Measuring the Noise & Vibration Response of Vehicles to Rumble Strips

By

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MISSOULA

ILLINGWORTH & RODKIN, INC.
Acoustics • Air Quality

California Hwy Patrol Academy Test Track

Safe & Quiet Site

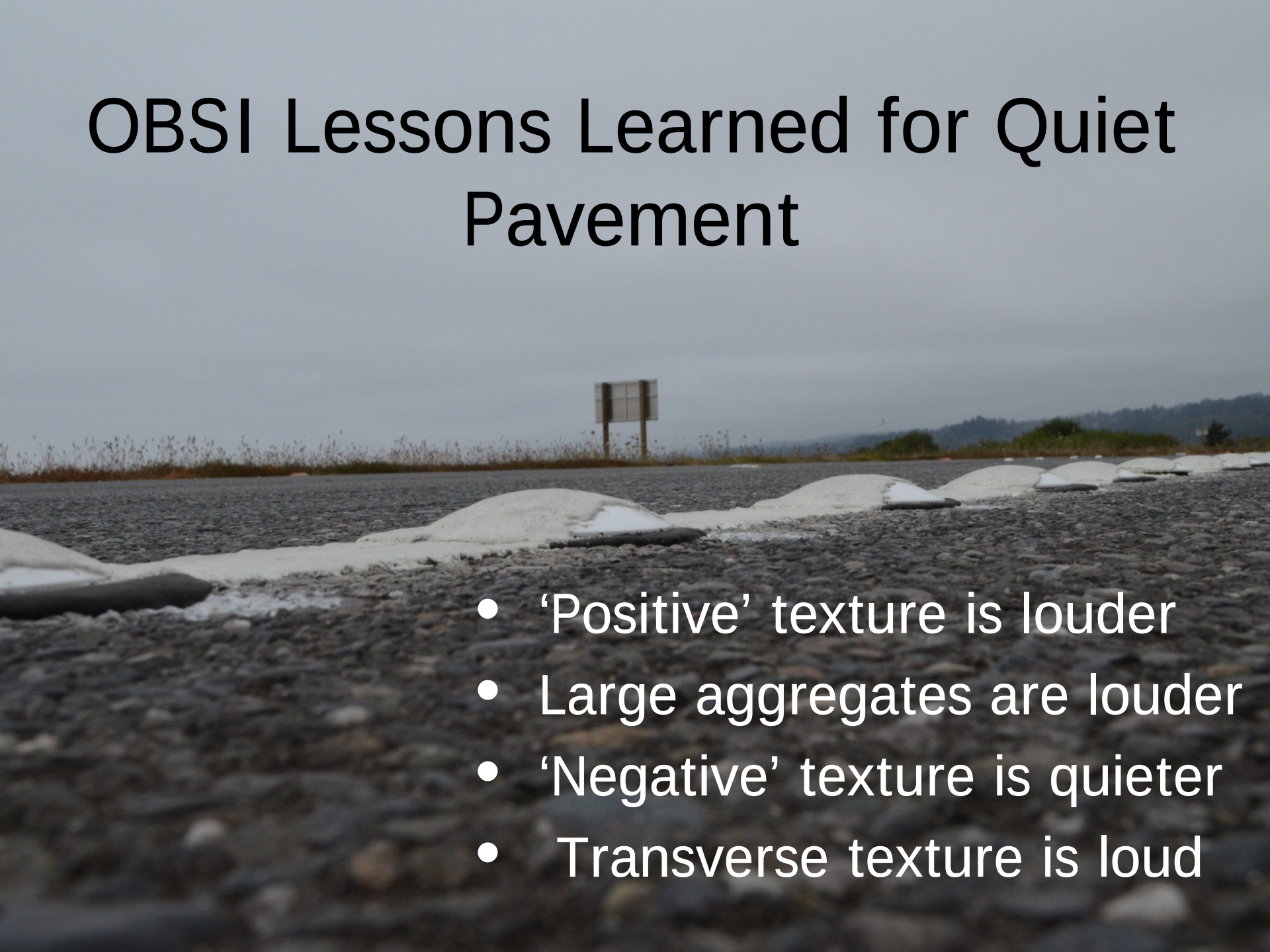
OBSI Development

AASHTO TP-76

Overview - Caltrans 'Mumble Strip' Development Time Line

May-01	Caltrans Rumble Study at CHP Test Track under Caltrans Safety Engineer, Craig Copelan
29-Aug-01	Internoise paper by Watts, et. al., from TRL, Optimization of Traffic Calming Surfaces
7/23/2007	DRI Jorgen Kragh INCE presentation on Low Noise Rumble Strips on Roads - Pilot Study
2009	Acousticians from Danish Road Institute on Caltrans sabbatical discuss rumble strip issues. They coin the term 'mumble strip'.
1-Jan-09	District 1 (D1) requests HQ design guidance for developing rumble strips which produce lower roadside noise levels.
4-Aug-09	Dr. Donavan writes 7 page Recommendation for Initial Quiet Rumble Strip Design
Fall 2009	D-1 develops plansheets based on Paul's Recommendation Design Memo
to	D-1 goes thru design, PS&E, Traffic Ops review iterations refining application of concept
Summer 2012	D-1 constructs demonstration project for testing mumble strip design; requests follow up measurements to verify.
5-Mar-12	Caltrans DRISI Rumble Synthesis finalized
17-Sep-12	HQ measures mumble strips in D1 under contract 43A0269. Many complex measurements taken.

OBSI Lessons Learned for Quiet Pavement



- ‘Positive’ texture is louder
- Large aggregates are louder
- ‘Negative’ texture is quieter
- Transverse texture is loud

Rumble Strip Design Needs

- Maintain or Increase Interior S & V Levels
- Lower Roadside Noise Levels
- Bicycle Friendly
- Fit Within Roadway X-section
- Limit Depth of Material Removal
- Cost Effective
- Easy to Construct


Many Rumble Strip Studies have ‘Fatal’ Acoustic Flaws
Applying for a US Patent


Paul --

Conflicting Requirements

Produce maximum warning signals inside the vehicle

- Audible noise
- Noticeable vibration

Produce minimal disturbance

- Noise outside vehicle
- Vehicle drive dynamics
- Bicycle Users



Evaluation of Mumble & Rumble Strip Designs

Sinusoidal Profile


Cylindrical grinds 12 in on-center

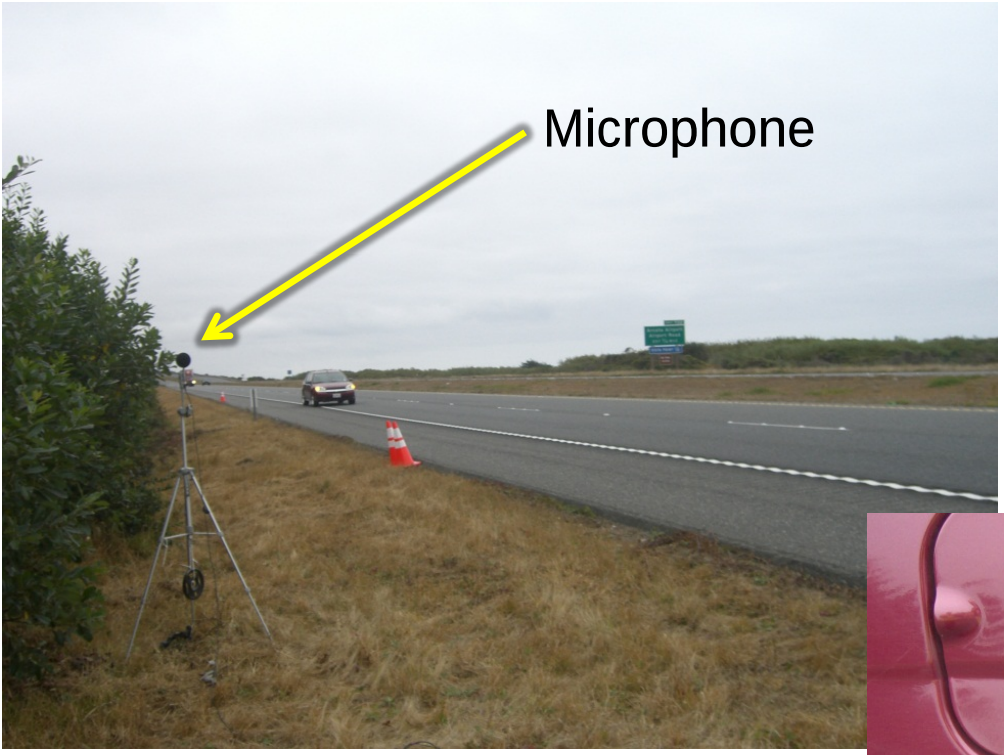
Quieter Rumble Strip Concept

- Move inputs down to lower frequencies
- Avoid abrupt transitions
- Sinusoidal shape to minimize tire distortion
- Patent Pending

