EVALUATING THE PERFORMANCE OF SINUSODIAL RUMBLE STRIPS

TRB ADC 40: MID YEAR MEETING

JUNE 27TH, 2018

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Problem Statement

- Roadway departure crashes account for 66% of all highway fatalities in Oregon (FHWA, 2010).

- The noise and vibration generated by rumble strips (RS) alerts drivers when they are departing the traveled way.

- Shoulder rumble strips (SRS) reduce run-off-road (ROR) fatal injury crashes by 33% and all ROR crashes by 15% (Torbic et al, 2009) .

- Even though they are inexpensive to install, easy to maintain, and have a very long service life, it is not always possible to install RS on many roadway segments due to noise concerns.

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Project Scope

- The study evaluates the **feasibility of using sinusoidal RS as a substitute for traditional milled RS** on roadway segments with lane departure crash problems

- A quantitative and empirical **comparison of the in-vehicle noises and vibrations and roadside noises of sinusoidal and traditional RS** will indicate if the sinusoidal pattern provides sufficient warning to drivers

NCHRP 641 recommends a 6 to 12 dBA increase in noise to alert drivers that they are encroaching on a RS

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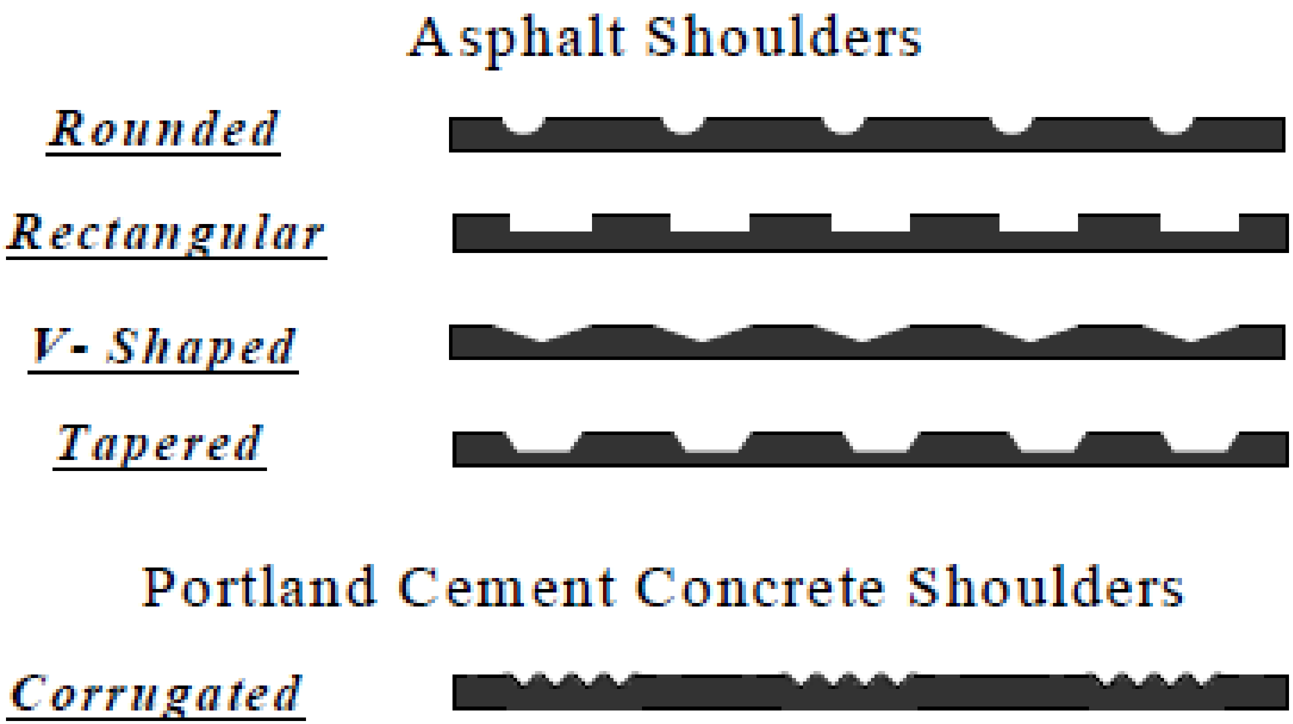
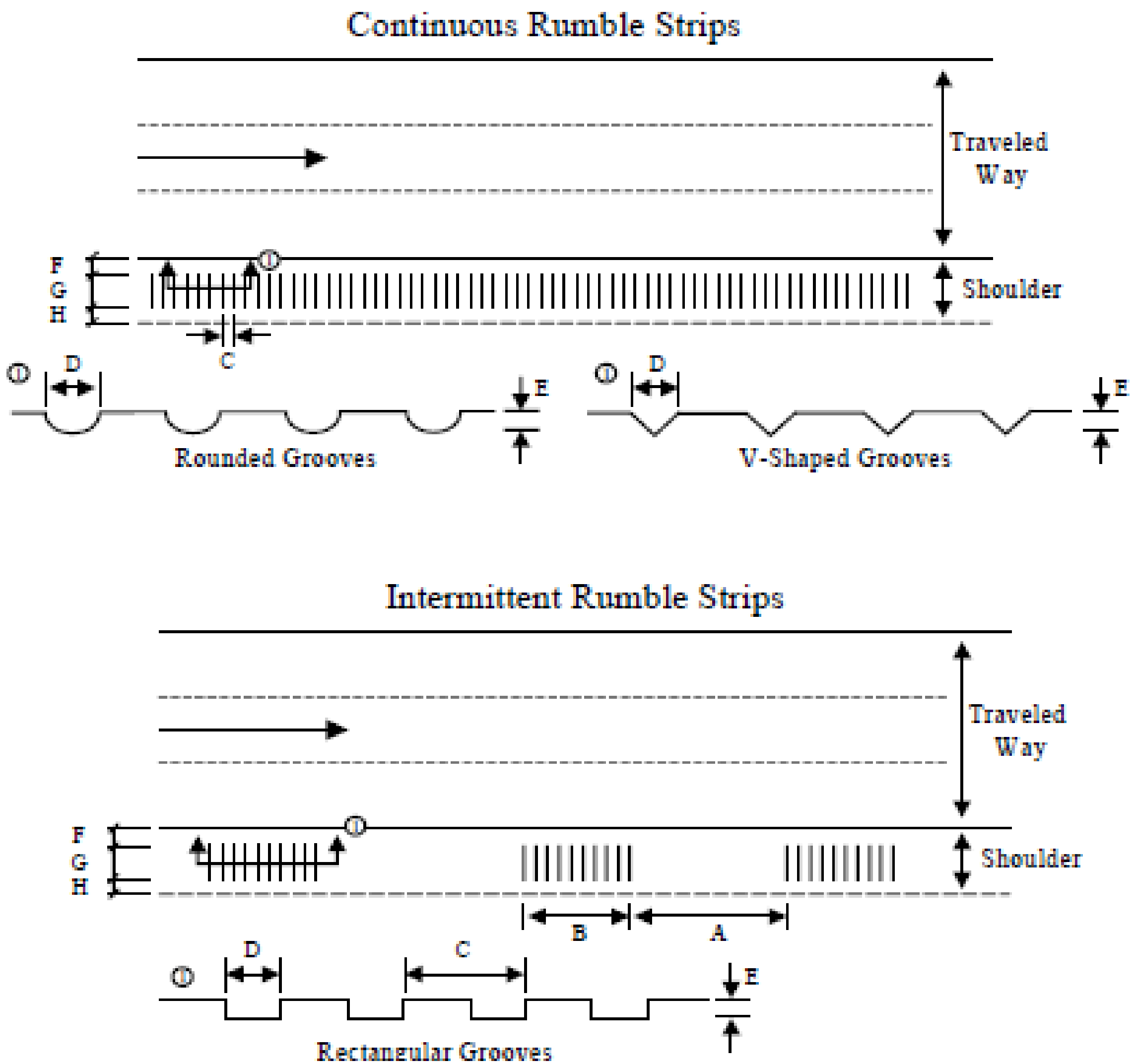
Rumble Strip Designs



Rounded RS Designs (Bucko, 2001)

Rumble Strip Dimensions



RS Geometric Characteristics (Bucko, 2001)

Tested Rumble Strip Geometry

DIMENSION	DESCRIPTION	SITE A: SINUSOIDAL	SITE B: ROUNDED
A	Gap between RS clusters	10’	10’
B	Length of RS cluster	28’	31’
C	Wavelength	16”	12”
D	Length of individual RS mill	16”	8”
E-1	**Depth of RS mill at trough**	**3/8”**	**1/2”**
E-2	Depth of RS mill at crest	1/16”	0”
F	Distance between edge of lane line and inside edge of RS mill	12”	6”
G	**Width of RS mill**	**14”**	**9.5”**
H	Distance between outside edge of RS mill and edge of pavement	7’	8’

RS Field Measured Geometric Characteristics

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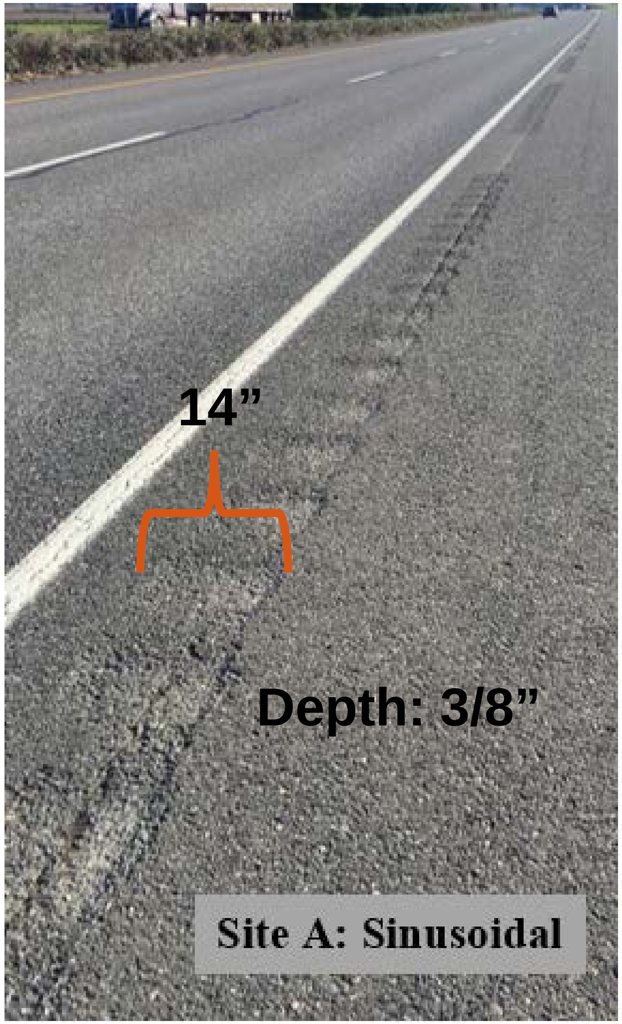
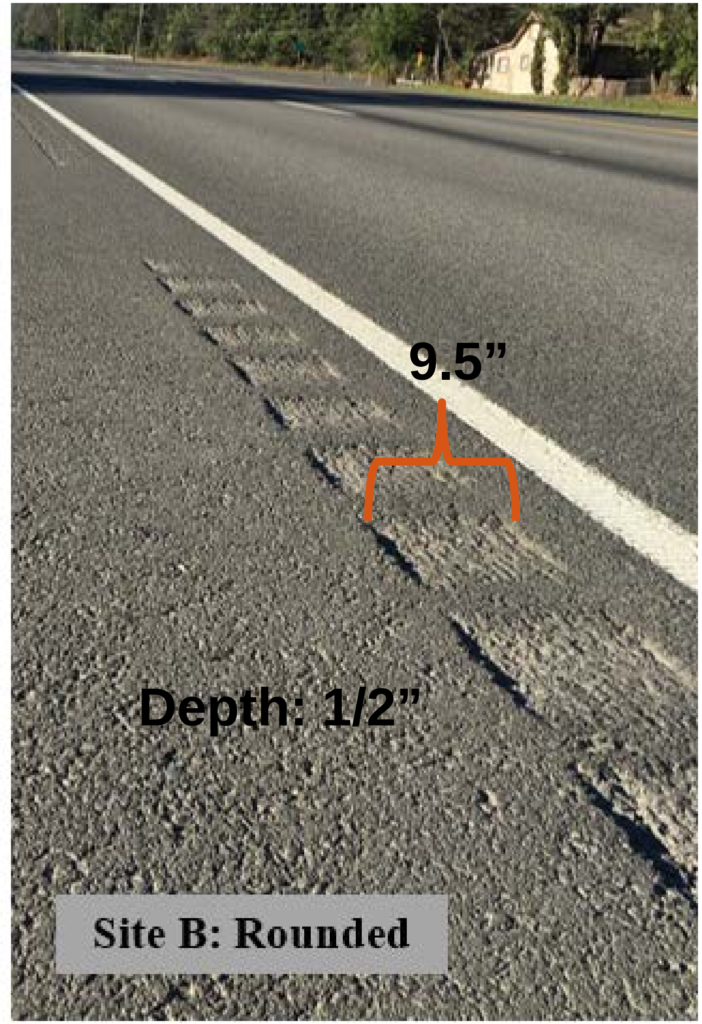
Tested Rumble Strips





