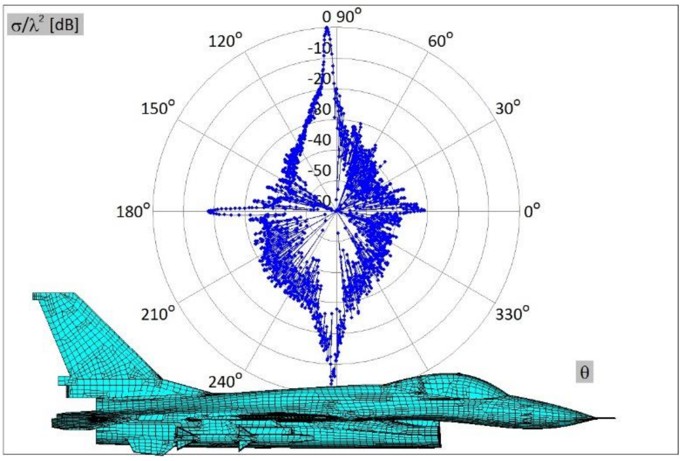

Figure 2. F16 monostatic RCS

In order to illustrate what the number of unknown coefficients means for the simulation of this airplane and how it influences the final simulation time, Table 1 shows the data of interest at five different frequencies.

Table 1. Scalability of the F16 EM solution

Frequency [GHz]	No. of unknowns	Simulation time [sec]
0.1	7,698	38
0.3	17,484	61
1.0	62,511	342
2.4	220,599	4,733
3.0	320,822	9,863

F35 Fighter Simulation

This challenging model can be used to demonstrate the efficiency of techniques for reduction of number of unknowns without impacting the accuracy. As illustration, the first simulation is bistatic RCS at 1.5 GHz. Fighter is 15.7 m long with wing span of 12.3 m. That makes it 78.5 wavelengths electrically long. Simulation requires 91,828 unknowns without any reduction.

Since the incoming wave is placed below the airplane, we can place the entire upper surfaces of the airplane in the shadow region and reduce number of unknowns on it. In addition, we can reduce referent frequency used for determining level of current expansion (between 1st and 8th order) on quads for 30% (from 1.5 GHz to 1.05 GHz). After this, number of unknowns reduces to 33,852 (over 63% reduction). Simulation time without reduction is 444 seconds (1800 directions) while reduced models runs only 71 seconds (over 6 times speed up). The hardware configuration is identical to the one used for F16 simulations.

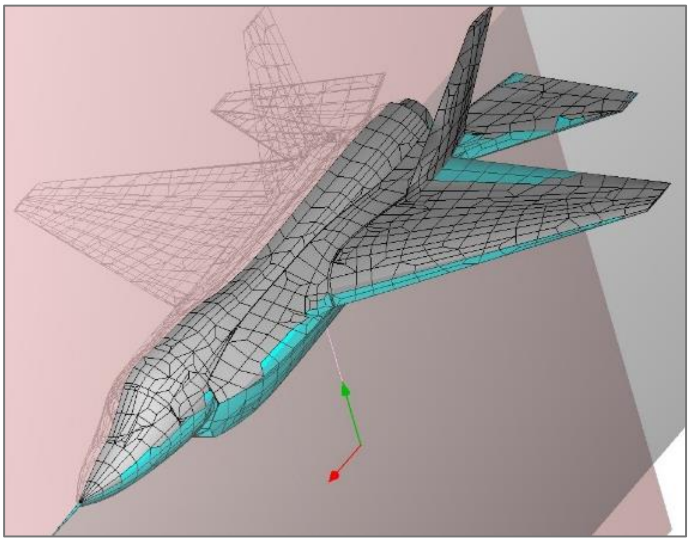

Figure 3. Fighter after applying the shadow – bistatic RCS at 1.5 Ghz

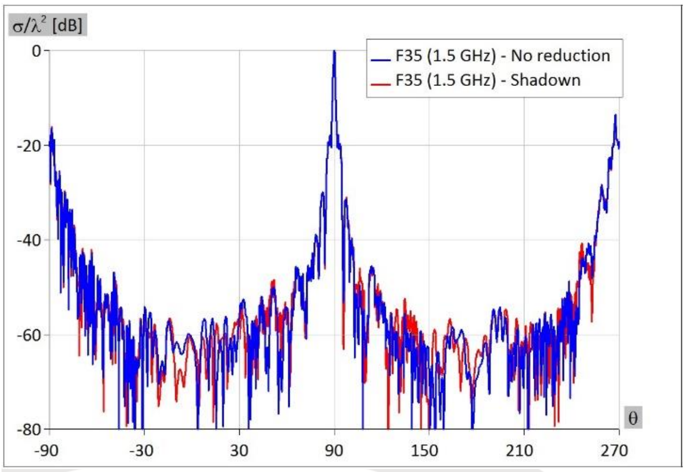

Figure 4. Influence of shadow reduction

Just like for F16, Table 2 illustrates how the same model of this airplane can be used for simulation at different frequencies and how that influences the simulation time. All simulation times are given for the monostatic RCS simulations at the previously described hardware configurations, same as in the F16 case.