Purpose of Measurement Program

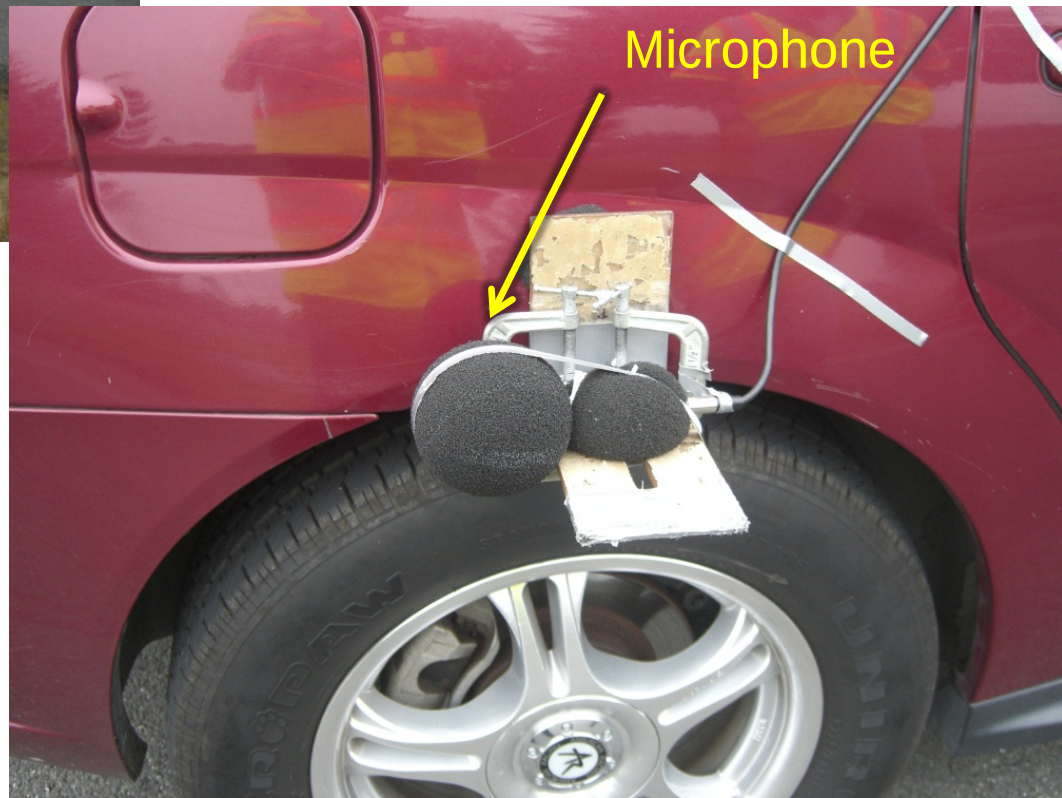
- Compare the performance of the sinusoidal design to a conventional design for
  - Reducing exterior noise
  - Maintaining or increasing operator input both audible & tactile
- Examine response of different vehicle types to rumble strips
- Assess different measurement methods

