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# Reverberation Room Simulation

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# Project Definition

- Blachford Acoustics Laboratory
  - Located in West Chicago, IL

Blachford ACOUSTICS GROUP


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# Project Definition

- Simulation of reverberation room
  - Goals
    - Predict room behavior at low frequencies
    - Simulate room modifications
  - Model Validation
    - Standard deviation
      - Spatially averaged SPL on two planes
    - Reverberation time

# Room Layout

- Solid concrete floor, walls, and ceiling
- Five stationary diffusers
- One rotating diffuser
- Vertical and horizontal transmission loss panels
- Buck chamber
- Loudspeaker broadband source

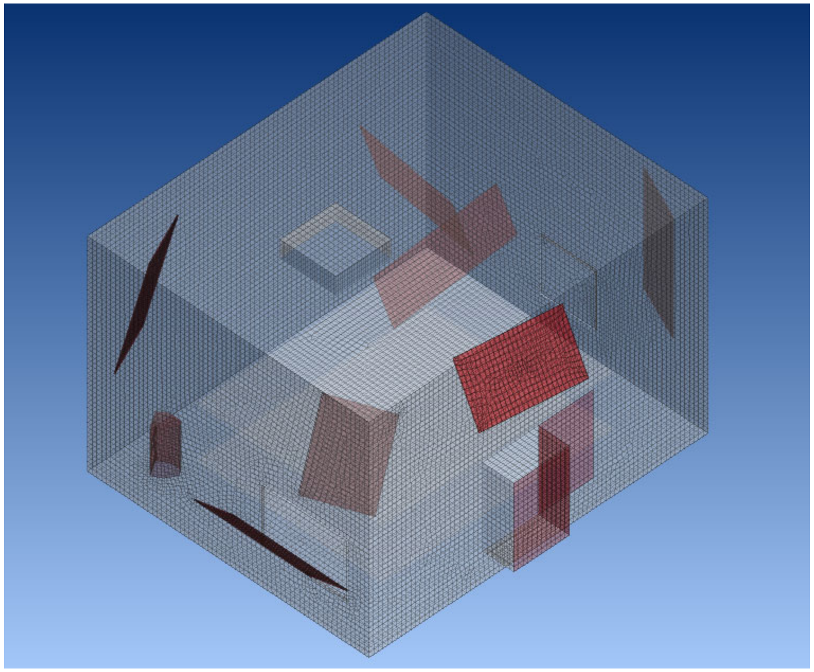
# Process and Setup

- Actran VI – FEM Software
  - Creo Parametric
  - Hypermesh


- Mesh Convergence Study
  - Quadratic elements
    - 5 elements per wavelength
  - Mesh adaptivity enabled

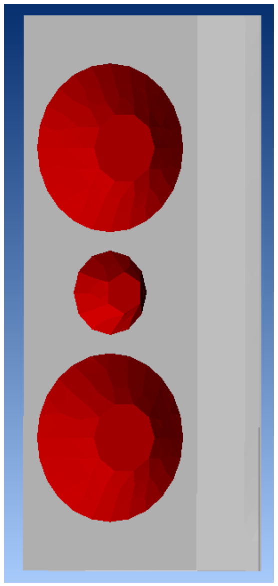
# Model Setup

- Frequency Range and Resolution
  - 1/3 octave bands from 100 Hz to 400 Hz
  - 1 Hz Resolution



# Boundary Conditions

## Source



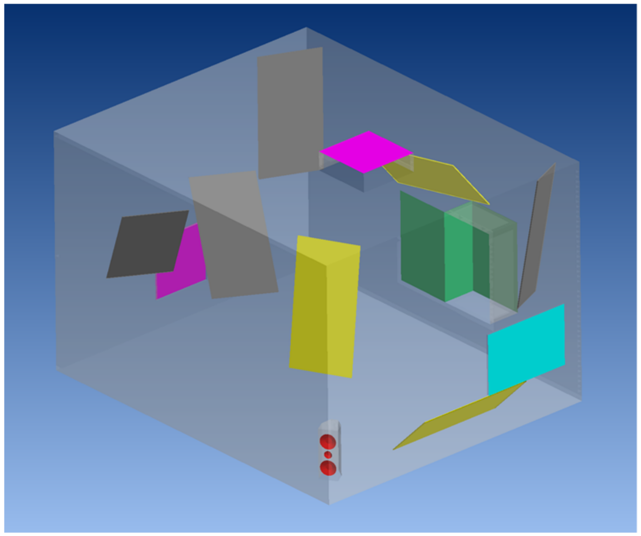
Unit Velocity (1 m/s)

## Absorption Coefficient

$$Z_{norm} = \frac{1+\sqrt{1-\alpha}}{1-\sqrt{1-\alpha}}$$

# Absorption Coefficients

| Material | Surface Color | Frequency (Hz) | | |
|---|---|---|---|---|
| | | 125 | 250 | 500 |
| Gypsum Board on Studs | Green | 0.29 | 0.10 | 0.05 |
| Thin Metal Panel | Magenta | 0.13 | 0.09 | 0.08 |
| Glass | Cyan | 0.10 | 0.06 | 0.04 |
| Plywood | Yellow | 0.05 | | |
| Corrugated Metal | Gray | 0.01 | | |
| Concrete | Transparent | 0.01 | | |



# Reverberation Time Determination

- Reverberation time was calculated in the frequency domain
    - Potential and Kinetic Energy
    - Total Dissipated Power
    - Radiated Power
  - The energy decay rate is assumed to be equivalent to reverberation time measurements

# ASTM Standard Test Method: C423-17

The measured bare room absorption (2-year average) was used to determine the reverberation time

