Using the Fast Multipole Boundary Element Method to update loads in system level SEA models

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Introduction

Using SEA for interior sound pressure level predictions is a common application for a wide range of vehicles, such as trains, automobiles, construction equipment and light and heavy trucks. A standing question in these modelling tasks is how to accurately describe the exterior sound field, such as those from tires and exhausts sources in an automobile application, and ventilation openings in heavy machinery. Traditionally the alternatives to model the exterior sound field are using experimental data or empirical models for similar designs.

Recent developments in computational Boundary Element Methods (BEM) have made Fast Multipole Method (FMM) BEM [1] an attractive tool in predicting the exterior sound field for use in system level SEA models.

The objective of the current study is to analyse how different Fast Multipole BEM modelling details effects the calculated interior sound pressure and how different solve options effects solve performance. In particular, the study focus on how sensitive the FMM BEM results are, and how calculation times vary, with respect to:

- Geometrical details
- Mesh quality
- Mesh density
- Frequency resolution
- FMM solver options

Predicting the exterior sound field

Different approaches can be used to calculate the exterior sound field, and there are different ways to implement the effects thereof in an SEA model.

One option for defining the exterior sound field is to use test data for prescribing the surface pressure [2] on an SEA model. This is common practice for cases where test data is available, but the drawback is that it is manual and time consuming. Another concern with this approach is that it is not fully predictive.

Another alternative is to use semi-empirical methods to constrain levels in the outer cavities [3], such as in Figure 1, but this is a complex and time consuming task, which has proven difficult to generalize.

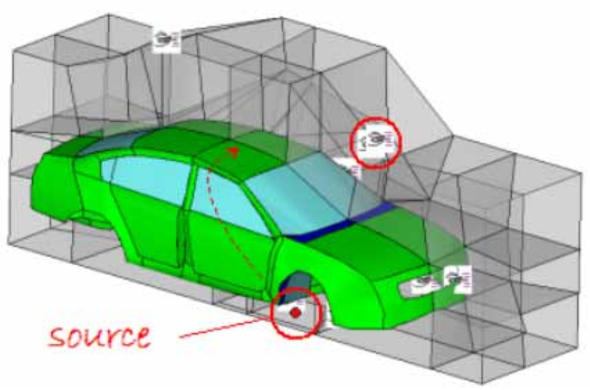

Figure 1.Typical Airborne SEA model for interior noise analysis, here shown with the exterior cavities used to model the exterior sound field.

Yet another alternative is to use simulation based on Fast Multipole BEM. The process is to calculate the detailed exterior sound field using Fast Multipole BEM [4, 5], and post-process it to calculate the average pressure over surface areas corresponding to the SEA shell and plate exterior subsystems. Then in the SEA model, the average pressure is assigned on these exterior SEA subsystems using diffuse acoustic field sources or constrained cavity levels.

Using FMM for the exterior sound field

The Fast Multipole method (FMM) is a numerical method useful for solving large BEM models. It is faster and uses less memory than traditional BEM, and with Fast Multipole BEM it is possible to solve BEM models with more than 1 million DOFs.

Fast Multipole BEM uses “Multipole” approximations of interaction of “distant particles” and uses an iterative multilevel solution approach for solving the system of equations. In general, Fast Multipole BEM is well suited for a number of applications

- Solving large detailed BEM Models
- Investigating diffraction/shadowing effects
- Updating the “loads” in a existing SEA model

A quantitative comparison of traditional BEM and Fast Multipole BEM is given in Figure 2.

Fast Multipole BEM, as used in this study, is available in the VA One 2008 BEM module [6].

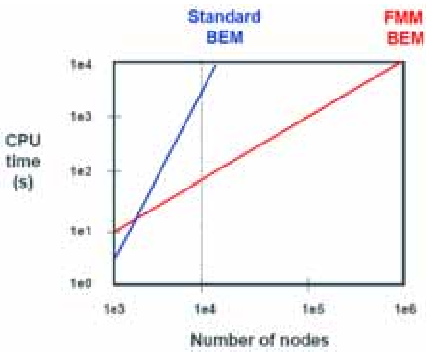

Figure 2. FMM performance compared to standard BEM.