RS Comparison

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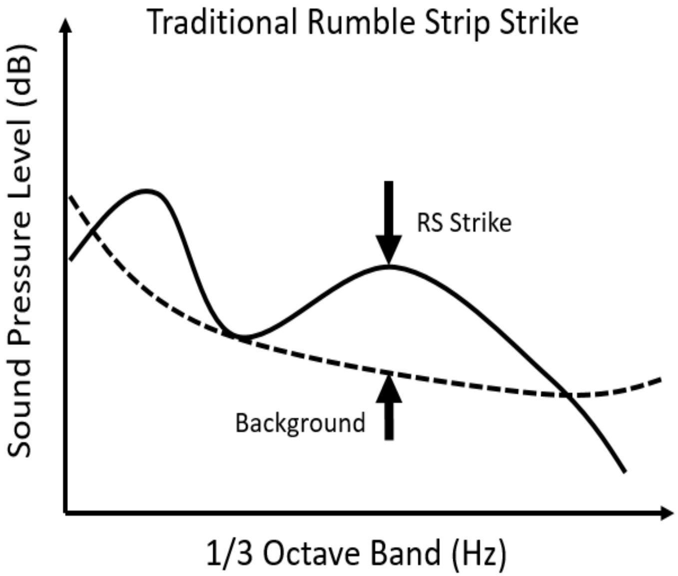
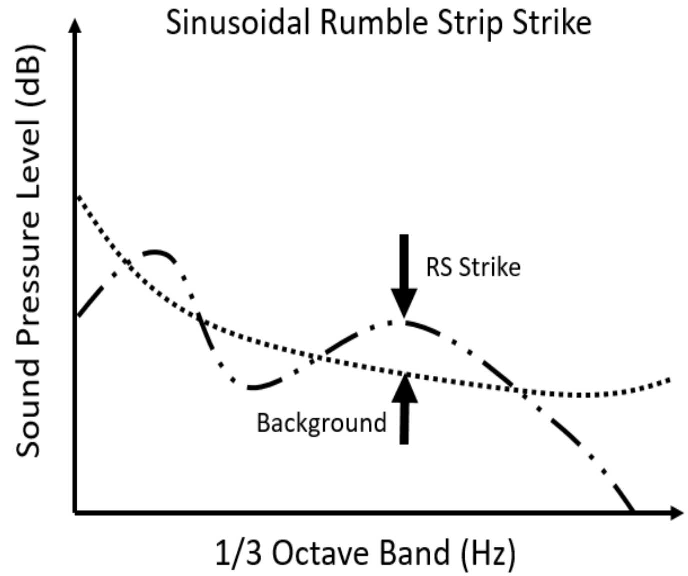
Research Design: Exterior Performance Measures





$$\Delta \text{ Traditional dB} = \text{RS Strike dB} - \text{Background dB} \tag{1}$$

$$\Delta \text{ Sinusoidal dB} = \text{RS Strike dB} - \text{Background dB} \tag{2}$$

$$\text{Sinusoidal Noise Reduction} = \sum \Delta \text{ Traditional dB} - \sum \Delta \text{ Sinusoidal dB} \tag{3}$$

$$\text{For all frequencies where RS strike dB} > \text{Background dB}$$

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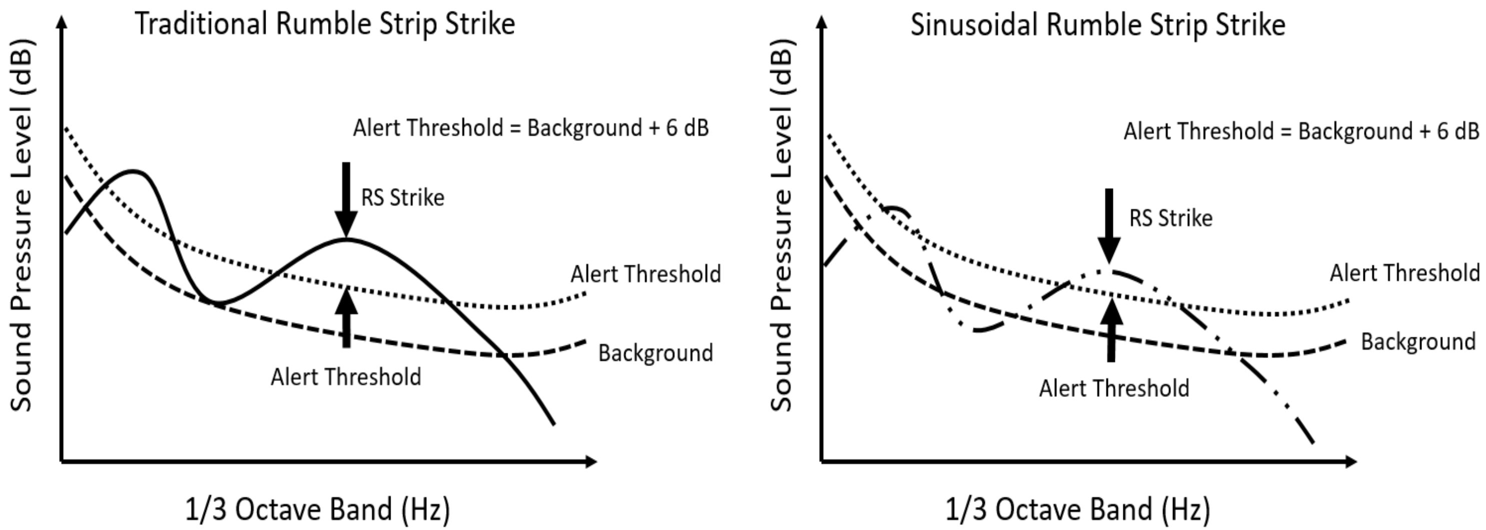
Research Design: Interior Performance Measures



Δ Traditional Alert dB = RS Strike dB – Alert Threshold dB (4)

Δ Sinusoidal Alert dB = RS Strike dB – Alert Threshold dB (5)

$$\text{Percent Reduction in Driver Alert } = 1 - \frac{\sum \Delta \text{ Sinusoidal Alert dB}}{\sum \Delta \text{ Traditional Alert dB}} \quad (6)$$

$$\text{For all frequencies where RS strike dB} > \text{Background dB}$$

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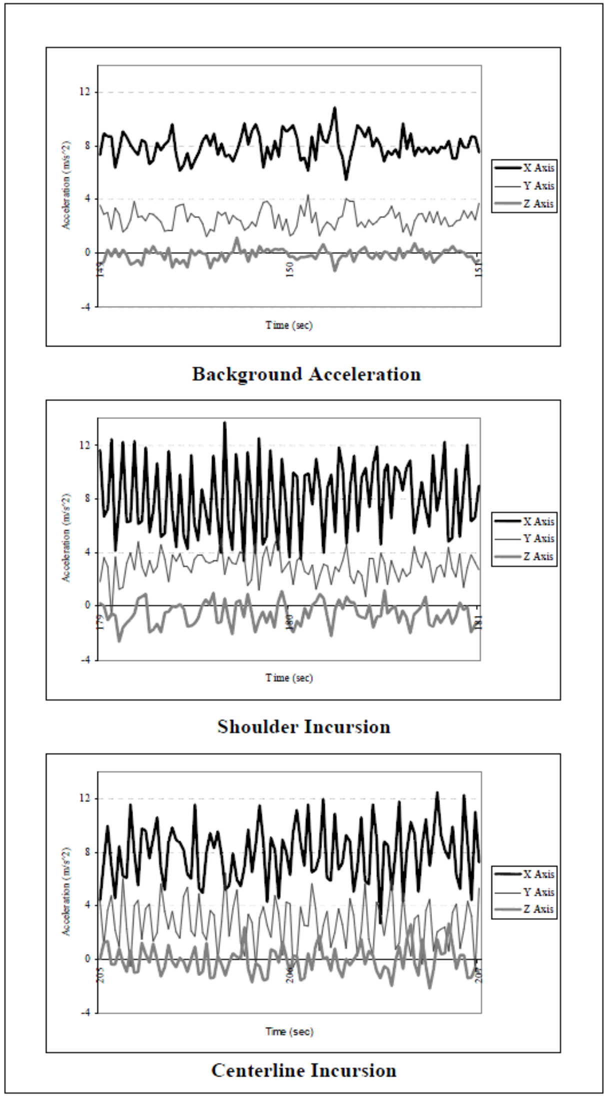
Research Design: Vibration Performance Measure

Interior haptic feedback will be evaluated based on the procedure developed by Dulaski and Noyce in 2016

The average acceleration will be tabulated for each axis (X, Y, and Z) for each acceleration signature as shown, as well as the variance and standard deviation.