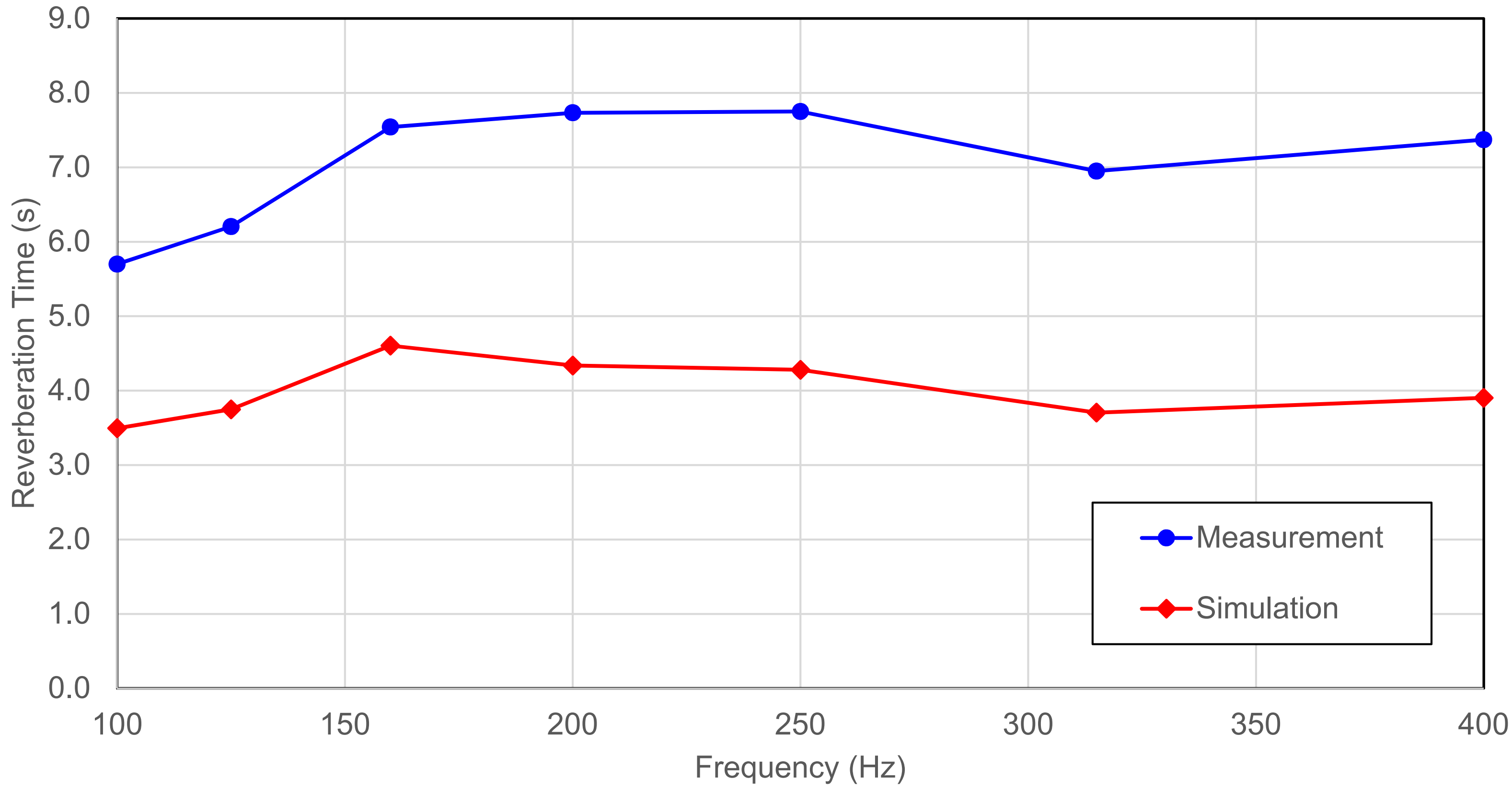
Equation 1:

$$A = 0.9210\frac{Vd}{c} \longrightarrow d = \frac{Ac}{0.9210V} \longrightarrow T_{60} = \frac{60}{d}$$

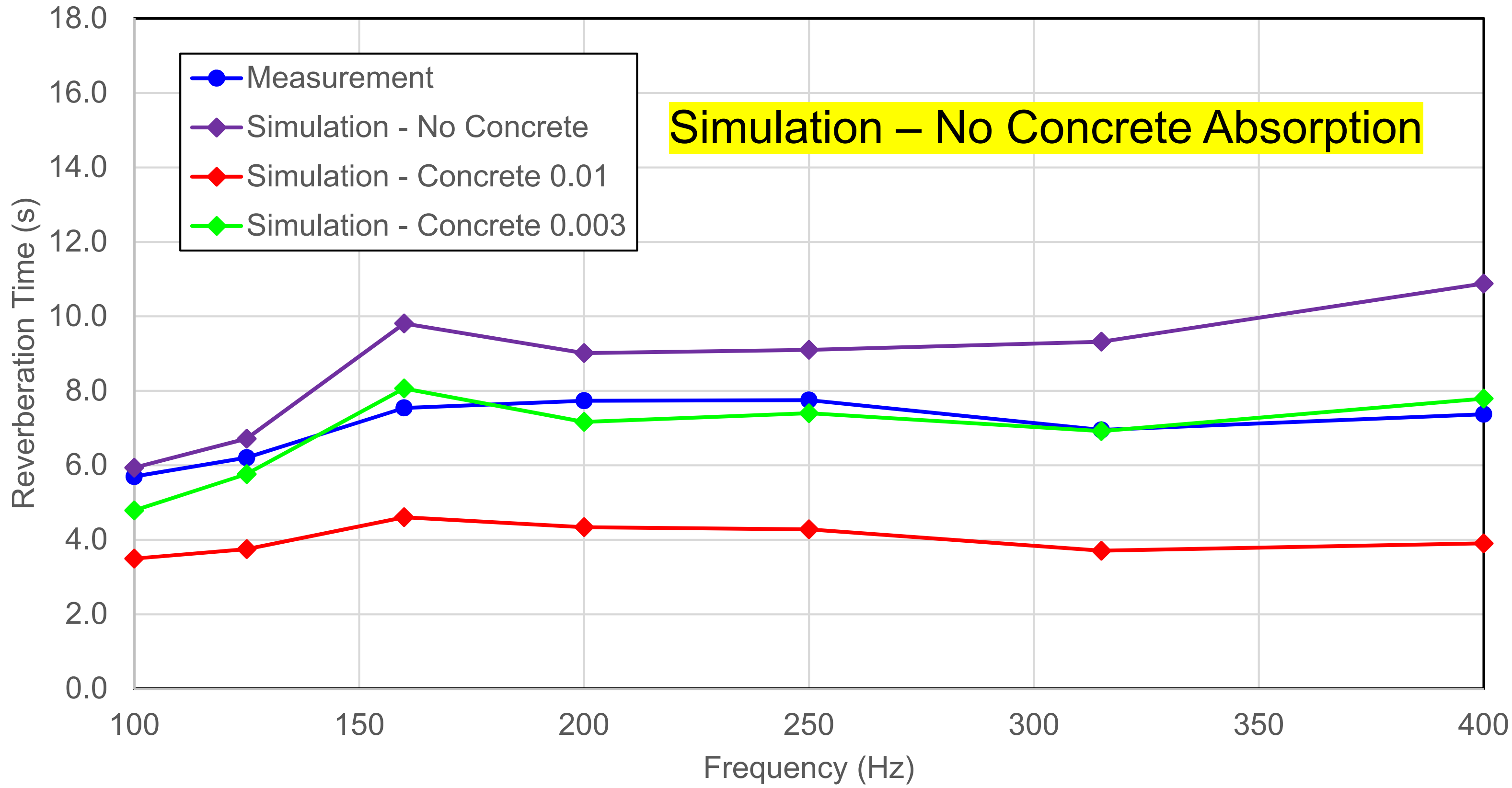
where,

$A = \alpha_{diff}S$ = Room Absorption [m²]
$V$ = Room Volume [m³]
$d$ = Decay Rate [dB/s]
$c$ = Speed of Sound [m/s]

