Enhanced DFAT simulation:
optimization and correlation study

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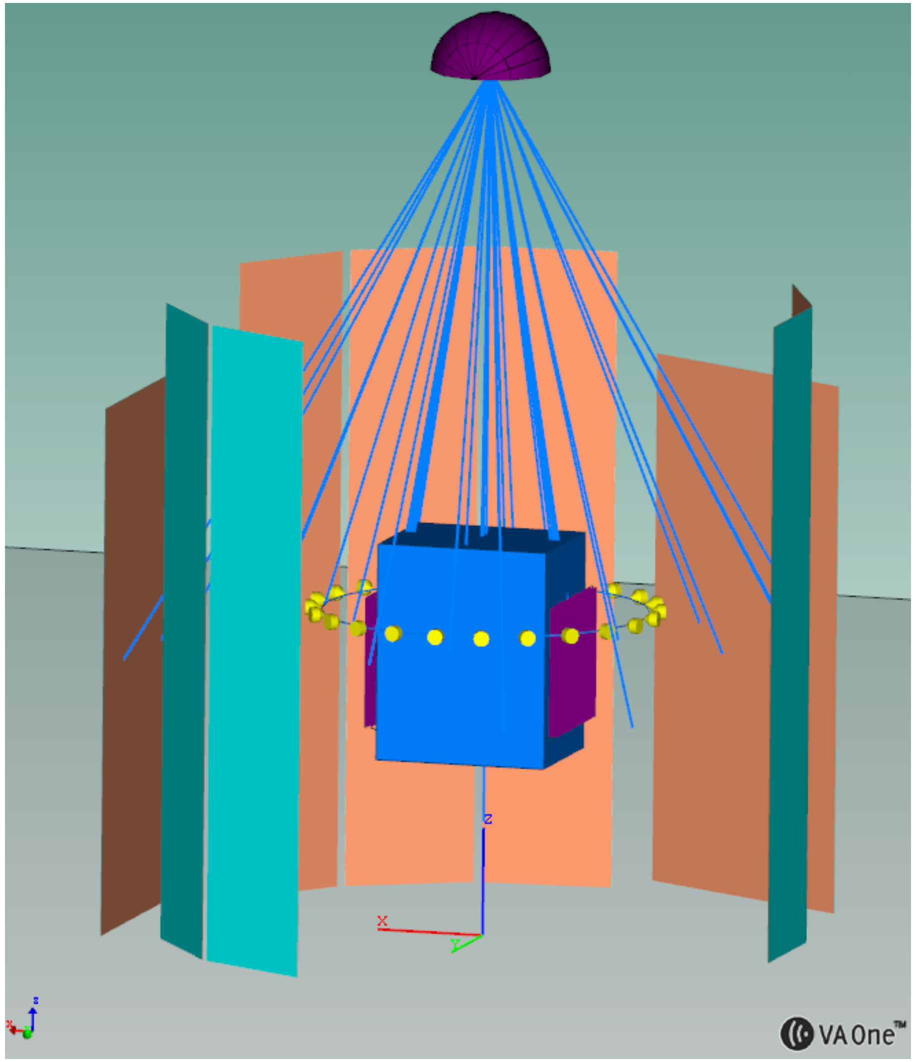
DFAT® Testing – What Is It?

- DFAT® = Direct Field Acoustic Testing®
- The specimen is positioned in the center of a group of speaker stacks which can be set up in a variety of environments
- Replaces or complements expensive reverberant chamber acoustic testing of aerospace systems of different sizes
- Main testing goals:
  - *Reach desired excitation level*
  - *Generate an acoustic field as close to a diffuse acoustic field as possible*

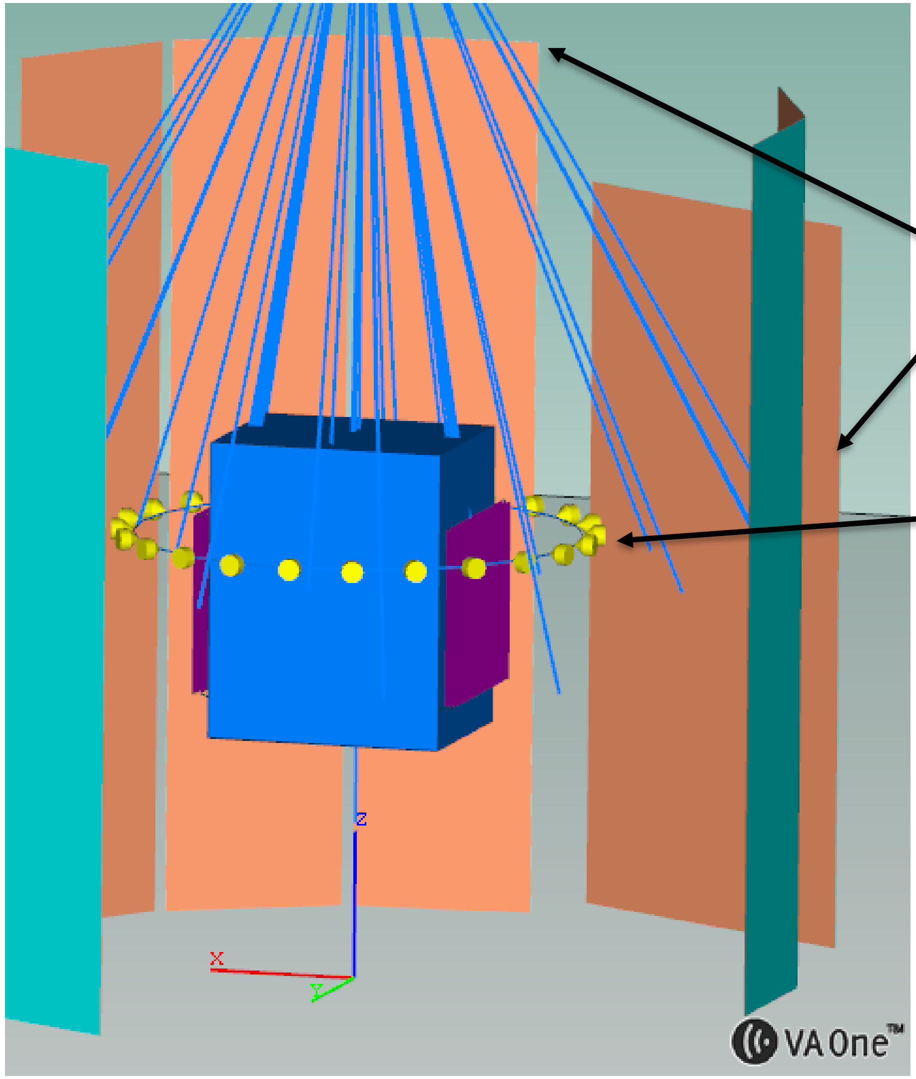
Typical Spacecraft DFAT® Test - Maryland Sound International (courtesy of Orbital Sciences Corporation) – Public Domain

Modeling the DFAT ® Test (1)

- Why?
  - *Confirm desired field character (diffuse)*
  - *Help design/confirm optimal placement and correlation of speakers*
- Boundary Element Method (BEM) is used to model the test setup
  - *Industry-standard VA simulation tool for modeling space application dynamic environments and structural response*
  - *Unbounded fluid with floor as reflecting plane and speakers as BEM surfaces*



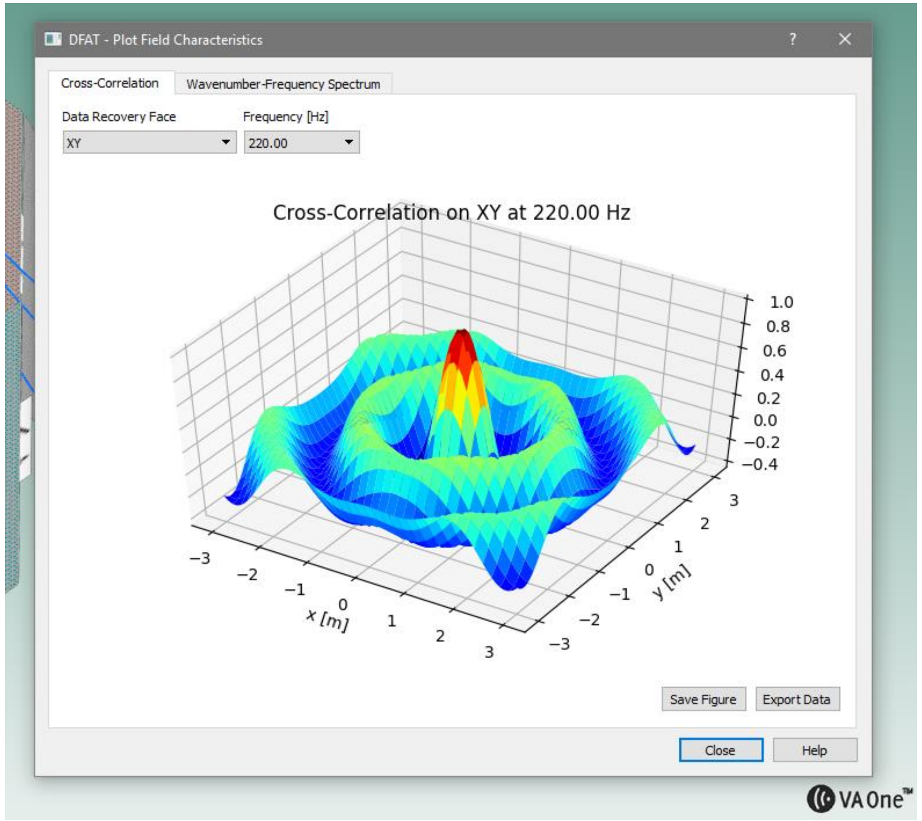
Modeling the DFAT ® Test (2)



- Speakers are modeled with simple BEM surfaces:
  - *Measured speaker impedance is applied to radiating (interior) side of speaker surface*
  - *Excitation is modeled as a velocity constraint*
  - *Sources are partially correlated (based on number of independent controllers modeled)*
- Microphones are placed near the structure
- Test article is the only flexible structure in model
- Optimal cross-correlation and amplitude of speakers are derived from a target acoustic field (such as a DAF) using transfer functions from the BEM simulation. This emulates the physical test where an active control system is used.

