ISO 16254: Evaluation of Uncertainty

Submitted by ISO

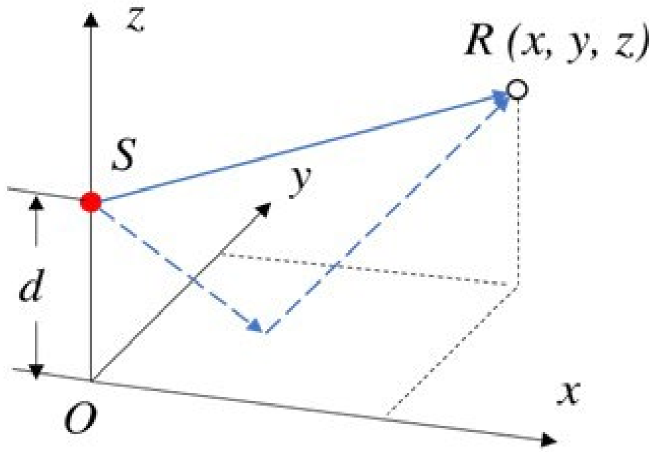
TF – QRTV 11th of July 2022

Overview

- **Single-microphone responses to environmental factors**
  - Introduction to model design and included parameters
    - *Consideration of testing conditions (nominal, atmospheric, and measurement ranges)*
  - Justification of the main impact quantities
  - Key contributors to environmental variation
  - Summary of single-sensor responses to environmental factors
- **Multipoint-sensor responses to environmental factors**
  - 5-Microphone array proposal
    - *Single- to multipoint-sensor response comparison*
- **Mitigating distance related main impact quantities**
  - Introduction to multiphasic corrections in multipoint sensor arrays
- **Future Studies**
- **Summary of results**
- **Conclusions**

Introduction

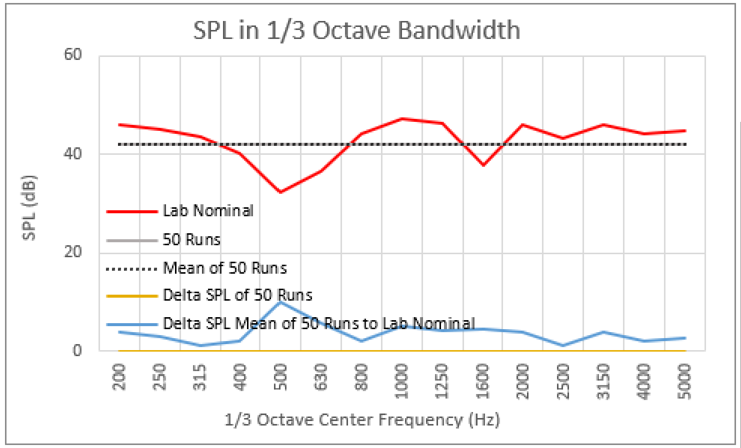
- An evaluation method was developed to investigate the environmental uncertainty in sound propagation for the sound profile and pass-by noise of AVAS/PFAF systems.
- The variation between an input sound power of a 60 dB point source is evaluated at field point, $\boldsymbol{R}$.
- The main impact quantities considered:
  - Temperature, T $(°C)$
  - Pressure, P (Pa)
  - Relative humidity, RH (%)
  - Wind speed, W_s $\left(\frac{\text{m}}{\text{s}}\right)$
  - Wind gradient index, $W_g(n)$
  - Temperature gradient, $T_g(T, z)$ $\left(\frac{°\text{C}}{\text{m}}\right)$
  - Surface absorption, α (%)
  - Source height above ground, $\boldsymbol{d}$
  - Sensor/detector position, $\boldsymbol{R}(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$

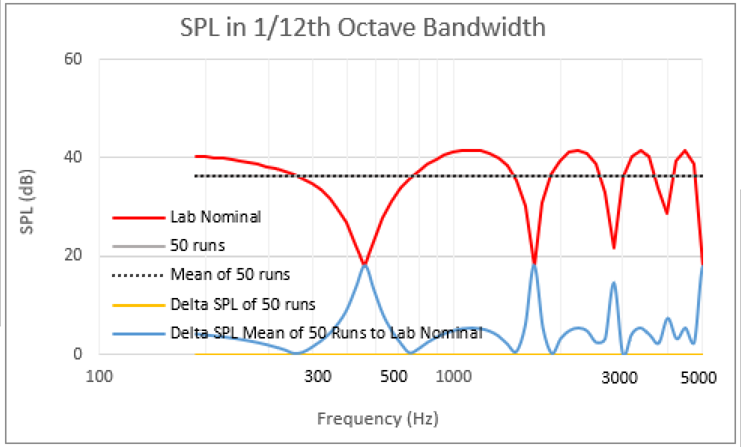


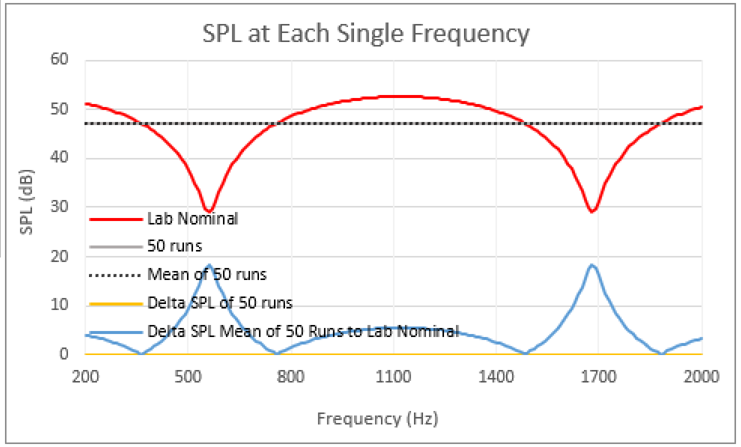
Environmental Uncertainties on Sound Propagation – For an Evaluation of AVAS Sound and Pass-by Noise. Wang, C (2020)

Introduction

- Results are given in 1/3 octave, 1/12 octave, and pure tone frequency response for the single receiver/sensor
- Below are the baseline results with the contribution from the reflected path removed using 100% ground surface absorption (flat, gray/dotted line) versus the lab nominal condition (red line).
- The deviation in sound pressure level (SPL) from the mean of 50 randomized trials is indicated by the blue line. The yellow line represents the overall change in SPL between the 50 trials.







Introduction

Default parameter values for test cases and comparisons

Indoor Lab Nominal Values	Nominal Environmental Factors	Relevant Atmospheric Range
$T = 20\ °\text{C}$	$T = 20\ °\text{C}$	$T = 20 \pm 20\ °\text{C}$
$P = 101.325\ \text{kPa}$ (mean sea level)	$P = 101.325\ \text{kPa}$ (mean sea level)	$P = 101.325\ \text{kPa} \pm 8\%$
$RH = 40\ \%$	$RH = 50\ \%$	$RH = 50 \pm 40\ \%$
$W_s = 0 \frac{\text{m}}{\text{s}}$	$W_s = 0 \frac{\text{m}}{\text{s}}$	$W_s = 0 \pm 5 \frac{\text{m}}{\text{s}}$
$W_g = 0\ s^{-1}$	$W_g = 0\ s^{-1}$	$W_g = 0 - 1.06\ s^{-1}$
$T_g = 0\ \frac{°\text{C}}{\text{m}}$	$T_g = 9.8 \times 10^{-3}\ \frac{°\text{C}}{\text{m}}$ (dry adiabatic)	$T_g \approx 4.37 \pm 4.37\ \frac{°\text{C}}{\text{m}}$
$\alpha = 0$	$\alpha = 0.05$	$\alpha = 0.05 \pm 0.03$
$\boldsymbol{d} = 0.3\ \text{m}$	$\boldsymbol{d} = 0.3\ \text{m}$	$\boldsymbol{d} = 0.2 - 0.8\ \text{m}$
$\boldsymbol{R} = < 0, 2, 1.2 >$ (m)	$\boldsymbol{R} = < 0, 2, 1.2 >$ (m)	$\boldsymbol{R} = < 0 \pm 0.05, 2 \pm 0.5, 1.2 \pm 0.05 >$ (m)

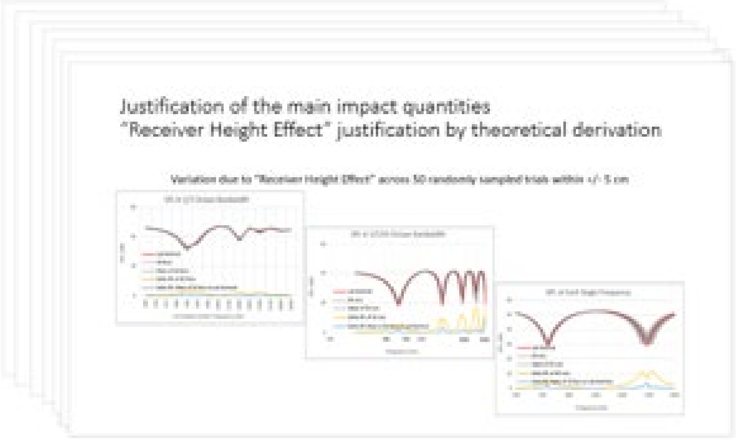
Justification of the main impact quantities

- By measurement – results from specific experiments/sources (historical atmospheric conditions, convective heating experiments)
- By theoretical derivations based on physical relations (e.g., sound speed, temperature gradient, distance effect)

Justification of main impact quantities

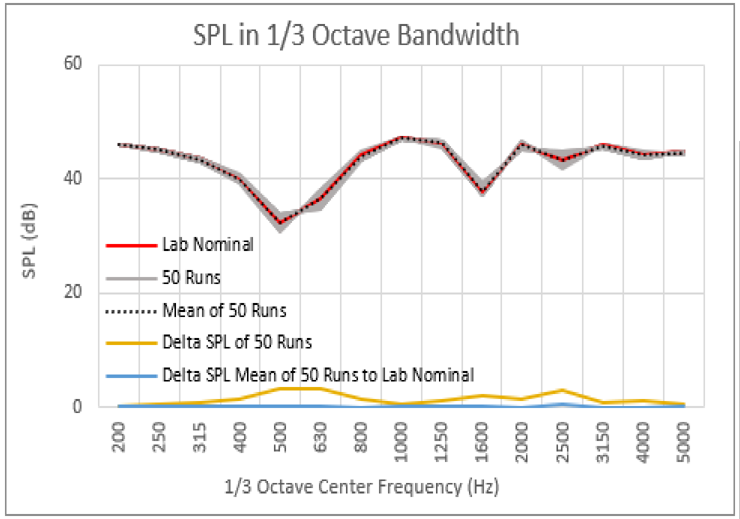
	Input Quantity	estimated deviations of the meas. result (peak-peak)		Status	Justification by	
					measurement	theoretical derivations
Run to Run	Temperature $(0-5.6\,°C)$			Proposal	X	
	Pressure (MSL +/- 1% Pa)			Proposal	X	
	Relative Humidity (+/-10%)			Proposal	X	
	Wind Velocity $\left(0 \pm 5\,\frac{m}{s}\right)$			Proposal	X	
	Wind Gradient (4 ± 1)			Proposal		
	Temperature Gradient $(°C, f(T_s,z))$			Proposal	x	
	Ground Surface Absorption (5%)			Proposal	x	
	Source Height (50 cm $\pm$ 30)			Proposal		
	Receiver x-Displacement (0 $\pm$ 5 cm)			Proposal		
	Receiver y-Displacement (2 m $\pm$ 50 cm)			Proposal		
	Receiver z-Displacement (1.2 $\pm$ 40 cm)			Proposal		
Day to Day	Temperature $(0-40\,°C)$			Proposal	X	
	Pressure (MSL +/- 8% Pa)			Proposal	X	
	Relative Humidity (10-90%)			Proposal	X	
	Wind Velocity $\left(0 \pm 5\,\frac{m}{s}\right)$			Proposal	X	
	Wind Gradient (4 ± 1)			Proposal		
	Temperature Gradient $(°C, f(t,z))$			Proposal	x	
	Ground Surface Absorption (5% $\pm$ 3)			Proposal	x	
	Source Height (50 cm $\pm$ 30)			Proposal		
	Receiver x-Displacement (0 $\pm$ 5 cm)			Proposal		
	Receiver y-Displacement (2 m $\pm$ 5 cm)			Proposal		
	Receiver z-Displacement (1.2 $\pm$ 40 cm)			Proposal		
Site To Site	Temperature $(0-40\,°C)$			Proposal	X	
	Pressure (MSL +/- 8% Pa)			Proposal	X	
	Relative Humidity (10-90%)			Proposal	X	
	Wind Velocity $\left(0 \pm 5\,\frac{m}{s}\right)$			Proposal	X	
	Wind Gradient (4 ± 1)			Proposal		
	Temperature Gradient $(°C, f(t,z))$			Proposal	x	
	Ground Surface Absorption (5% $\pm$ 3)	0,75	1,50	Proposal	x	
	Source Height (50 cm $\pm$ 30)	0,00	0,00	Proposal		X
	Receiver x-Displacement (0 $\pm$ 5 cm)	0,40	0,00	Proposal		X
	Receiver y-Displacement (2 m $\pm$ 5 cm)	0,00	0,00	Proposal		X
	Receiver z-Displacement (1.2 $\pm$ 40 cm)	1,00	0,50	Proposal		x

