Full-Wave Monostatic RCS of a Bee

Introduction

Full-wave 3D EM simulation of a single bee is presented in this application note. The simulation is carried out as monostatic RCS. In order to reduce the required number of unknowns and decrease the simulation time, a symmetry plane is used. Bees as many other insects are bilaterally symmetrical, so applying the symmetry plane is possible.

Also, certain model simplifications were applied in order to accelerate the simulation and hence further shorten the simulation time. Compared results for full and simplified models are presented.

Bee Model in WIPL-D

WIPL-D model of a bee is shown in Figure 1. EM simulation was performed @ 10 GHz. The model originates from a CAD file. The bee body is considered to be dielectric, with relative dielectric constant εr=30. Losses were not included.

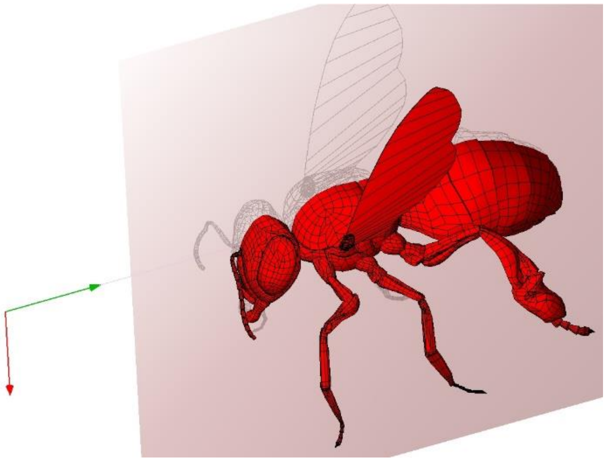

Figure 1. Model of a bee in WIPL-D.

In terms of electrical size, bee is a rather small RCS object. However, due to enormous complexity of its surface, it can be meshed into a very large number of elements (WIPL-D Pro uses quadrilaterals). The major aim of the mesh and the simplification process is to achieve minimum umber of mesh elements (plates). The model shown above comprises of 6,213 quads.

Simulation Results

The result of the monostatic RCS simulation is shown in the Figure 2. The presented bee model requires around 25,000 unknowns and simulation time is around 600 seconds on the Intel Core i7-7700 CPU @ 3.60 GHz machine with 32 GB of RAM and NVIDIA GeForce GTX 1080 GPU card.

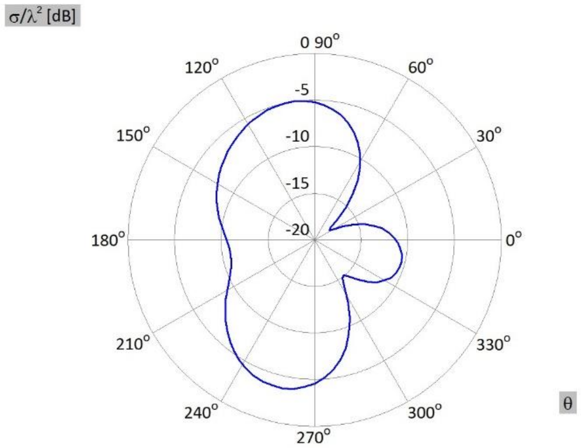

Figure 2. Monostatic RCS of the full 3D bee model.

The process of MoM EM simulation mostly consists of matrix fill-in and then the inversion. For electrically small structures the first part is the dominant one. The EM simulation of bee is somewhat in between. It is electrically small structure, but it has to be meshed into large number of details. This inherently increases number of unknowns since the lowest order basis functions are used over the entire model. However, the matrix fill-in over a larger number of unknowns remains the dominant part of EM simulation.

This particular model requires higher integration accuracy of the MoM matrix fill-in due to long and thin plates used to model the bee's legs. Since integration accuracy in increased, matrix fill-in time is much longer than expected for this problem size, which yields to longer total simulation time.

Legs of the bee, being thin as are, should not affect much the 3D simulation results. Model of the bee without legs is shown in the Figure 3. This model requires far smaller number of unknowns (around 6,600 as a consequence of only 1,900 quad mesh elements) than the full bee model and the simulation time only is much shorter (around 23 seconds). Here are the reasons for this significant reduction of the number of unknowns and the simulation speed-up:

- Model without legs does not require higher integration accuracy and matrix fill-in time is decreased.
- Since the total required number of unknowns is reduced and the matrix fill-in time is shortened, the total simulation times is decreased.