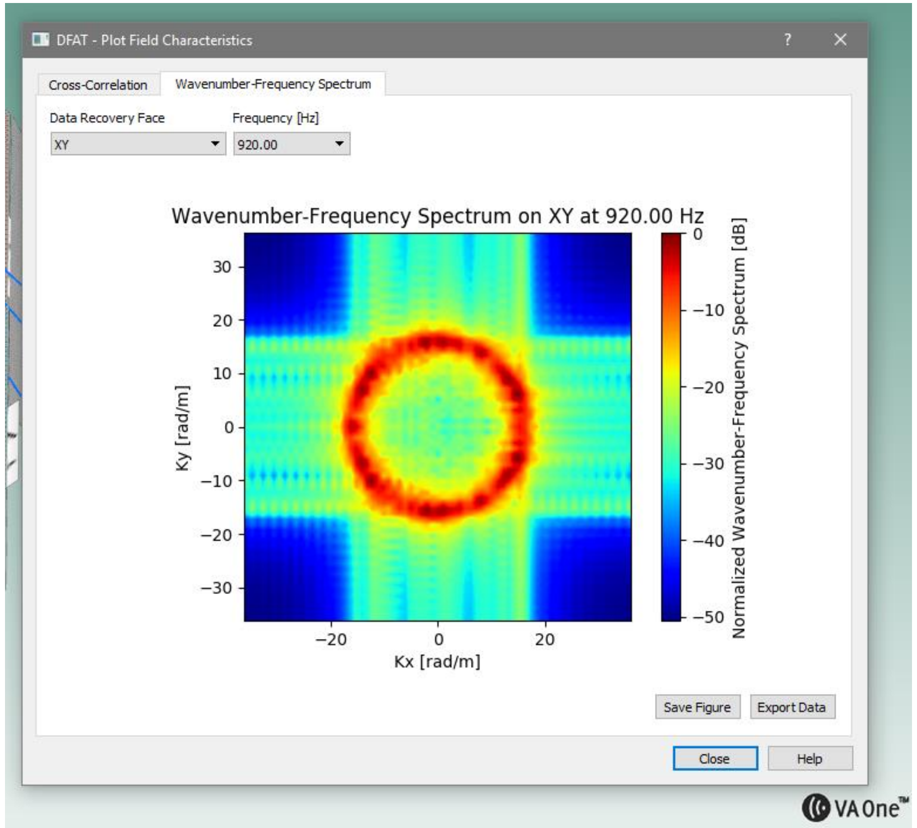
Investigating Diffusivity / Field Character

Cross-Correlation spectra



Spatial FFT

Wavenumber-frequency spectra



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DFAT Theory

Term definition

Cross Spectral Pressure response → $[S_{pp}] = [H_{pw}][S_{ww}][H_{pw}]^H$

Cross Spectral Modal structural response → $[S_{qq}] = [H_{qw}][S_{ww}][H_{qw}]^H$

Cross Spectral Excitation matrix is `n_speakers x n_speakers` and is optimized to have a diffuse field at the control microphones

- $[S_{xx}]$ is a cross-spectral matrix (Excitation or Response)
  - Diagonal represents the amplitude
  - Off diagonal terms represent the cross correlation
- $[H_{xy}]$ is a matrix of transfer functions

From coupled BEM/FE results

Excitation term

Amplitude

Cross-Correlation

$$[S_{ww}] = \begin{bmatrix} S_{ii} & \cdots & S_{ij} \\ \vdots & \ddots & \vdots \\ S_{ji} & \cdots & S_{ii} \end{bmatrix}$$

- One term per speaker.
- Depending on how speakers are “wired-up” to the control system, might have fewer than `n_speakers` independent variables.
  - For instance, if entire speaker stack is correlated (driven by the same control channel), only `n_stacks` independent variables

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DFAT process

3-step process

Initial solution:

$$[S_{ww}] = pinv([H_{pw}])[S_{pp}]pinv([H_{pw}])^H$$

No differentiation between amplitude and cross correlation

DFAT process

3-step process

Initial solution:

$$[S_{ww}] = pinv([H_{pw}])[S_{pp}]pinv([H_{pw}])^H$$

No differentiation between amplitude and cross correlation

Optimization

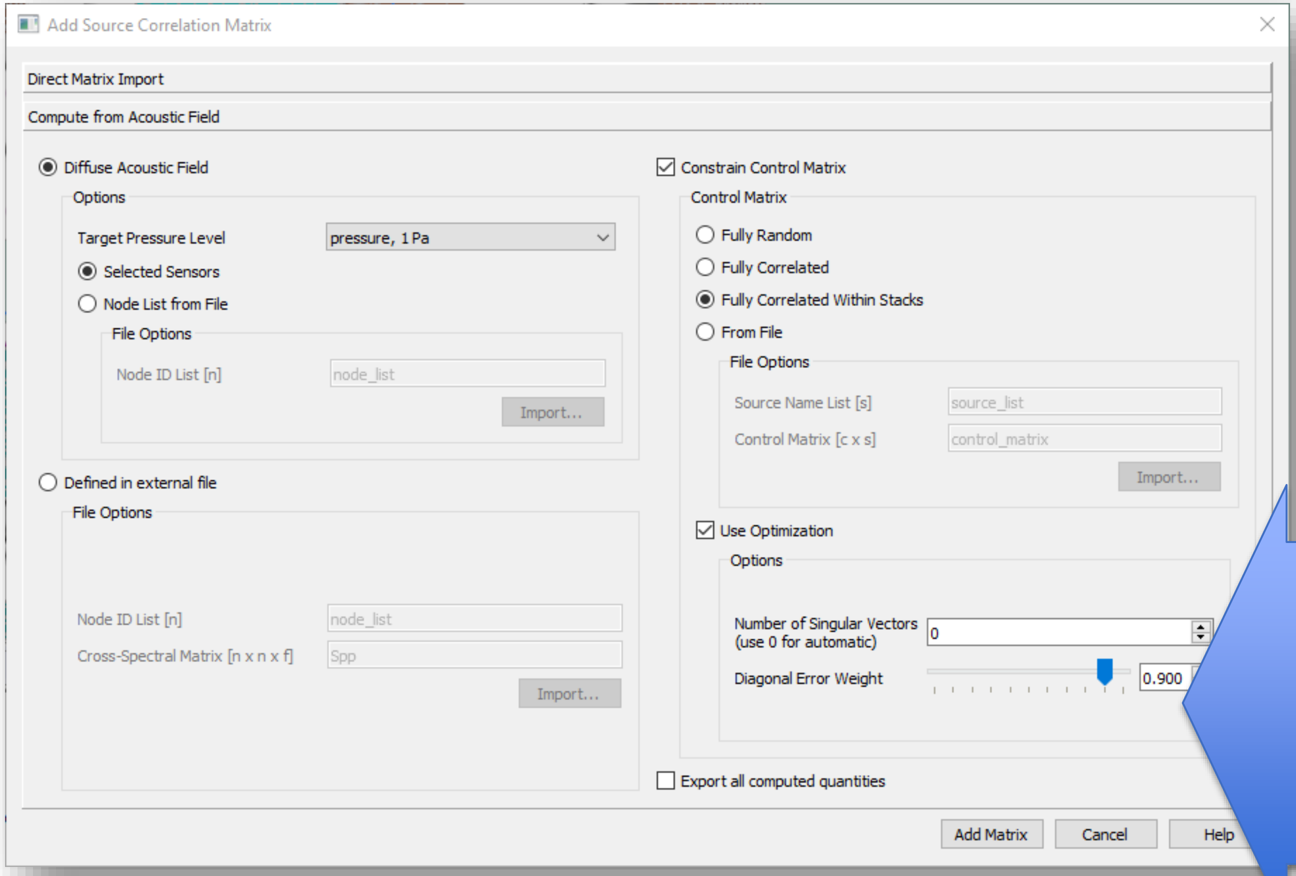
Using optimization algorithm to prioritize amplitude vs cross-correlation

Optimization

- Uses a quasi-Newton optimization algorithm (BFGS) to find the $[S_{ww}]$ that results in the best match to the target acoustic field (in this case, a DAF).
  - *The optimizer finds the vectors and values that define a modified Singular Value Decomposition of $[S_{ww}]$ to ensure the result is physically valid.*
  - *Varying the number of singular vectors allows one to trade accuracy for computational speed. An automatic setting is also available that uses the rank of the initial guess to estimate the number.*

- Optimizes both **sound pressure levels** and **diffusivity**. The weight between those two goals can be selected.

DFAT Simulation Approach



New optimization feature

DFAT process

3-step process

Initial solution:

$$[S_{ww}] = pinv([H_{pw}])[S_{pp}]pinv([H_{pw}])^H$$

No differentiation between amplitude and cross correlation

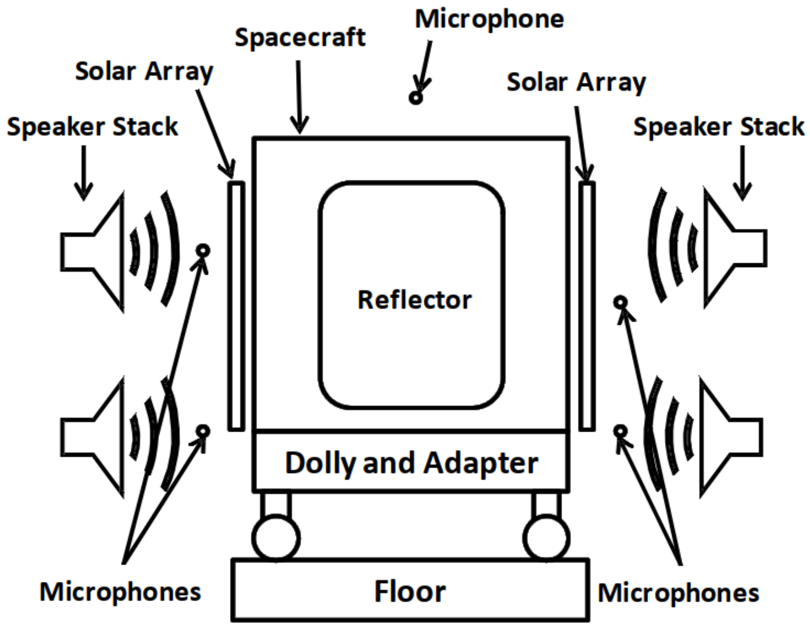
Optimization

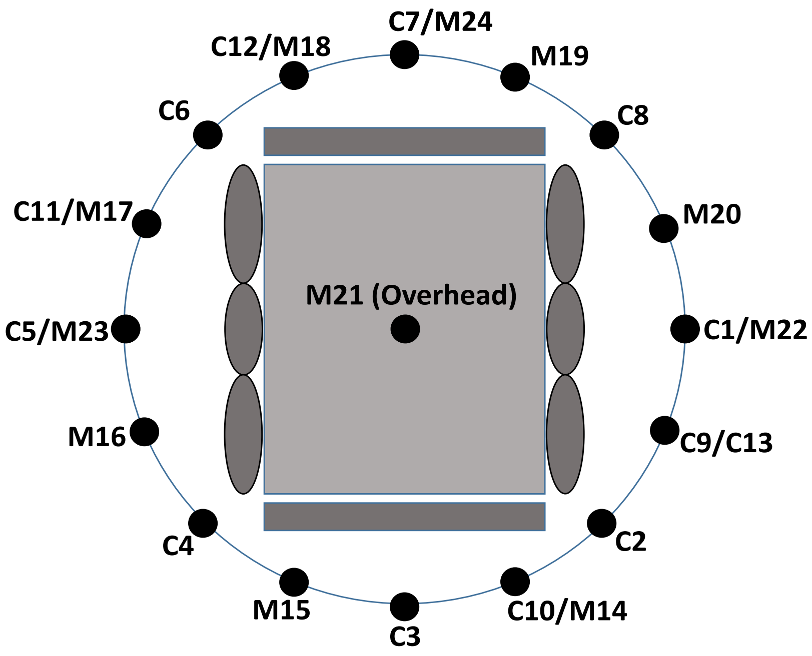
Using optimization algorithm to prioritize amplitude vs cross-correlation