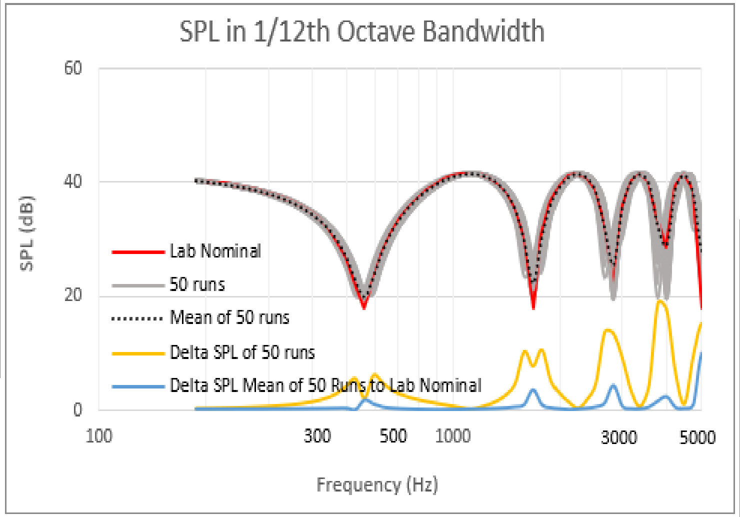
Status of completeness: 0%

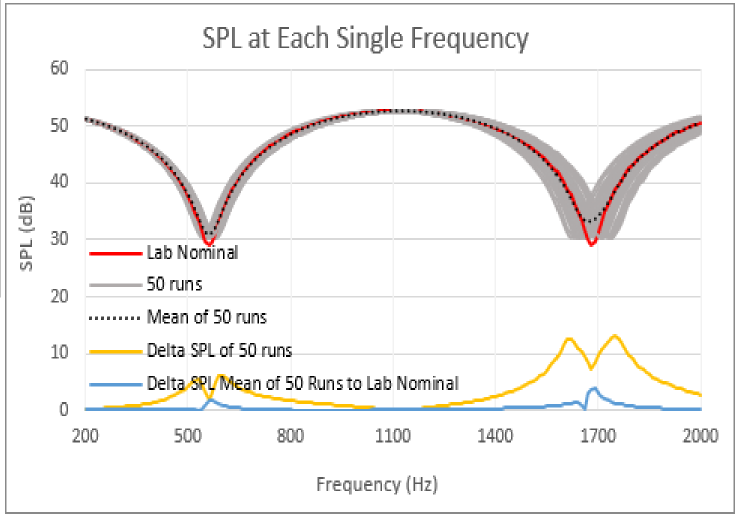


Justification of the main impact quantities
“Temperature Effect” justification by theoretical derivation

Variation due to “Temperature Effect” across 50 randomly sampled trials within atmospheric tolerance

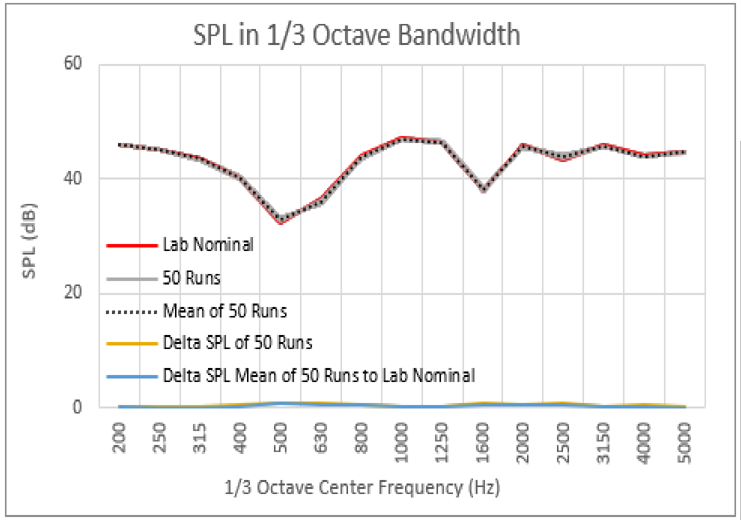


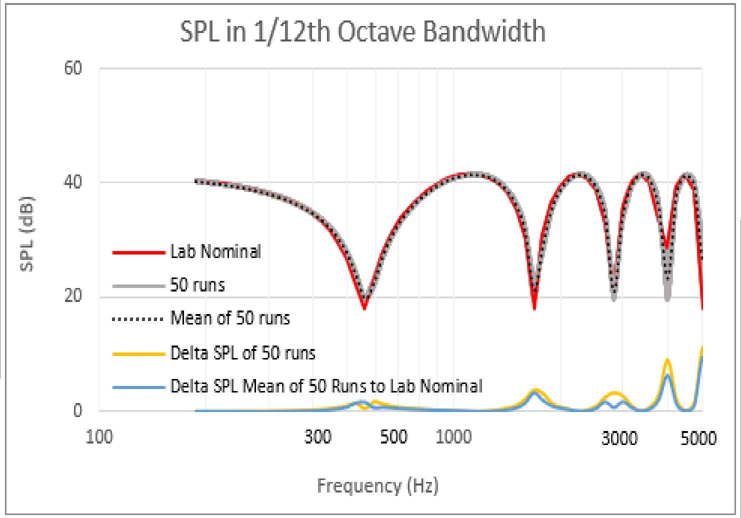


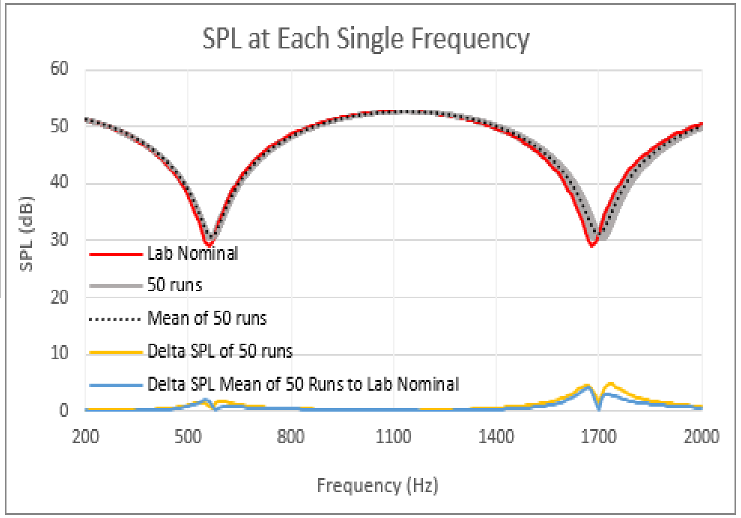


Justification of the main impact quantities: “Temperature Gradient Effect” justification by theoretical derivation

Variation due to “Temperature Gradient Effect” across 50 randomly sampled trials within atmospheric

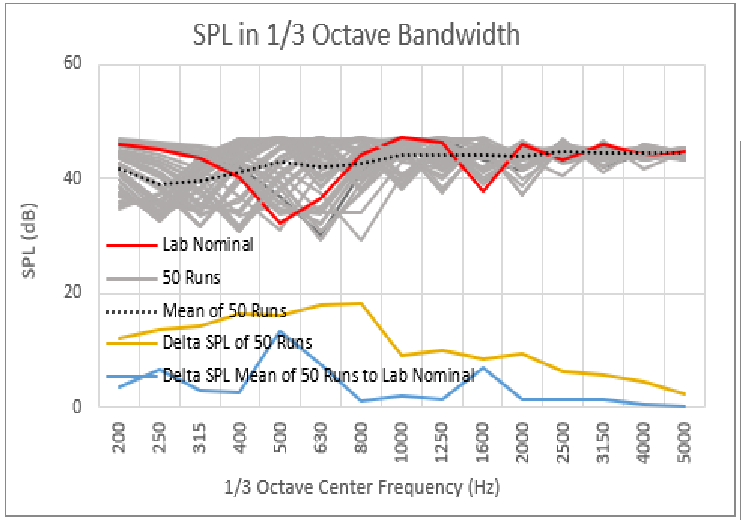


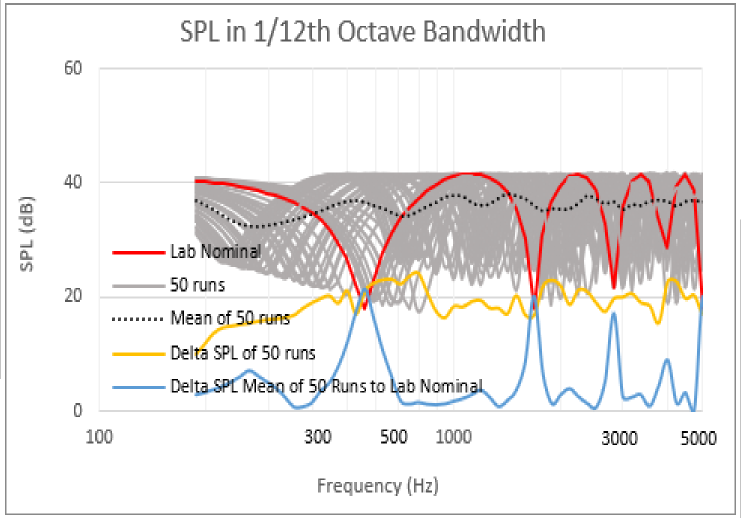


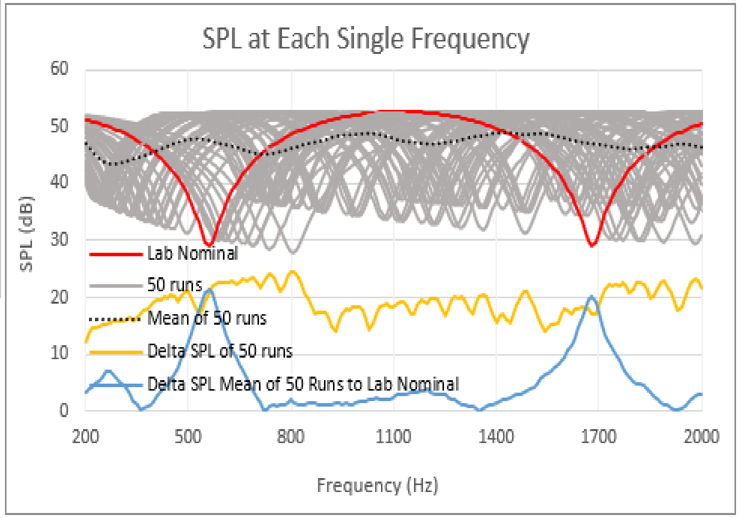


Justification of the main impact quantities
"Source Height Effect" justification by theoretical derivation

Variation due to "Source Height Effect" across 50 randomly sampled trials within 0.2-0.8 m







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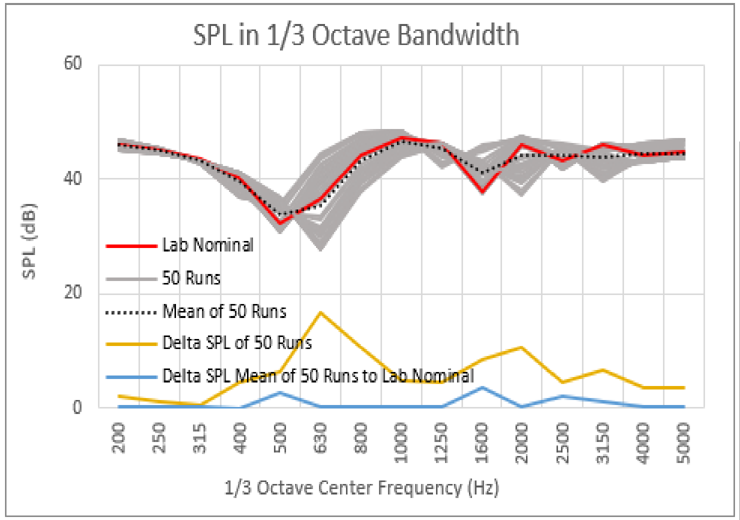
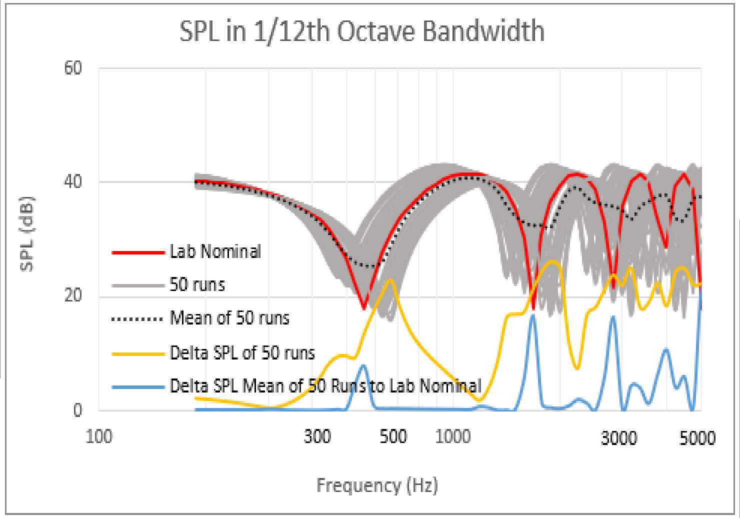
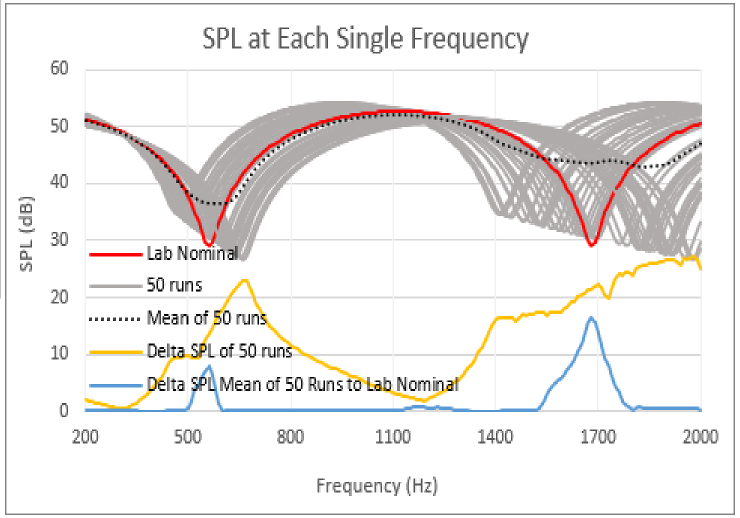
Justification of the main impact quantities
"Driver Effect" justification by theoretical derivation