VA One process

The process to use Fast Multipole BEM implemented in VA One for defining the exterior sound field is quite straightforward, and can be described in four short steps:

1. Shrink-wrap the complete geometry, either CAD or a Finite Element model, to get a 'watertight' fluid surface.

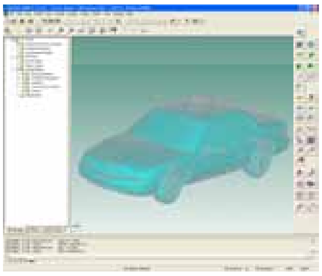

Figure 3. Shrink wrapped geometry.

2. Solve for the detailed surface pressure using Fast Multipole BEM solver in VA One with a rigid face scattering model, with all sources included.

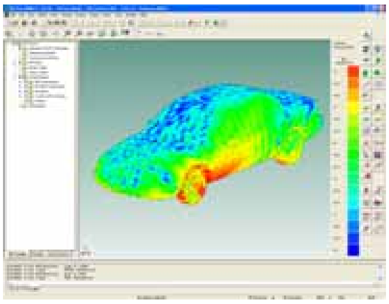

Figure 4. Detailed exterior pressure field.

3. Calculate the average pressure over surfaces corresponding to the SEA exterior subsystems (this is a standard results provided for any face). Also average over 1/3rd octave frequency bands.
4. Apply this calculated sound pressure as diffuse acoustic field, one on each SEA subsystem.

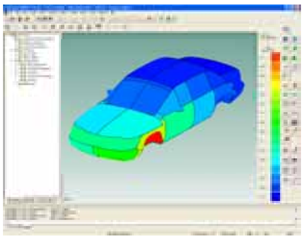

Figure 5. Resulting frequency and space average exterior pressure distribution on the SEA model.

All the steps are performed in VA One, and steps 3 and 4 can be automated using the scripting capabilities of VA One.

Sensitivity of prediction

The current study focuses on how model details and solve options effects results calculated by the FMM solver. Looking at frequency and space average pressure response, the following aspects of the model were studied.

Geometry details: In the current study up to 3 dB changes were noted on results depending on the geometry details. Sharp edges in general increase CPU by a factor 1.5, where a "smooth" geometry is preferable.

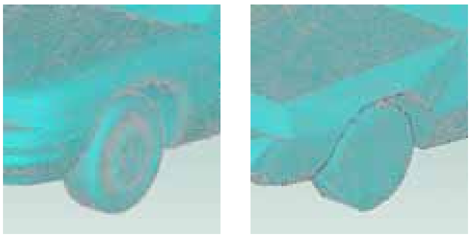

Figure 6. Smooth and coarse geometry.

Source location: no impact on CPU time requirements, and some expected impact on the interior sound pressure level.

Mesh regularity: No impact on results was seen, but irregularity increases CPU requirements. In the current study a regular mesh solves 22% faster.

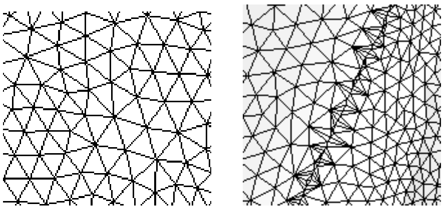

Figure 7. Regular and irregular mesh.

Mesh density: 6 elements/wavelength is sufficient, and CPU requirements scales with mesh density.

Frequency resolution: The CPU requirement is proportional to number of frequency points, and the current study found that 3 points per 1/3rd octave band is sufficient.

Surface impedance: up to 5 dB changes on results as expected, and no impact on CPU requirements.

FMM solver options: Using optimized settings for convergence tolerance and the Burton-Miller parameter (use to avoid irregular frequencies in exterior problems), the Fast Multipole BEM solver can achieve a 10× gain on CPU time with less than 2 dB difference in predicted results, compared to default settings.

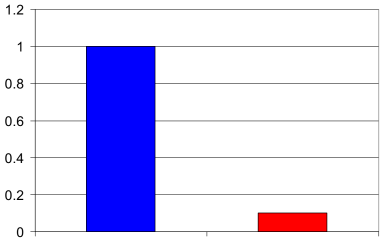

Figure 8. Solve performance; blue: default settings, red: optimized settings.