Post processing

- Levels
- Wavenumber Frequency spectrum

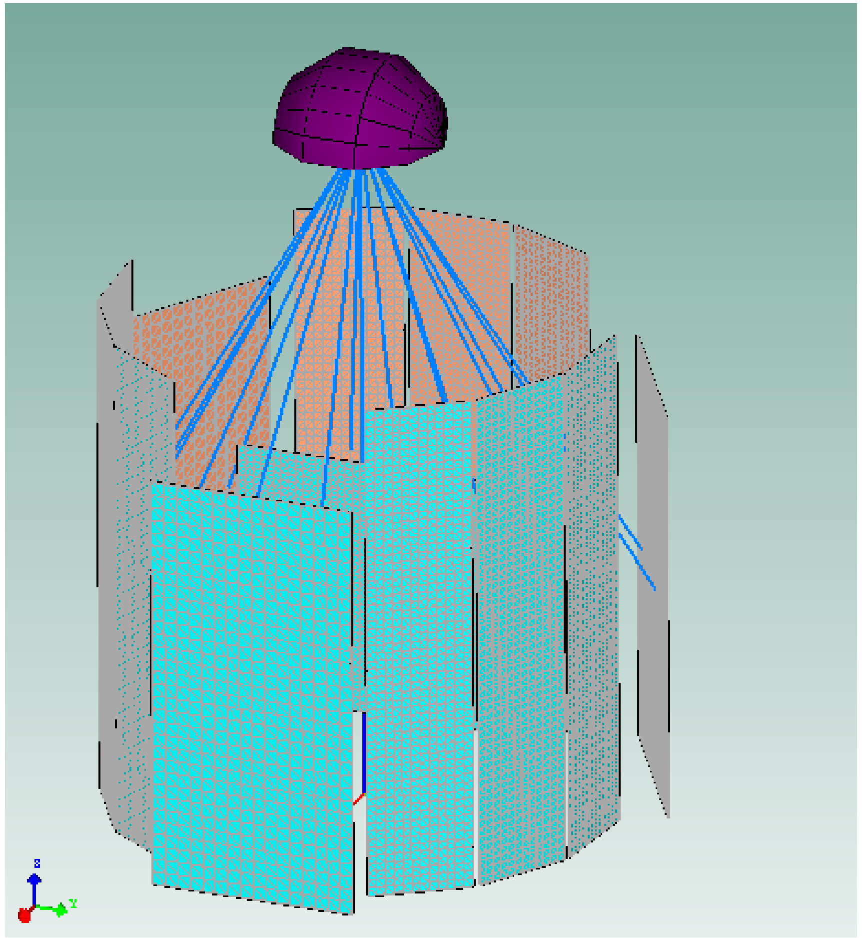
Validation example – data courtesy of Northrop Grumman Acknowledgements to Daisaku Inoyama and Tom Stoumbos



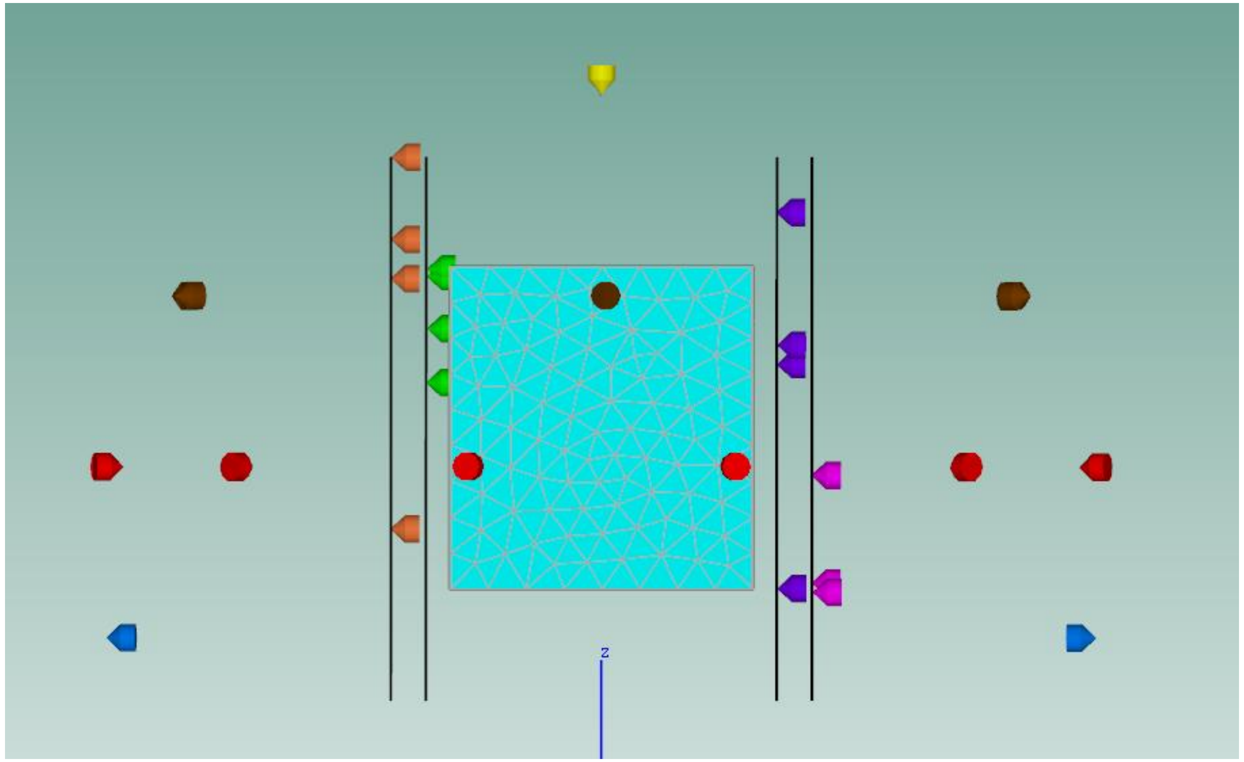


Simulation model

- Speaker stacks are represented



- Control and monitor microphones are placed



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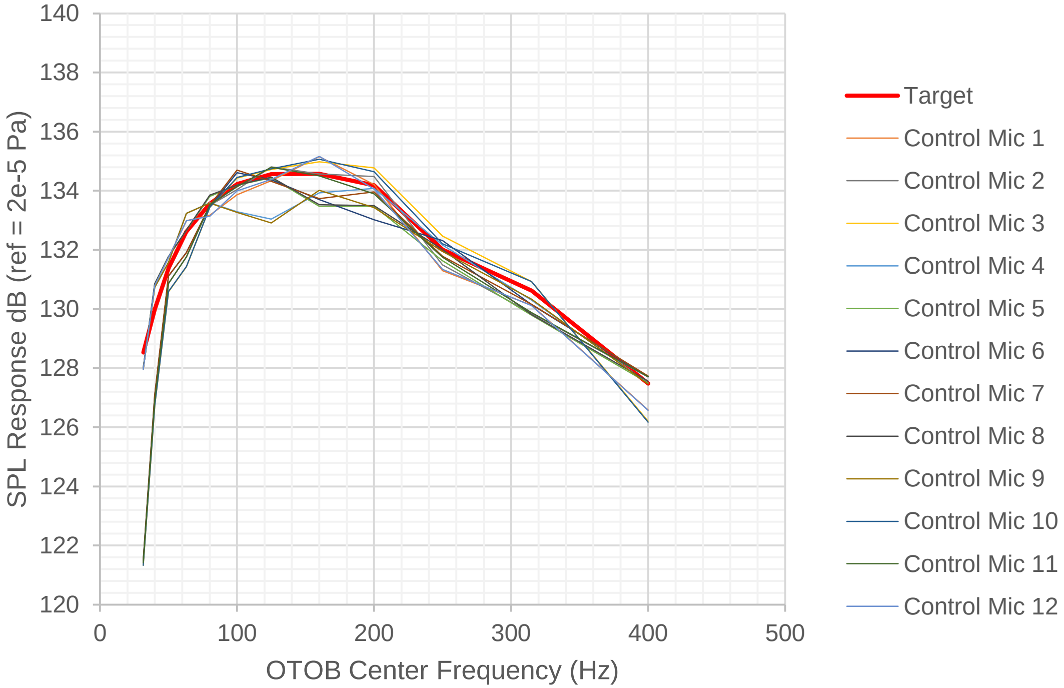
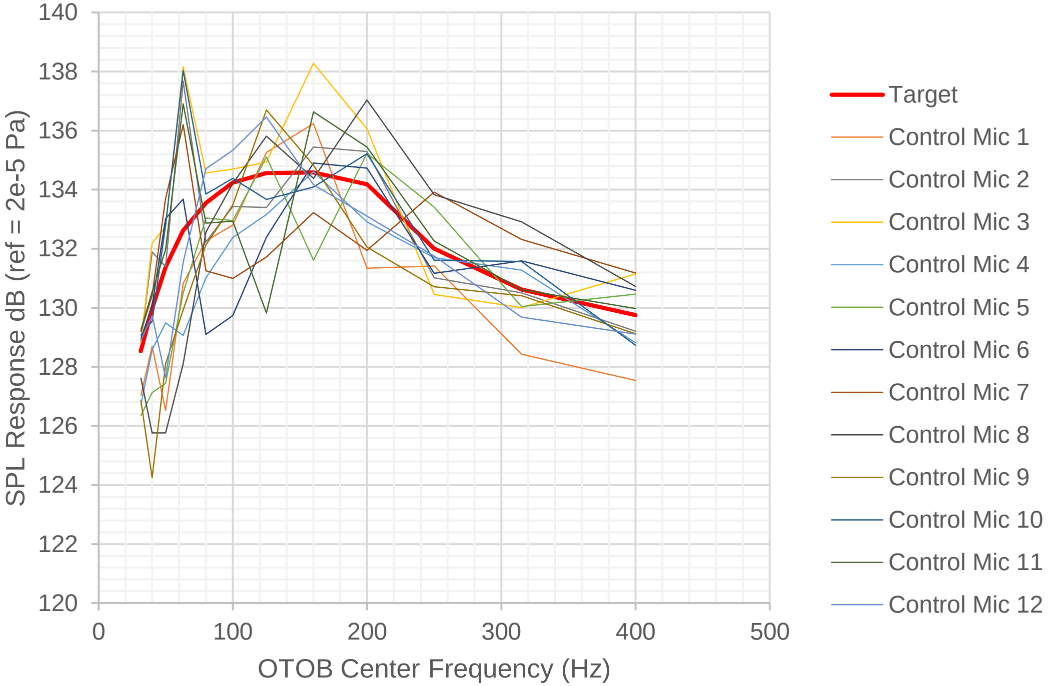
Control microphones vs target

- Simulation



- Test



- Simulation at virtual microphones is very close to the target curve (red), test is further away
- Greater test variability relative to target is likely due to use of older test setup configuration