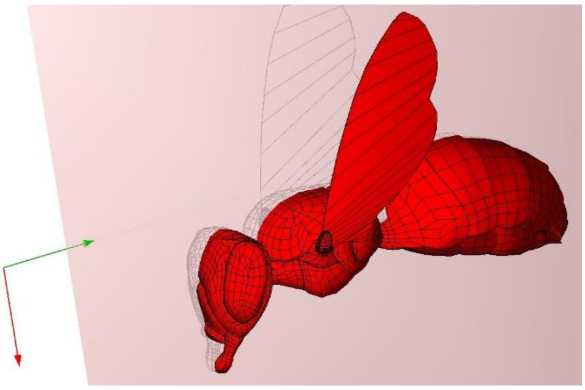

Figure 3. Model of the bee without legs in WIPL-D.

Comparison of the results for no-leg bee model and full bee model is shown in Figure 4. These results are very similar and have no significant differences.

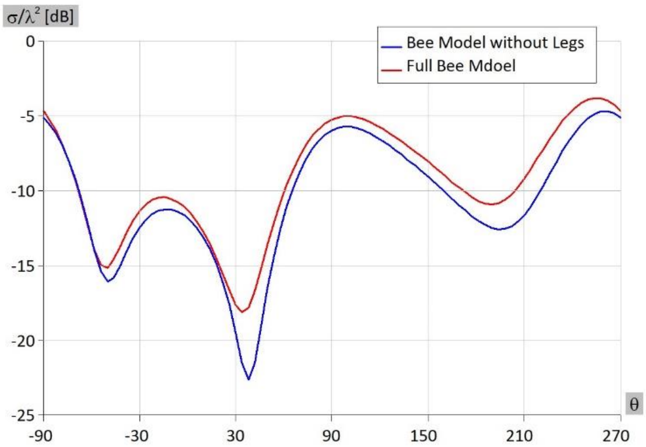

Figure 4. No-leg bee model and full bee model – comparison of the results.

Summary

The characteristics of the machine used for the simulations are:

- Intel Core i7-7700 CPU@3.60 GHz CPU
- 32 GB of RAM,
- NVIDIA GeForce GTX 1080 GPU card.

Required numbers of unknowns and simulation times are listed in Table 1.

Table 1 Summary table with simulation times in respect to model and number of unknowns.

Model	*Number of Unknowns*	Matrix Fill-in Time [s]	Matrix Inversion Time [s]	Total Simulation Time [s]
Full Model	24,958	571	28	627
Without legs	6,554	17	2	23

The difference in sum of the simulation times for the first two phases and the total simulation time is due to calculation of larger number of monostatic directions. This is actually a significant advantage of the MoM, compared to say MLFMM or any iterative method. Once the MoM matrix is solved, inexpensive forward-backward substation is carried out for any given number of directions.

It can be observed that using no-leg bee model instead of full bee model does not affects the simulations results, but drastically shortens the simulation time.

Conclusion

This application note presents efficient monostatic RCS simulation of a highly detailed CAD model of a bee. The simulation has been carried out by WIPL-D Pro CAD software product, offering CAD modeler and in-house developed quad mesher as well as Method of Moments based kernel.

The body of a bee has been modeled as homogenous dielectric with high Er. Due to all the realistic details included in the CAD file, the simulation is far more complex than for simple Radar Cross Section (RCS) objects of similar size. In the first stage, the full bee model is meshed into over 6,000 plates and simulated on regular desktop PC (any modern laptop or desktop will do). In the next phase, the long and narrow legs of the CAD bee model have been eliminated. The results indicate that such model shows excellent accuracy but is order of magnitude easier for the MoM simulation. All simulations are carried out with the inherent bee symmetry.

Owing to the highly efficient in-house parallelization of matrix fill-in time (the dominant component in this EM simulation), the simulation on a standard desktop quad-core for the full bee lasts couple of minutes, while the no-leg model is run in seconds. In addition, owing to the GPU solver the simulation of a full bee has been speeded up for couple of seconds for a less significant part of the simulation time - the matrix inversion. Even a single inexpensive GPU card turns a desktop PC into a workstation allowing to solve problems with even 100,000 unknowns in reasonable time.