# Initial Model Reverberation Time



# Add Concrete Sound Absorption



# Add Air Attenuation

Calculate complex speed of sound

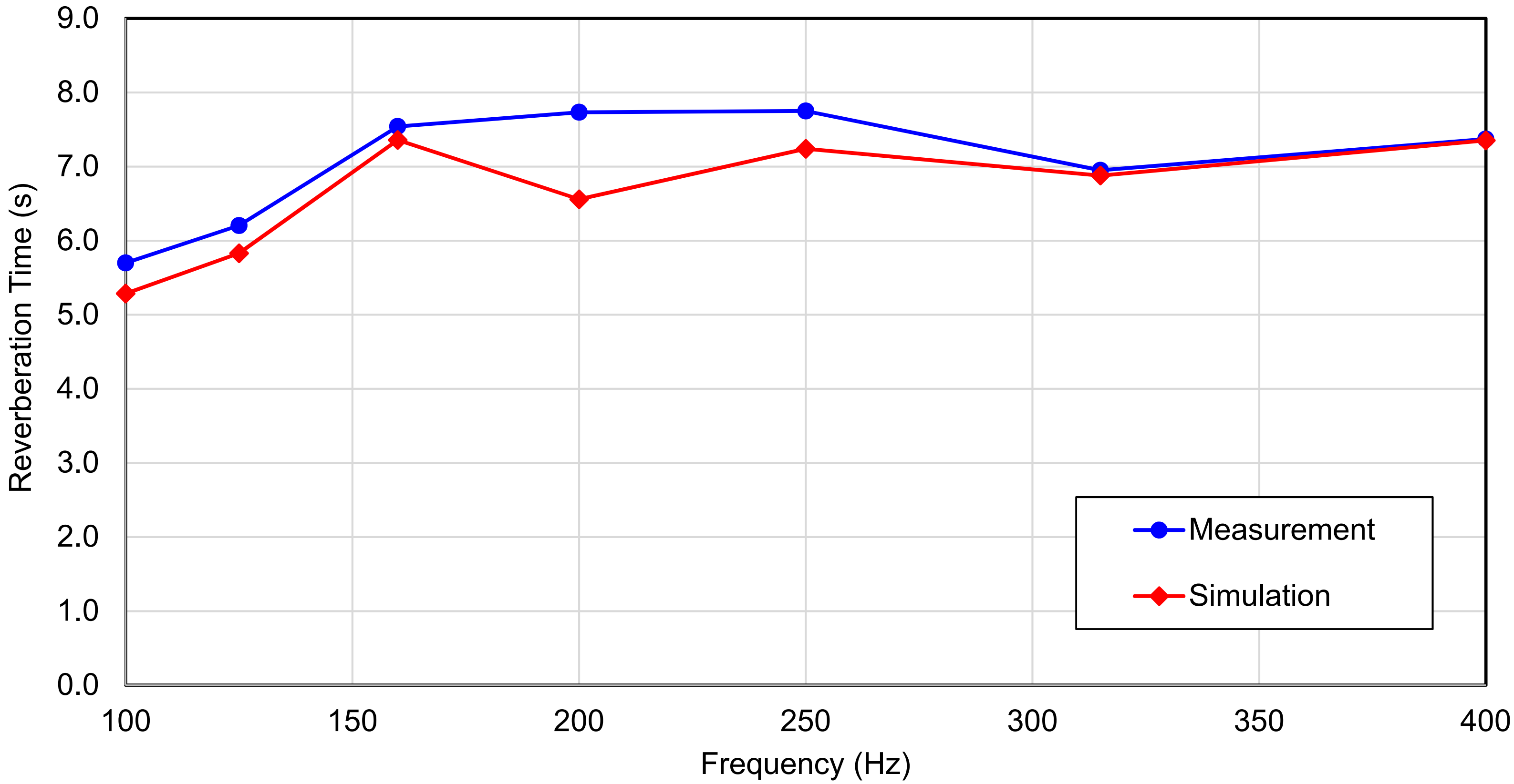
Add a little more information showing how this air loss factor is selected.