Analysis of Variance (ANOVA) will be used to evaluate the difference between the strike and background condition



Steering Column Accelerometer Results (Dulaski, 2006)

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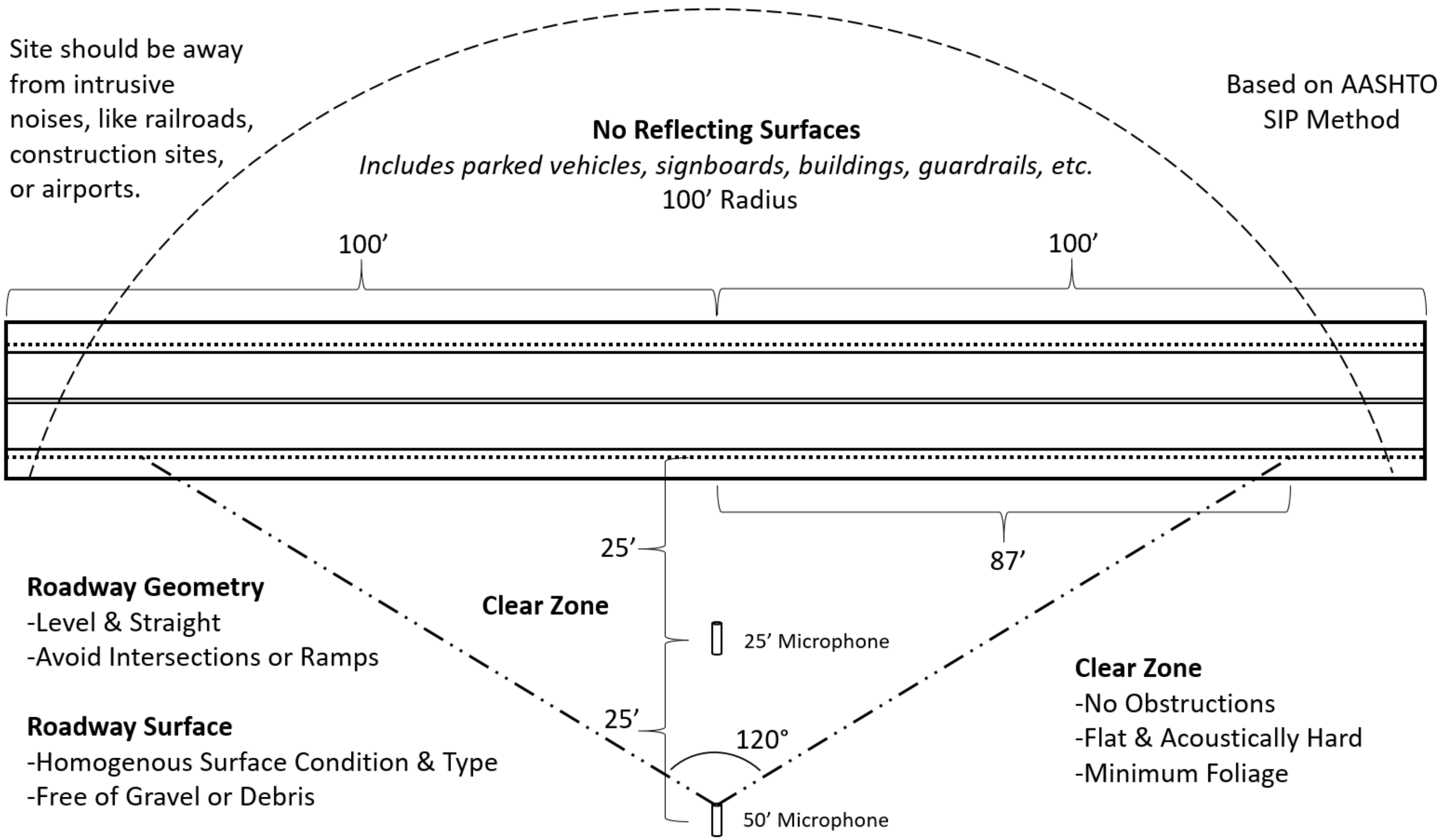
Research Design



Site Selection Guidelines based on AASHTO SIP Method

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Site Selection

Site Locations for Testing (© OpenStreetMap contributors)

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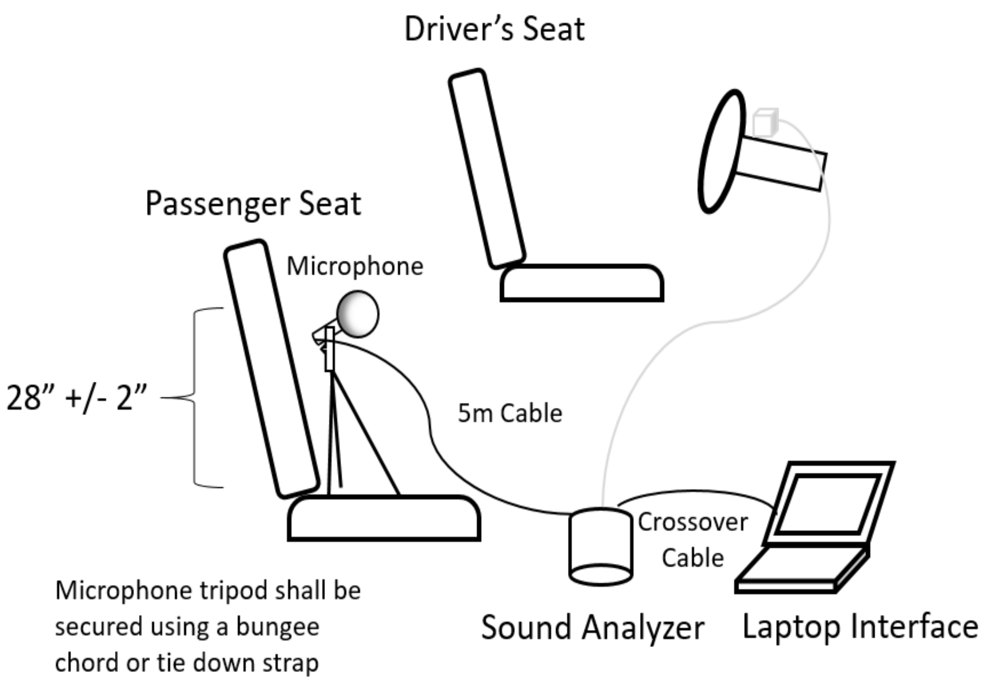
Research Design



Interior Set Up:
Interior Sound Measurement

- Microphone should be place 28 in +/- 2 in above the centerline of the seat, but no closer than 6 in from walls or upholstery.

- The microphone should be facing forward, in the direction of travel, and the seat shall be in the middle position of horizontal and vertical adjustments

Interior Sound Equipment Diagram

Based on SAE Standard J1477: Measurement of Interior Sound Levels of Light Vehicles for automotive testing & Ziaran, 2013

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Interior Noise Instrumentation

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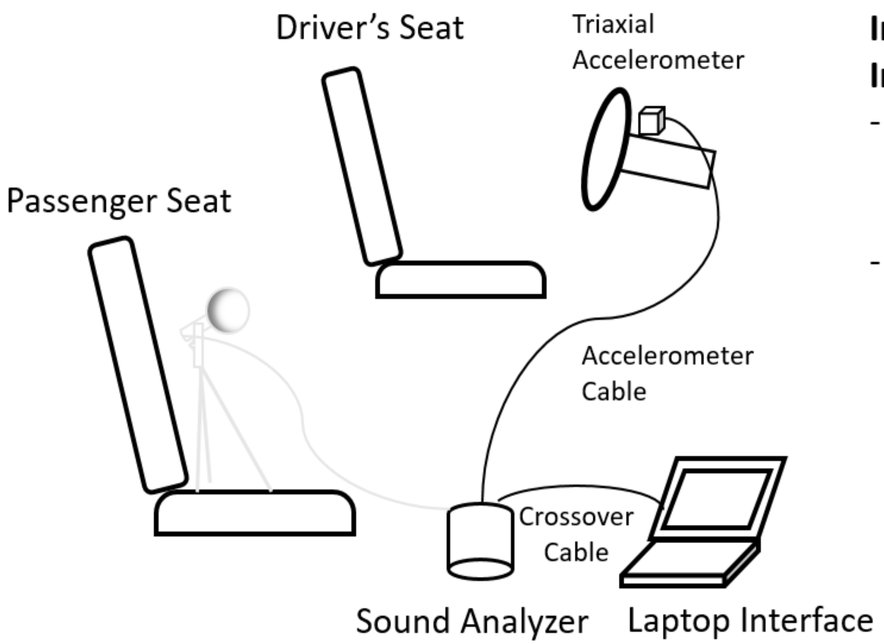
Research Design



Interior Set Up:
Interior Vibration Measurement

- Accelerometer is attached to steering column using adhesive gel
- Cable should be routed along dash to minimize interference to driver

Interior Vibration Equipment Diagram

Based on Bucko, 2001 & Dulaski, 2006

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Interior Vibration Instrumentation

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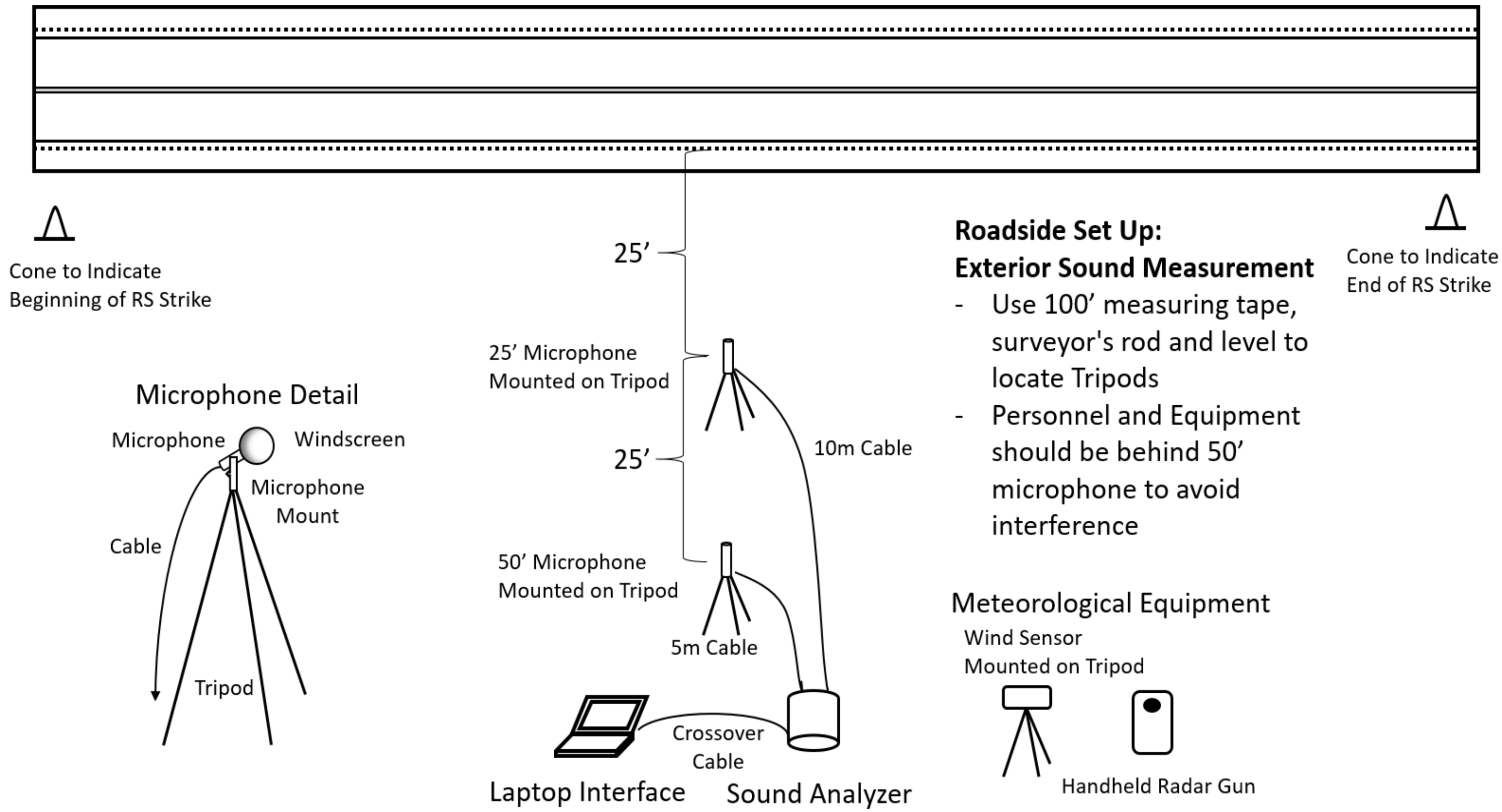
Research Design