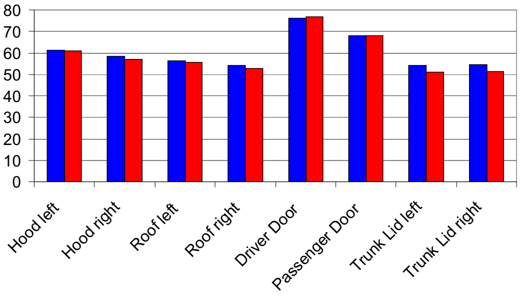

Figure 9. Difference in interior predicted sound pressure levels. Blue: default settings, red: optimized settings.

It may be noted that the example model constitutes a real modeling case, with general solving statistics given below:

- 10 min/frequency; 2h for [400-1250] Hz (3 points per 1/3rd octave band)
- 1.4 GB of RAM required

Validation

Experimental validation of the approach is reported in Reference [7], where the sound pressure levels of the exterior cavities in the SEA model in Figure 10 were constrained to levels calculated by FMM BEM in VA One.

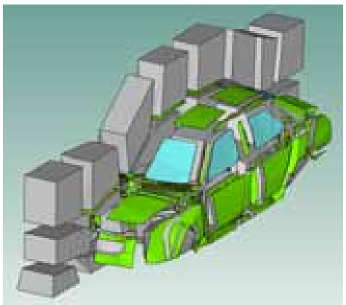

Figure 10. SEA model of the full vehicle.

The overall solution takes around 40 seconds on the same machine used for the underlying FMM BEM analysis.

Figure 11 shows the sound pressure levels for the driver's head space calculated by the SEA model with both FMM BEM simulated and with measured exterior noise levels. The results are also compared with the values for the interior noise directly measured. The differences between the SEA results with each approach for the exterior noise are within approximately 2 dB for the whole frequency range.

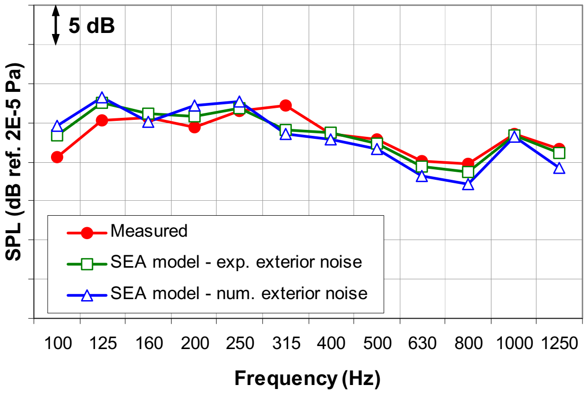

Figure 11. Interior sound pressure level for the driver's head space, from Ref. [7].

Conclusions

Modest system requirements regarding RAM memory and CPU time make the Fast Multipole BEM well suited for prediction of full vehicle exterior sound pressure loading for application in a SEA system models, using desktop computers.

The software used in the current study, VA One 2008, implements all components to go from a CAD or FE model of the vehicle, to an SEA model with an accurate description of the exterior sound field, making the methodology described readily available today.

References

[1] N. Gumerov, R. Duraiswami, *Fast Multipole Methods for the Helmholtz Equation in Three Dimensions*. 2004 Elsevier, Oxford, UK.

[2] D. Blanchet, R. DeJong, K. Fukui, "Development of a Modeling Technique for Vehicle External Sound Field Using SEA," Proceedings of INTER-NOISE 04, Prague, Czech Republic, 2004.

[3] J. Venor, A. Zopp, "Using SEA to Model Near Field External Sound Pressure Distributions based on Automobile Geometry", ESI VA Users Conference 2007.

[4] S. Müller, V. Cotoni and T. Connelly, "Guidelines for using Fast Multipole BEM to calculate the exterior acoustic loads in automotive SEA models", Proceedings SAE 2009, St. Charles, IL, USA.

[5] S. Chaigne, G. Sylvan, E. Duceau, J. Simon, "On the Use of the Fast Multipole Method for Accurate Automotive Body Panel Acoustic Load Predictions", Proceedings SAE 2007, St. Charles, IL, USA.

[6] VA One 2008 User's Guide, ESI Group, 2008. `http://www.esi-group.com`

[7] J. Cordioli, S. Müller and T. Connelly, "Validation of Interior Noise Prediction obtained using Statistical Energy Analysis and Fast Multipole BEM", Proceedings SAE 2009, St. Charles, IL, USA.