$$\eta = \frac{6\ln(10)}{T_{60}\omega}$$

$$k' = \frac{\omega}{c}\left(1 - j\frac{\eta}{2}\right)$$

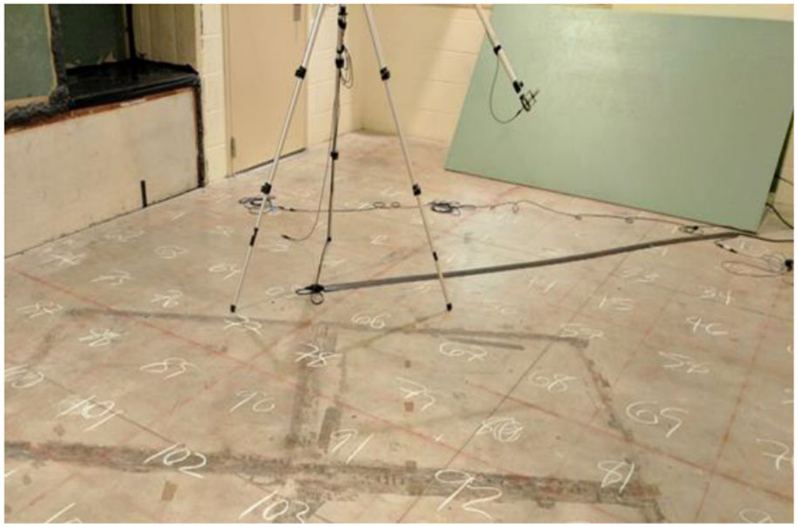
$$c' = \frac{\omega}{k'}$$

# Final Model Reverberation Time

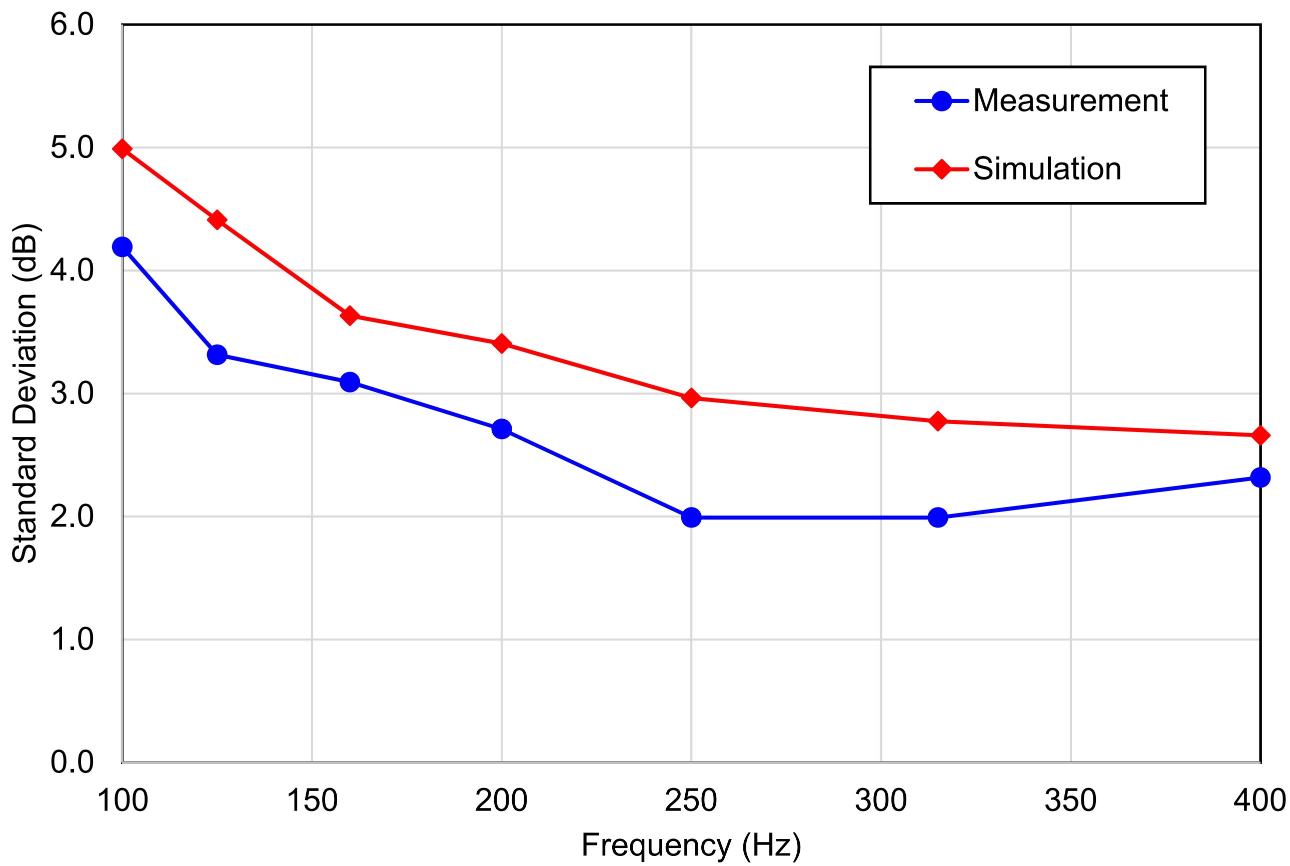


# Diffuse Field Validation

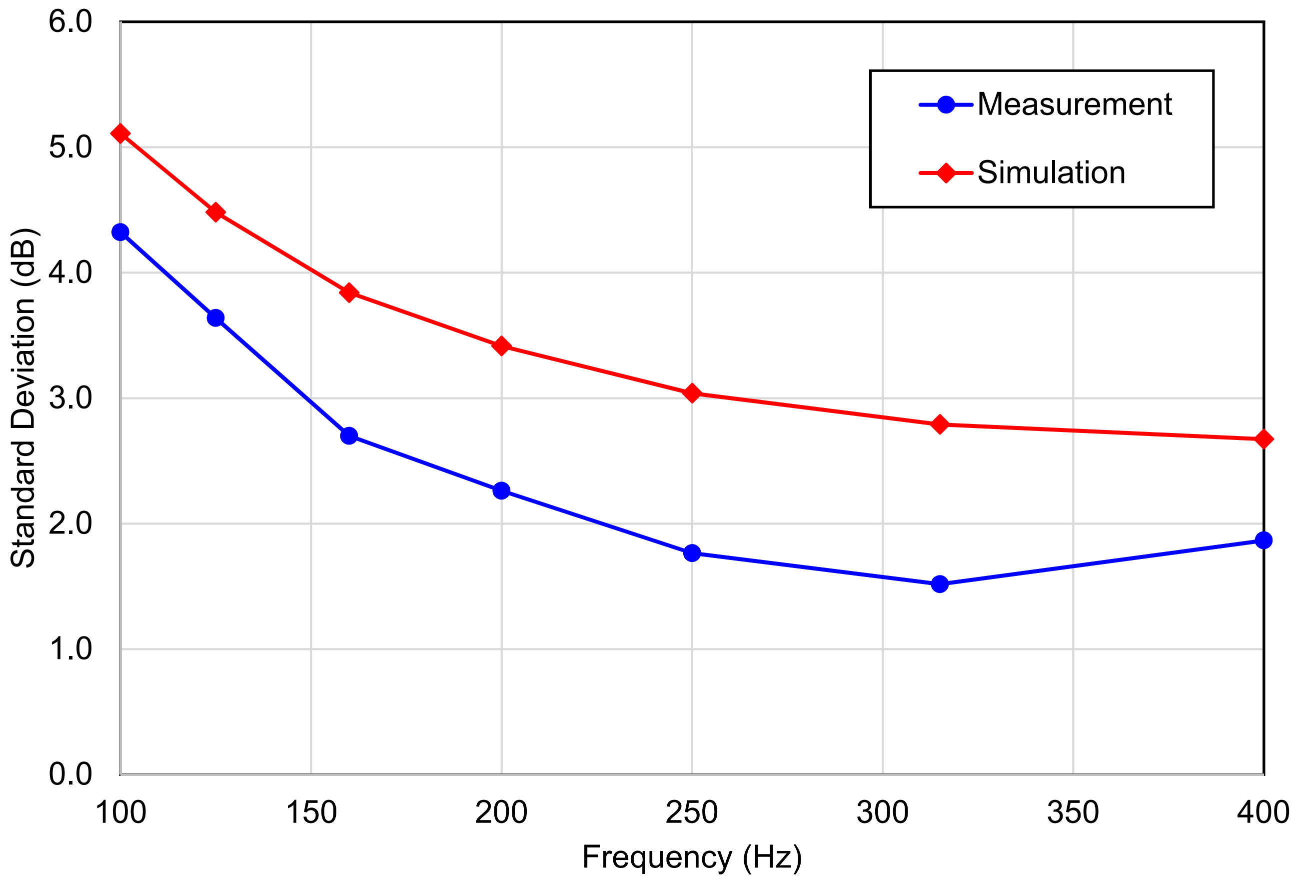
- Standard deviation of spatially averaged sound pressure levels
  - Rotating diffuser was rotated at 60-degree increments