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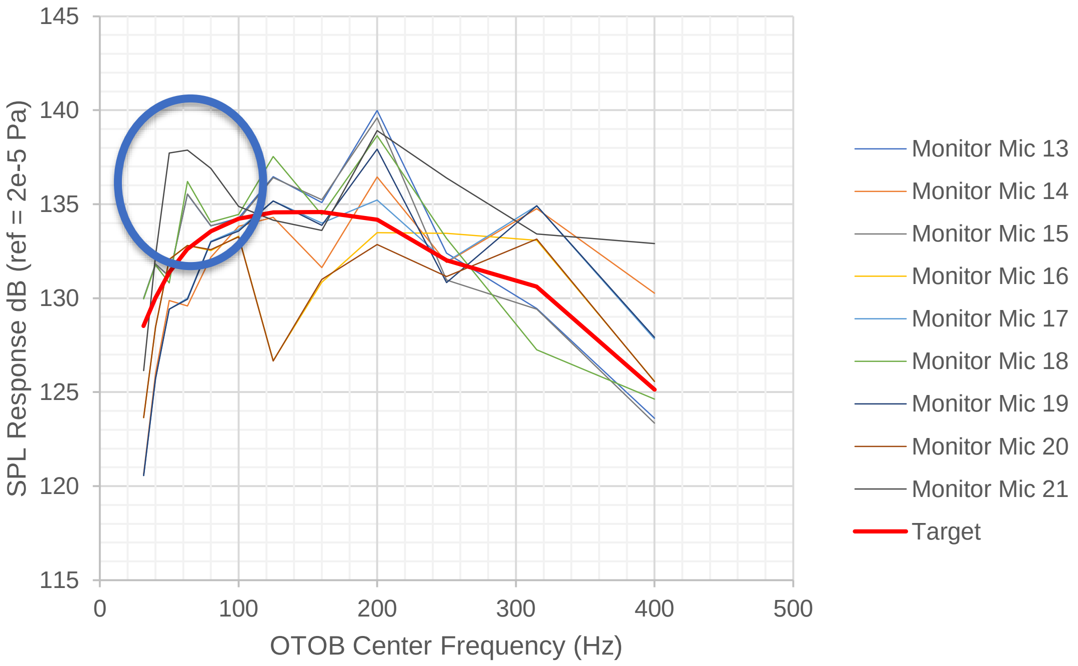
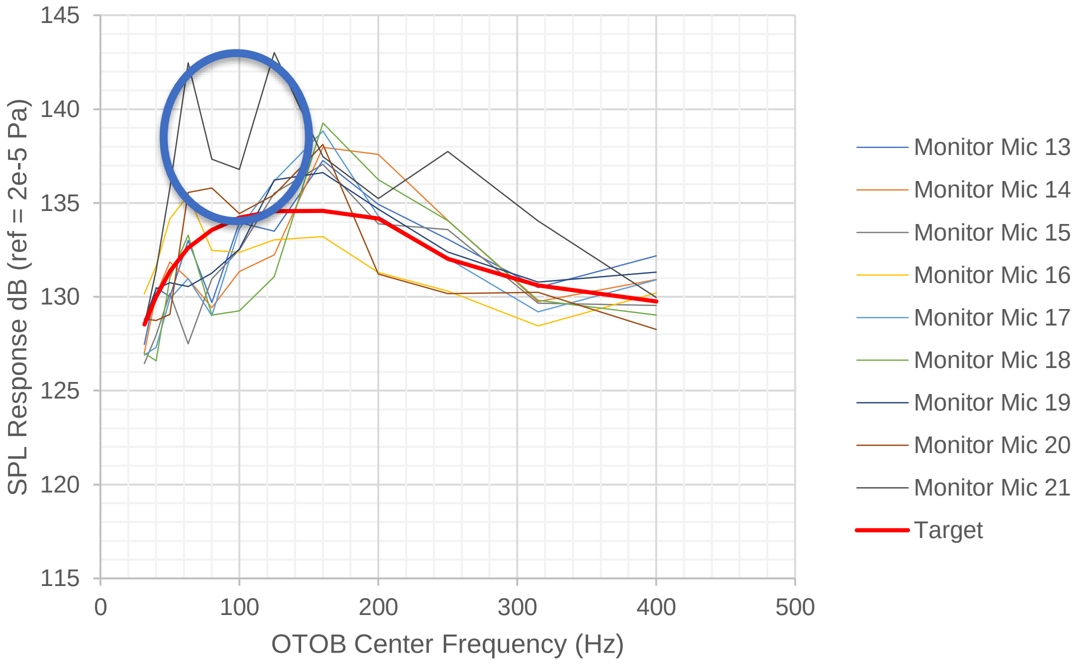
Monitor microphones vs target

- Simulation

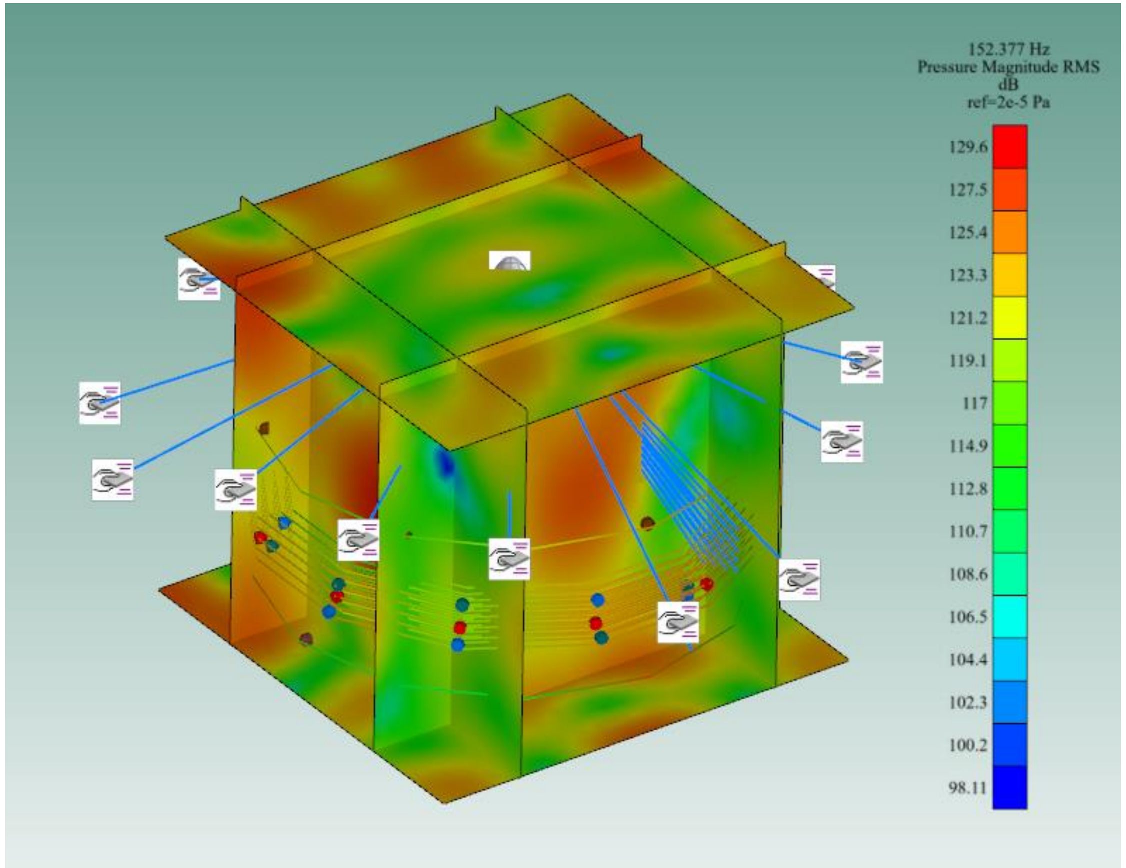


- Test



- Both simulation and test have similar trends
- One microphone at center of the stack shows higher levels, this trend is reflected by the simulation
  - Variability vs. target again likely due to the older test setup (regularly-spaced control microphone positions)

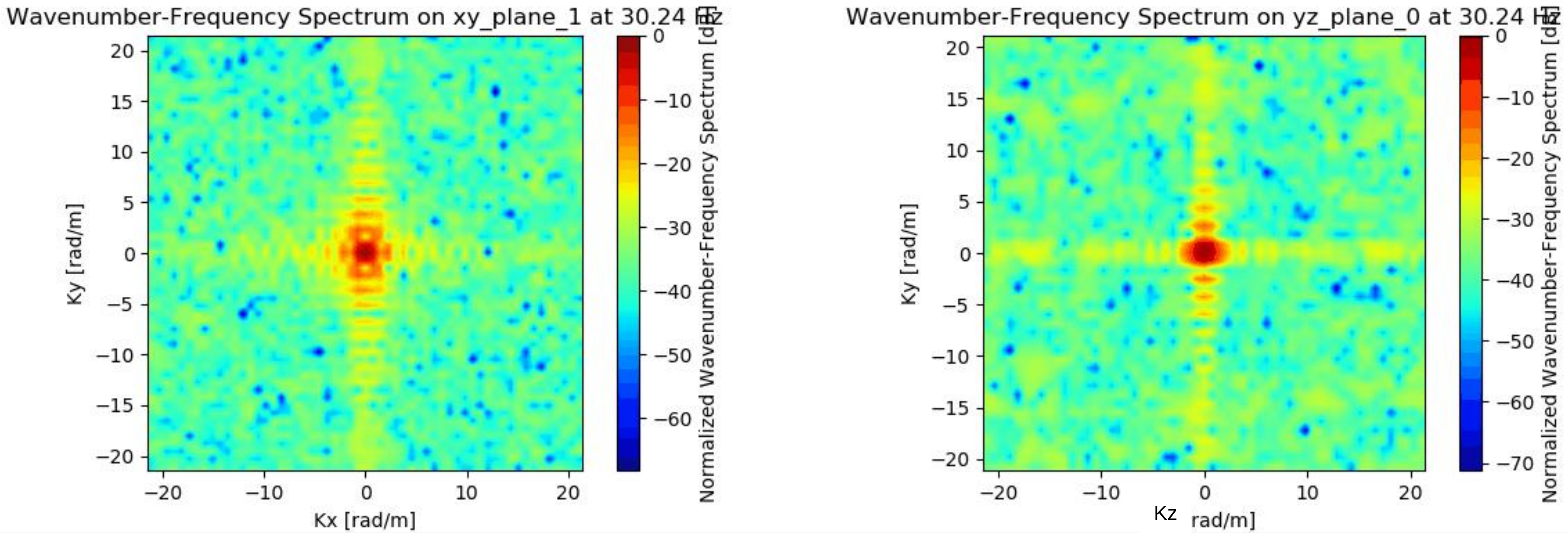
Spatial distribution of pressure may be simulated at all locations



Ability to identify hot and cold spots

This is a “picture” of the pressure distribution at a discrete frequency

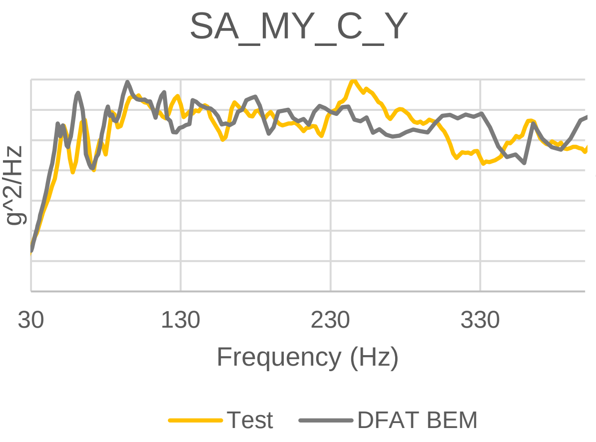
Wavenumber analysis gives indication of field correlation character

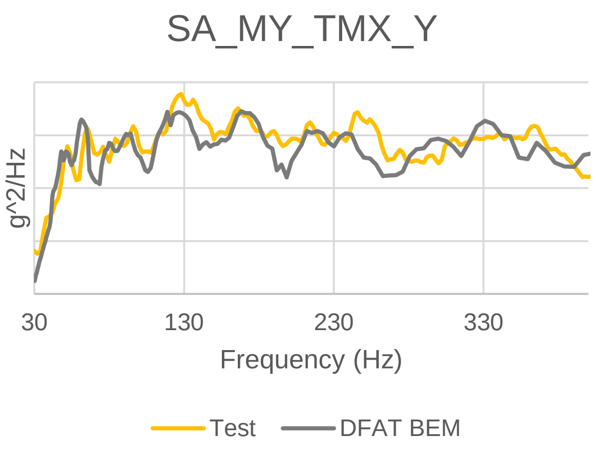


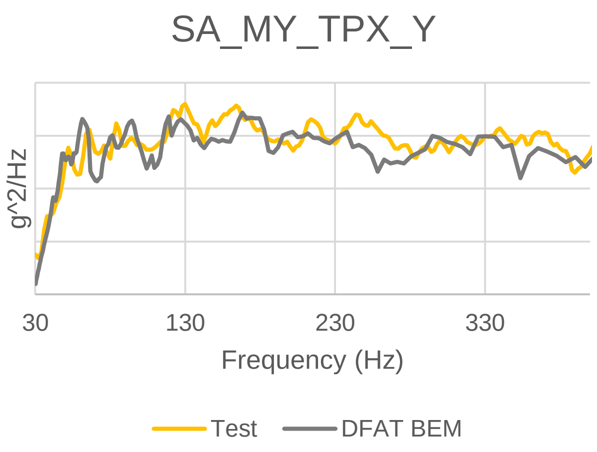
- XY Plane (Parallel to the ground): shows diffuse acoustic field characteristics
- YZ Plane (Normal to the ground): less diffusivity in the high frequency range