Exterior Sound Equipment Diagram

Based on AASHTO’s Statistical Isolated Pass-By (SIP) Method

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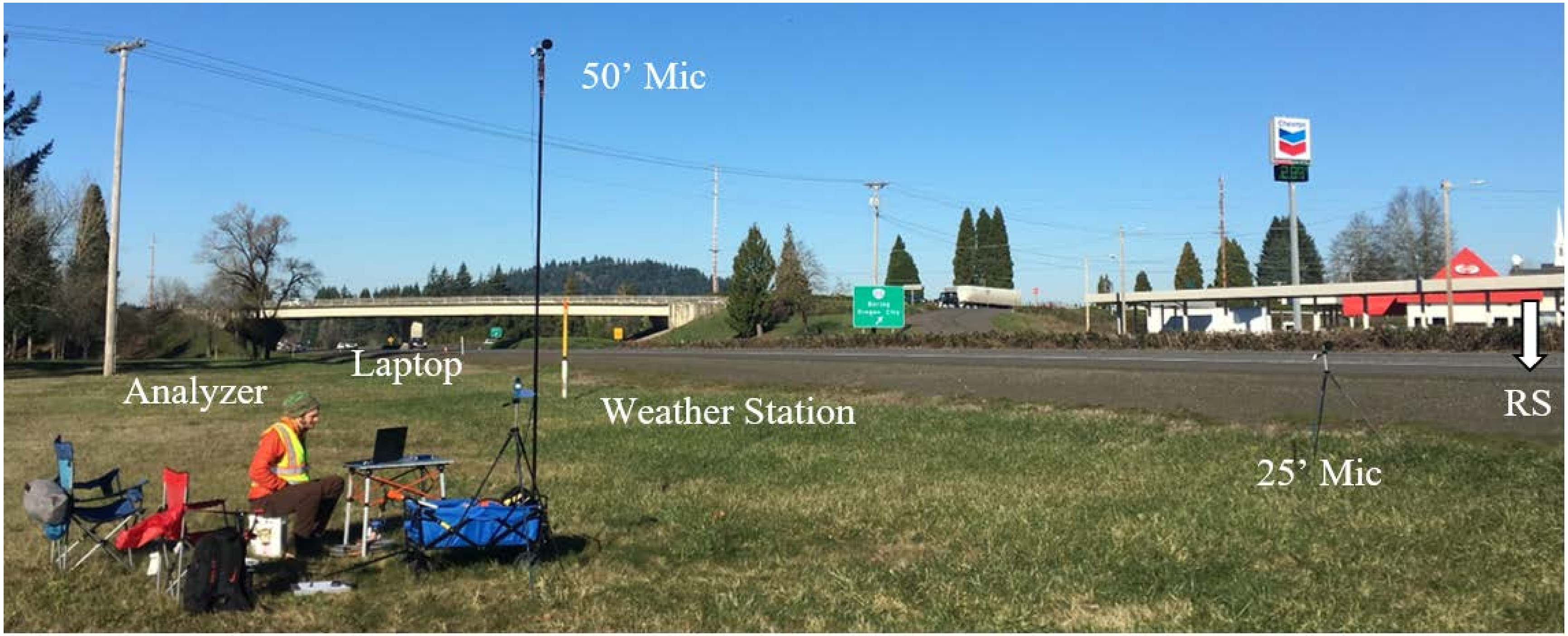
Exterior Noise Instrumentation



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Vehicle Types Tested: Passenger Car

2017 Ford Focus Hatchback

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Vehicle Types Tested: Van

2015 Dodge Grand Caravan Striking the Sinusoidal RS

Vehicle Types Tested: Heavy Vehicle

Volvo VHD Dump Truck

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Vehicle Types Tested: Heavy Vehicle

Heavy Vehicle Interior Microphone Setup

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Factor Groups

VEHICLE TYPE	RUMBLE STRIP TYPE	CONDITION	EXTERIOR	INTERIOR
Passenger Car	Sinusoidal	Baseline	3	12
		Strike	3	13
	Rounded	Baseline	3	13
		Strike	3	12
Van	Sinusoidal	Baseline	3	3
		Strike	3	4
	Rounded	Baseline	4	3
		Strike	5	3
Heavy Vehicle	Sinusoidal	Baseline	3	3
		Strike	3	3
	Rounded	Baseline	3	3
		Strike	3	3
		Subtotal	39	75
		Total	114	

Total Data Collected

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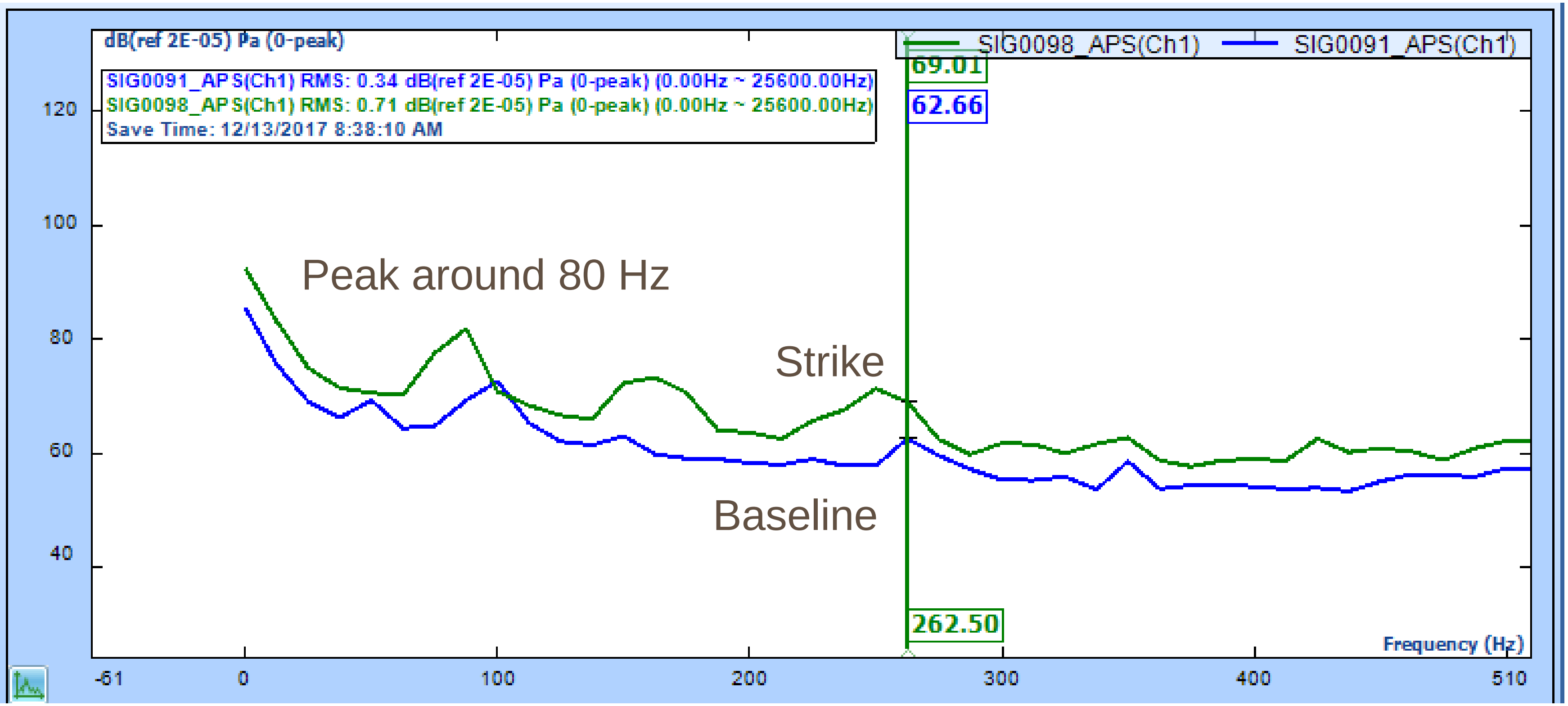
Exterior Measurement: Passenger Car



Passenger Car Frequency Comparison

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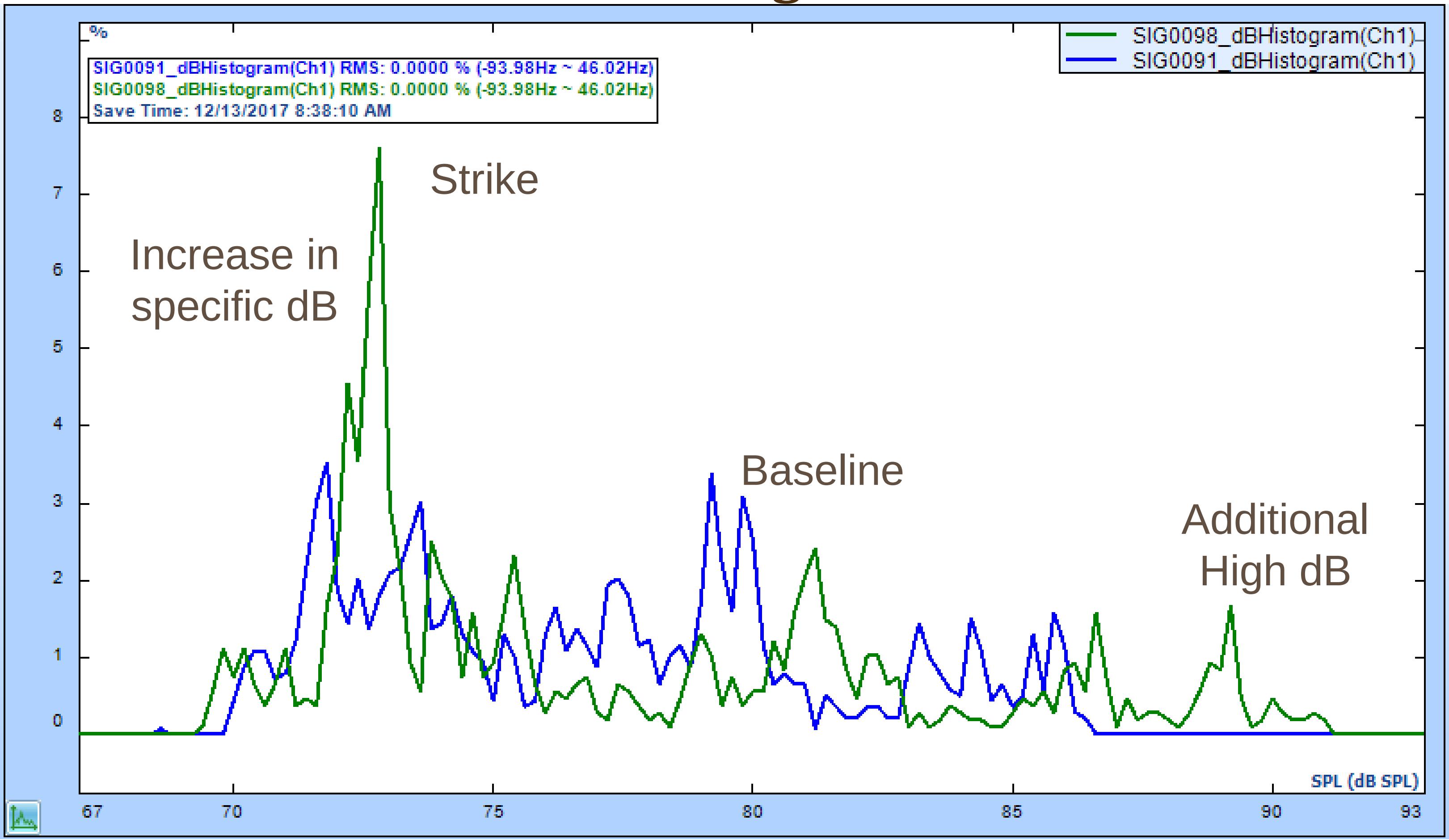
Exterior Measurement: Passenger Car