# Results 6 cm Plane

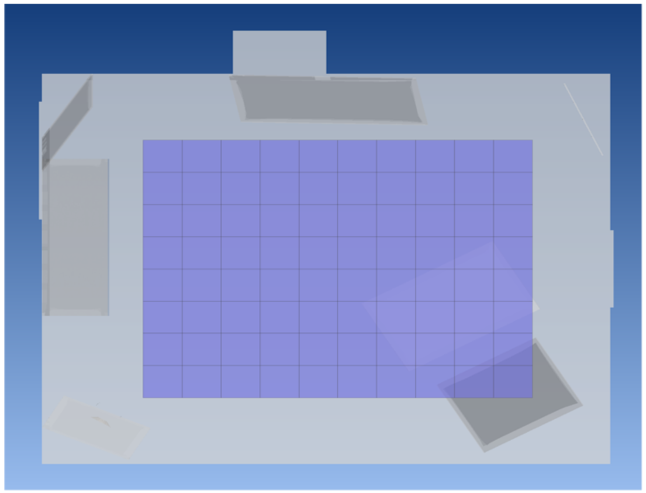


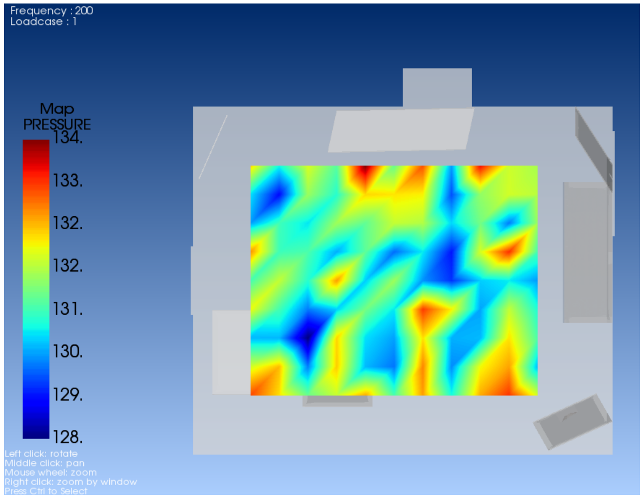
# Results 1.2 m Plane



# Diffuse Field Validation

- Standard deviation of spatially averaged sound pressure levels
  - 3 Hz running average





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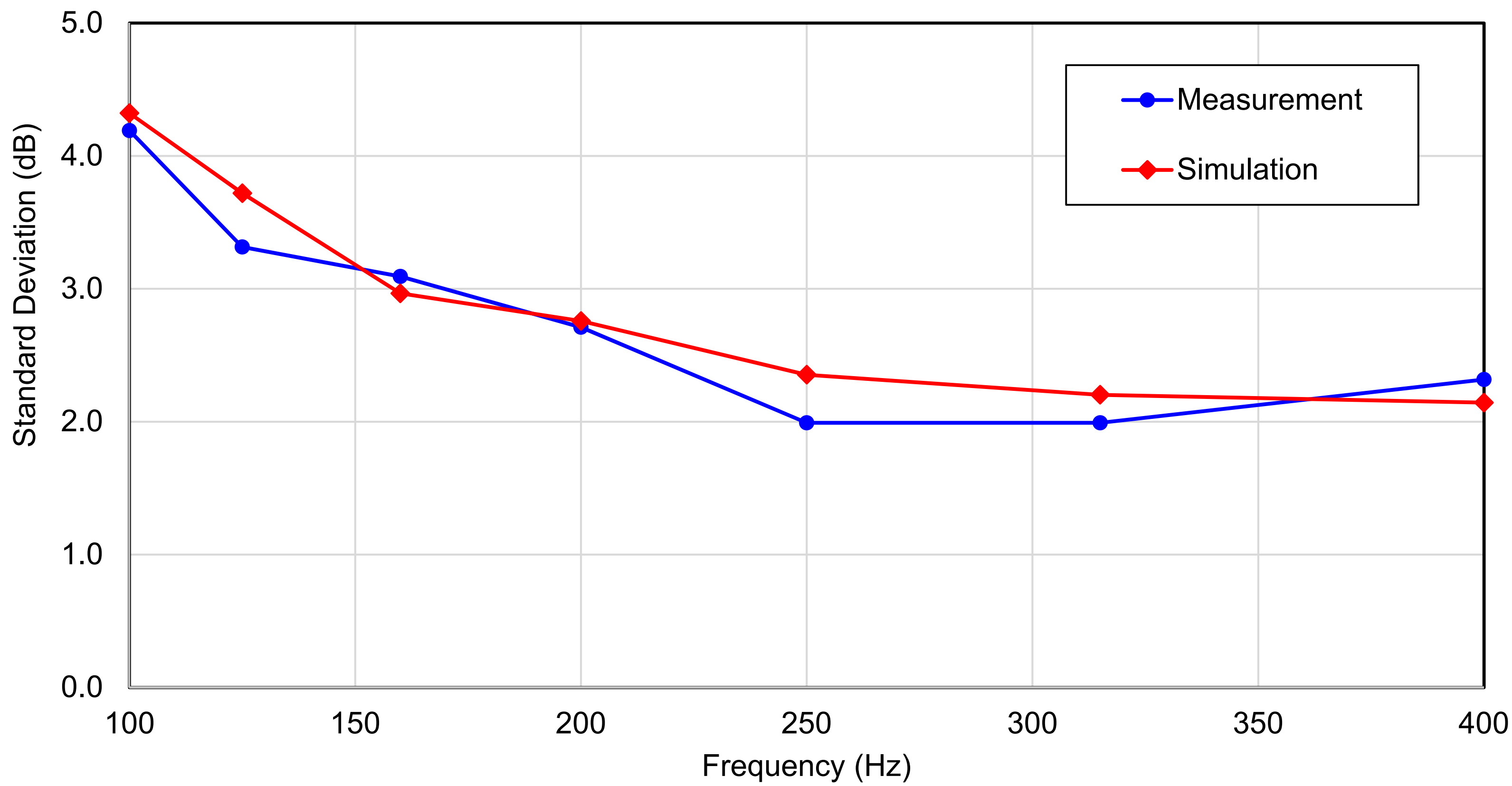