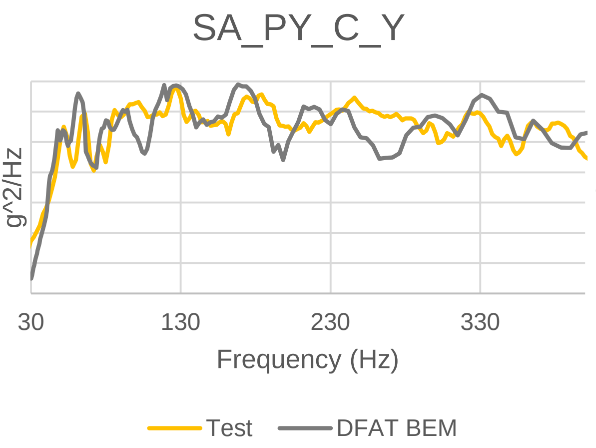
Structural response

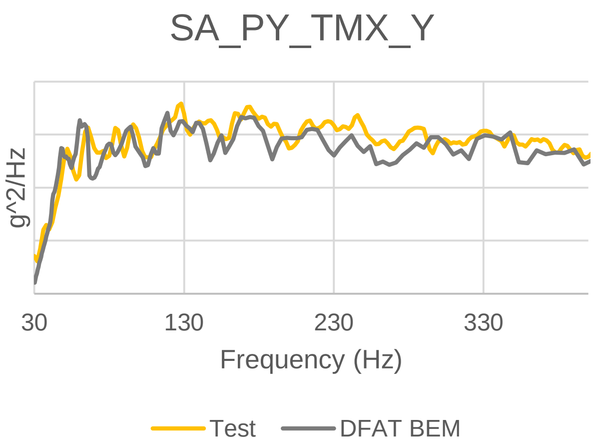
Accelerometers are placed on solar array