Passenger Car dB Histogram Comparison

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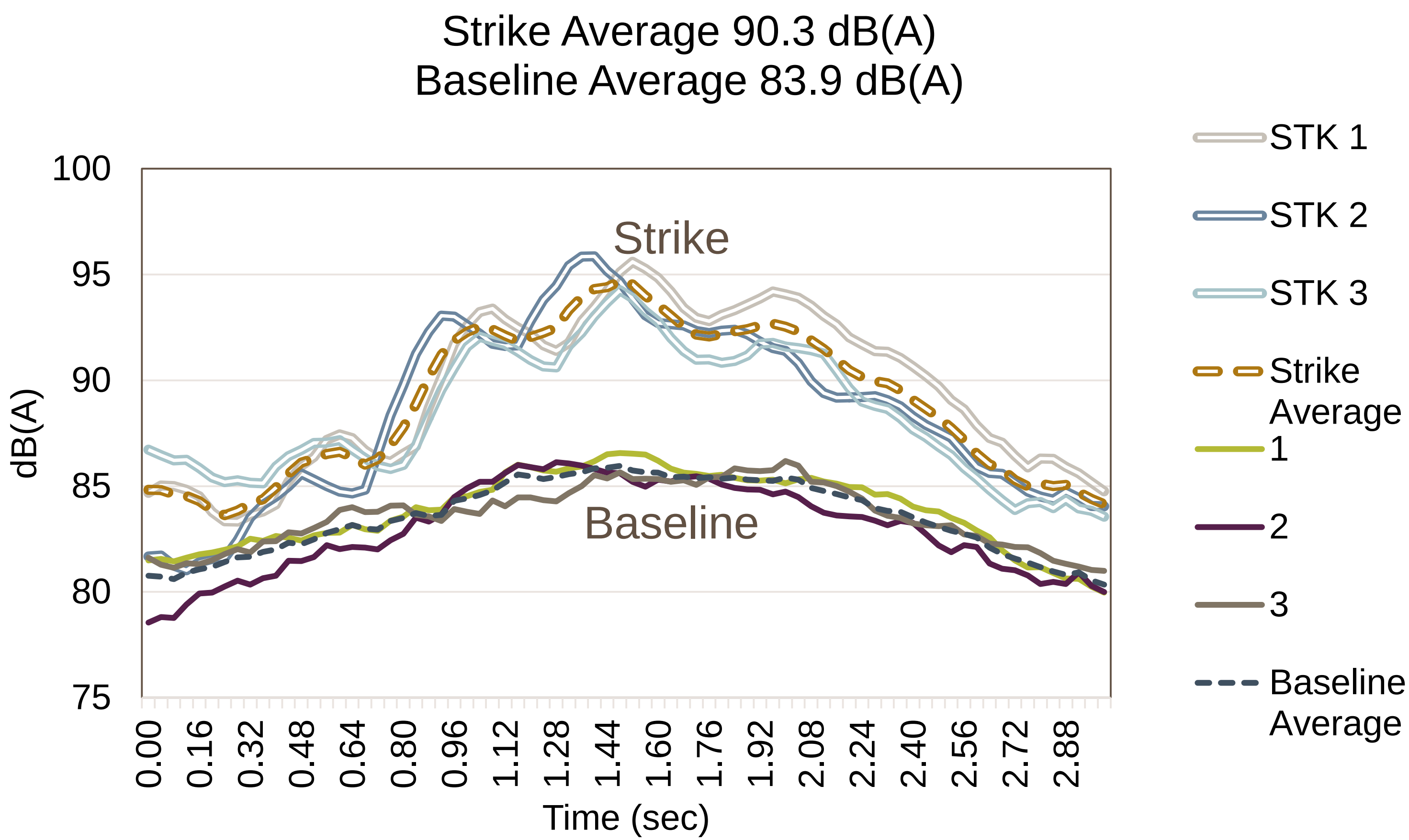
Exterior Measurement: Passenger Car



Passenger Car Rounded RS Exterior Sound Measurement

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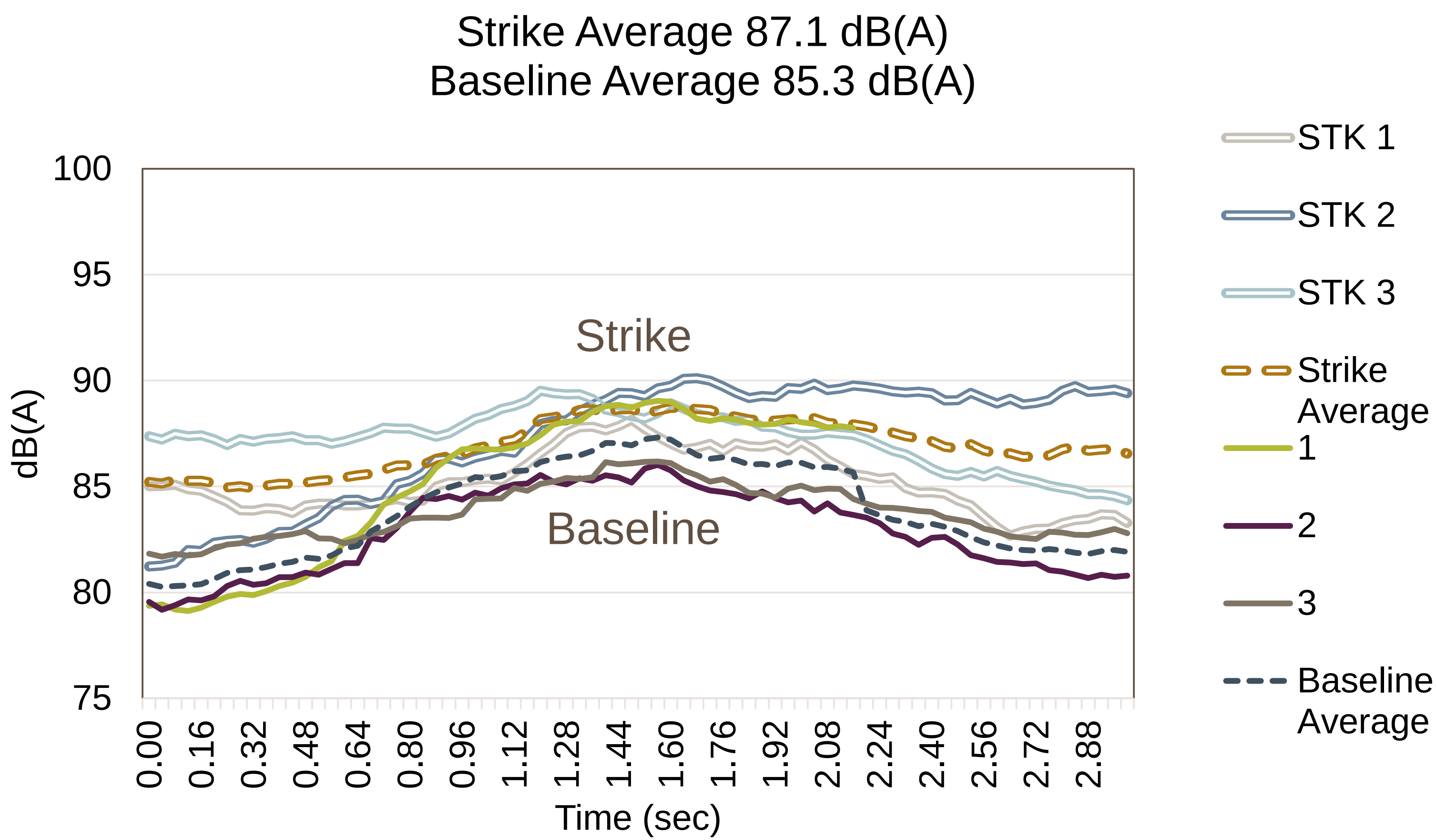
Exterior Measurement: Passenger Car



Passenger Car Sinusoidal RS Exterior Sound Measurement

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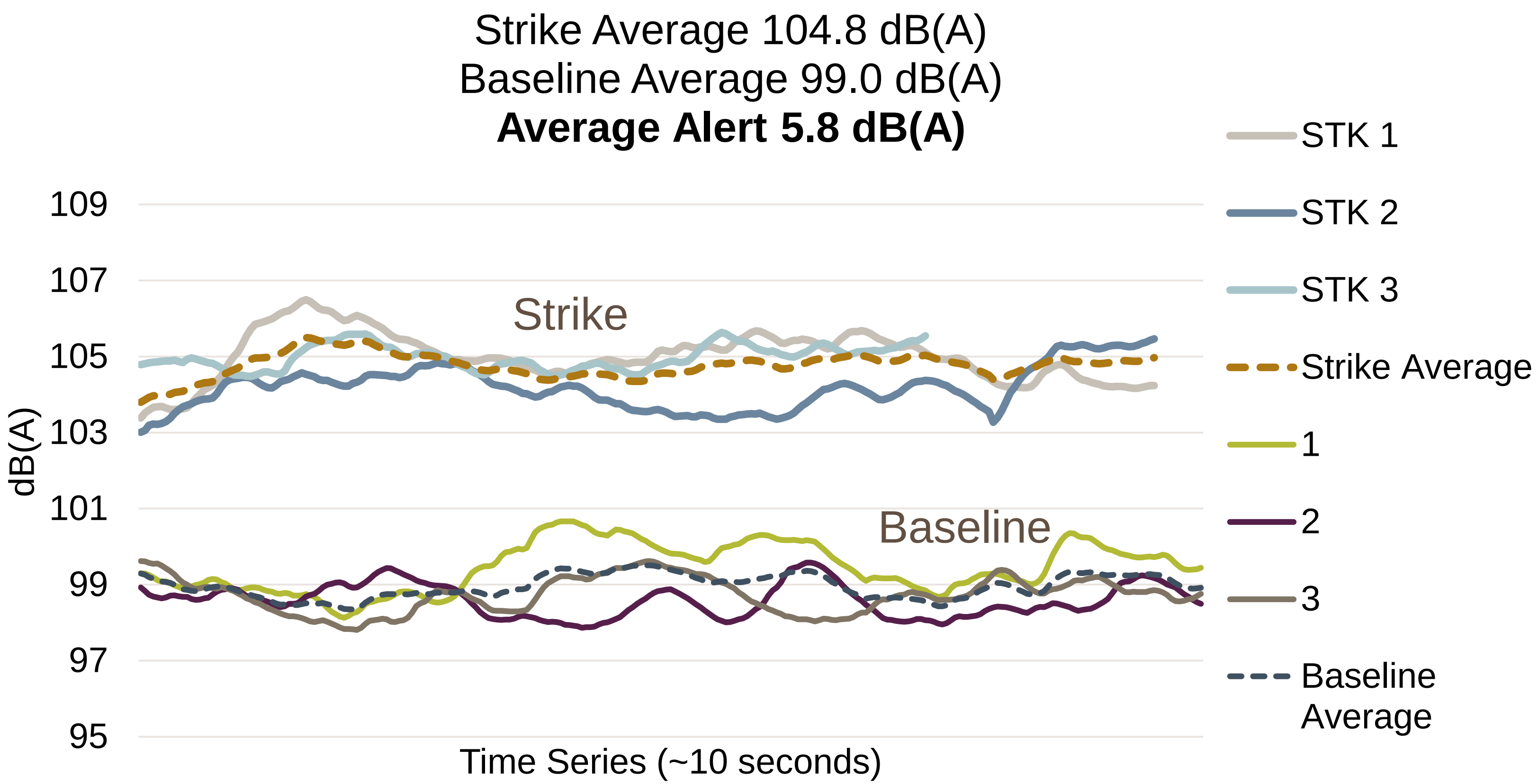
Interior Measurement: Passenger Car