Exterior Noise Measurements



Pass-by Noise

7.5m from centerline of test vehicle path, on & off strips



Exterior Noise

On-board above right rear wheel well

Interior Noise Measurements

Interior Noise

Passenger head position

Interior Noise

Middle of truck cab

Vibration Measurements

Seat Track

Right front passenger seat track rail – measures vehicle structural response

Steering Column

Indicates input to driver's hands on the steering wheel

Test Vehicles - 2012

2005 Chevrolet Malibu

Honda Civic

20, 40, 60 mph

2007 Honda Civic

60 mph

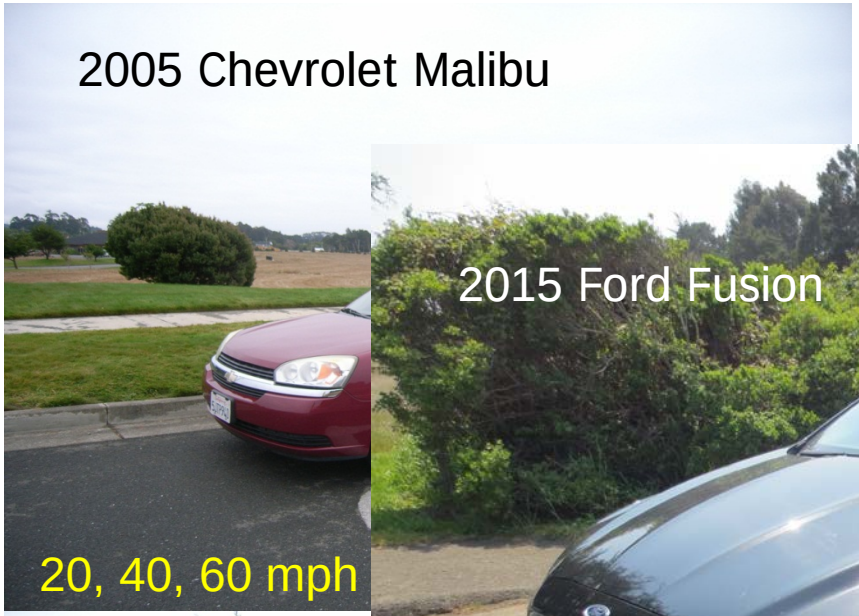
2000 Ford Expedition

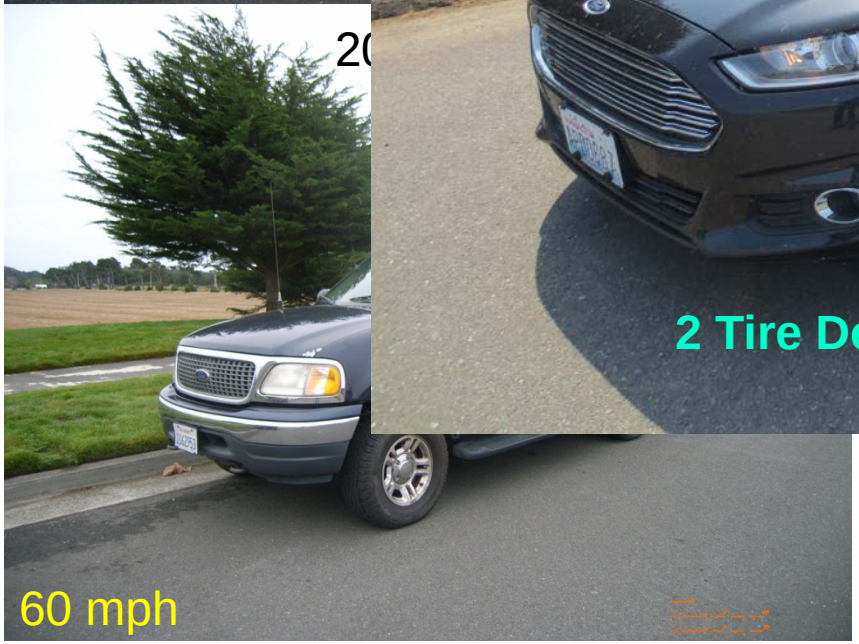
60 mph

International 4 Yard Dump Truck

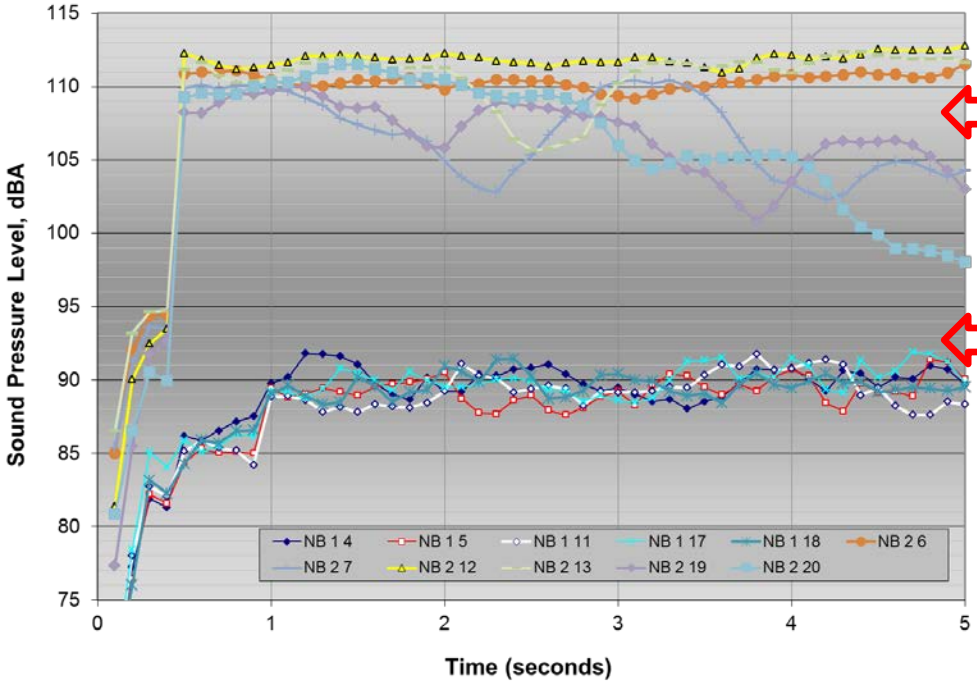
60 mph, no on-board exterior

Test Vehicle - 2015



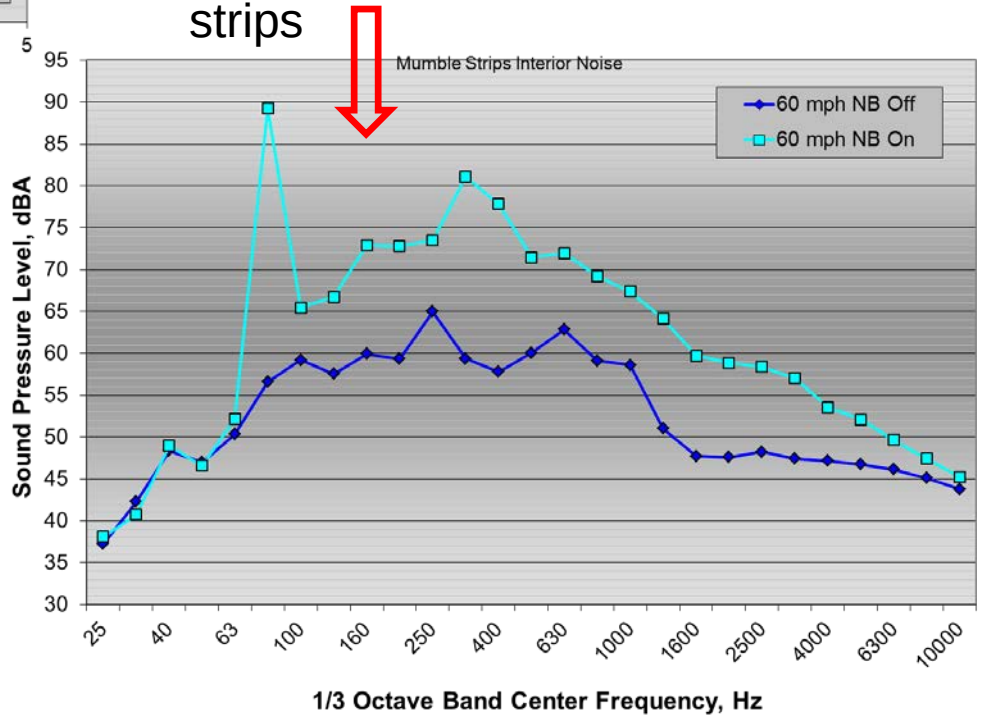


On-Board Data Processing

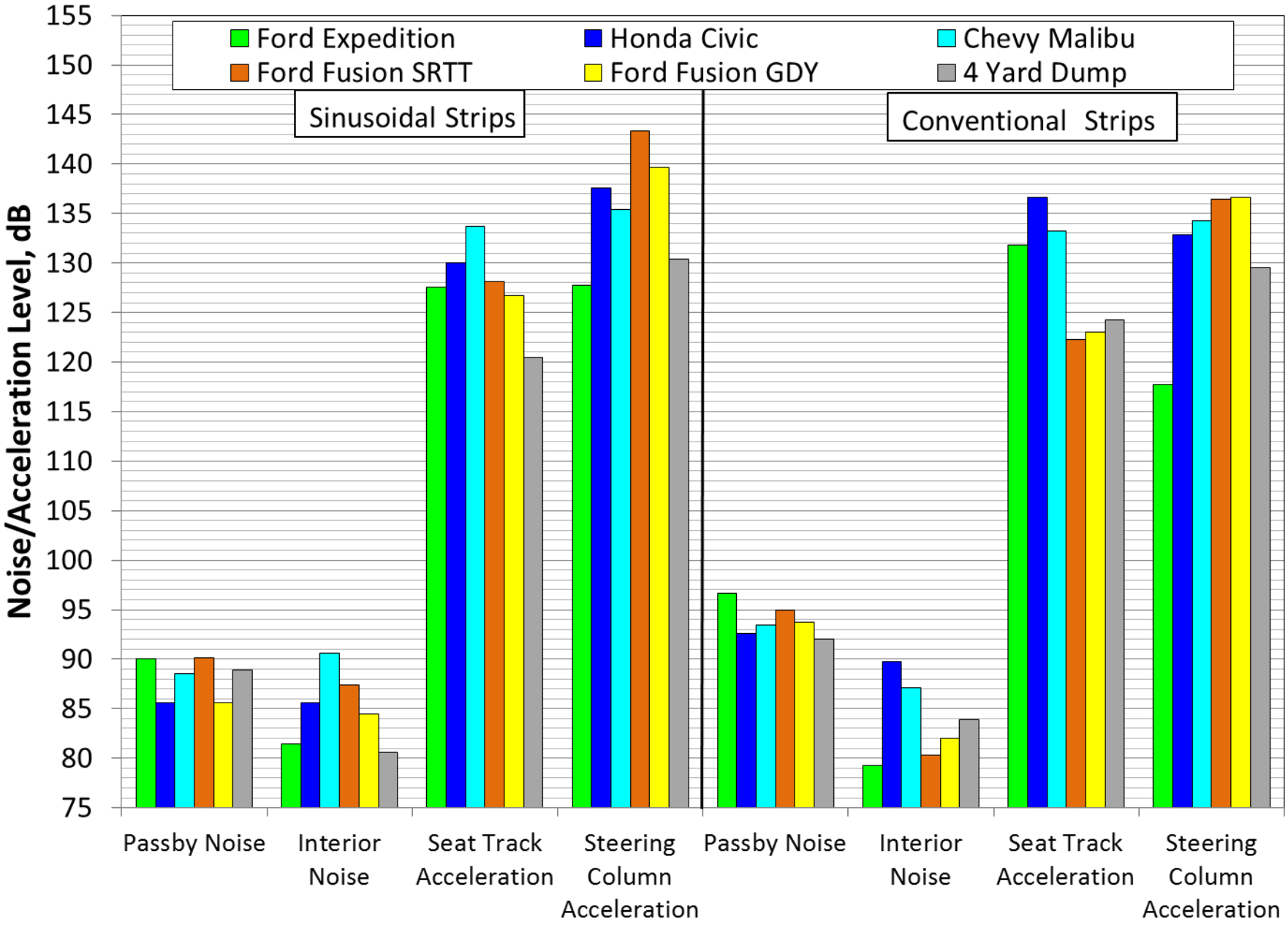


- Select consistent time segment for highest level of on-strip data (e.g. #12, 1.9 to 3.2 sec.)
- Select consistent time segment for lower level of off-strip data (e.g. #11, 2.4 to 3.7 sec.)
- Average ⅓ octave spectra for identified time block for on & off strips

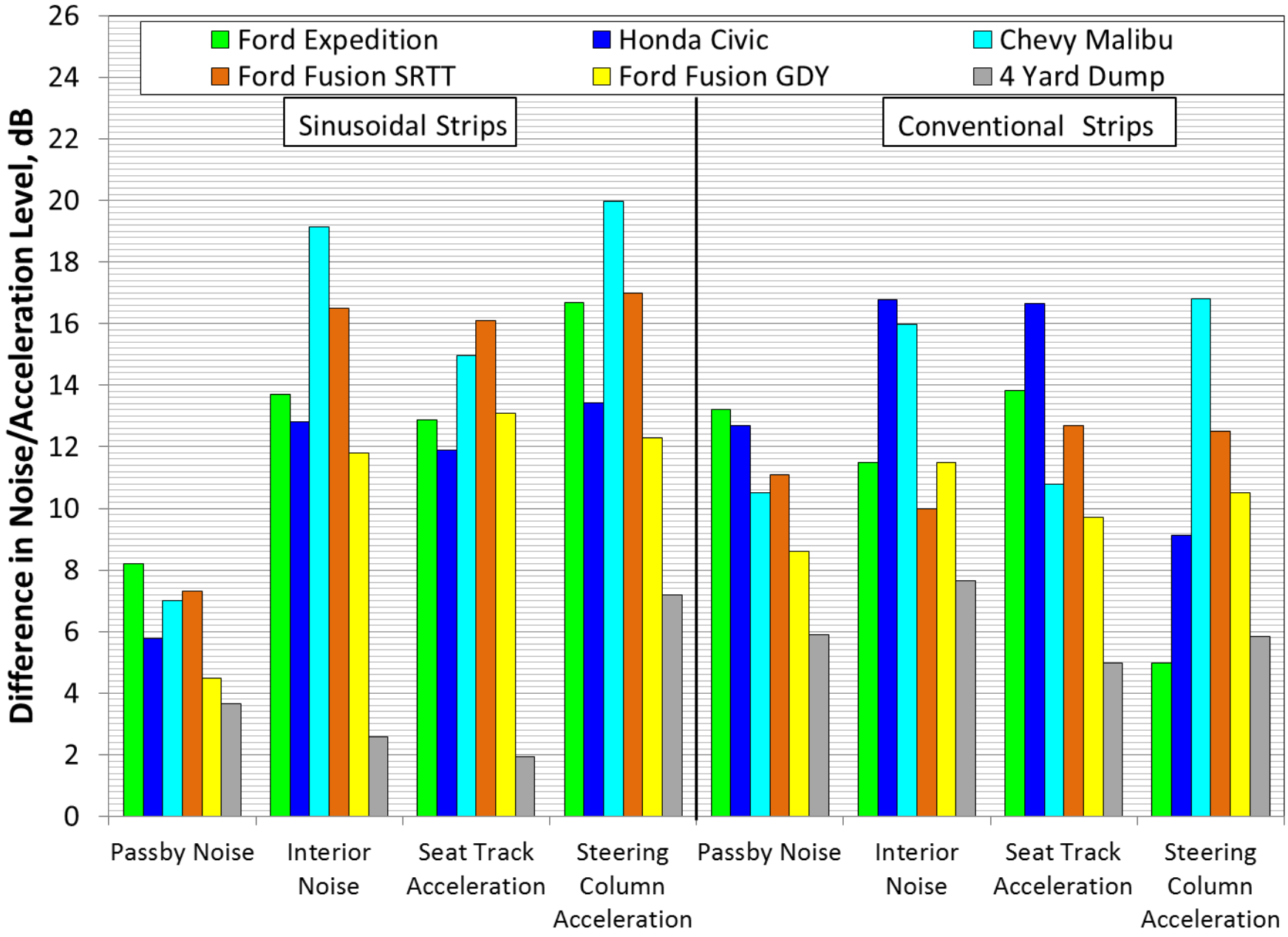
Malibu Interior Noise for On & Off Mumble Strips