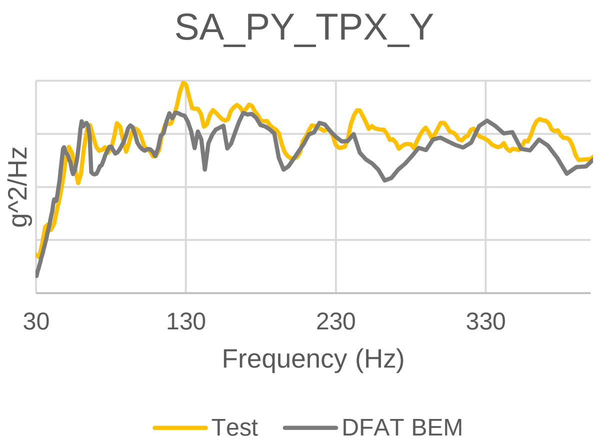


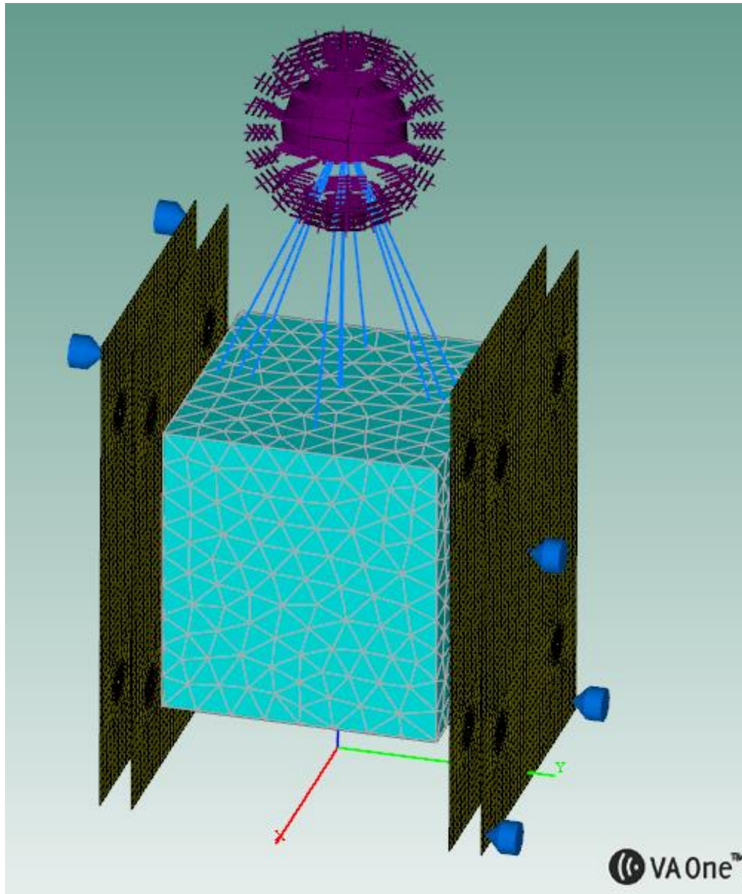




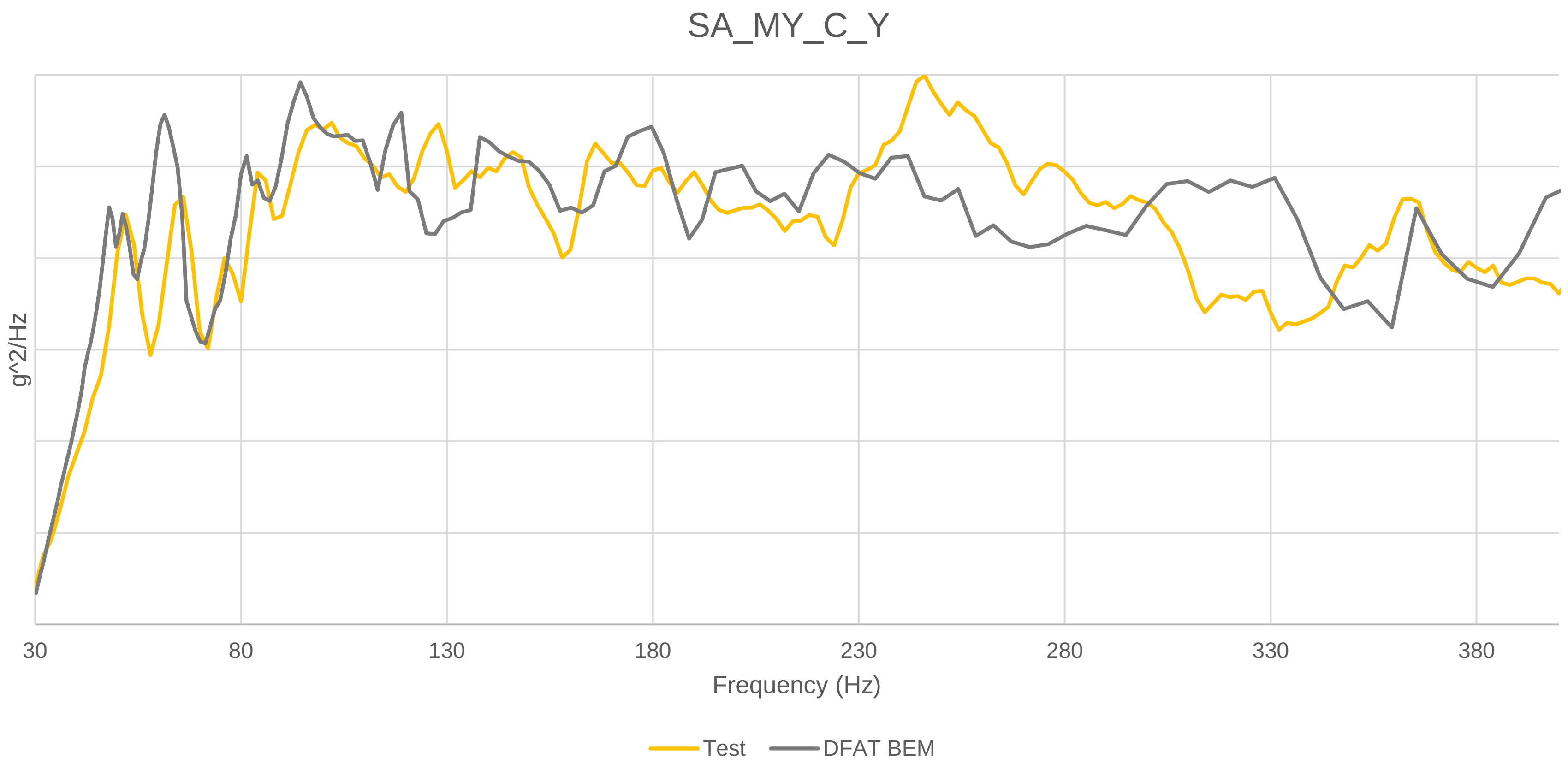






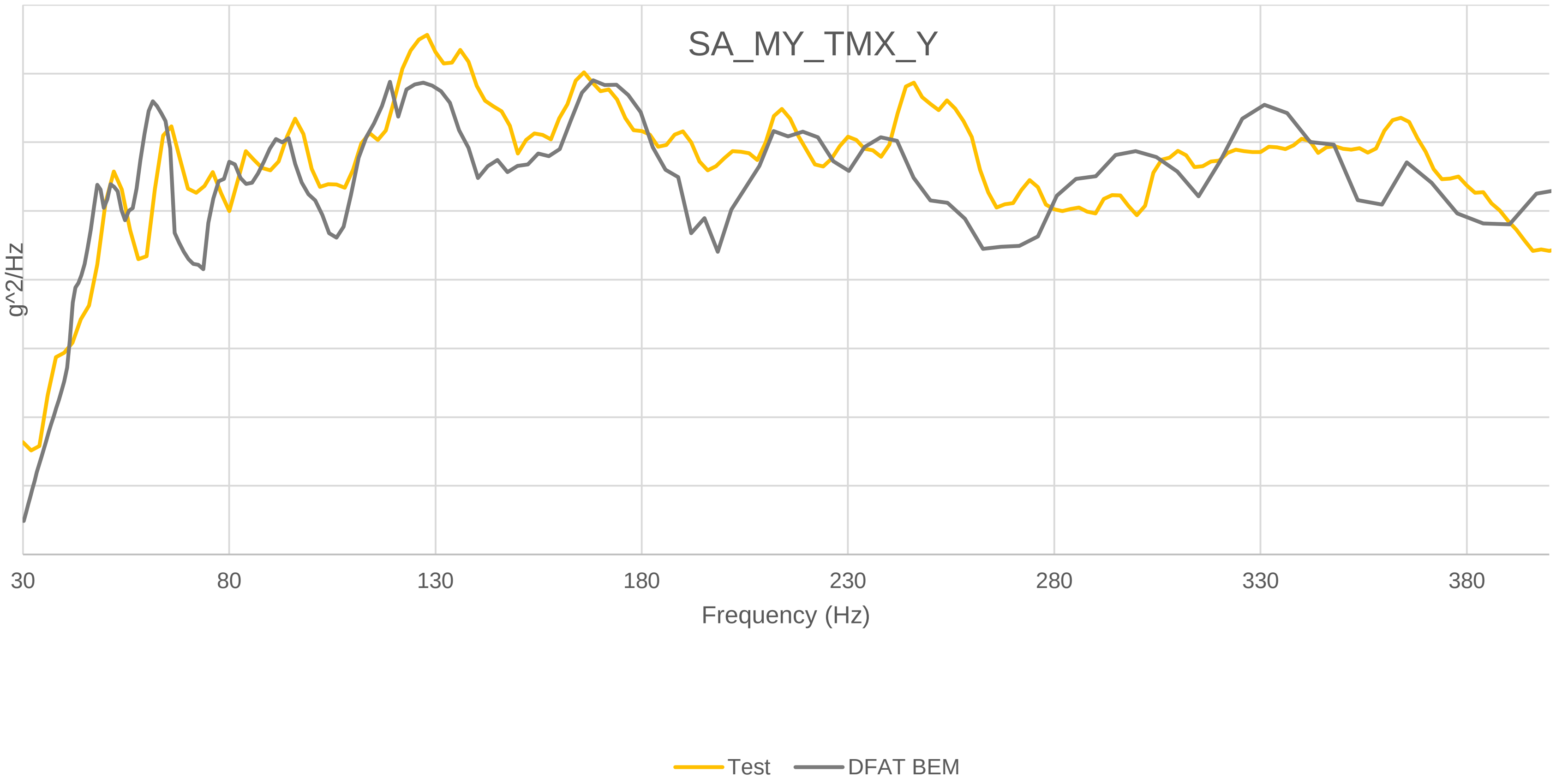


Structural response



- First simulation result is presented
  - no “tuning” of FE / BEM model
- Good low frequency prediction
- Spectrum trend is captured
- Result accuracy also dependent on the finite element model

Structural response



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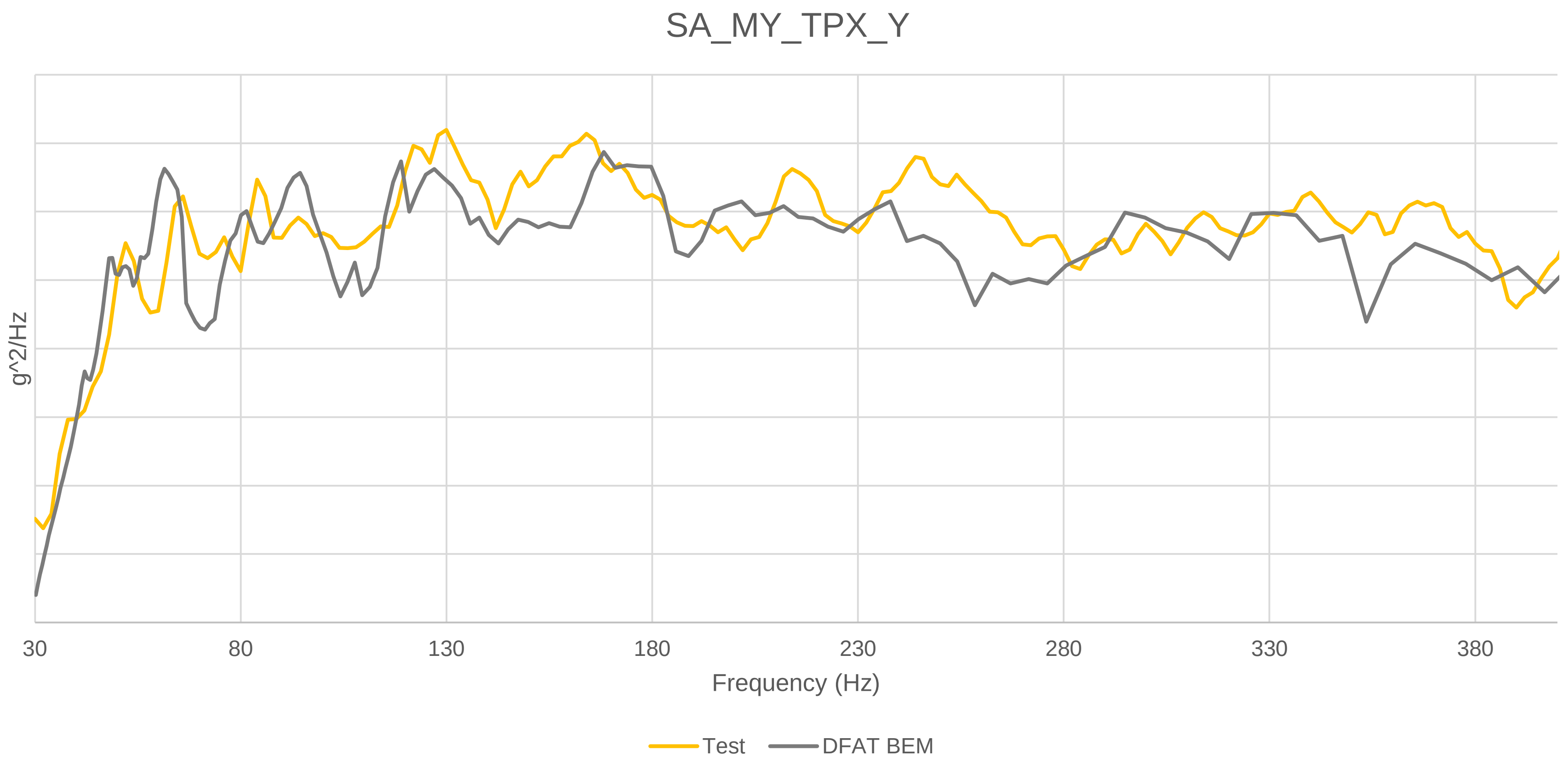

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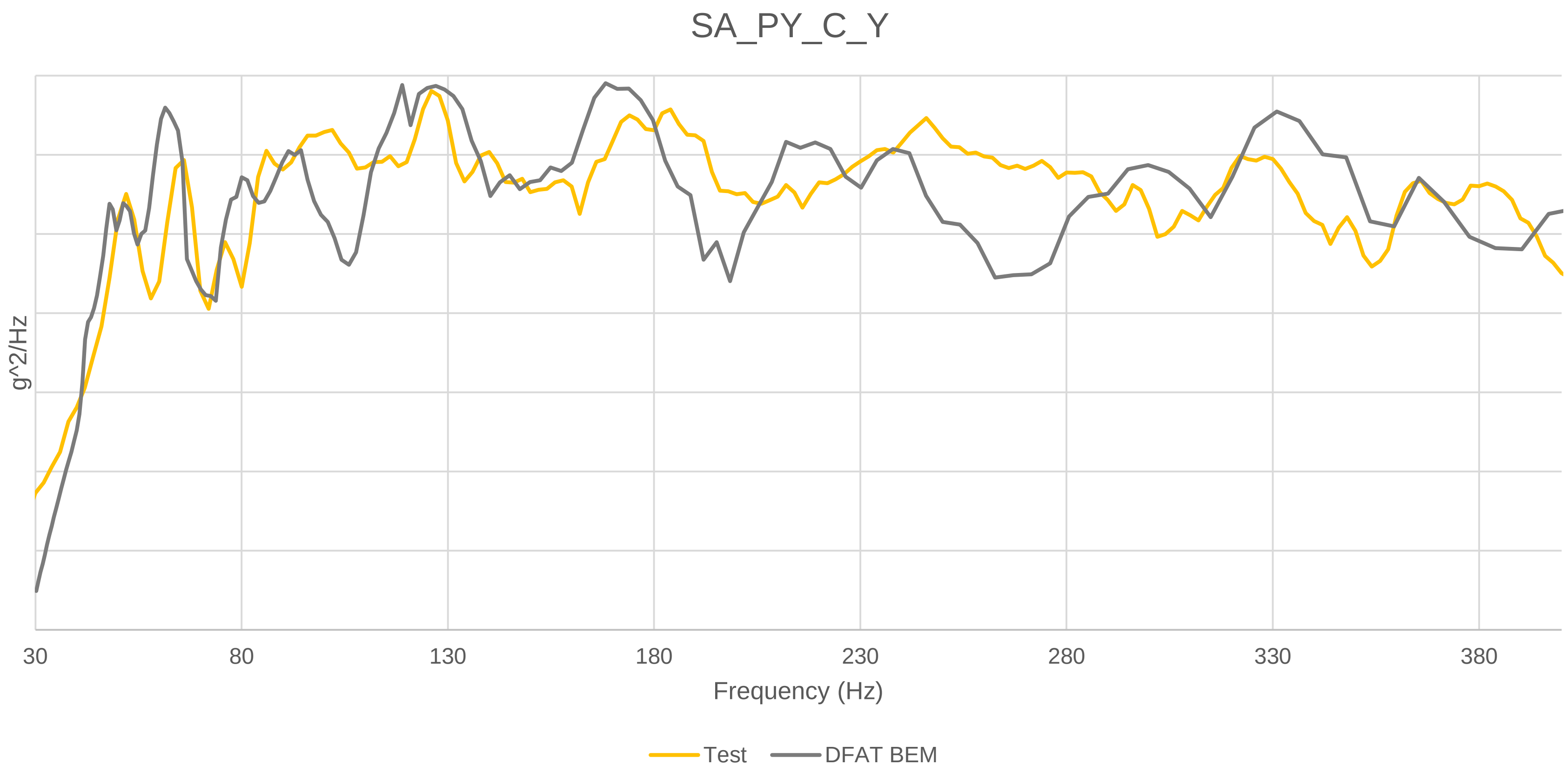

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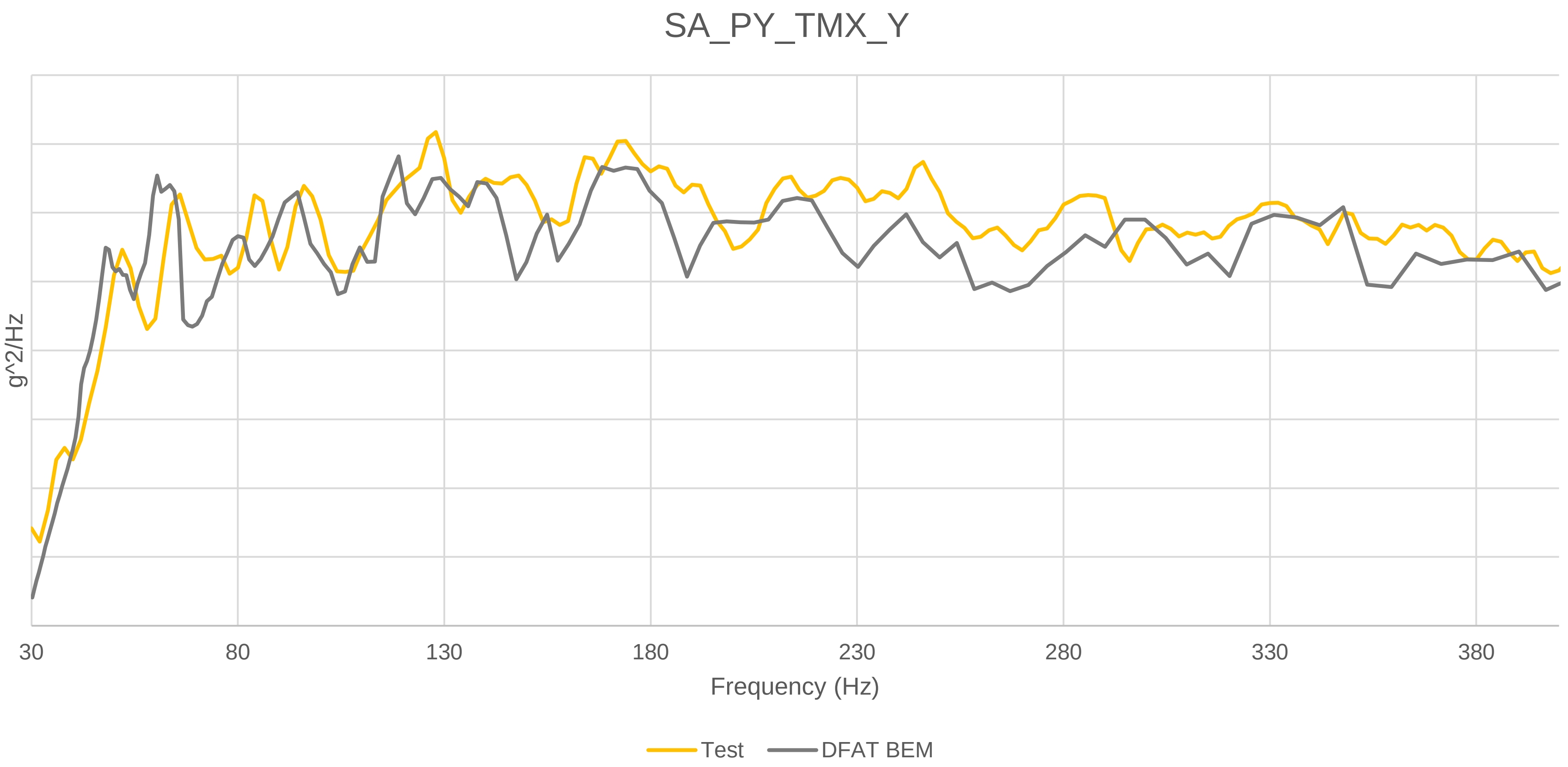