Passenger Car Sinusoidal RS Interior Sound Measurement

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Factor Groups Measurements

VEHICLE TYPE	RUMBLE STRIP TYPE	CONDITION	EXTERIOR Avg dBA	INTERIOR Avg dBA
Passenger Car	Sinusoidal	Baseline	84.6	99.0
		Strike	87.1	104.8
	Rounded	Baseline	83.9	100.4
		Strike	90.3	111.8
Van	Sinusoidal	Baseline	85.9	96.9
		Strike	86.0	101.2
	Rounded	Baseline	89.4	96.9
		Strike	94.2	107.0
Heavy Vehicle	Sinusoidal	Baseline	88.5	101.1
		Strike	94.5	108.1
	Rounded	Baseline	91.6	103.1
		Strike	95.0	104.0

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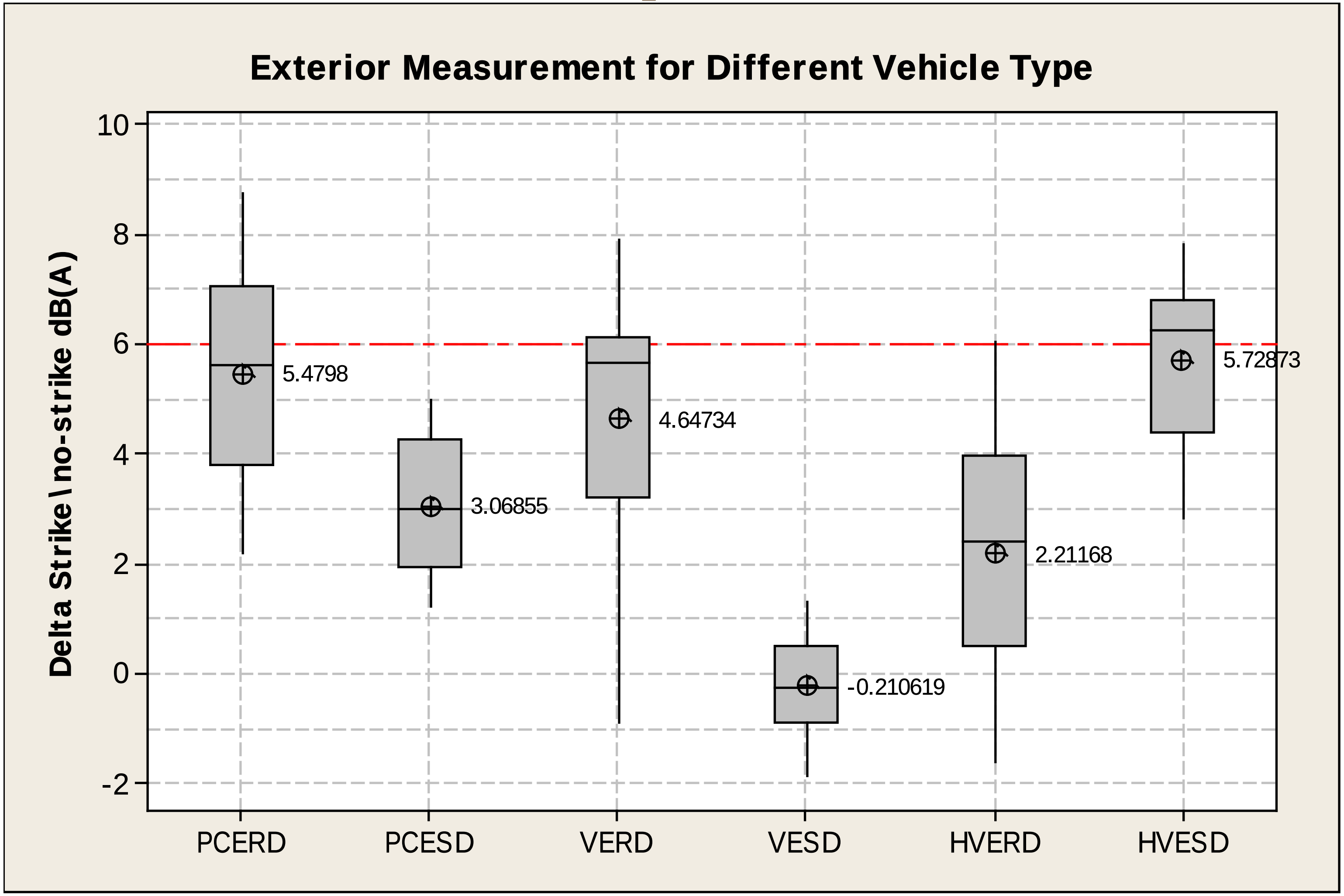
Exterior Measurement Comparison



Delta = Strike dBA – Baseline dBA

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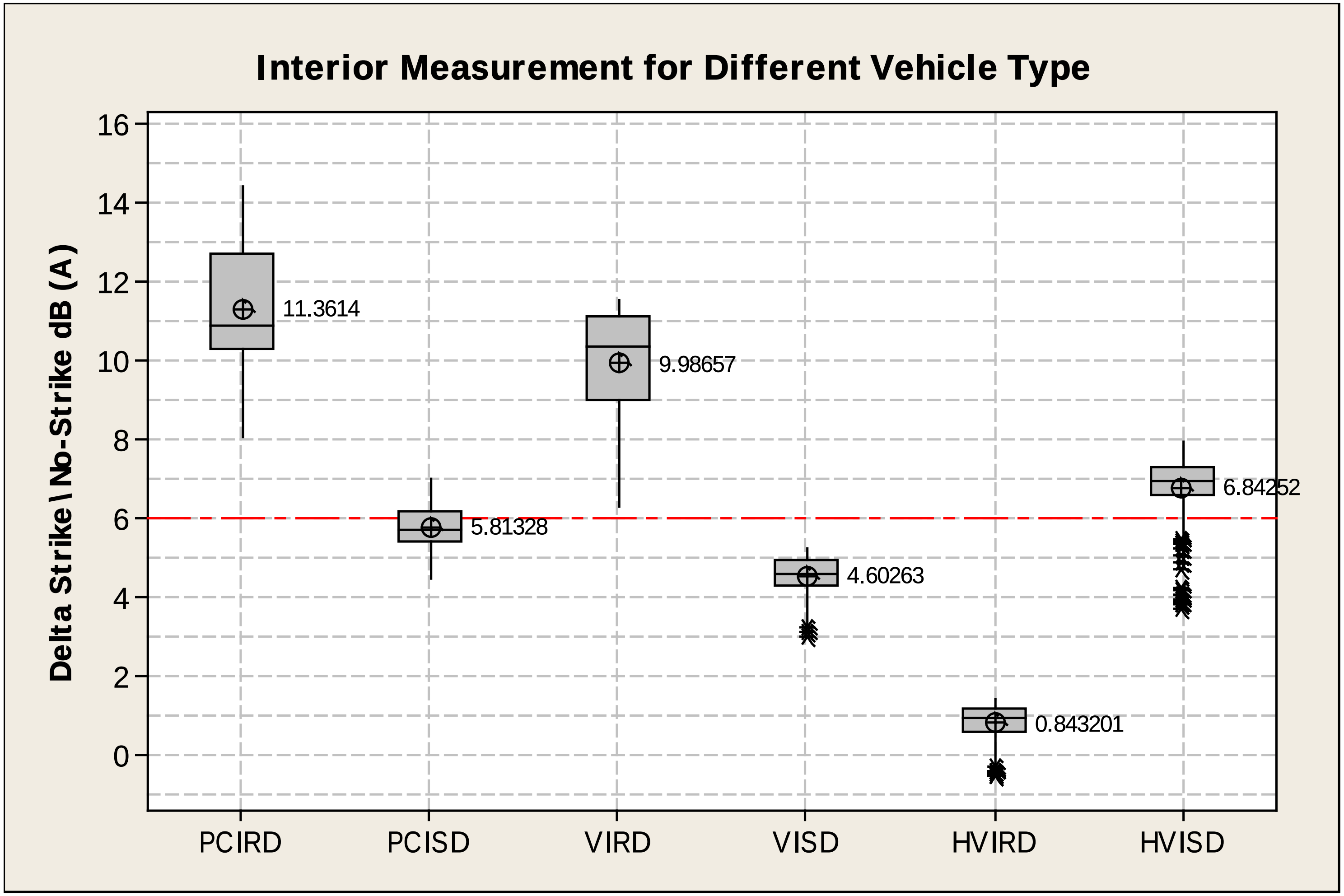
Interior Measurement: Alert Levels



Interior Alert Levels

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Questions?

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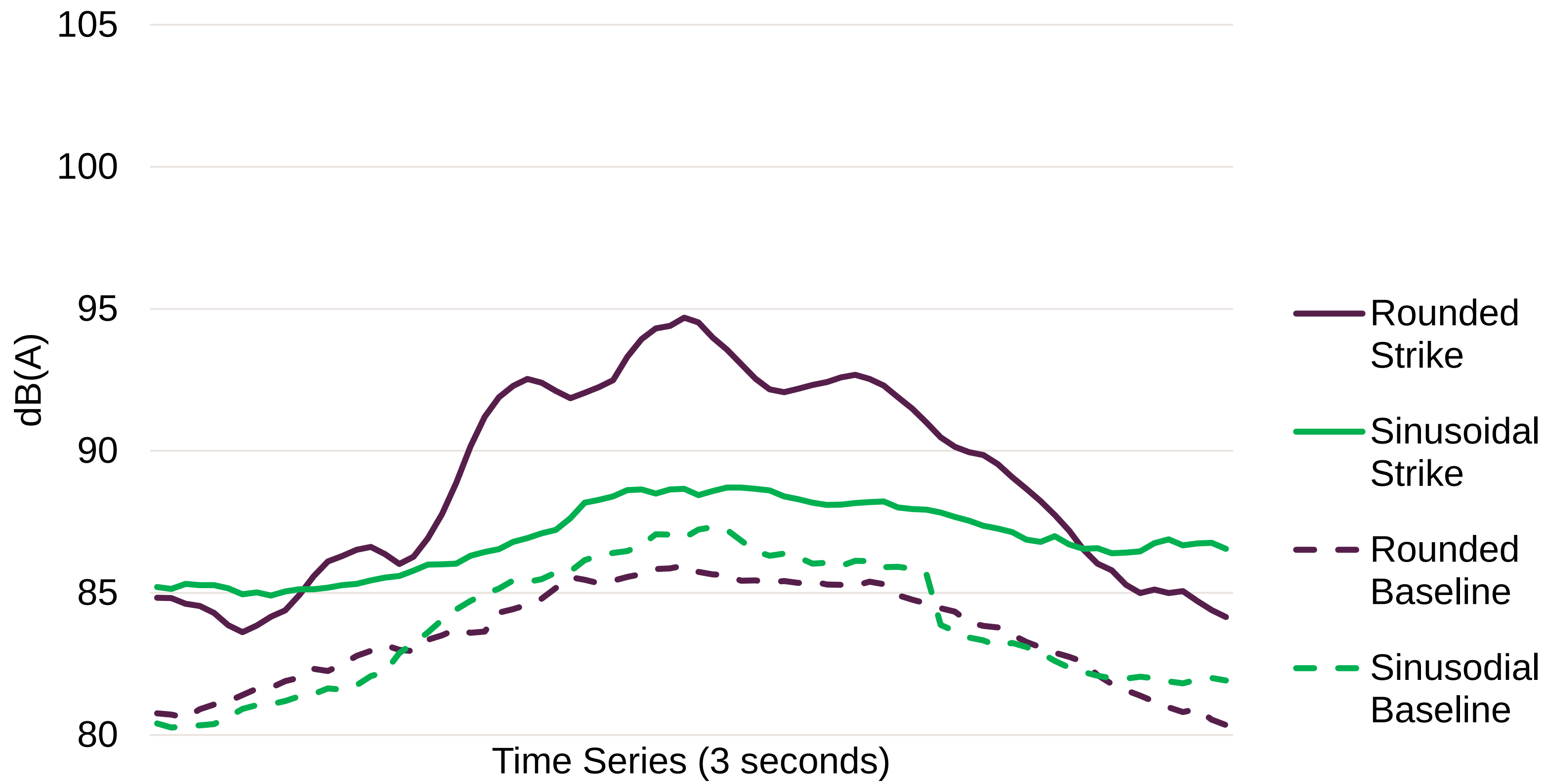
Exterior Measurement: Passenger Car