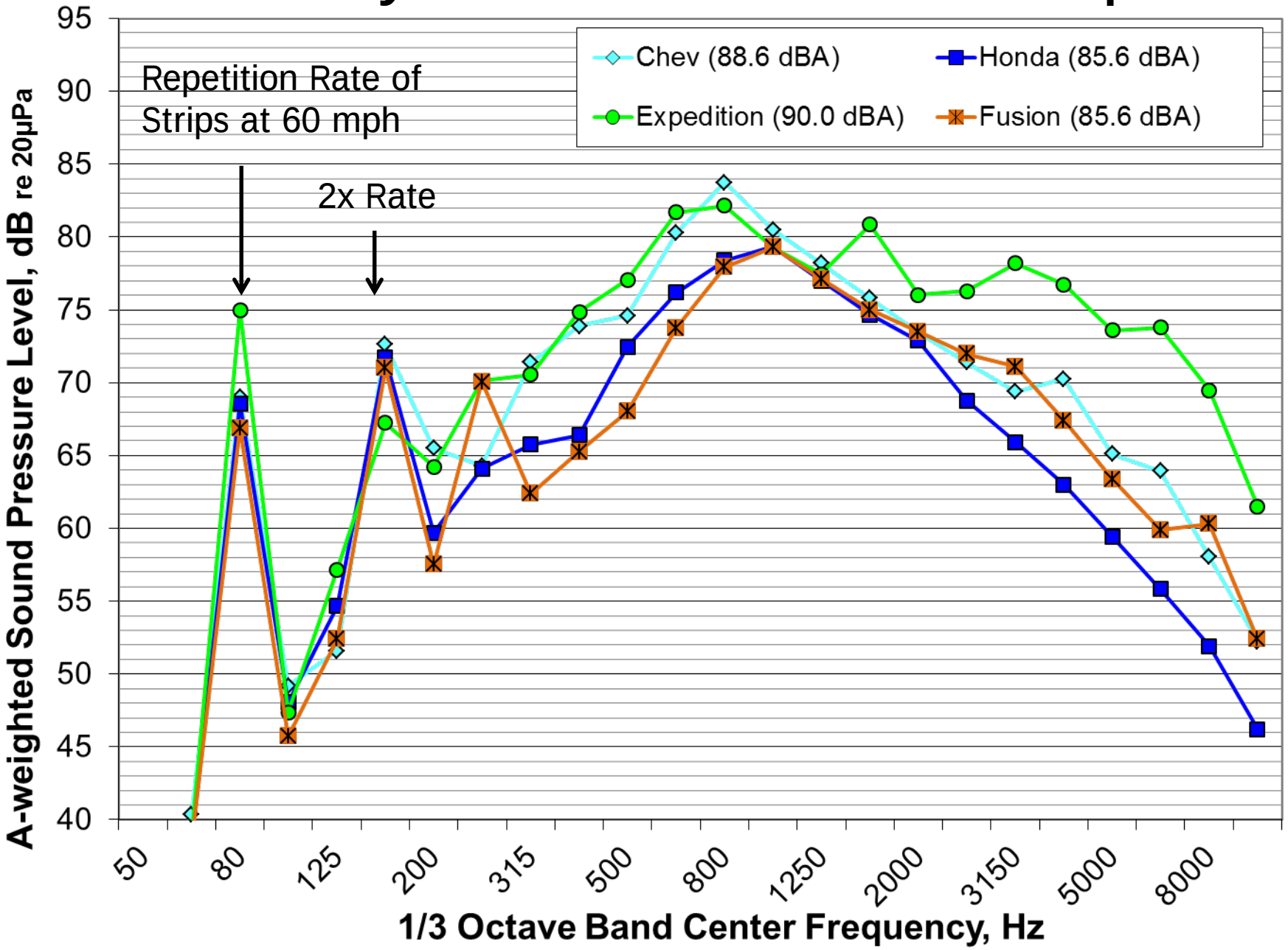
Overall Noise & Vibration Results



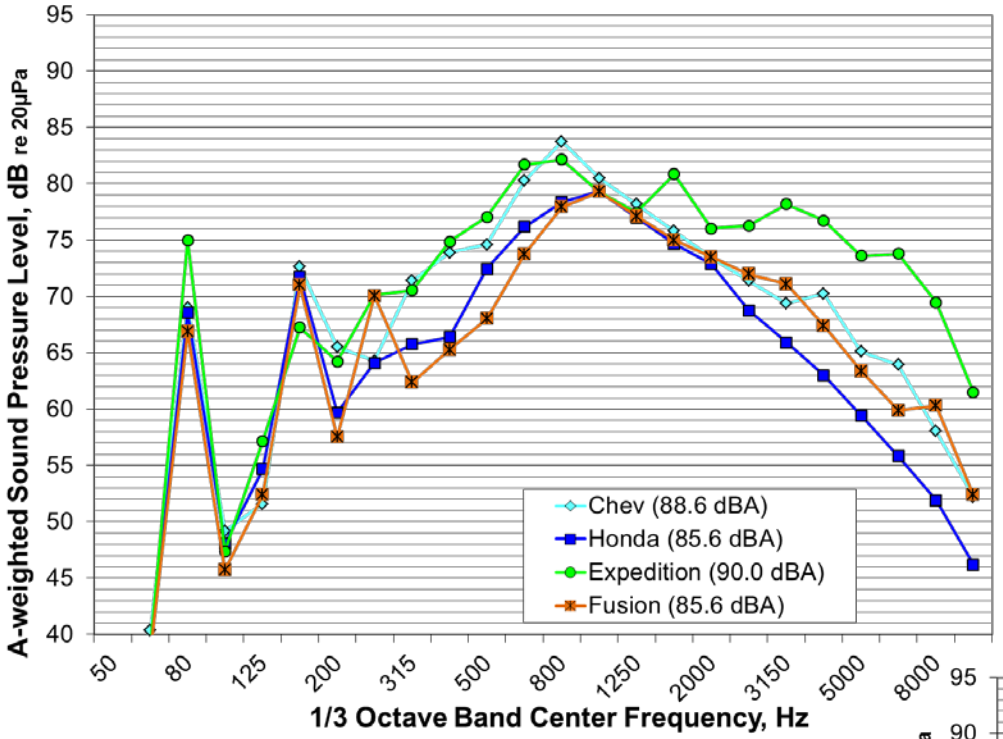
Difference in Noise & Vibration Levels On & Off Strips