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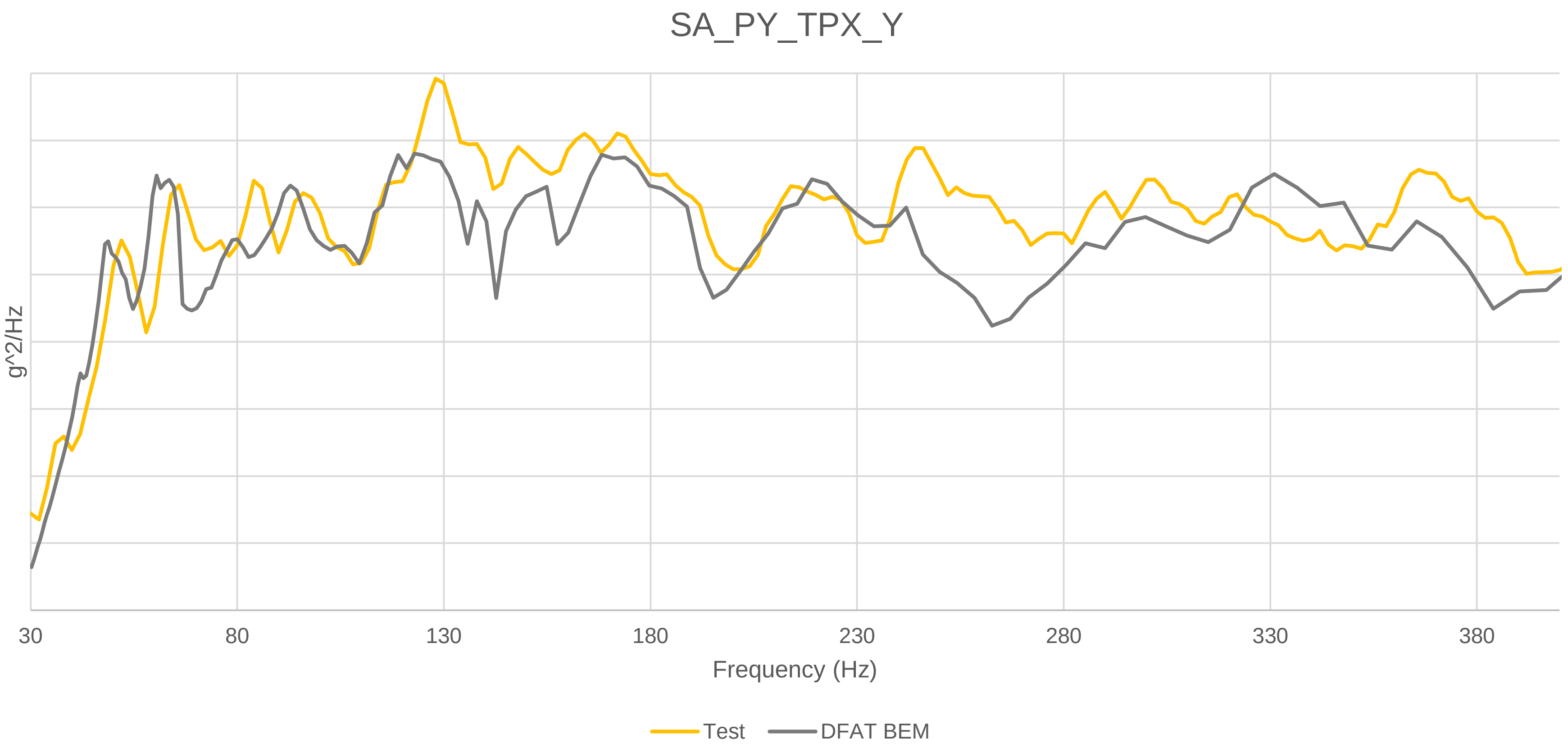

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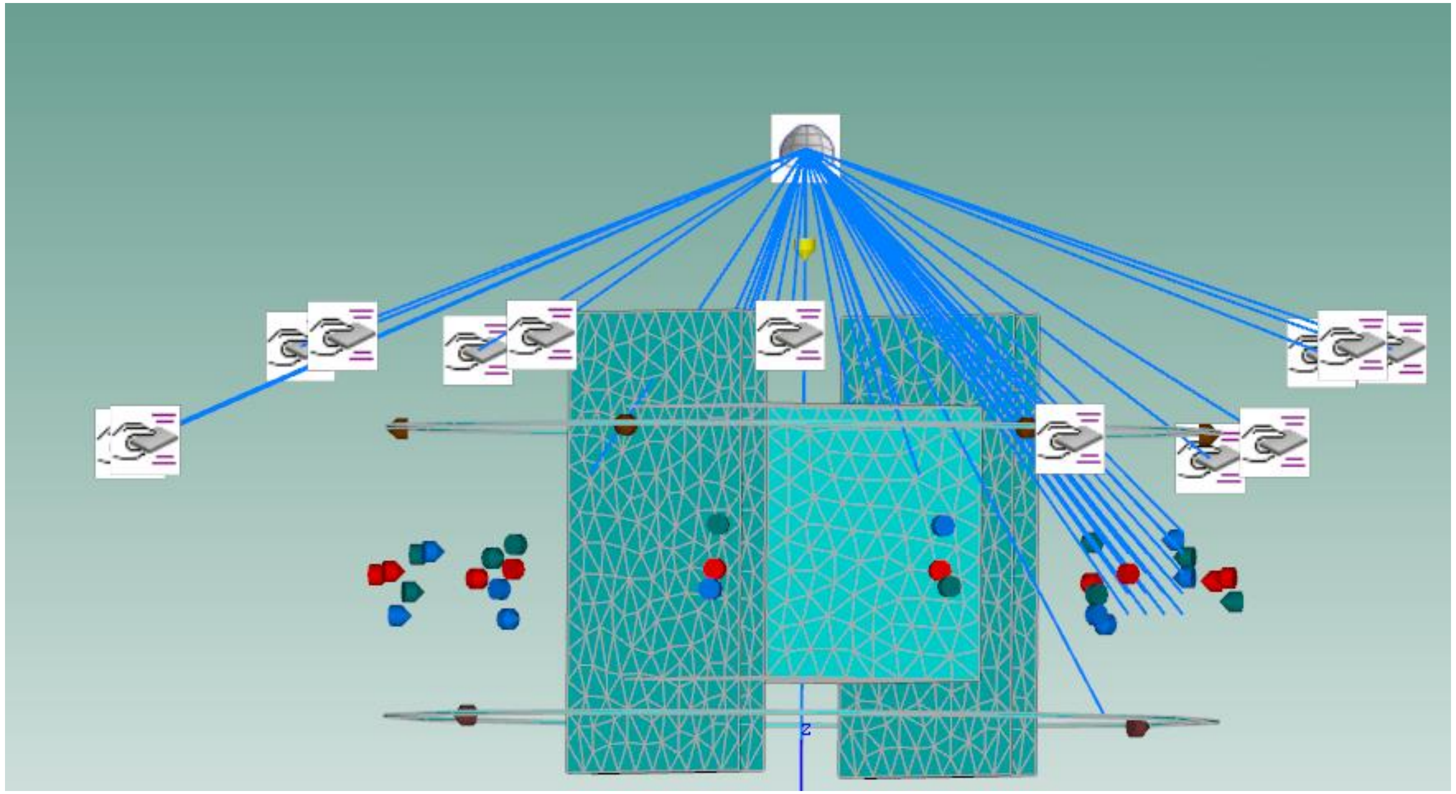
Studying variation of control mic positions

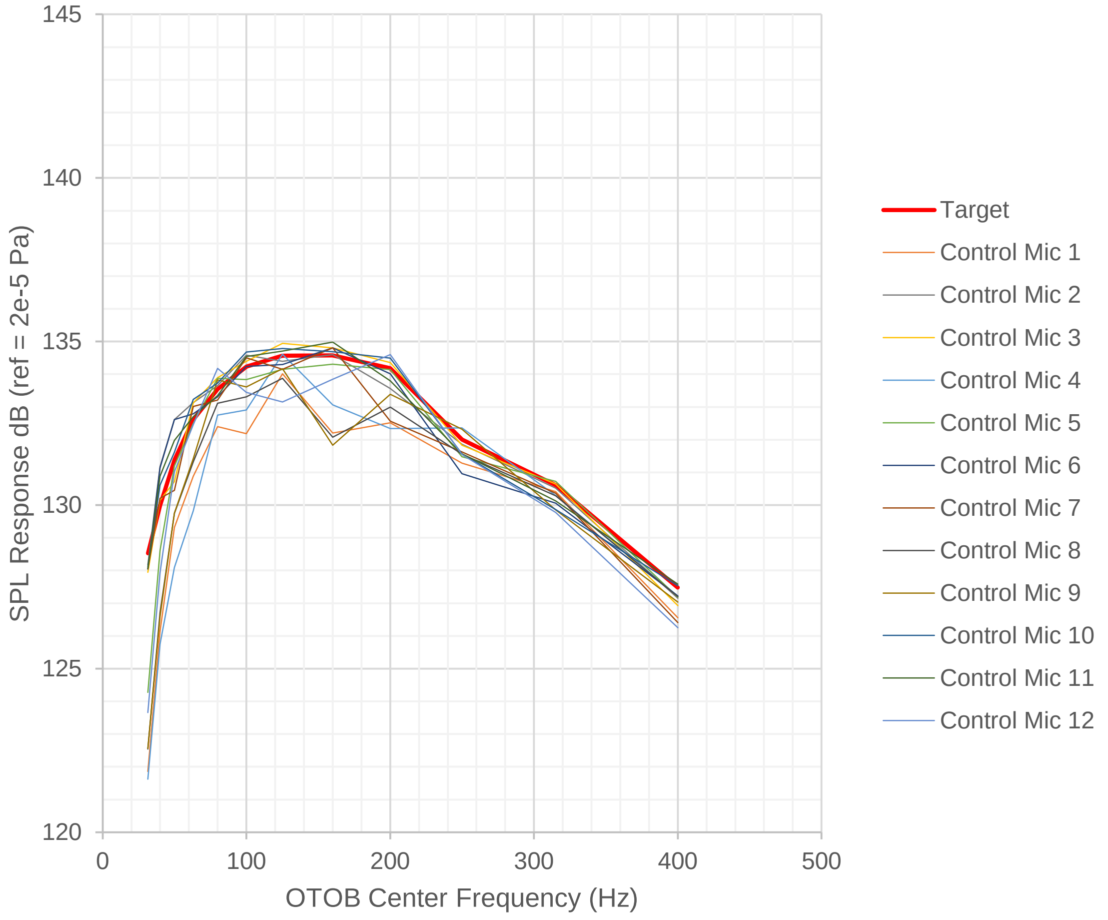
- 2 additional sets of control microphones
  - *Blue*
  - *Green*
- Locations permuted randomly

from baseline locations (red)