Passenger Car RS Exterior Comparison

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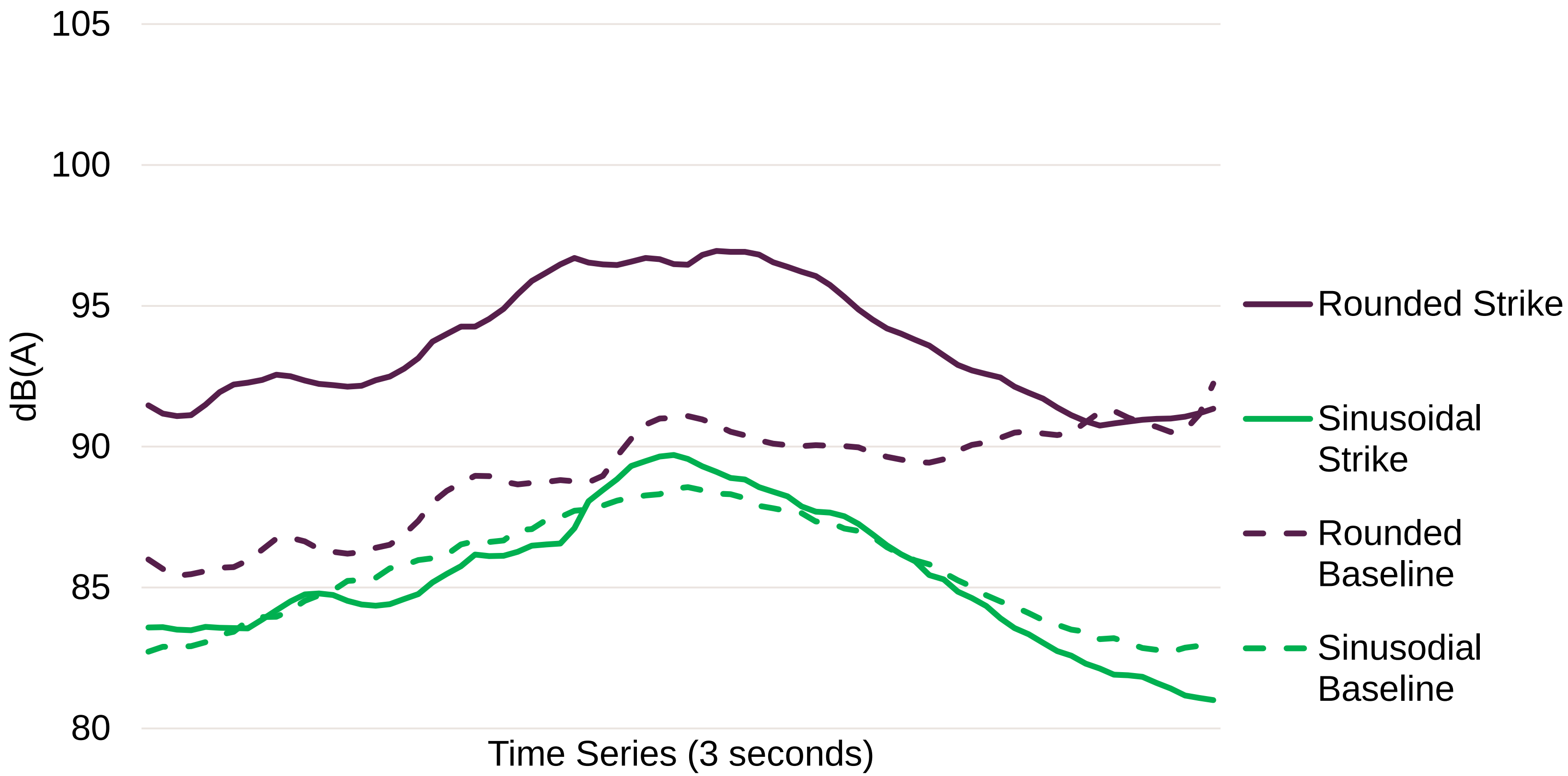
Exterior Measurement: Van



Van RS Exterior Comparison

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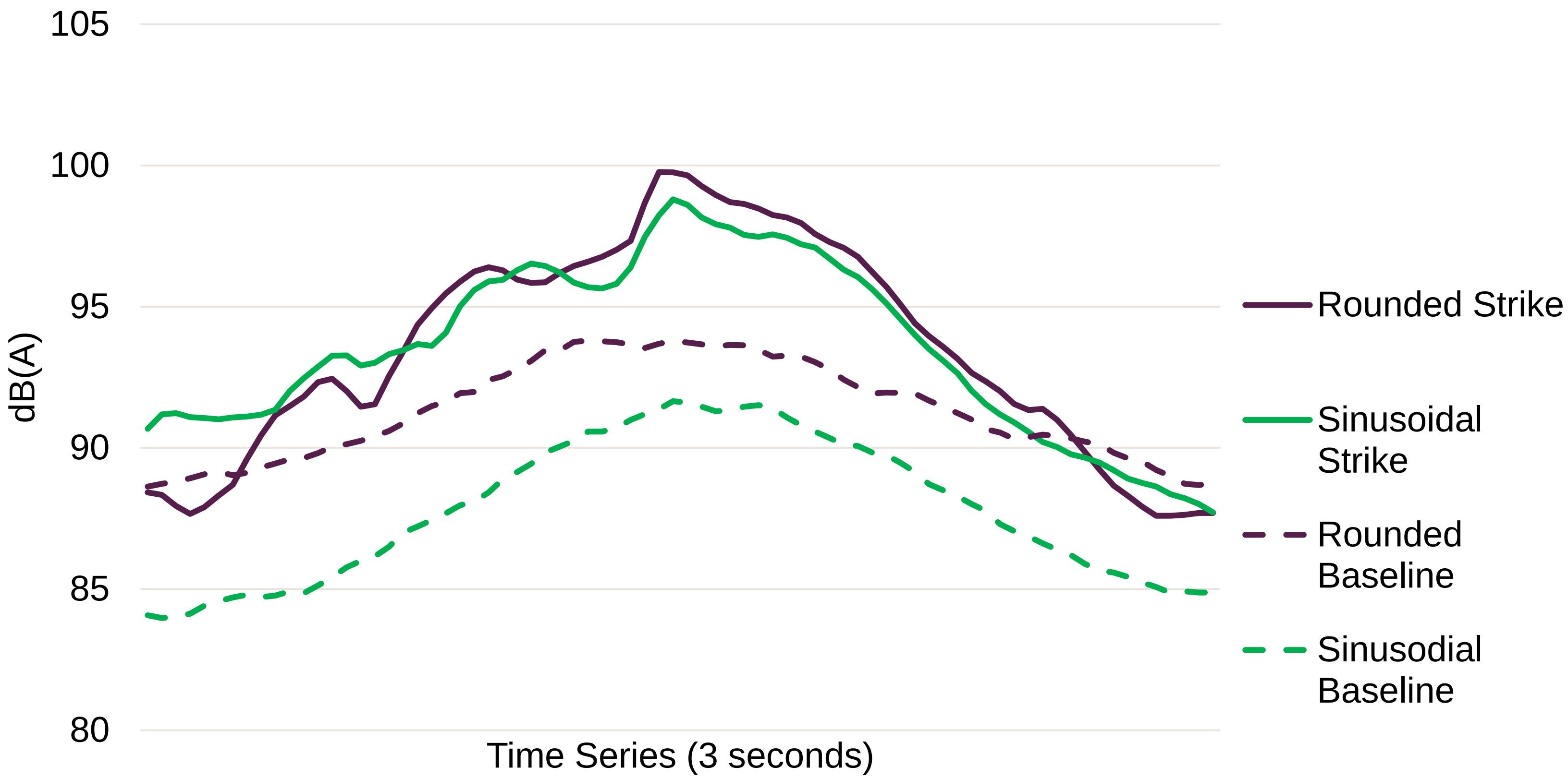
Exterior Measurement: Heavy Vehicle



Heavy Vehicle RS Exterior Comparison

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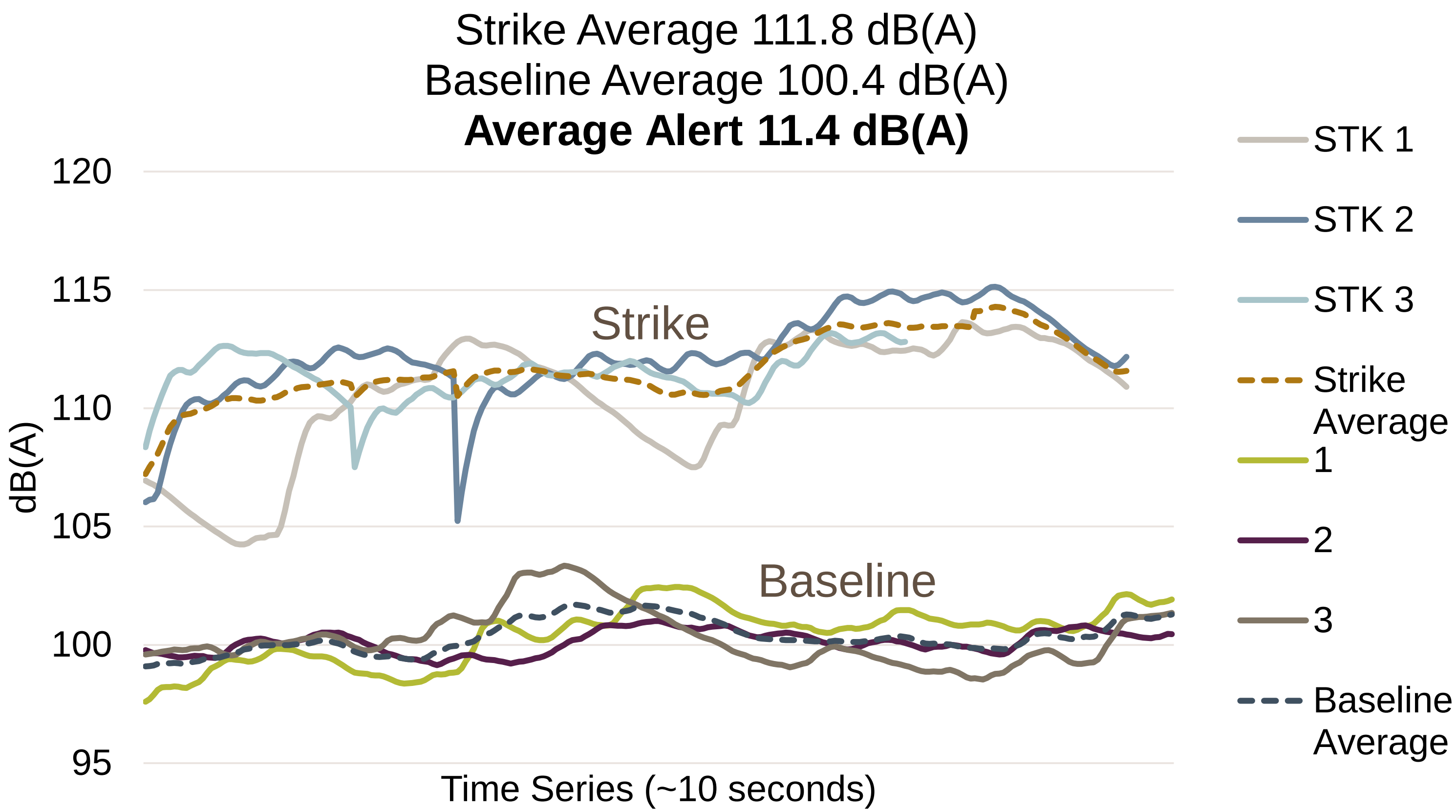
Interior Measurement: Passenger Car