Variation due to "Driver Effect" across 50 randomly sampled trials within +/- 50 cm

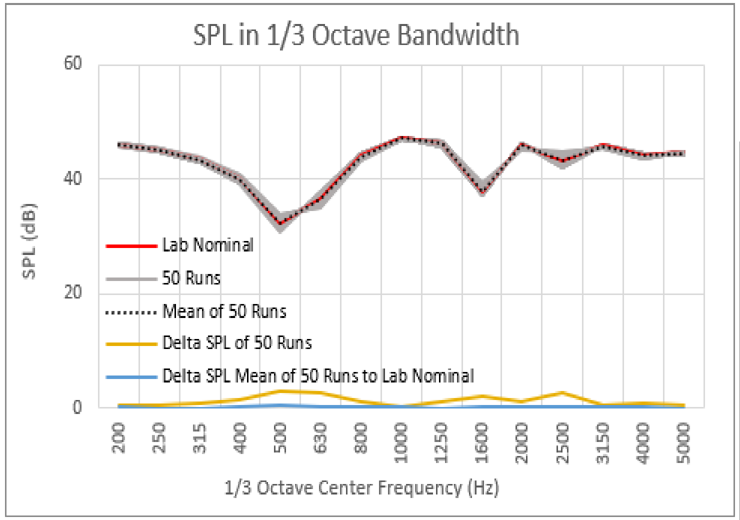


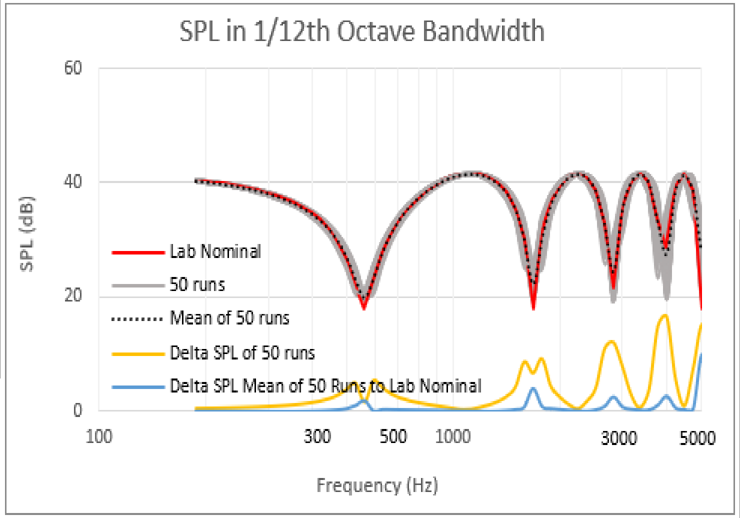


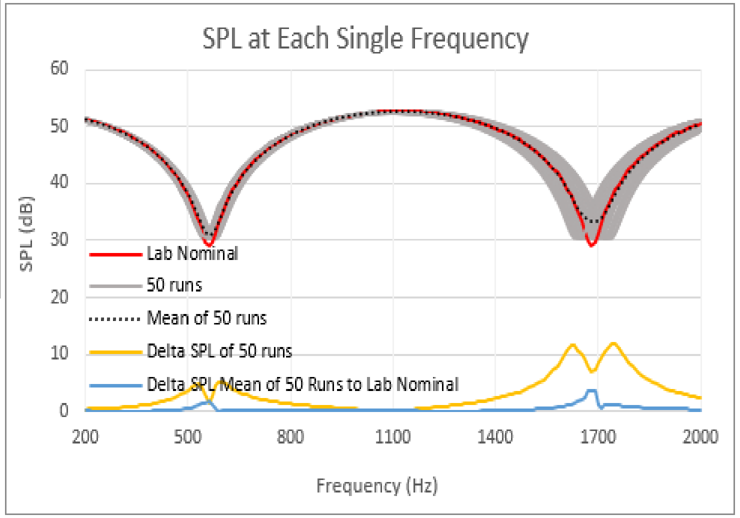


Justification of the main impact quantities
“Receiver Height Effect” justification by theoretical derivation

Variation due to “Receiver Height Effect” across 50 randomly sampled trials within +/- 5 cm