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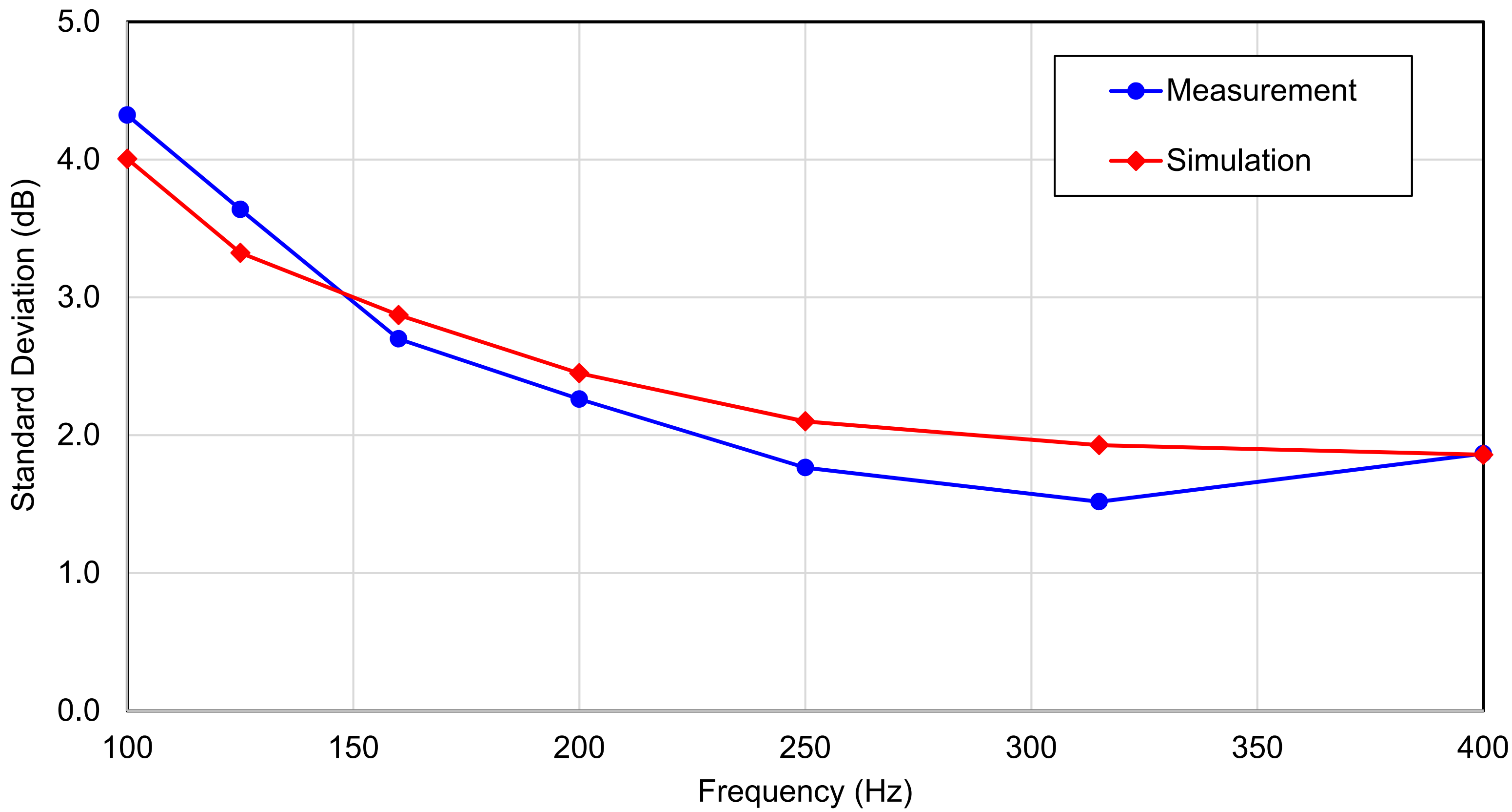
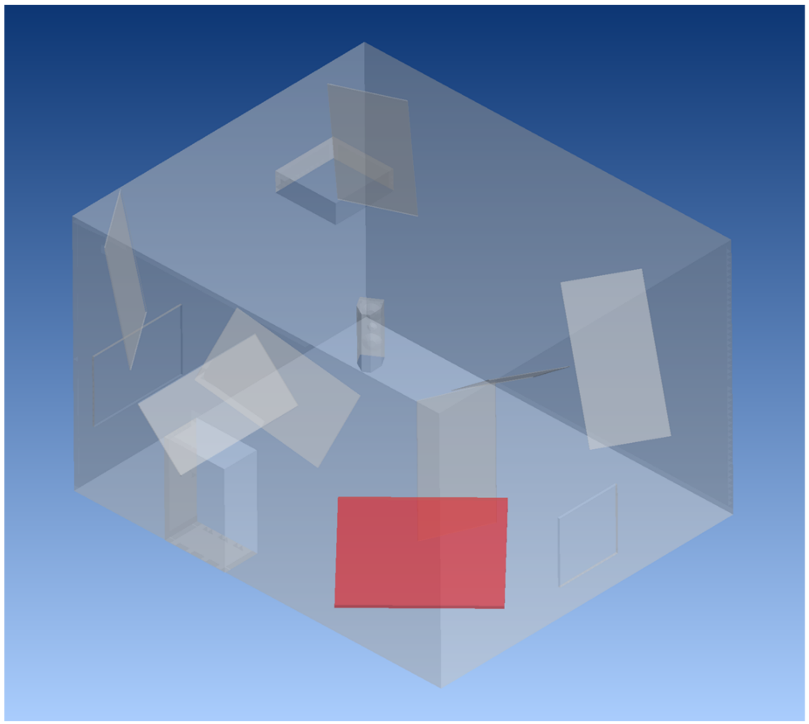


