Loudspeaker Simulation Efficiency & Accuracy

using i) A Conventional Model, ii) The Near-To-Far-Field Transformation
and iii) The Rayleigh Integral

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Agenda

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• Who We Are?

Loudspeaker simulations

• Simulation Objective
• Simulation Procedures
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  • Near-to-far-field (COMSOL)
  • Rayleigh integral (FEA2SCN+Klippel)
• Loudspeaker Cases
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Who We Are?

iCapture provides **consulting, technology implementation and training** in the field of multiphysics:

- Electromagnetic
- Vibroacoustic &
- Structural Dynamic

product **development & simulations**.

Since 2011 iCapture is a **Certified COMSOL Consultant**.

Work in **loudspeaker, wind, medical** and other industries.
Simulation Objective

• Pressure (and impedance) frequency response
Simulation Procedures

- Conventional model

“Microphone” location
Simulation Procedures

- Near-to-far-field transformation in COMSOL

\[
C(P)p(P) = \int_S \left( i\rho \omega v_n(Q)G(r) + p(Q) \frac{\partial G(r)}{\partial n} \right) dS
\]

- \( P \) indicates an observation point.
- \( Q \) is a point on the closed surface \( S \).
- \( C(P) \) is the spatial angle in the measurement point, here \( 4\pi \).
- \( \rho \) is the density of the medium.
- \( v_n(Q) \) is the normal velocity in point \( Q \) with the normal denoted \( n \), and
- the full space Green’s function is defined:
  \[
  G(r) = \frac{e^{-ikr}}{r}
  \]
  where
- \( r \) is the distance between points \( P \) and \( Q \).
Simulation Procedures

- Near-to-far-field transformation in COMSOL

\[ C(P)p(P) = \int_S \left( i\rho \omega v_n(Q)G(r) + p(Q) \frac{\partial G(r)}{\partial n} \right) dS \]
Simulation Procedures

- Rayleigh integral via FEA2SCN and Klippel Scanner

Assumption:
Flat geometry in baffle

\[ p(P) = \int_{S} \frac{i \rho \omega_n(Q)}{2\pi} G(r) dS \]
Loudspeaker Cases

Totally Flat 6”  Convex Cone 6”  Concave Dome 3”
Results

- Totally Flat 6”
Results

• Totally Flat 6”
Results

- Concave Cone 6”
Results

• Concave Cone 6”

Cone Driver - Differences

Sound Pressure Level [dB SPL]

Frequency [Hz]

- PFAR inaccuracy
- Rayleigh geometric topology inaccuracy
- Rayleigh mass of air loading inaccuracy
- Rayleigh total (geometry and mass of air) inaccuracy
Results

- Convex Dome 6”
Results

- Convex Dome 6”

Dome Driver - Differences

- PFAR inaccuracy
- Rayleigh geometric topology inaccuracy
- Rayleigh mass of air loading inaccuracy
- Rayleigh total (geometry and mass of air) inaccuracy
# Results

<table>
<thead>
<tr>
<th>Simulation</th>
<th>DOFs</th>
<th>FEA time [s]</th>
<th>FEA2SCN time [s]</th>
<th>Memory [GB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Full VA (0.5m air)</td>
<td>192,873 100%</td>
<td>386 100%</td>
<td>36</td>
<td>1.2</td>
</tr>
<tr>
<td>Flat VA+PFAR (0.08m air)</td>
<td>54,750 28%</td>
<td>126 33%</td>
<td>-</td>
<td>0.80</td>
</tr>
<tr>
<td>Flat Rayleigh (no air)</td>
<td>41,988 22%</td>
<td>100 26%</td>
<td>36</td>
<td>0.75</td>
</tr>
<tr>
<td>Cone Full VA (0.5m air)</td>
<td>211,916 100%</td>
<td>434 100%</td>
<td>37</td>
<td>1.2</td>
</tr>
<tr>
<td>Cone VA+PFAR (0.08m air)</td>
<td>74,118 35%</td>
<td>171 39%</td>
<td>-</td>
<td>0.83</td>
</tr>
<tr>
<td>Cone Rayleigh (no air)</td>
<td>59,114 28%</td>
<td>140 32%</td>
<td>37</td>
<td>0.84</td>
</tr>
<tr>
<td>Dome Full VA (0.5m air)</td>
<td>246,899 100%</td>
<td>635 100%</td>
<td>18</td>
<td>1.8</td>
</tr>
<tr>
<td>Dome VA+PFAR (0.08m air)</td>
<td>109,712 44%</td>
<td>325 51%</td>
<td>-</td>
<td>1.4</td>
</tr>
<tr>
<td>Dome Rayleigh (no air)</td>
<td>98,002 40%</td>
<td>306 48%</td>
<td>18</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Table 1** Simulation statistics for 133 frequencies solved with 8 cores 3.9GHz Xeon processors having 1333MHz RAM modules (index numbers in italic)
Conclusion

It is possible to do reduced vibroacoustic models via both the near-to-far-field transformation and the Rayleigh integral methods reducing the calculation time by 50-70 \% (for 3D the reduction is up to 75-85 \% via FEA2SCN).

With the near-to-far-field method accurate results are obtained for all loudspeaker cases.

With the Rayleigh integral method accurate results are obtained for the flat loudspeaker case. For the convex cone and the concave dome speaker cases the results deviate ±5.0 dB due to the curved (non-flat) geometries.