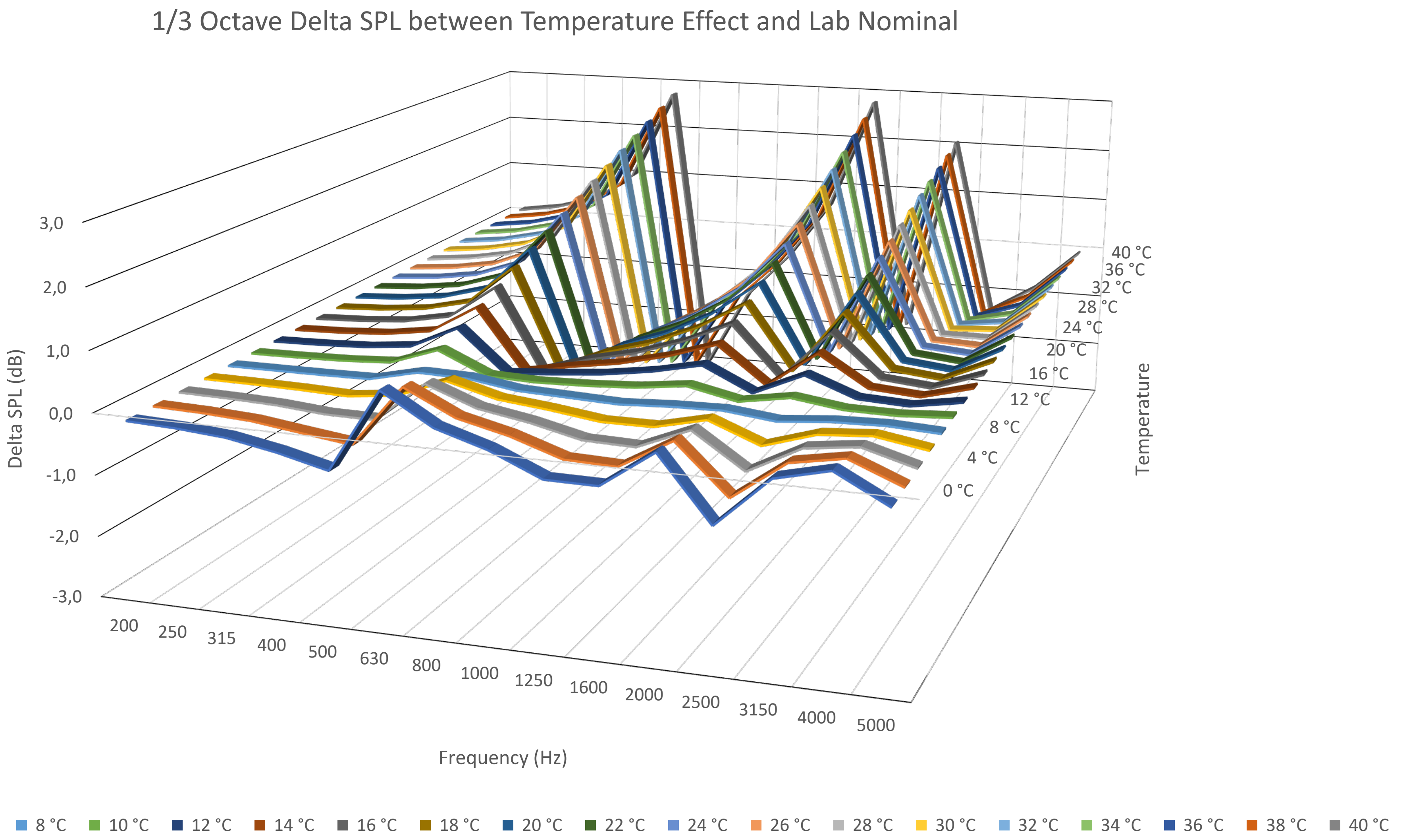




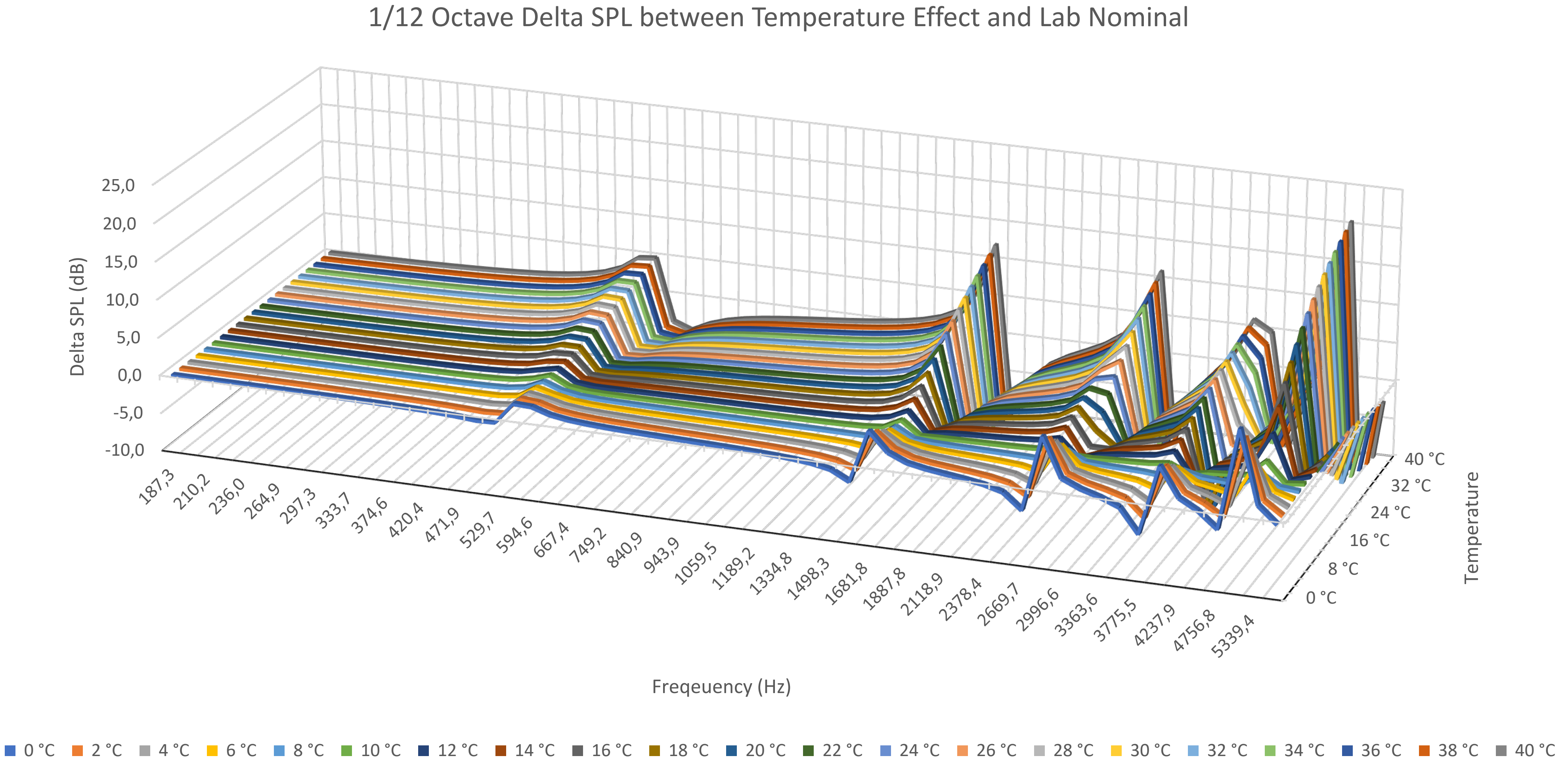


Key Contributors

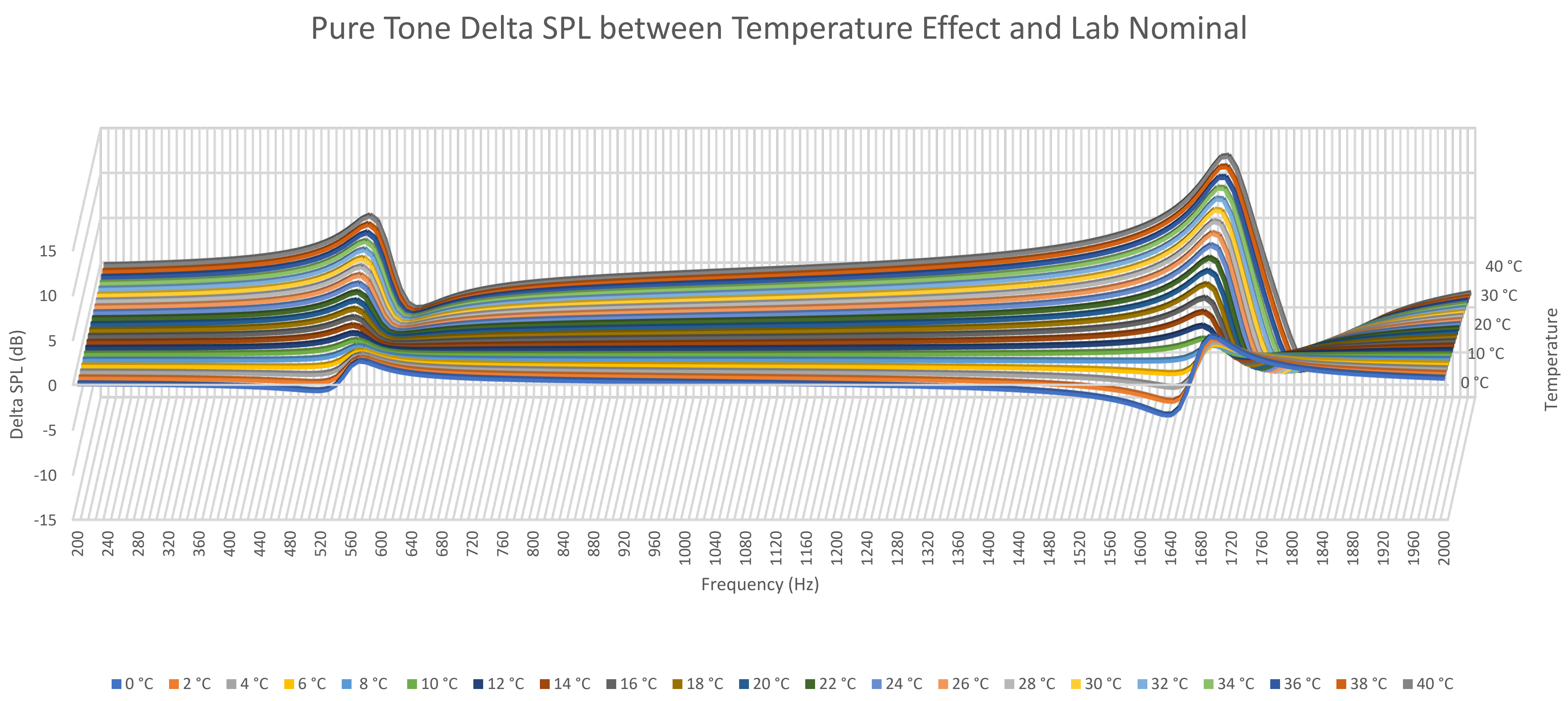
Justification of the main impact quantities "Temperature Effect" single-step comparison 1/3 octave



Justification of the main impact quantities "Temperature Effect" single-step comparison 1/12 octave

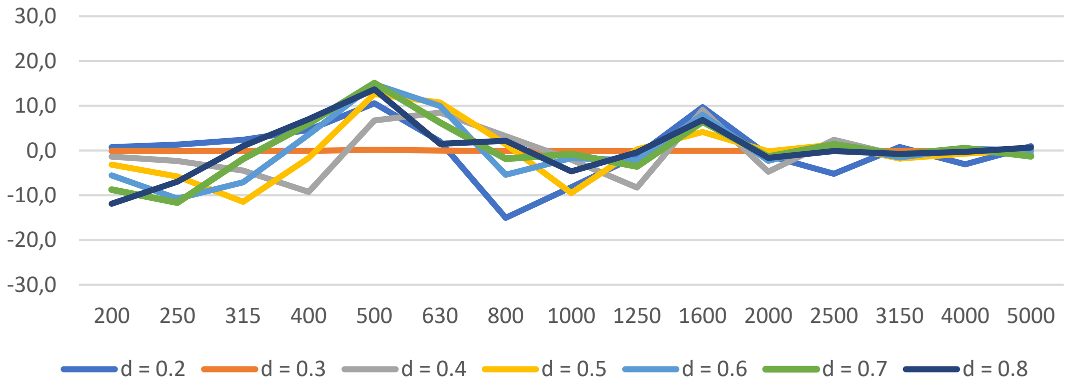


Justification of the main impact quantities
"Temperature Effect" single-step comparison pure tone

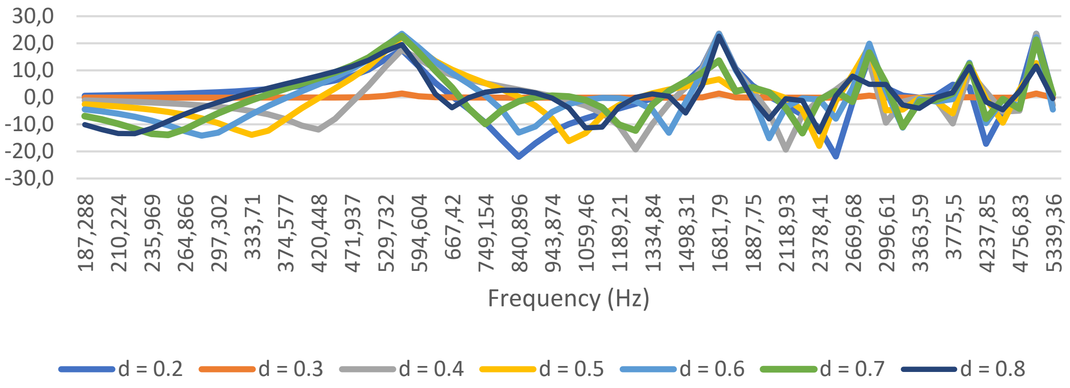


Justification of the main impact quantities “Source Height Effect” single-step comparison

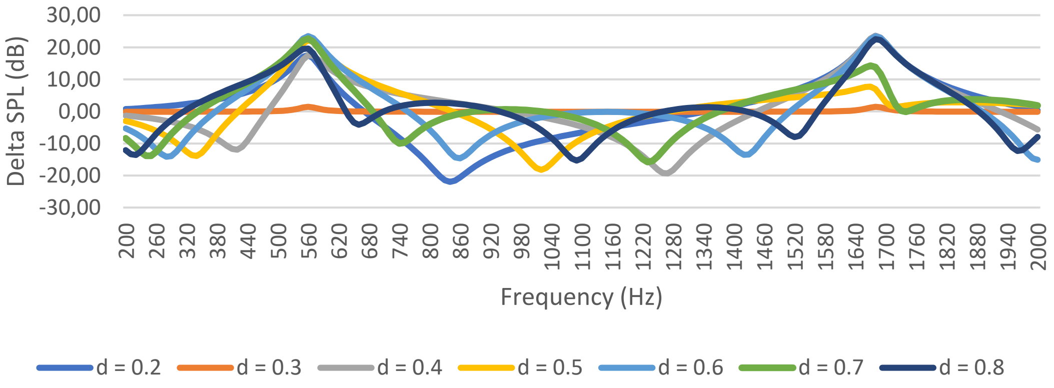
1/3 Octave Delta SPL between Source Height and Lab Nominal



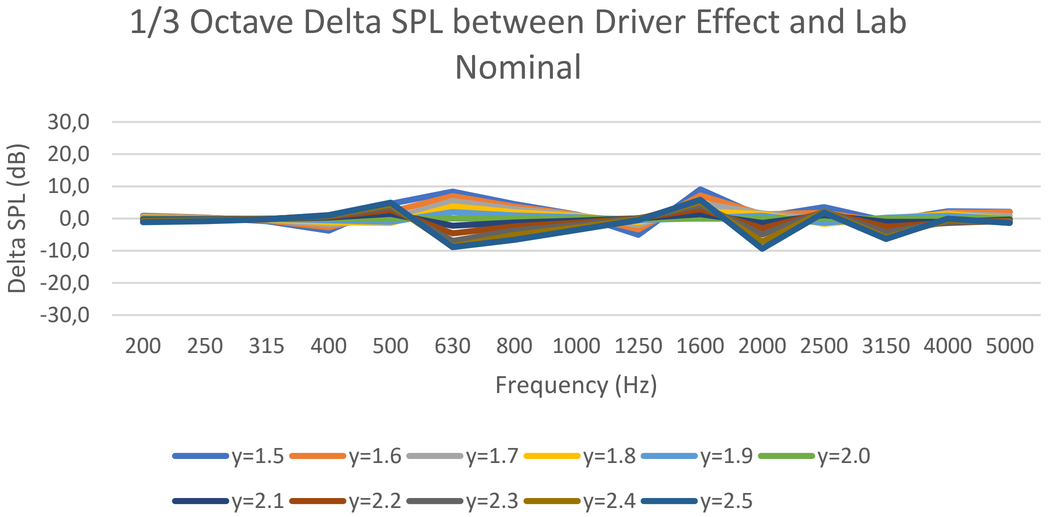
1/12 Octave Delta SPL between Source Height and Lab Nominal

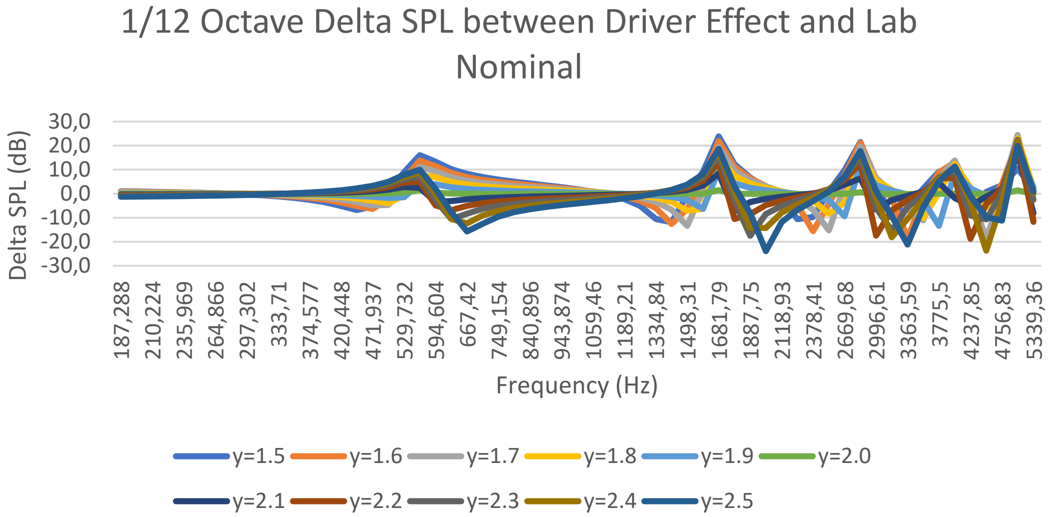


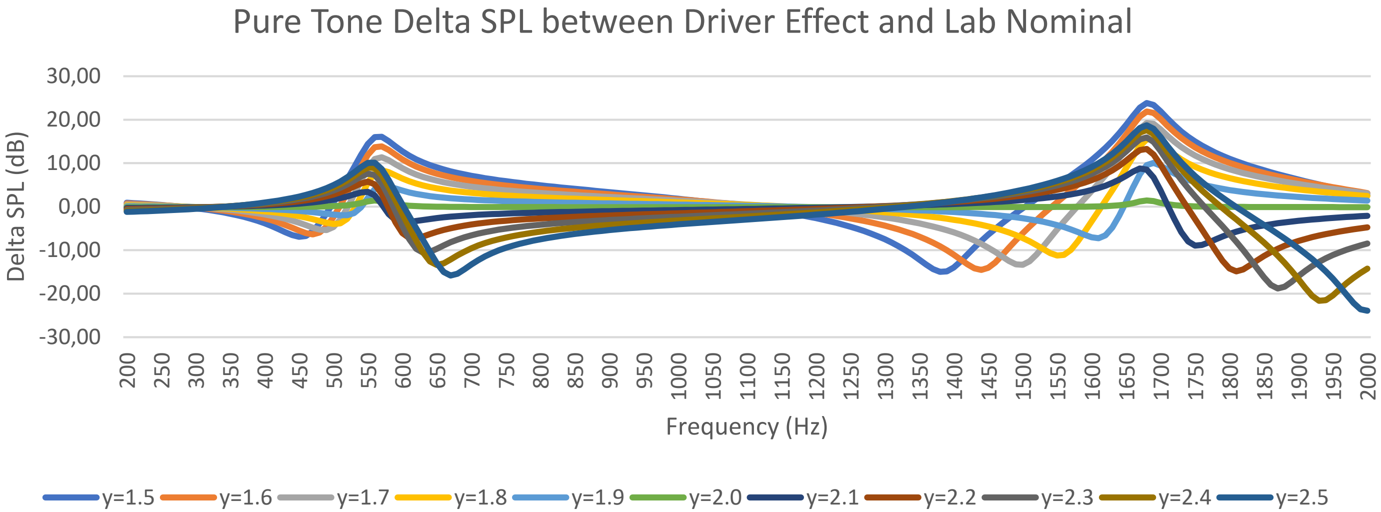
Pure Tone Delta SPL between Source Height and Lab Nominal