Table 2. Scalability of the F35 EM solution

Frequency [GHz]	No. of unknowns	Simulation time [sec]
0.1	3 482	13
0.3	10 798	27
1.0	46 780	188
3.0	288 492	7965

However, the most challenging simulation is monostatic RCS at 4 GHz. Number of incoming directions is 3600. Electrical size of the model (length) is 210 wavelengths.

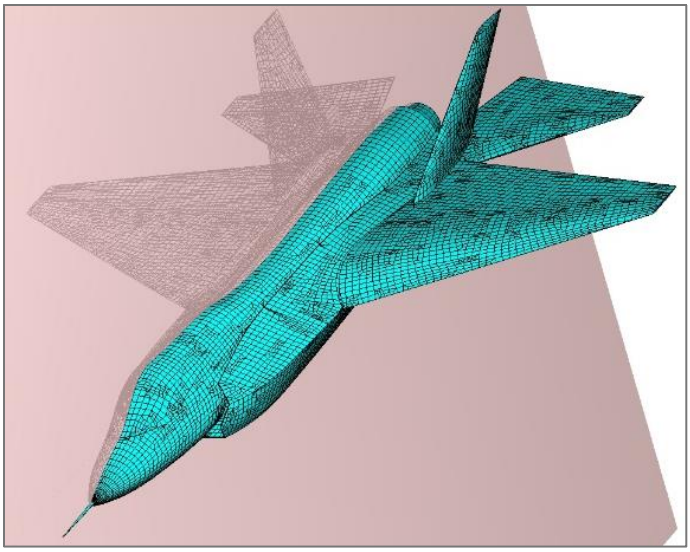

Figure 5. Fighter monostatic RCS at 4 GHz (dense mesh)

The required number of unknowns is 493,729 and it can be reduced by reducing referent frequency to 3.5 and 3 GHz. This yields 379,381 and 288,492 unknowns. All simulations are within the reach of the desktop configuration described previously.

Table 3. 2xCPU/4xGPU desktop F35 EM solution

Referent frequency [GHz]	No. of unknowns	Simulation time [hours]
3.0	288 492	2.6
3.5	379 381	4.3
4.0	493 729	8.7

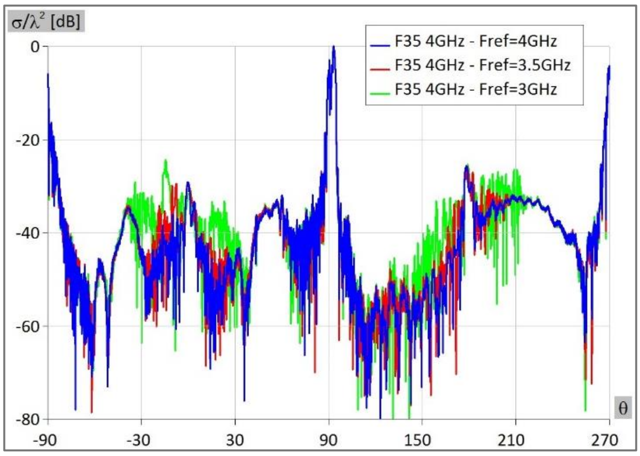

Figure 6. Influence of reduction at 4 GHz

F35 Simulations at 10 GHz (DDS Solver)

WIPL-D MoM implementation is among the most comprehensive and efficient full wave solution for high frequency EM problems. WIPL-D MoM applies surface integral equations (SIEs) of electromagnetic field in frequency domain by transforming SIEs into a system of linear equations which unknowns are weighting coefficients of adopted basis functions (BFs). MoM solution is expressed as a linear combination of BFs. By proper choice of BFs, the simulation converges toward exact solution when number of BFs increases.