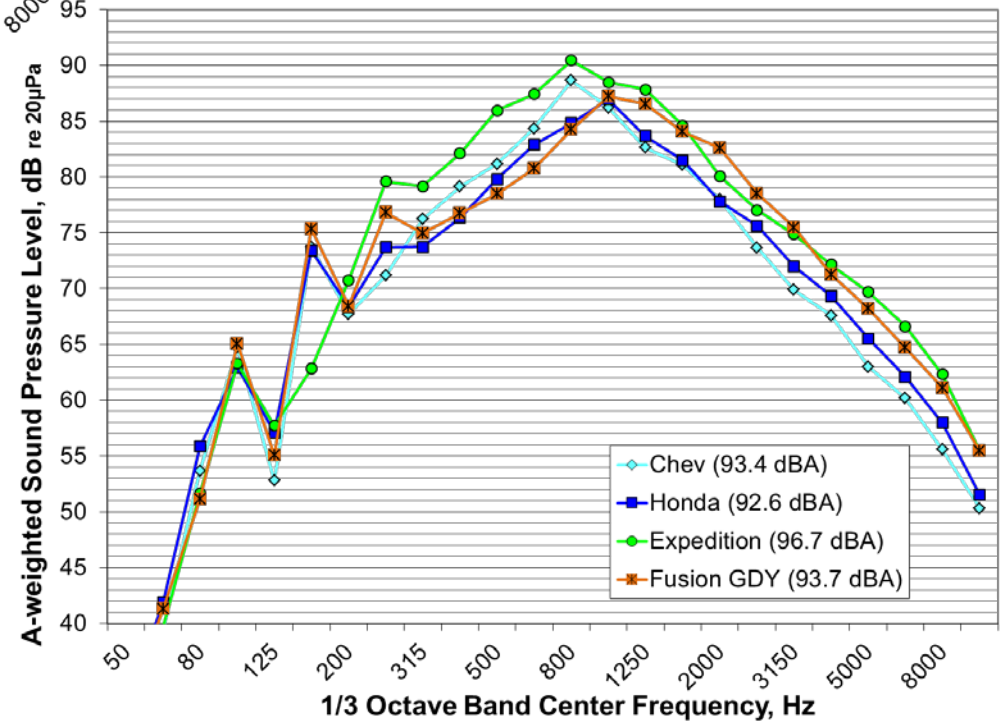
Pass-by Noise on Mumble Strips



Mumble & Ground Strip Pass-by Noise

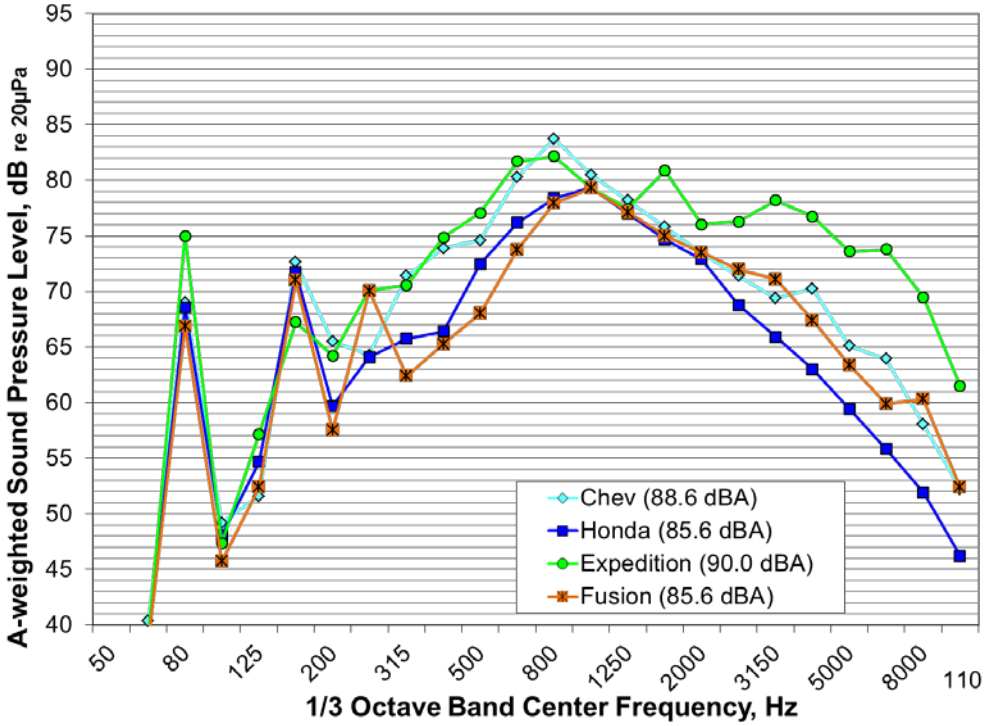


Mumble Strips

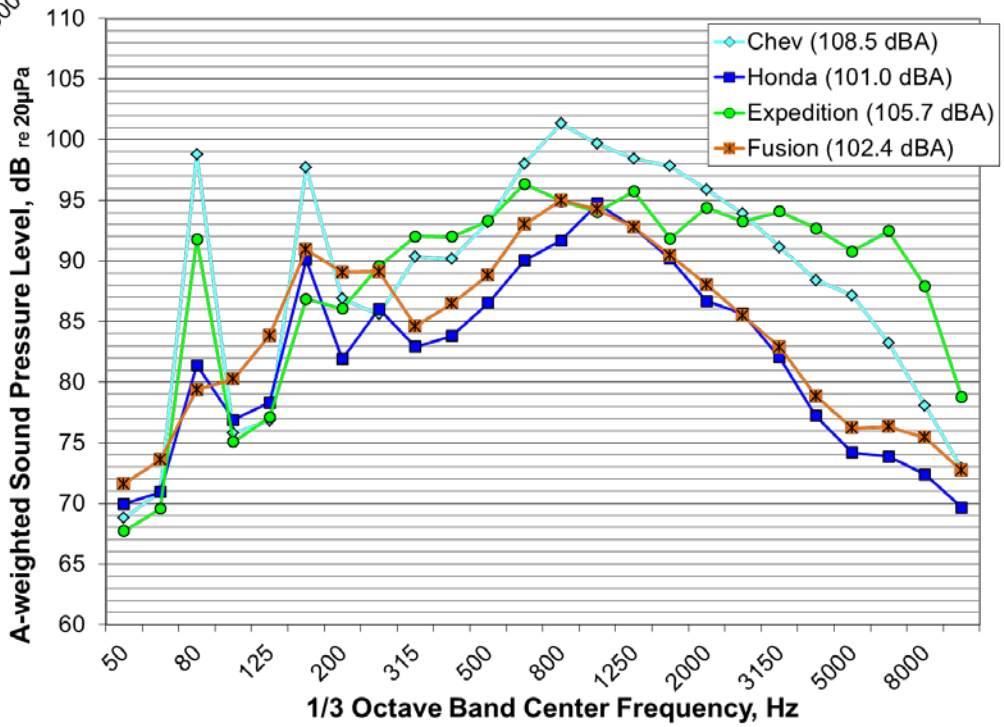


Ground Strips

Pass-by & Exterior Noise for Mumble Strips

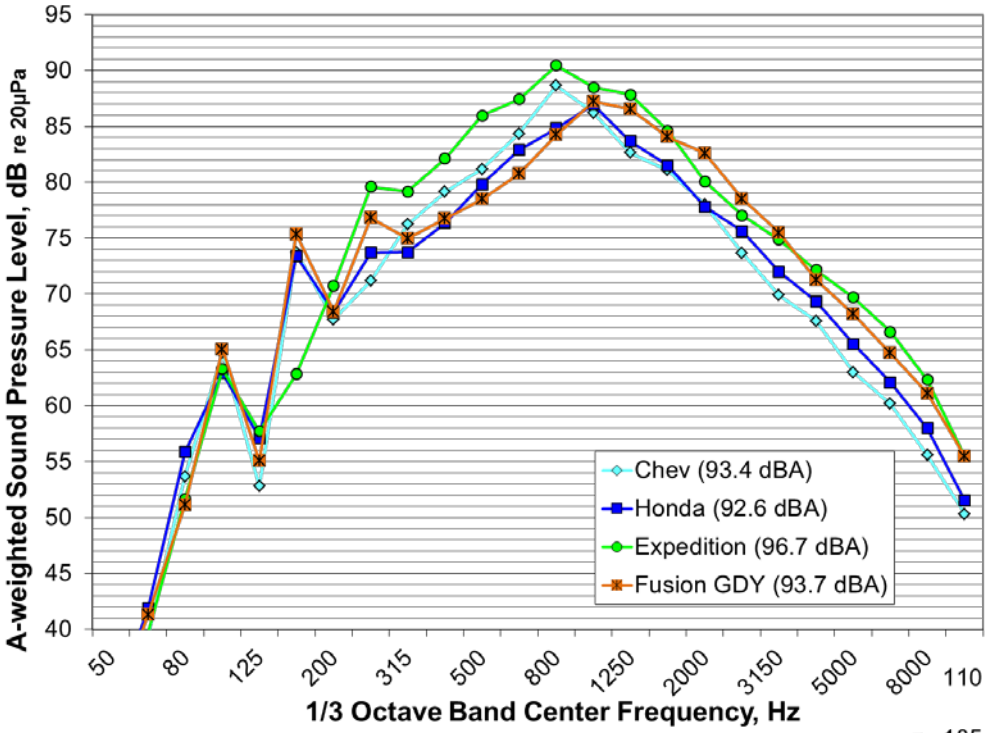