Justification of the main impact quantities “Driver Effect” single-step comparison

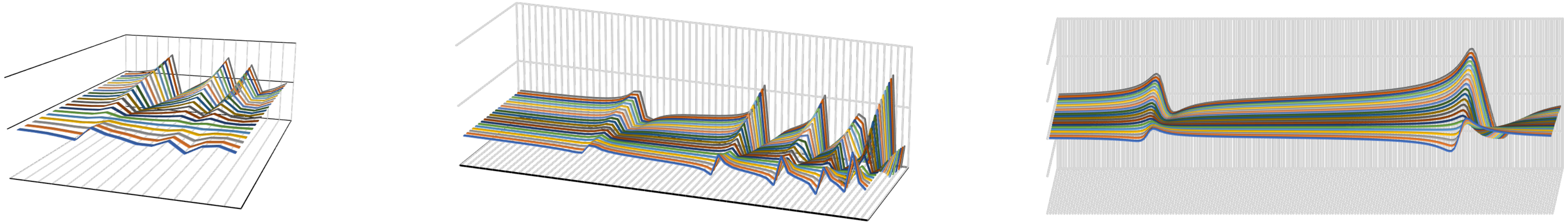






Summary

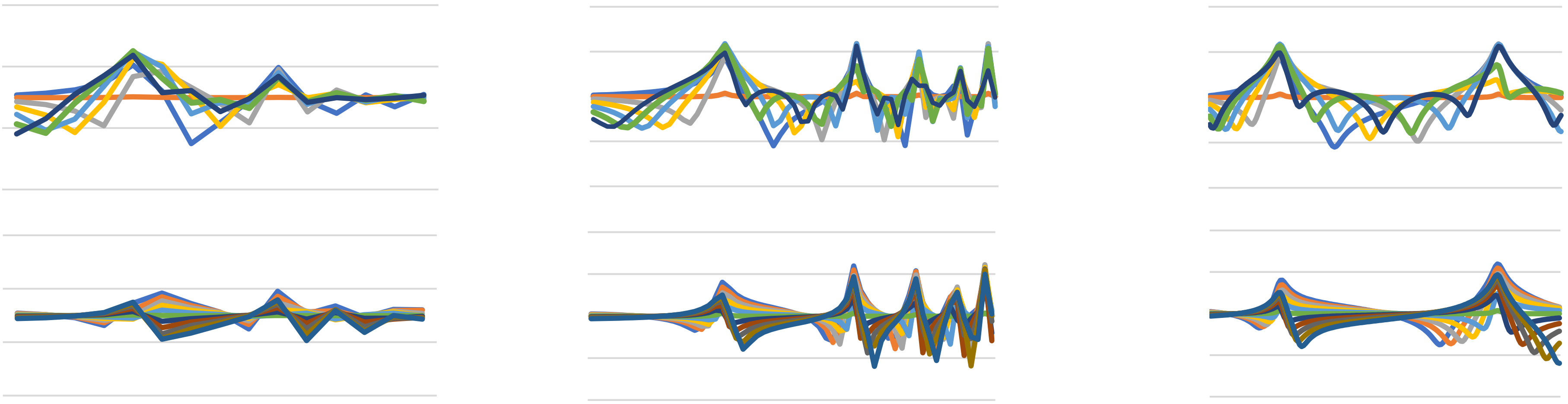
- Frequency-specific, periodic perturbations observed in "Temperature Effect" signal amplitude (aligned with lab nominal response curve)



- Source/Receiver position and "Driver Effect" affects frequency response

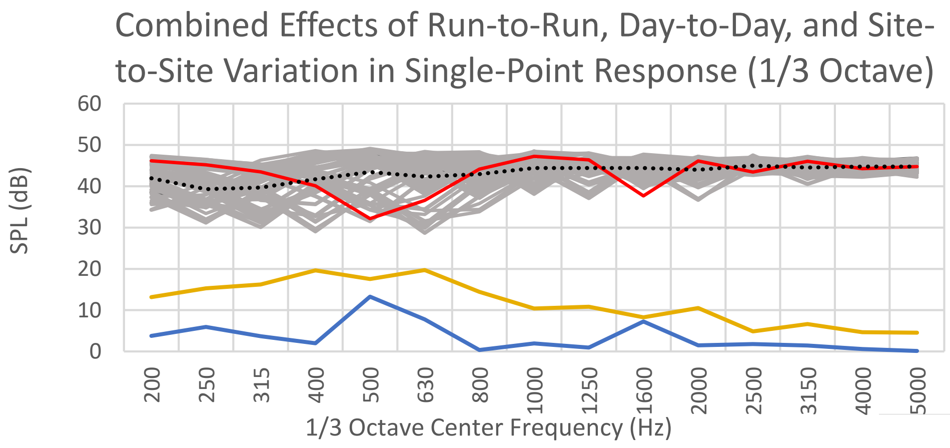
Source Height Effect

Driver Effect

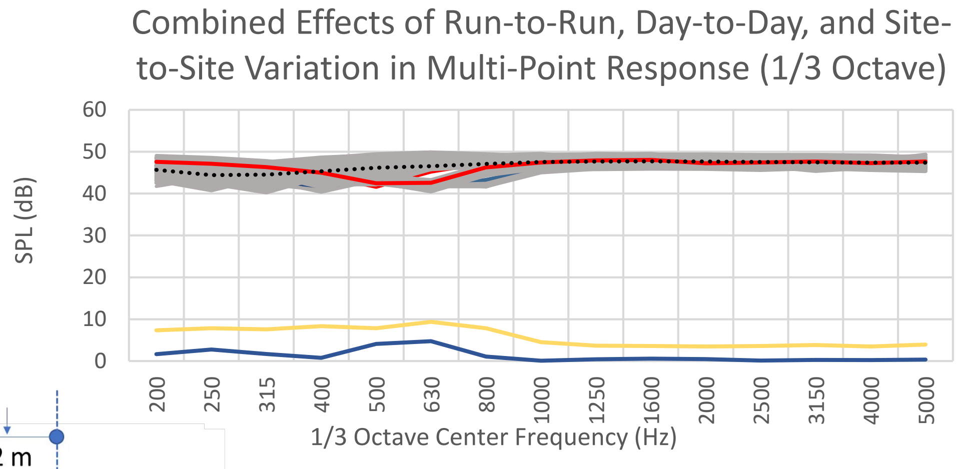


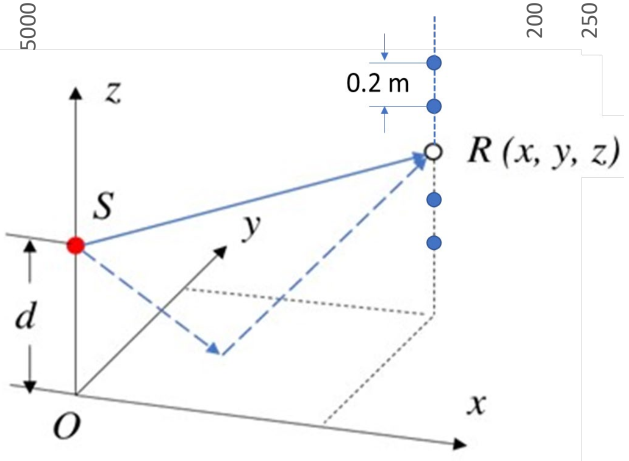
Proposal for a 5-microphone test procedure

- Purpose of study
  - Investigate the effectiveness of a 5-microphone array in mitigating environmental uncertainty by applying maximum recorded SPL of the 5 microphones with respect to the frequencies being measured.



Multi-Point Model



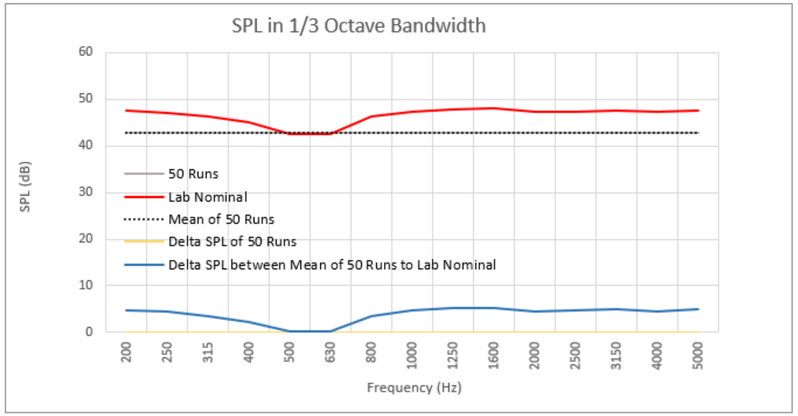


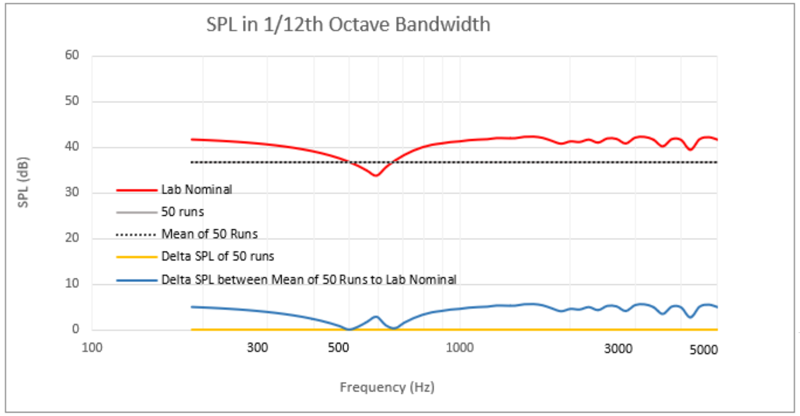
5-Microphone Array

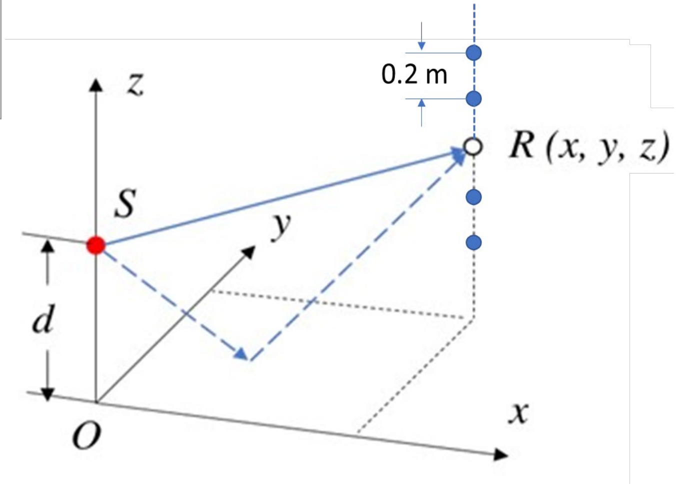
Envelope of 5 SPL Responses

Introduction

- Five microphones are placed 0.2 m apart with a central microphone at 1.2 m.
- The per frequency maximums of the 5 microphone responses are captured from each iteration.
- Below are the lab nominal results for the 5-microphone array versus the “zero reflection” case (gray/dotted line)