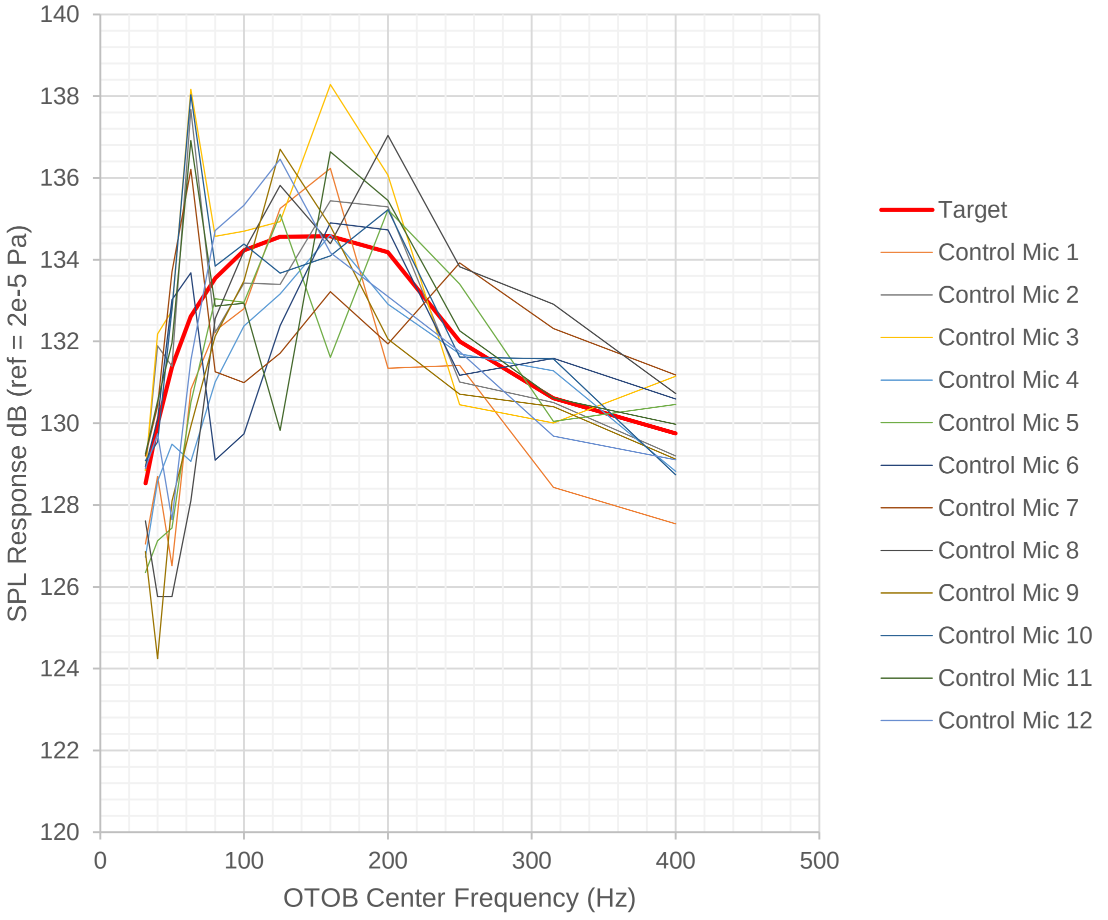


Blue set of control microphones – Control microphones

- *Simulation*

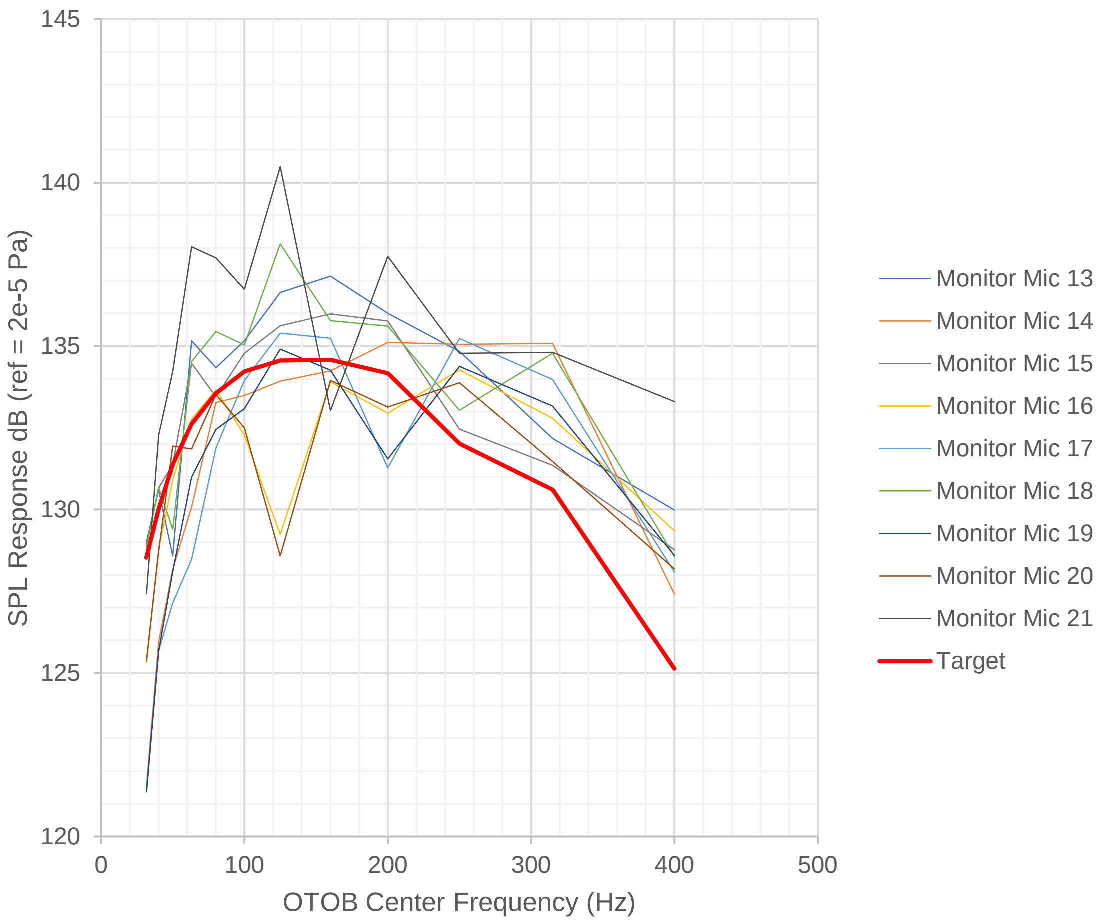


- Test



Blue set of control microphones – Monitor microphones

- *Simulation*



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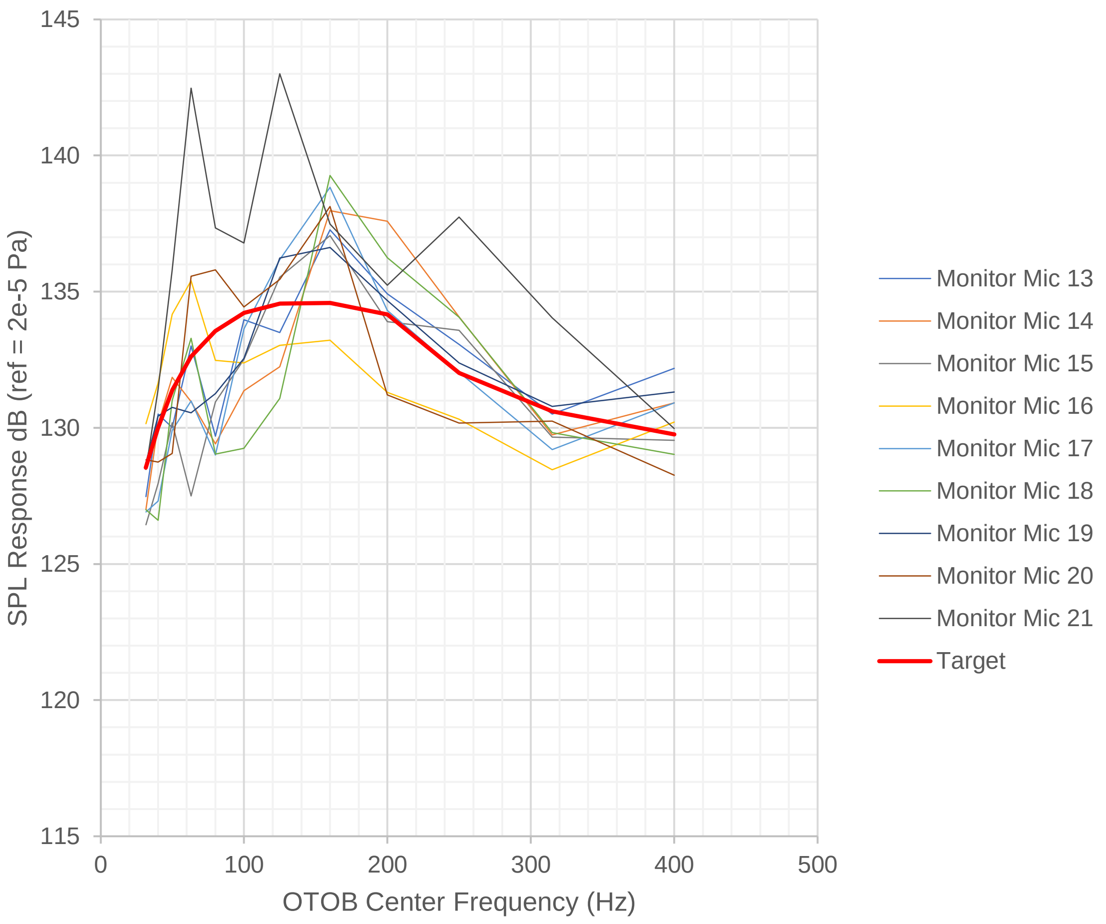

Conclusions

- Comparison results against test data
  - *Control and monitor microphones levels are comparable*
  - *Structural response is comparable and excellent for a first simulation with no model tuning*
  - *Contour plots indicate local acoustic response at all locations and frequencies of interest*
  - *Cross correlation information allows for evaluation of field characteristic (diffusivity)*

Moving forward – next steps

- Further acoustic and structural correlation studies for this data set and others
- Understand and reduce differences between test data and DFAT models
- Implement algorithm to account for speaker output power – limits and optimization

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