But at higher frequencies, the limitations of MoM appear. The main drawback is poor scalability as frequency increases. The number of BFs per wavelength squared is fixed, hence total number (N) of BFs (unknowns) raises quickly by increasing frequency. Furthermore, required memory to store MoM system matrix is $O(N^2)$

WIPL-D DDS Solver (Domain Decomposition Solver) constructs macro BFs (MBF) which cover larger surfaces (than typical BFs). The method is iterative and it converges toward MoM solution by employing correctional currents between iterations. In each iteration, it determines weighting coefficients for MBFs in a way to minimize difference with respect to MoM matrix. The method advanced implementation includes several unique features. One of them is to only include into the next iteration the MBFs which contribute the certain amount of residuum (default value is 60% and can be changed by user). Also, the user can choose whether the 0^{th} iteration will include all elements or only the elements illuminated by wave (in RCS regime) or close to antenna (in antenna placement regime).

Particularly, DDS is oriented towards electrically large problems. It needs less memory and significantly less CPU time. The method is suitable for inexpensive CPU platforms, especially with multicore CPUs. Its accuracy cannot be compared with rigorous MoM, but from engineering point of view it can provide sufficient accuracy in CPU time unreachable to MoM.

The efficiency of method will be illustrated at monostatic RCS calculation of F35 aircraft at 10 GHz. If the frequency is reduced for 12.5% (as proved in the previous section to yields an exact solution), the number of unknowns for the symmetric model is around 2,100,000. If the result of interest is monoststatic from bottom directions, the shadow can be applied to reduce number of unknowns to 1,300,000.

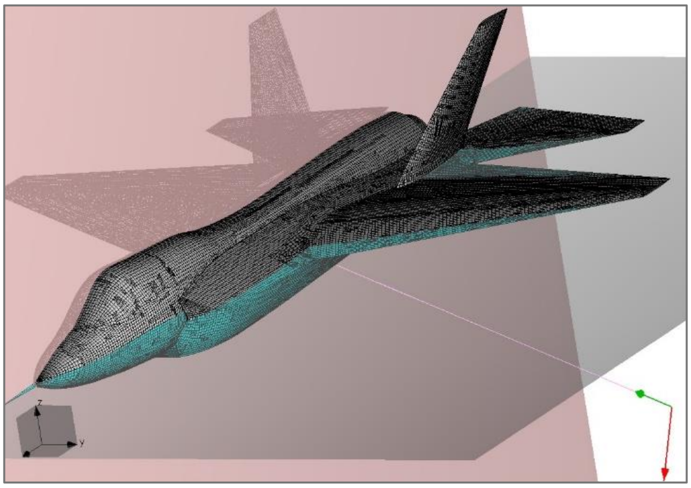

Figure 7. F35 at 10 GHz after shadow – monostatic RCS

The above-mentioned model is meshed into approximately 38,000 plates. The mesh is so dense that it is hard to recognize mesh elements in Figure 7. The DDS solution was applied so that parts of the structures not visible to incoming wave are not taken into account in 0^{th} iteration. The 1^{st} iteration includes all elements which contribute to residuum with 60% and it is sufficient for the simulation of excellent accuracy. The CPU simulation was done at previously described desktop, without using GPU cards.

The 0^{th} iteration lasts 3 hours, while the 1^{st} iteration lasts 4 hours. The characteristic of monostatic RCS simulations with methods such as MLFMM and PO is that they require different residuum for each incoming direction (different current distribution). In this example, RCS was calculated with 25 incoming direction, which made simulation almost two times longer than bistatic RCS. In order to get the result with more directions, interpolation was applied not to RCS result itself, but to current coefficients of the mesh.

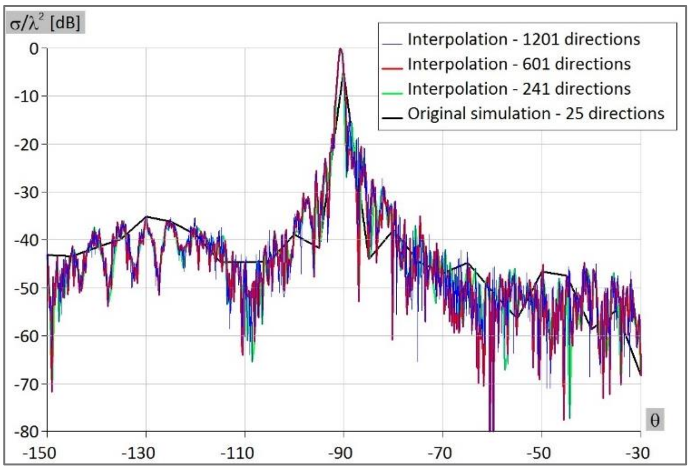

Figure 9. F35 monostatic RCS at 10 GHz