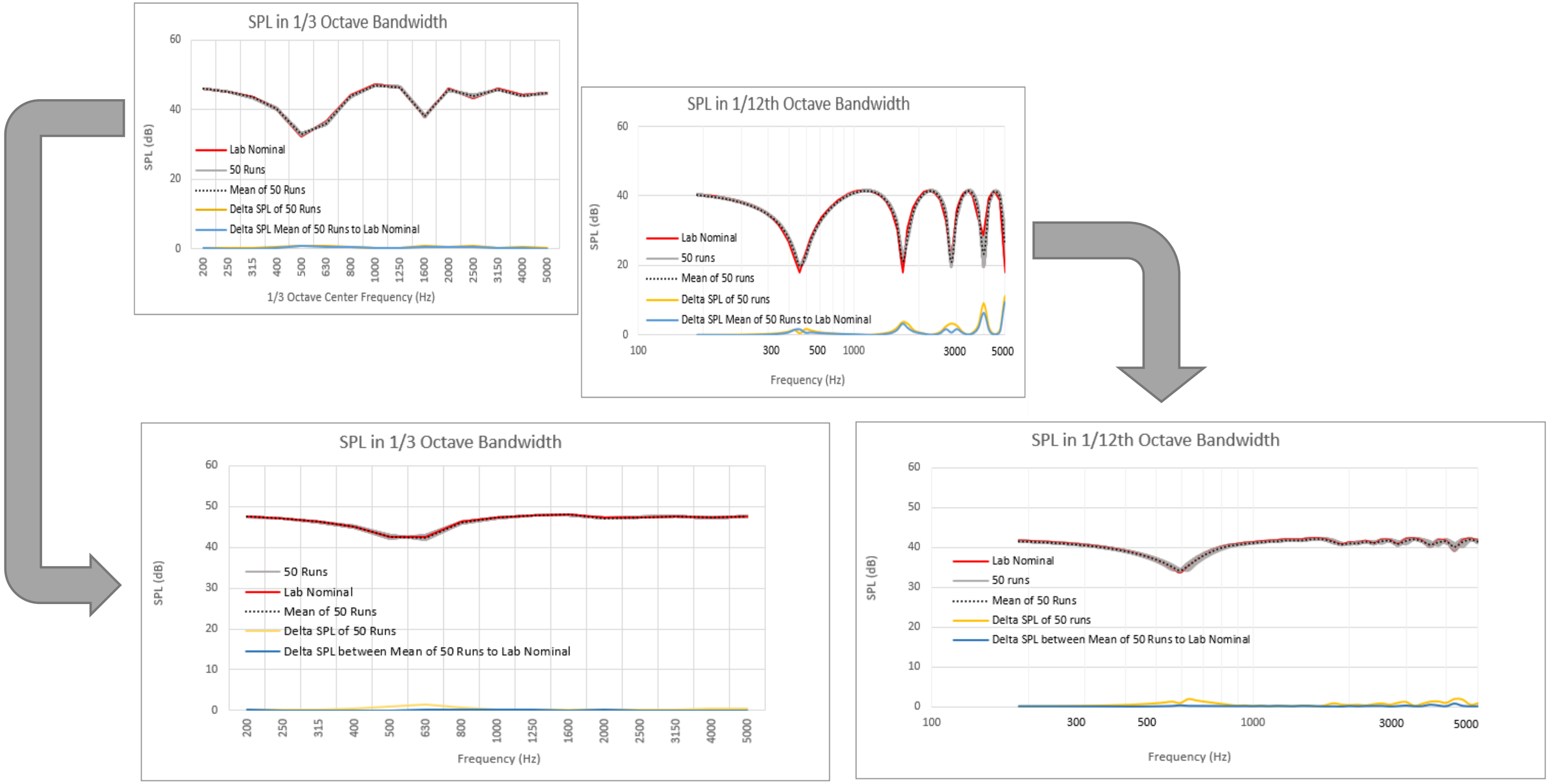






Justification of the main impact quantities
“Temperature Effect” justification by theoretical derivation

Variation due to “Temperature Effect” across 50 randomly sampled trials with 5-microphone Array



Justification of the main impact quantities: "Temperature Gradient Effect" justification by theoretical derivation

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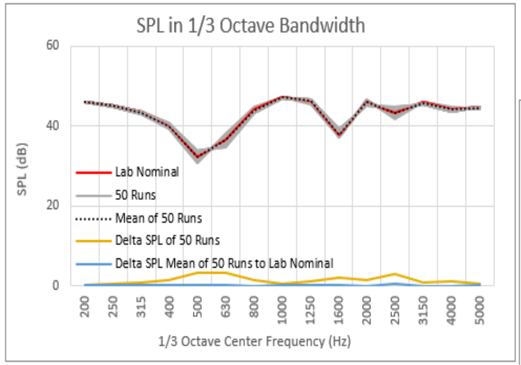
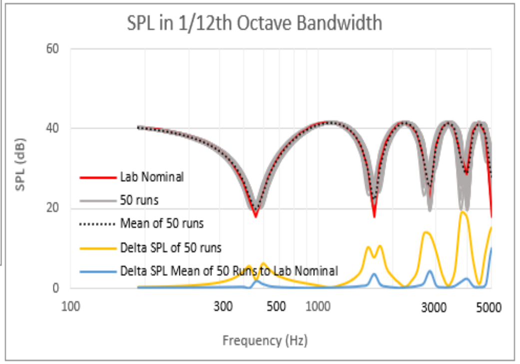
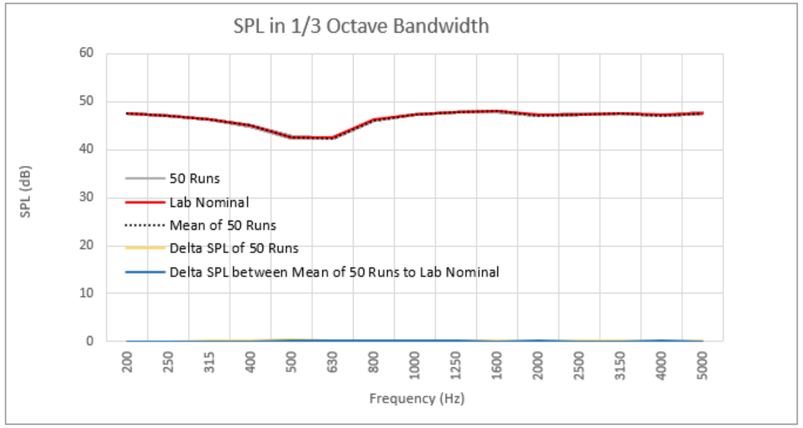
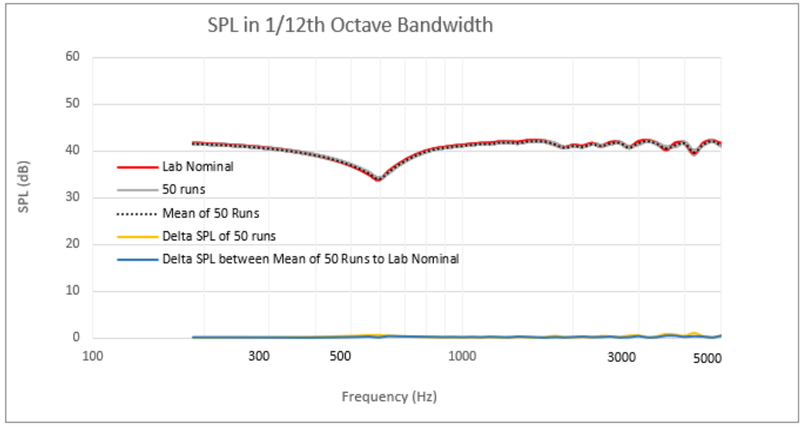
Variation due to "Temperature Gradient Effect" across 50 randomly sampled trials within atmospheric



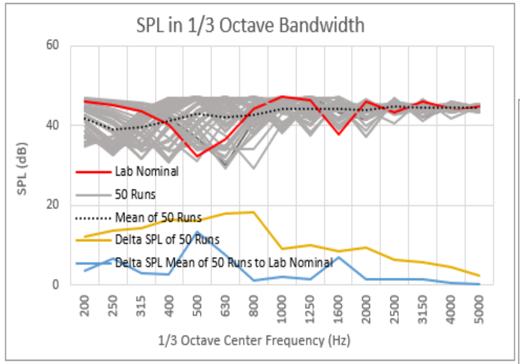


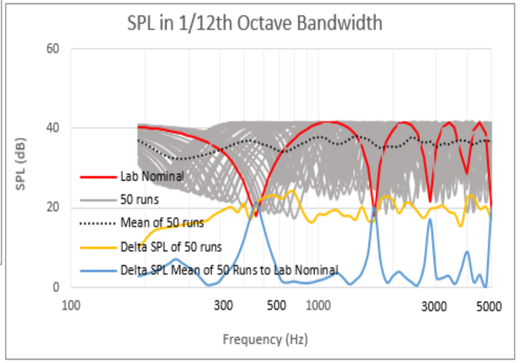


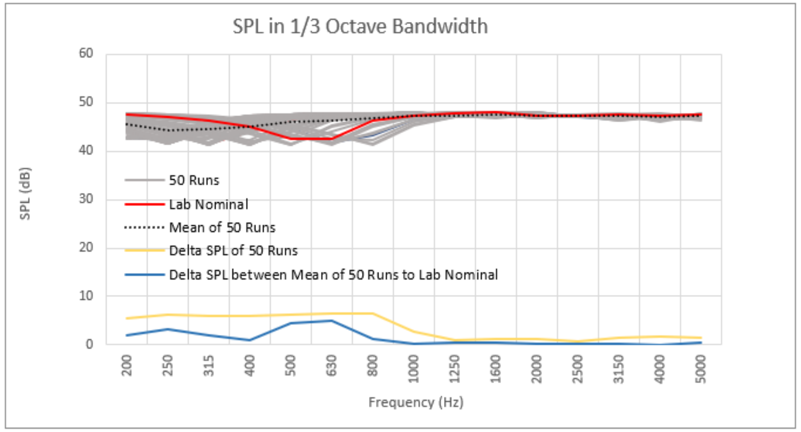


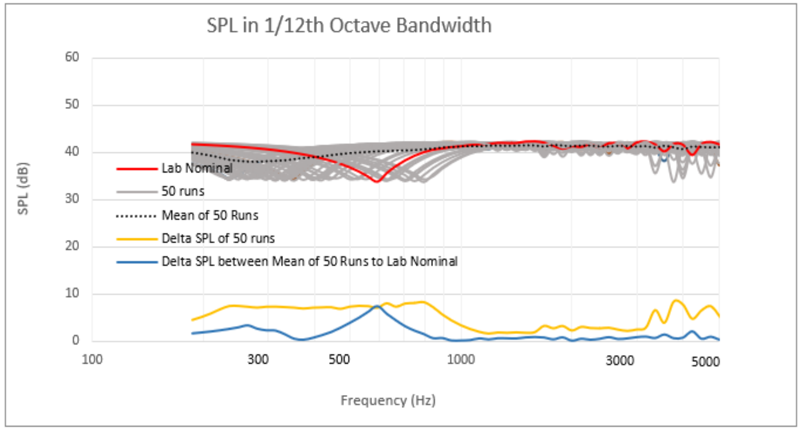
Justification of the main impact quantities
"Source Height Effect" justification by theoretical derivation

Variation due to "Source Height Effect" across 50 randomly sampled trials within 0.2-0.8 m



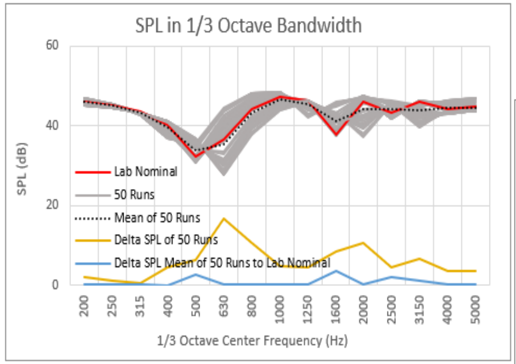


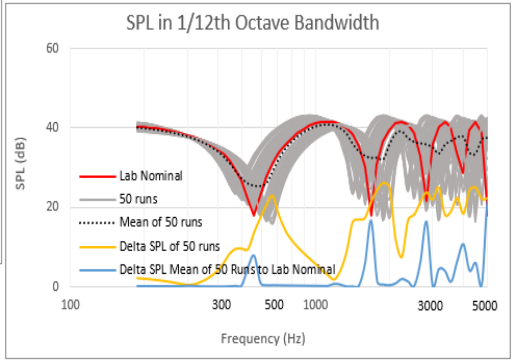


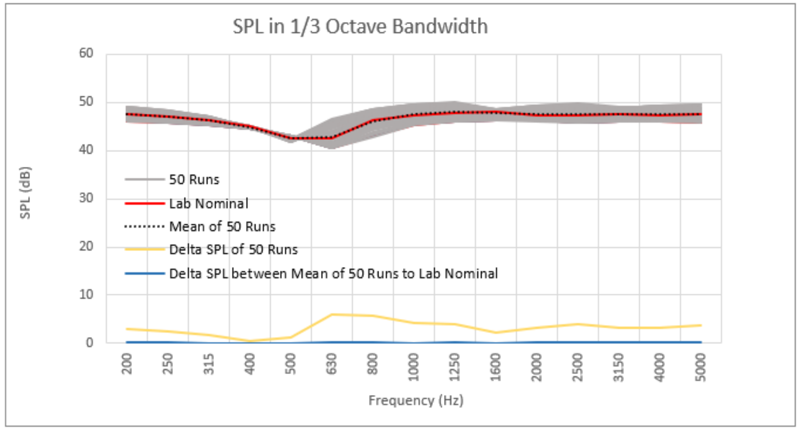


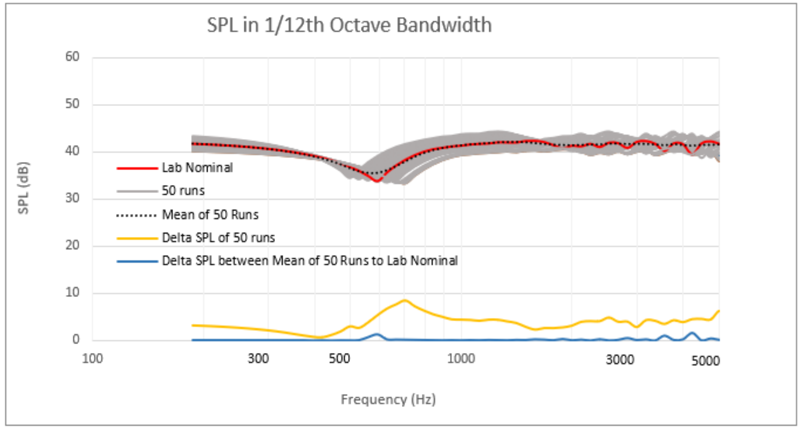
Justification of the main impact quantities
“Driver Effect” justification by theoretical derivation