# Reference Absorber



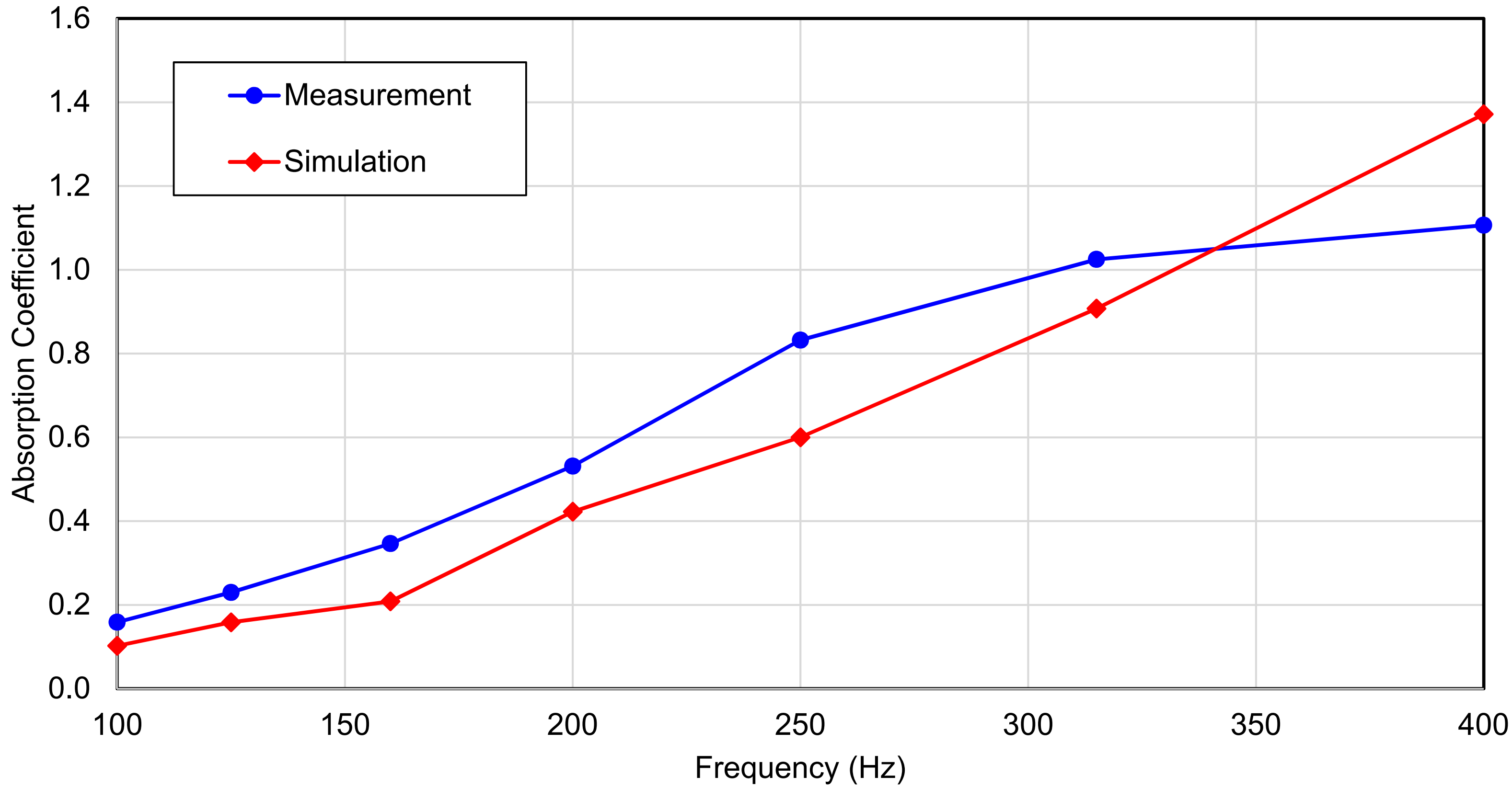
## Reference Absorber

Thickness: 5 cm

Flow Resistivity: 48,120 Rayls/m

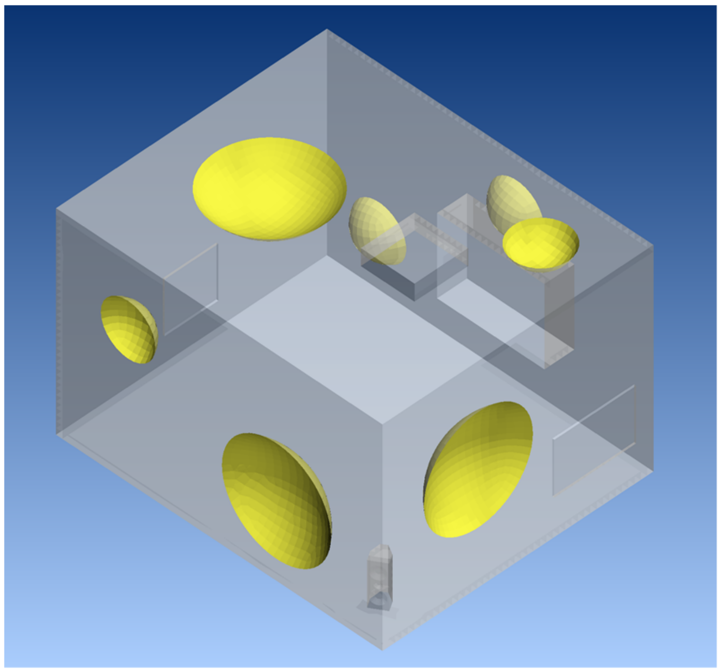
Delany and Bazley model

# Reference Absorber

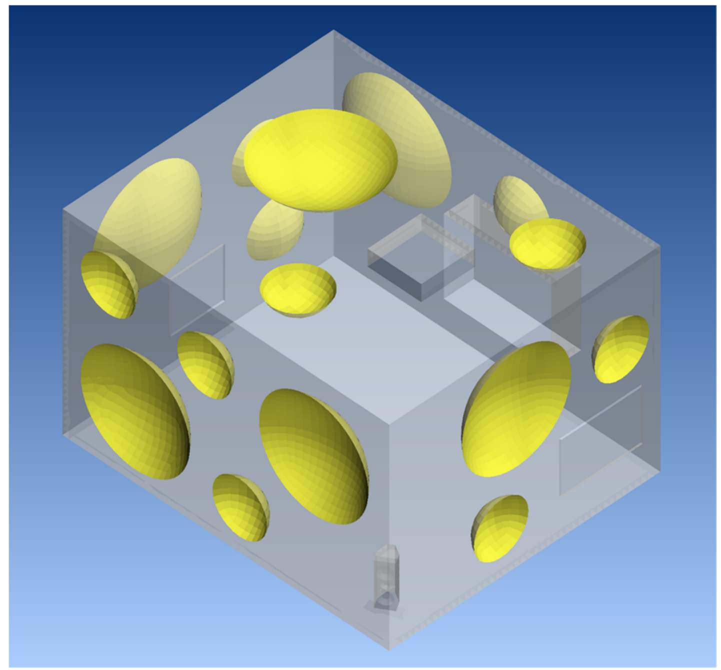


# Room Modifications

## Hemispherical Surface Diffusers

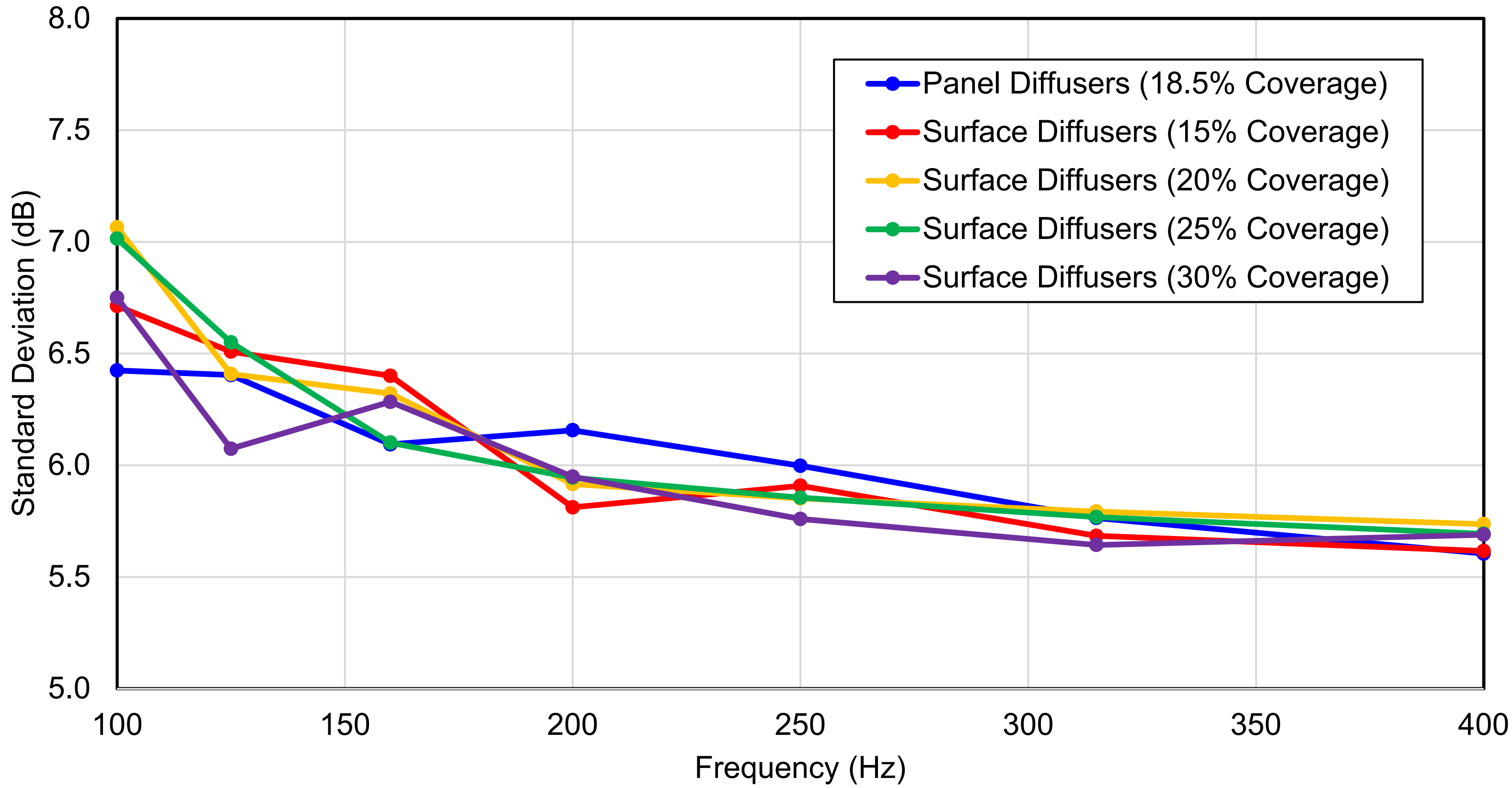


15% Surface Area Coverage