Pass-bys

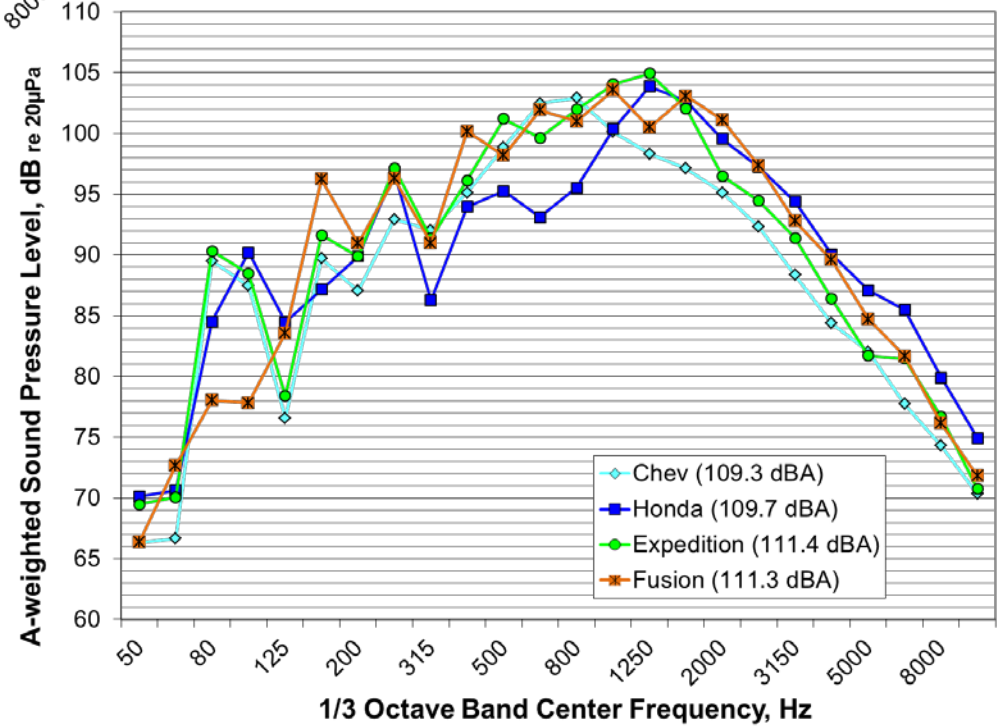


Exterior Noise

Pass-by & Exterior Noise for Ground Strips

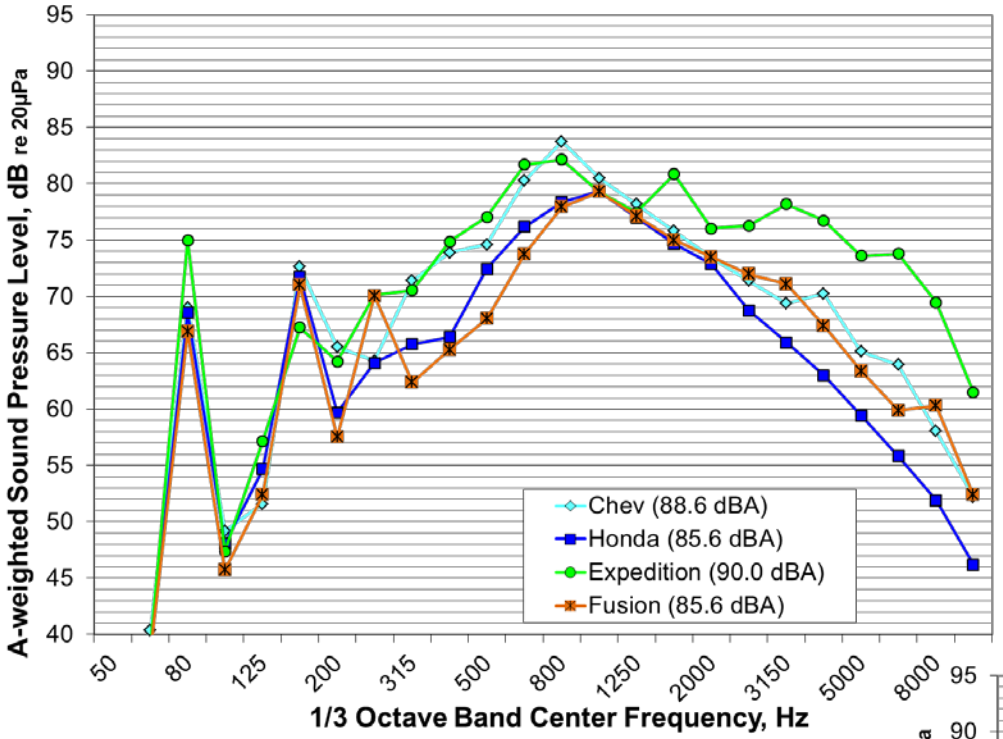


Pass-bys

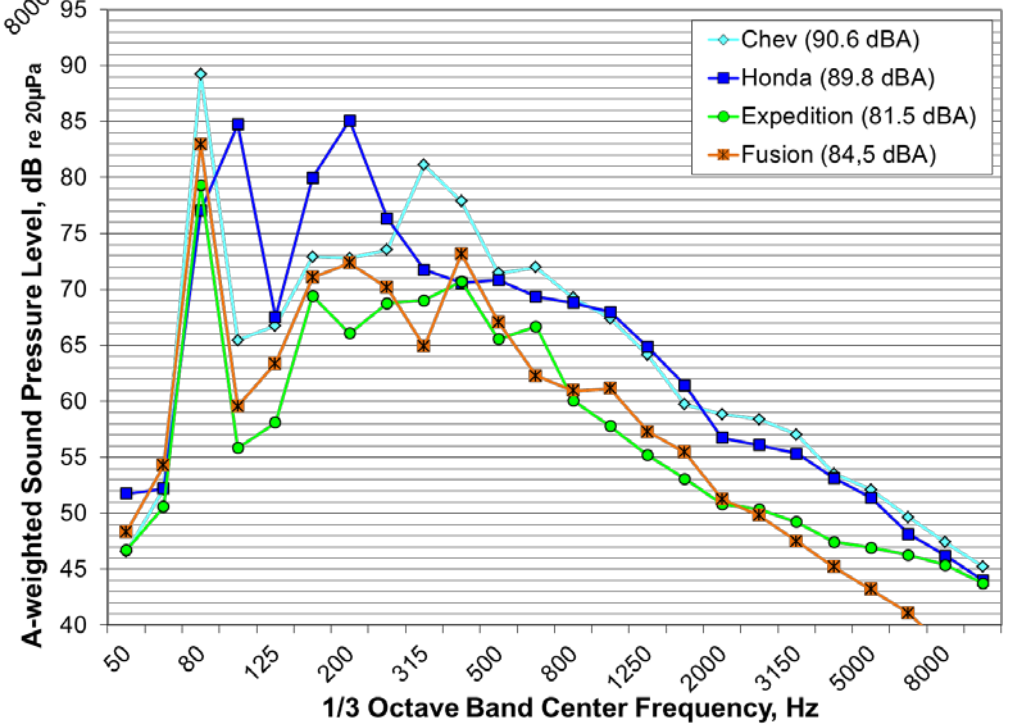


Exterior Noise

Pass-by & Interior Noise for Mumble Strip

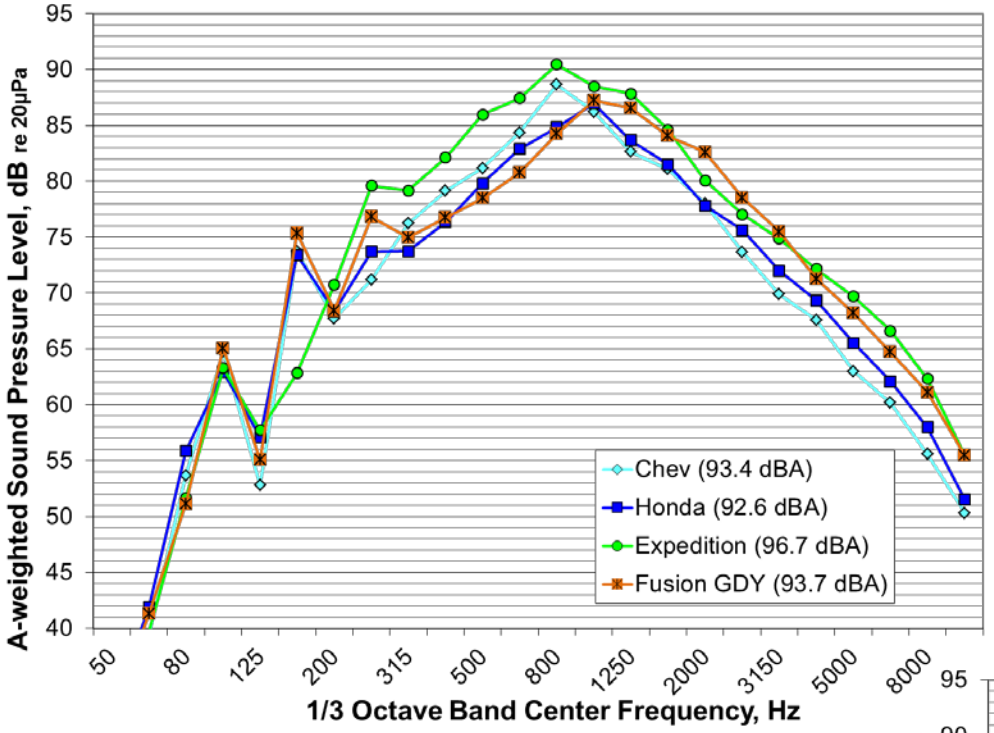


Pass-By Noise