Variation due to “Driver Effect” across 50 randomly sampled trials within +/- 50 cm



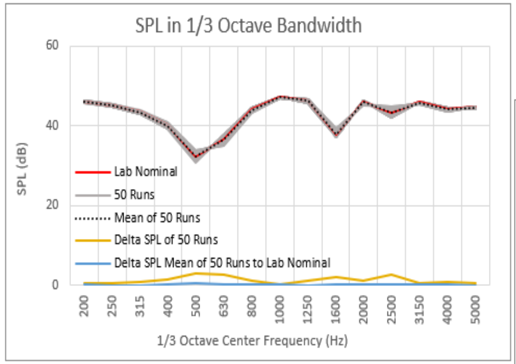


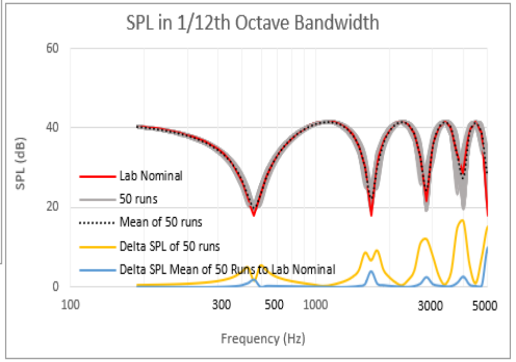


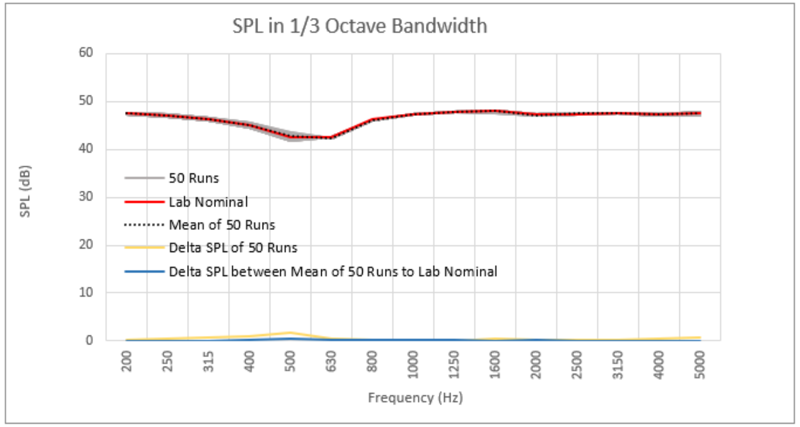


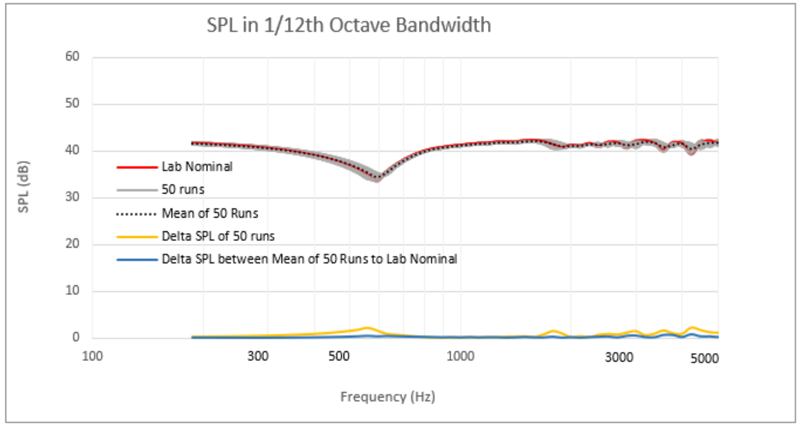
Justification of the main impact quantities
"Receiver Height Effect" justification by theoretical derivation

Variation due to "Receiver Height Effect" across 50 randomly sampled trials within +/- 5 cm



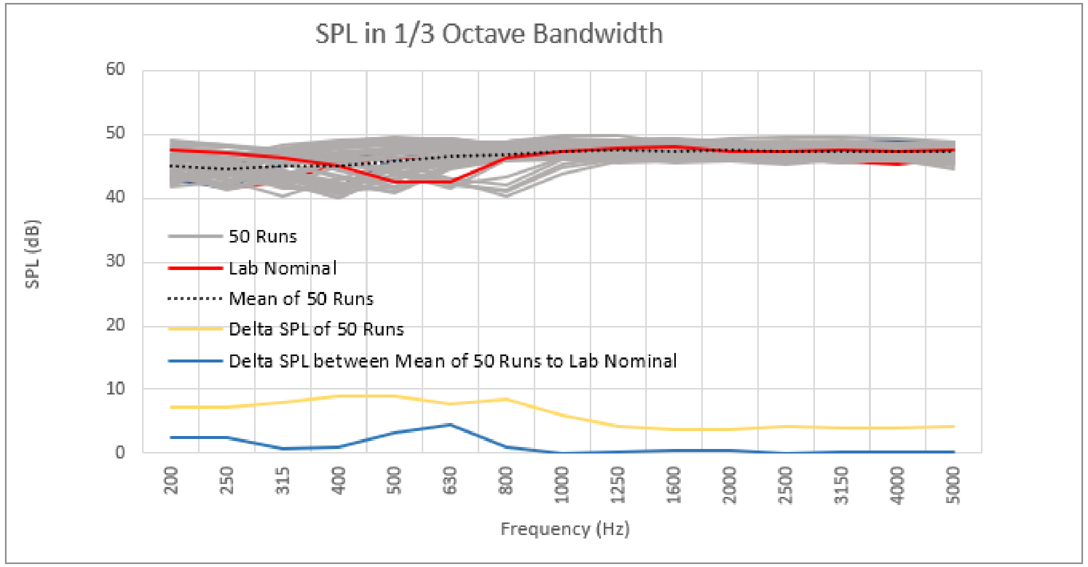


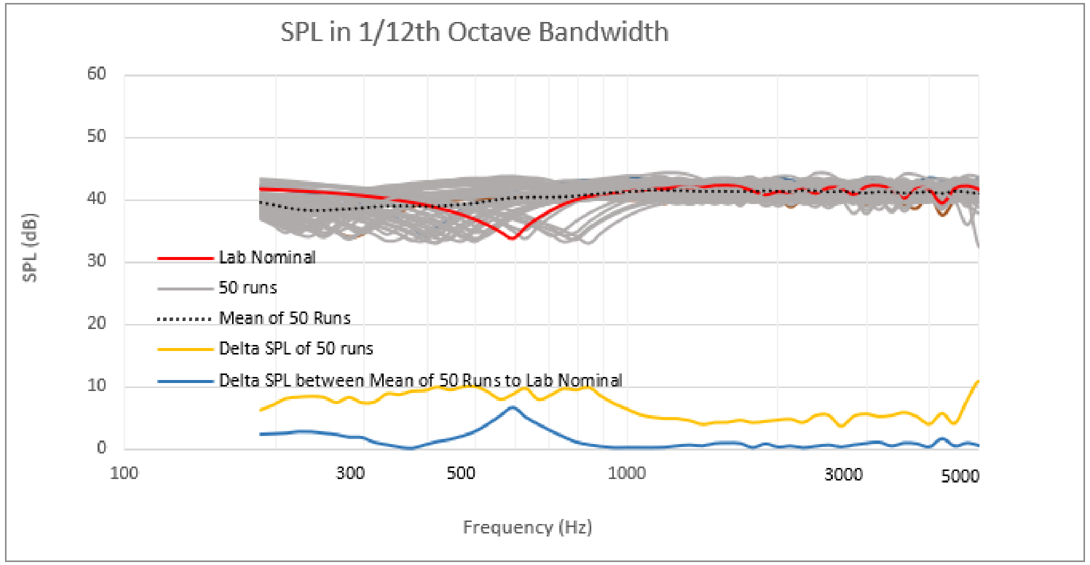




Justification of the main impact quantities "Environmental Uncertainty" justification by theoretical derivation

Variation due to "Environmental Uncertainty" across 50 randomly sampled trials including all impact quantities





Conclusions

- 5-microphone array reduces the influence from the main impact quantities by 50% overall
  - Sampling range includes atmospheric extremes (conservative compared to real-world observations)
- The most significant atmospheric impact quantities are effectively eliminated using multipoint sensor designs
  - Impedances due to gradient-based factors are removed (e.g., wind gradient and temperature-related effects)
- Distance effects remain the largest contributors to environmental variation
  - Source height, "Driver effect", and receiver height determine phase of incoming reflected path contributions, modulating frequency and amplitude response.
- Methods for mitigating distance-related main impact quantities are needed to remove frequency-dependent response.

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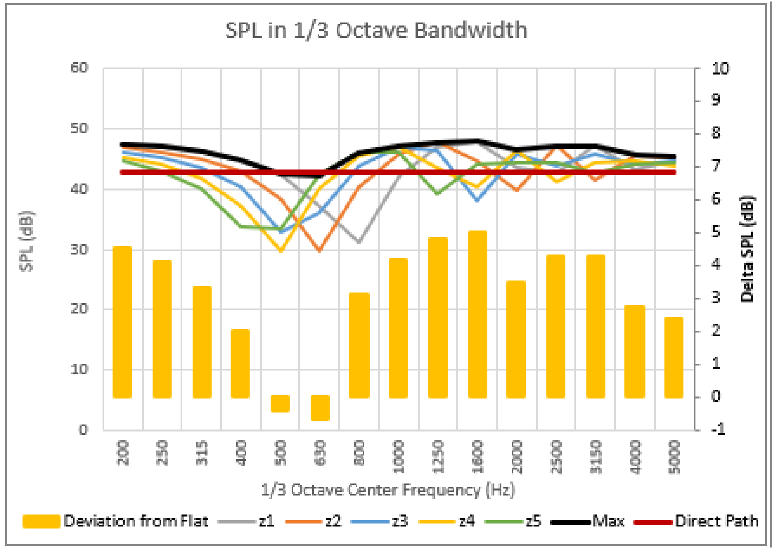
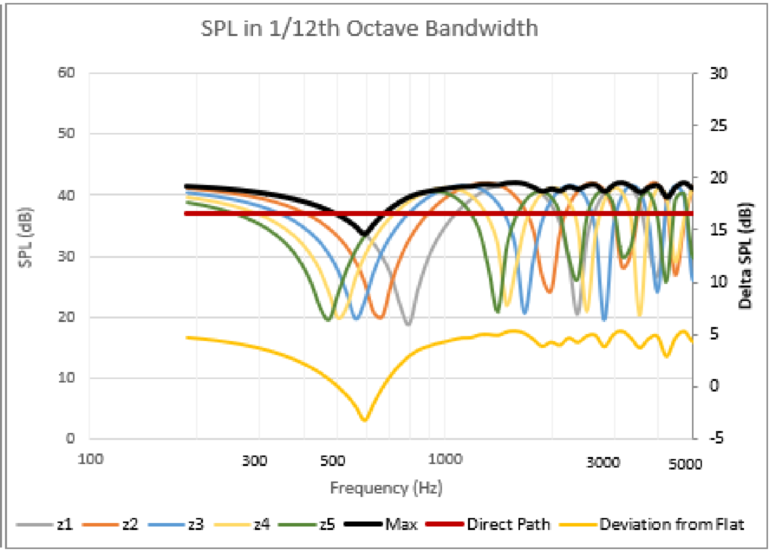
Mitigating Distance-Related Main Impact Quantities