30% Surface Area Coverage

# Standard Deviation 6 cm Above Floor



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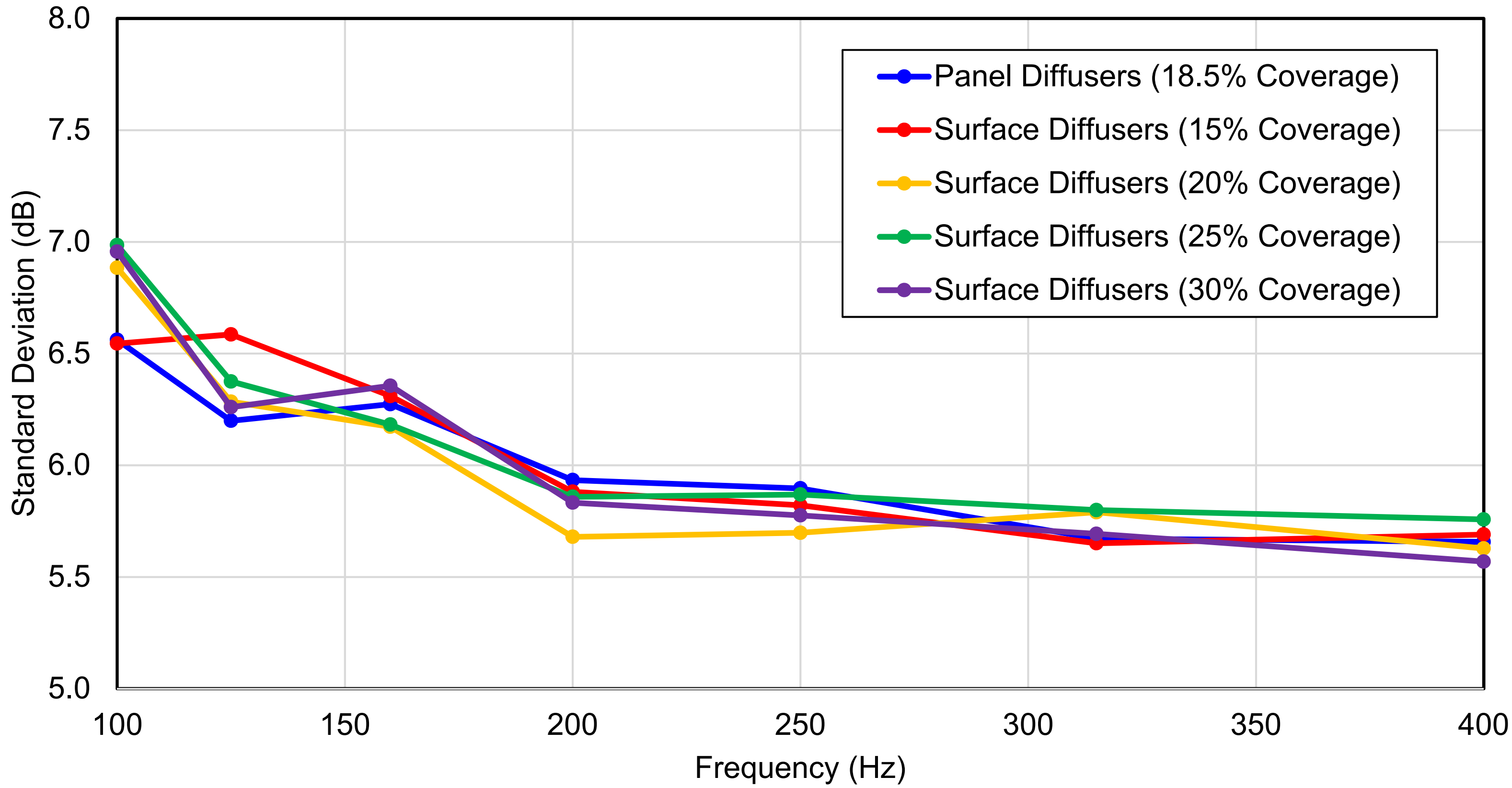

# Future Directions

- Further model validation
  - Compare measurements to simulation
    - Remove and/or change location of diffusers
    - Apply absorption to surfaces
- Simulate room modifications to improve diffuse field.