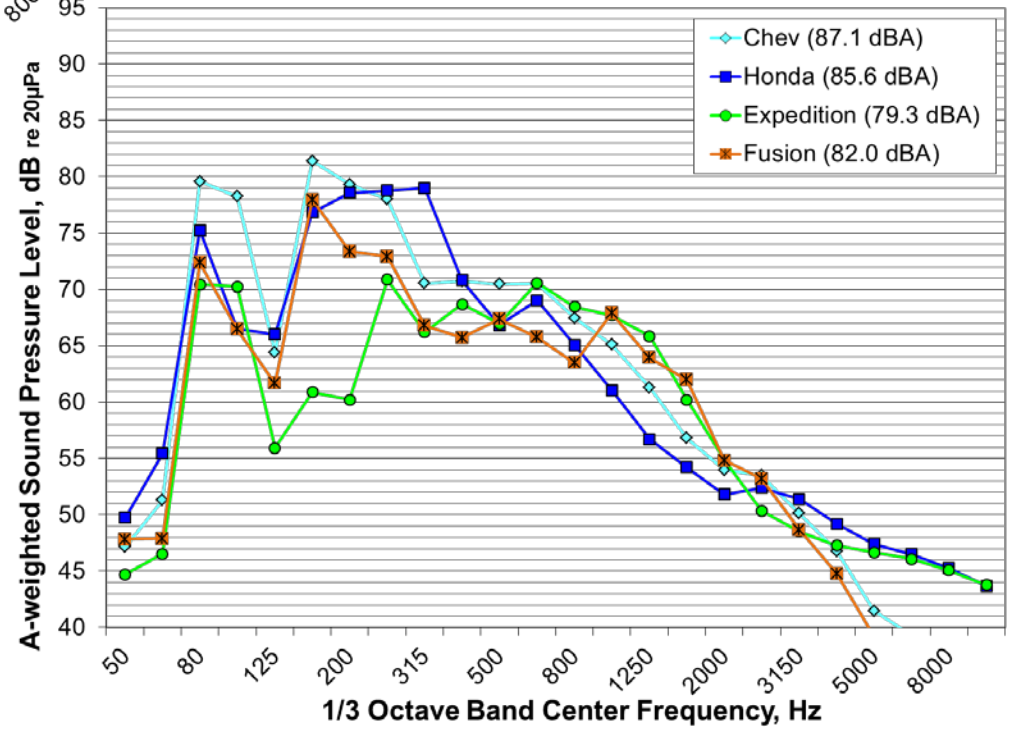


Interior Noise

Pass-by & Interior Noise for Ground Strips

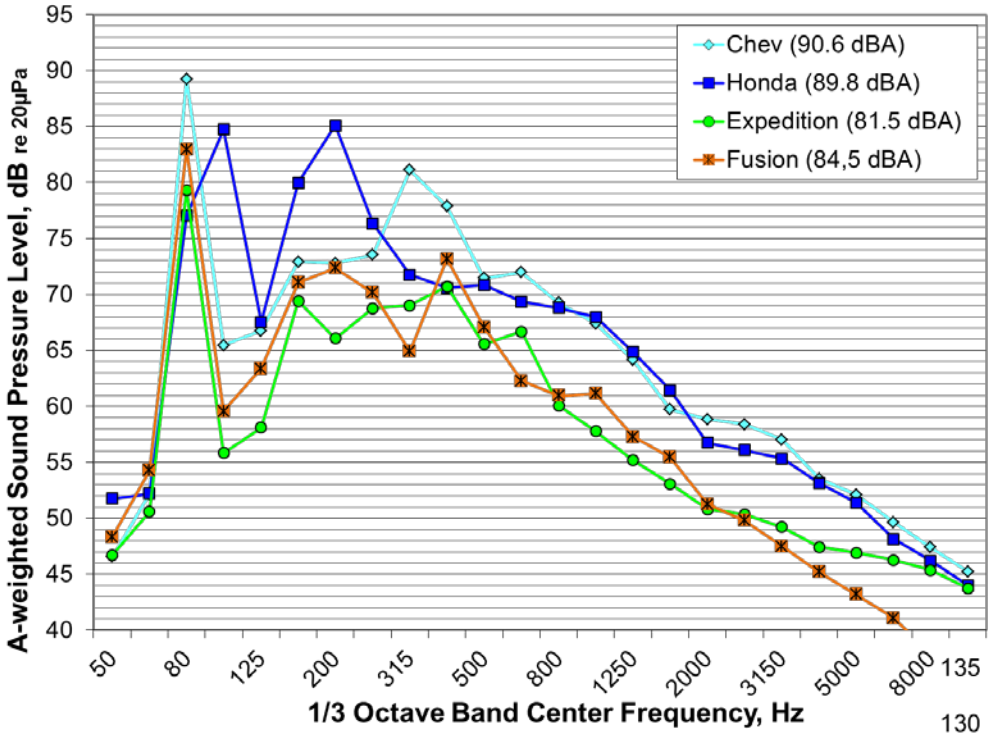


Pass-By Noise

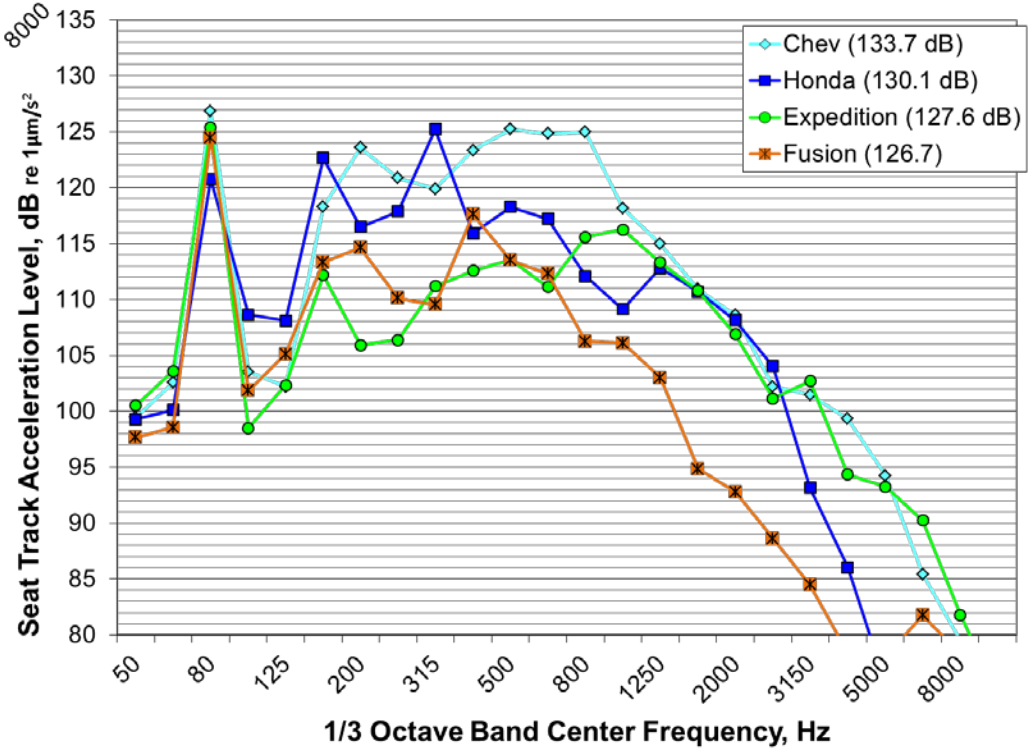


Interior Noise

Interior Noise & Seat Track Vibration for Mumble Strip

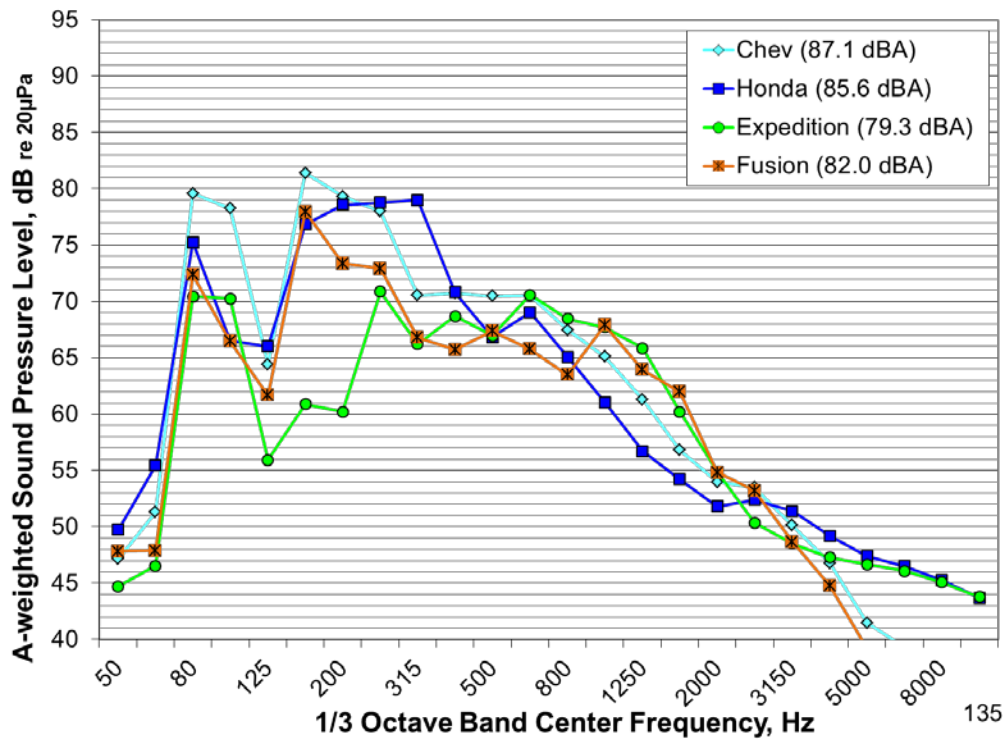