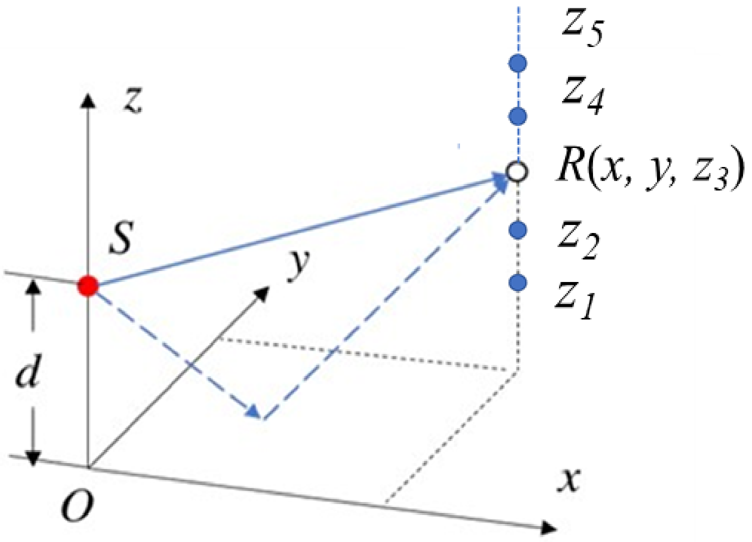
Multiphasic Corrections for 5-Microphone Arrays

Introduction

- Previously, microphone positions were restricted to 20 cm separations (centered at 1.2 m)
- A multiphasic approach corrects for reflected path "Distance Effects" by taking advantage of the reflected path contributions to peak amplitude
- The red line below is the direct path signal contribution compared to the direct and reflected path "measured" signal (in black) from the previous 5-microphone array configuration
- Varying the positions of the 5-microphones within the array configuration shifts the frequency response (proposed design in bottom right)







Optimal Multiphasic Correction

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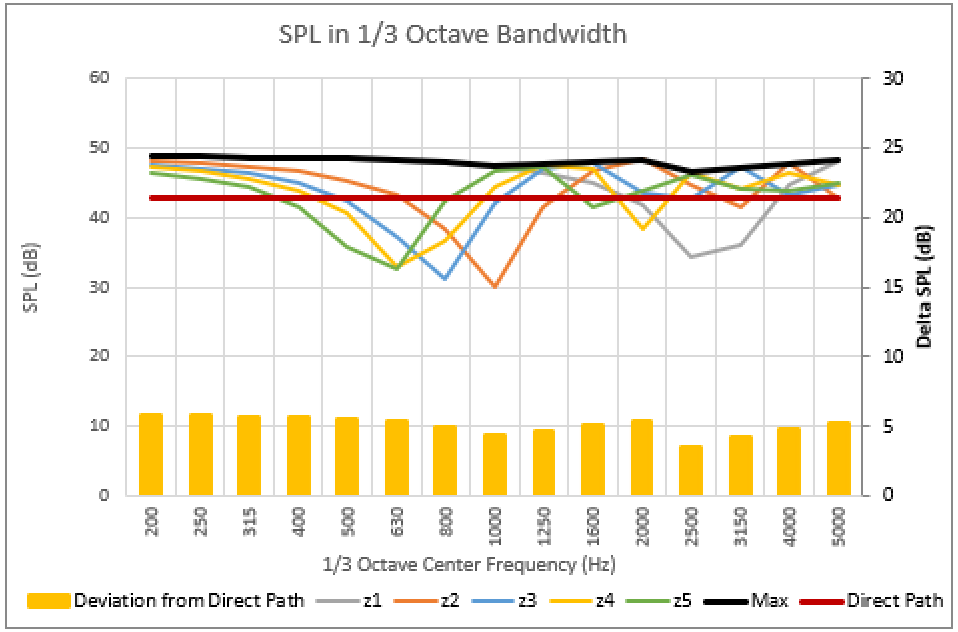
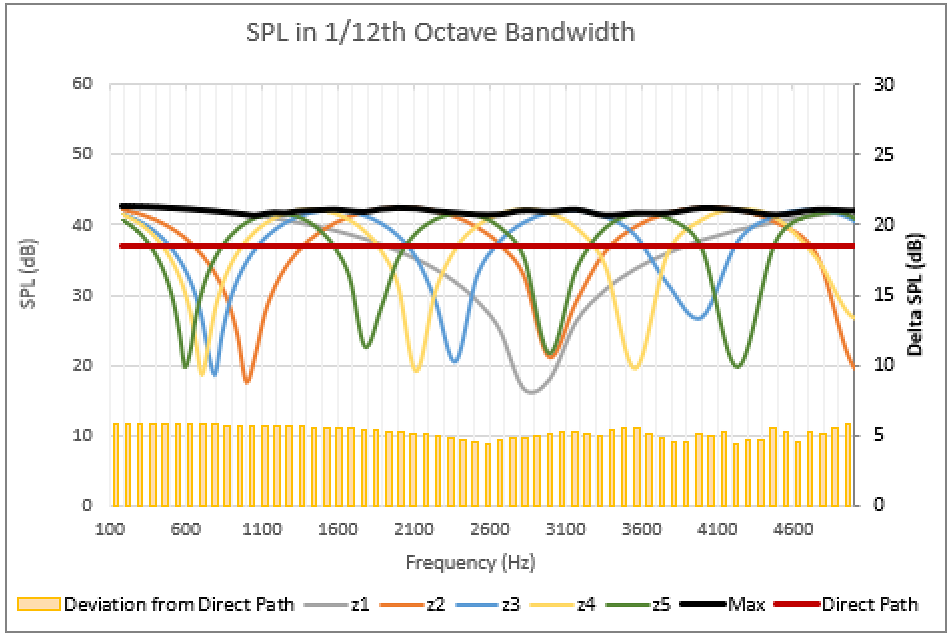
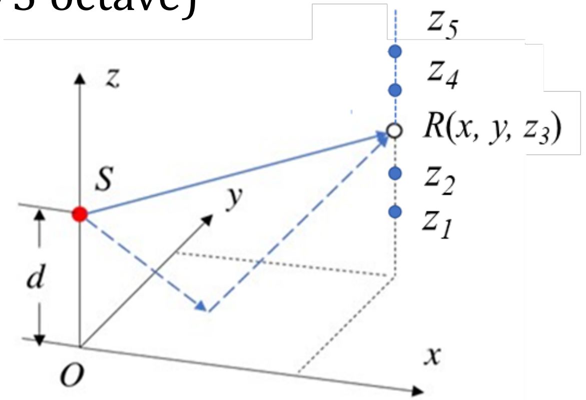


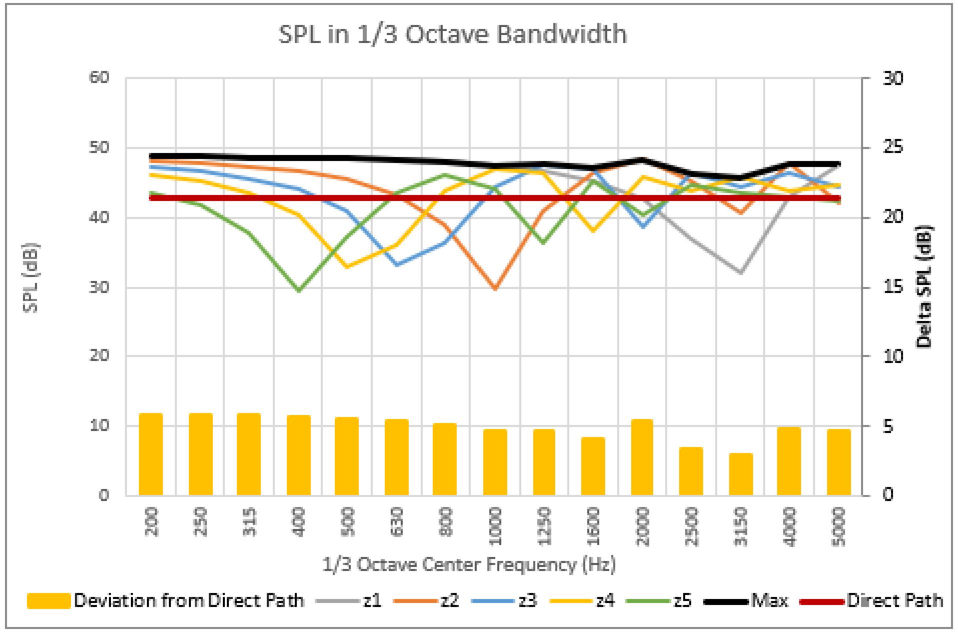


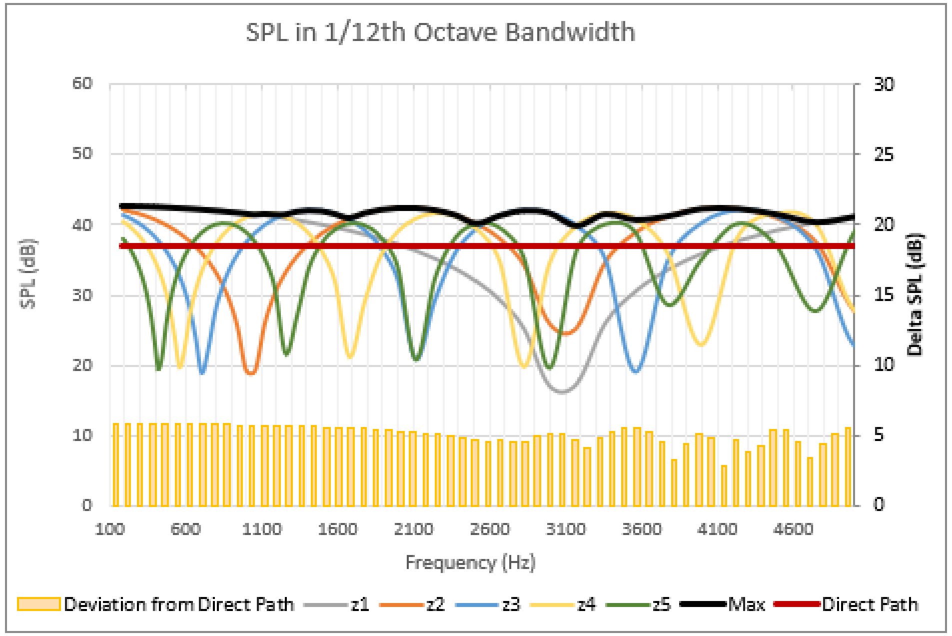
Microphone ID	Position Above Ground (cm)
Z1	20
Z2	60
Z3	80
Z4	90
Z5	110

- Reflected paths contribute ~5 dB increase across frequency bands (less than 1 dB variation in 1/12 octave and less than 3 dB in 1/3 octave)



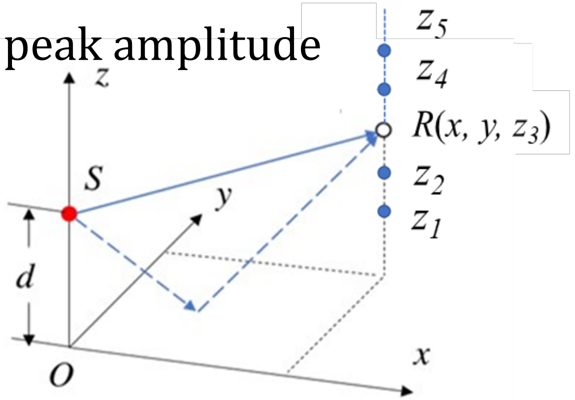
Testing Considerations





Microphone ID	Position Above Ground (centimetres)
Z1	20
Z2	60
Z3	80
Z4	120
Z5	185

- Considers children and wheelchair-bound populations up to 90-th percentile human height
  - minimizes high-frequency peak amplitude attenuation



Future Work

- Ellipsoidal microphone configurations to capture directional perception of frequency, amplitude, and phase conditions
- Investigate dynamical system solutions for real atmospheric conditions
- Develop “max-hold” criteria for ISO 16254 with respect to proposed array designs

Summary

- Single point receivers are highly sensitive to atmospheric and distance-related impact quantities
  - Sensitivities are frequency dependent (e.g., temperature amplifies anti-node responses)
- Multipoint receiver configurations are effective in reducing/eliminating atmospheric uncertainty
- Distance-related effects are reduced, but not eliminated, by constant-separation multipoint receiver configurations
- Multiphasic corrections eliminate frequency dependent responses due to distance-related effects
  - Distance-related amplitude attenuation is minimized using peak amplitudes from corrected multipoint arrays
- 5-microphone array design has a 50+% improvement over single-microphone test procedure

Conclusions

- Single-point measurements are inadequate for capturing stereophonic conditions representative of human hearing
- Multipoint arrays are effective at reducing/eliminating main impact quantities
    - Multipoint arrays yield more consistent test results using frequency-to-frequency peak amplitude methods
    - Multiphasic correction reduces frequency-dependent uncertainties, yielding a flatter frequency response.