Passenger Car Rounded RS Interior Sound Measurement

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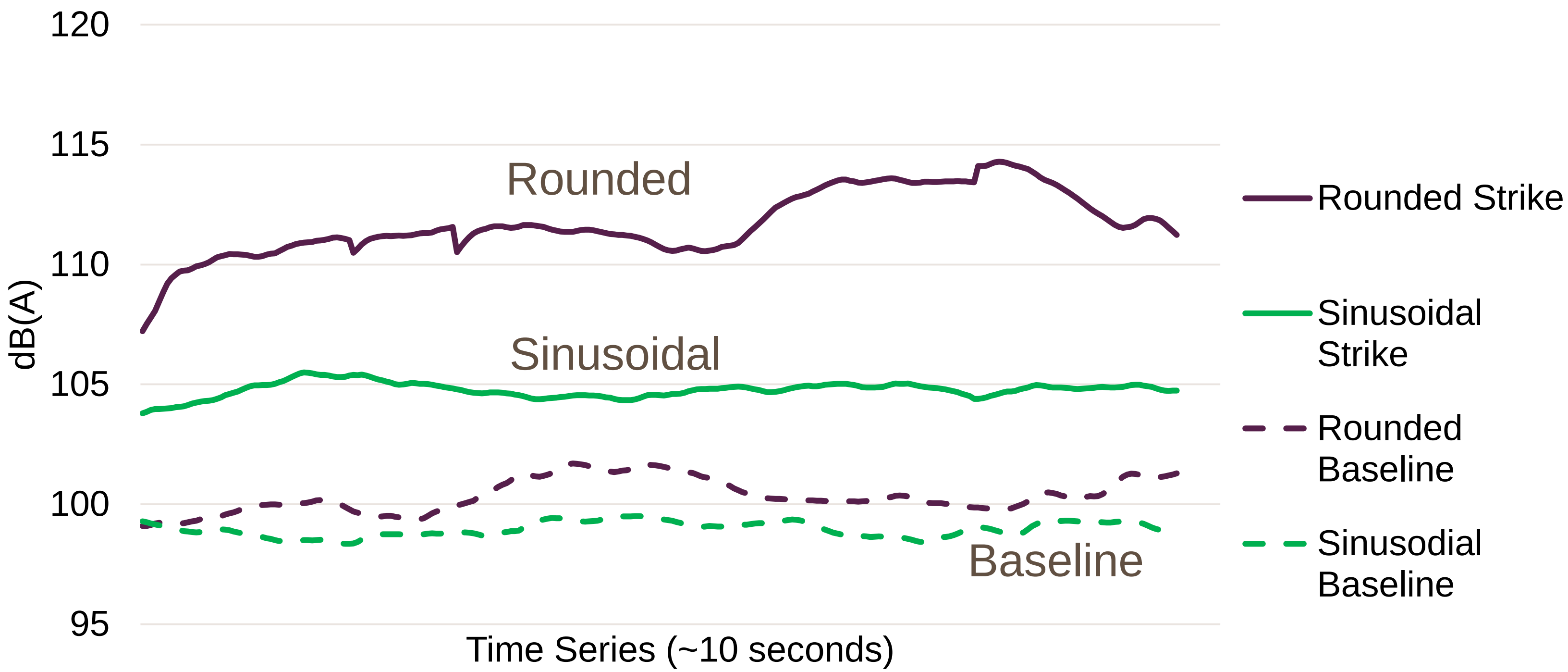
Interior Measurement: Passenger Car



Passenger Car RS Interior Comparison

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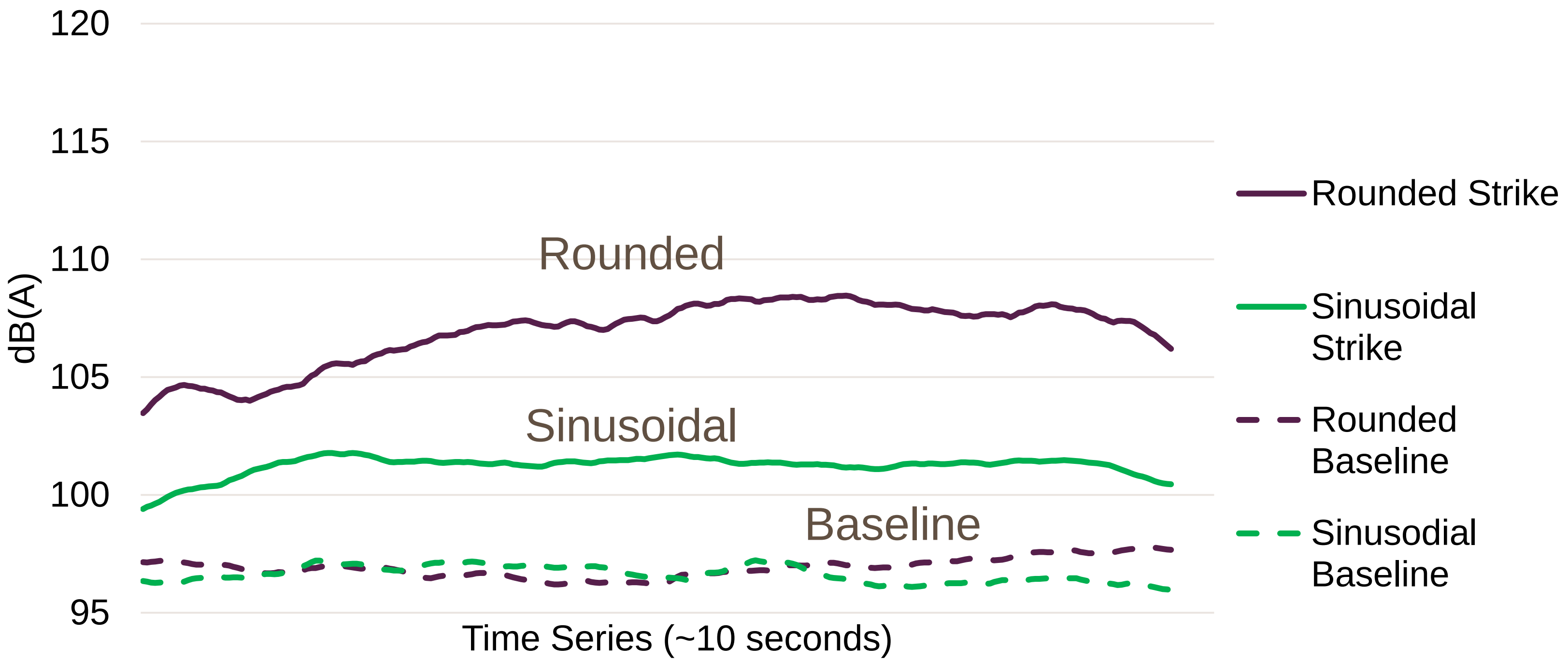
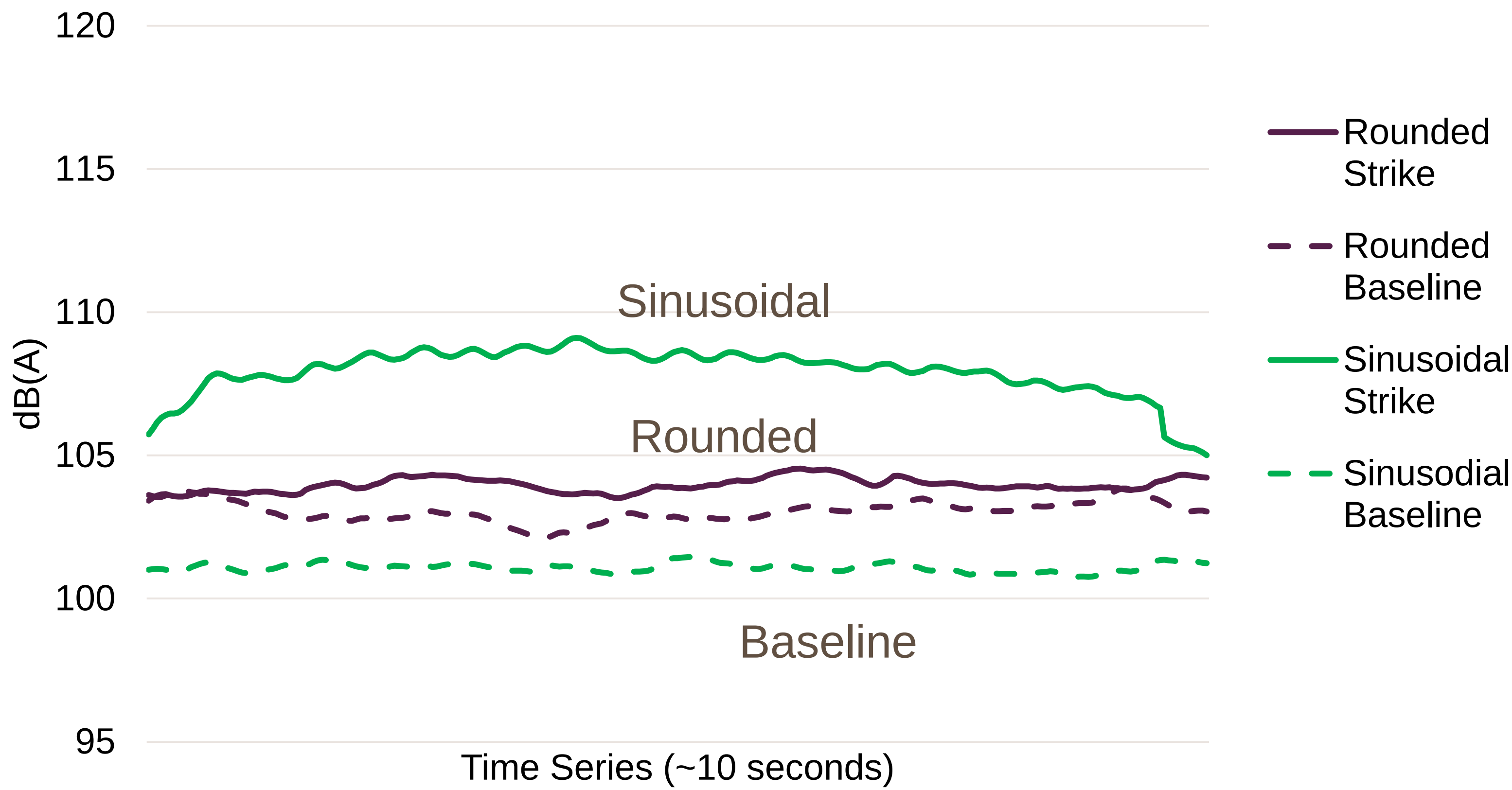
Interior Measurement: Van



Van RS Interior Comparison

Interior Measurement: Heavy Vehicle



Heavy Vehicle RS Interior Comparison

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