Interior Noise

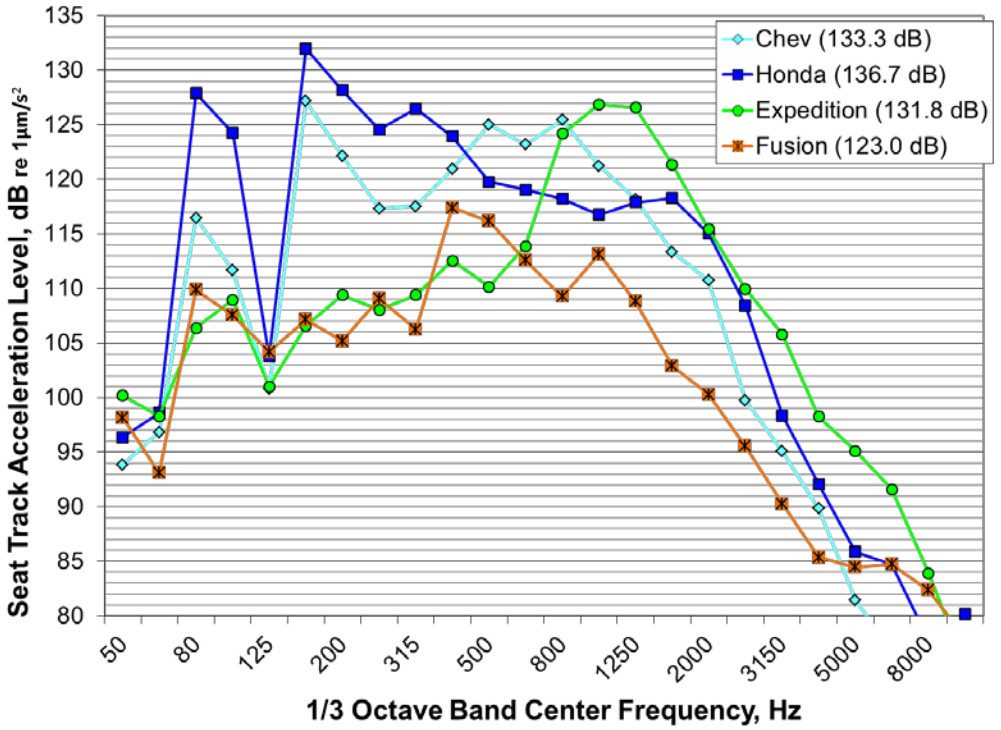


Seat Track Vibration

Interior Noise & Seat Track Vibration for Ground Strips

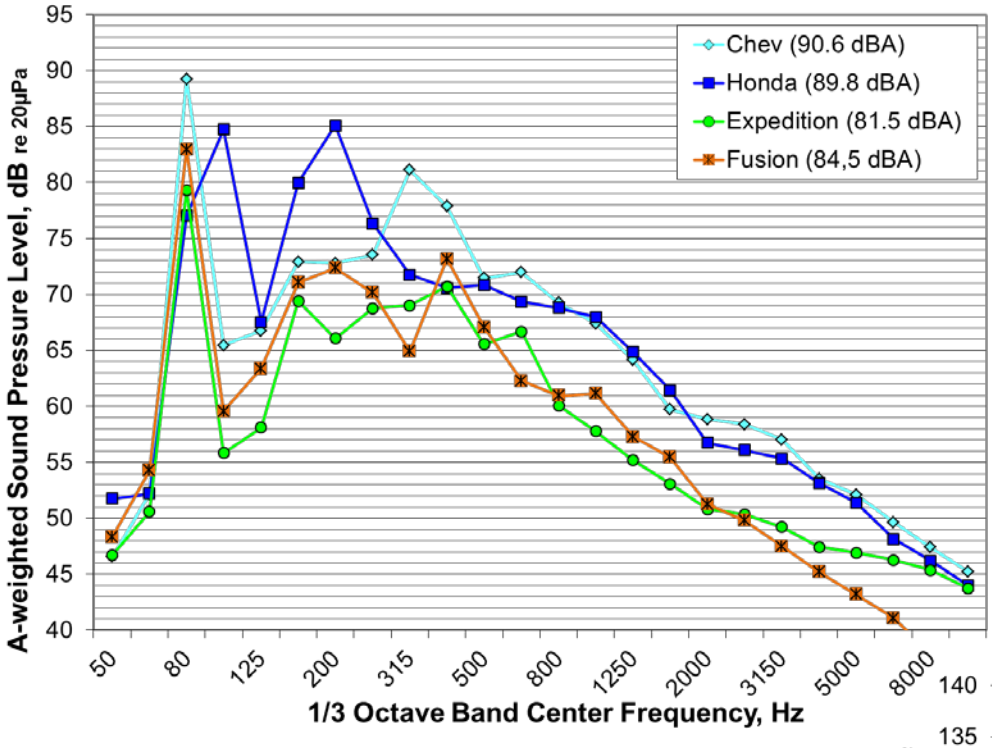


Interior Noise

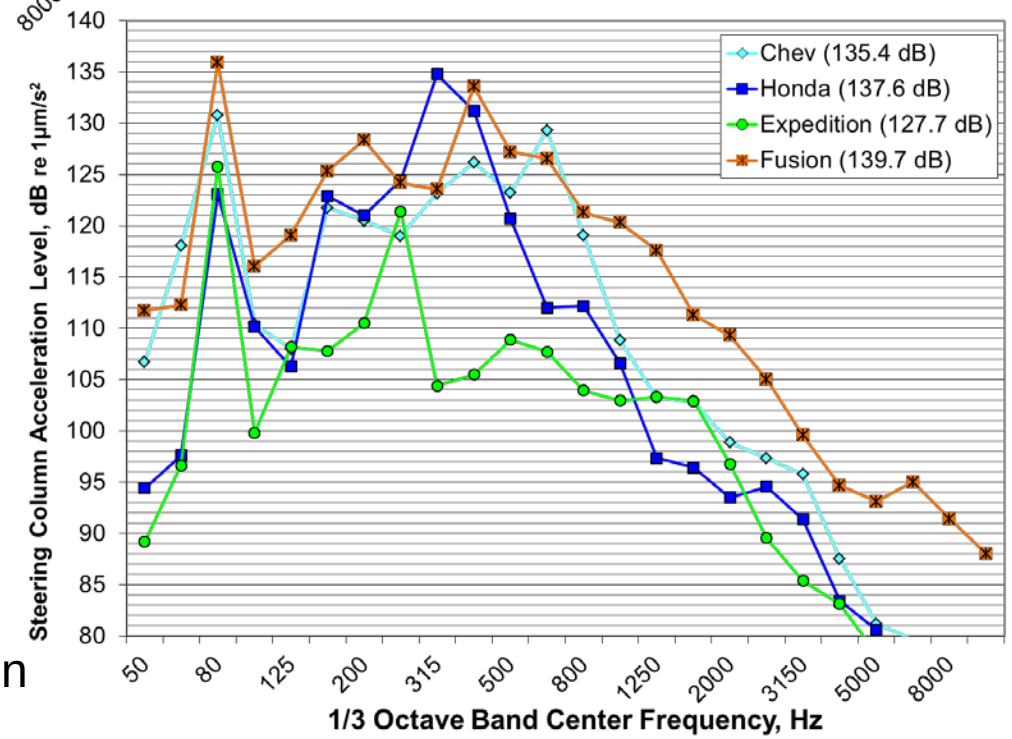


Seat Track Vibration

Interior Noise & Steering Column Vibration for Mumble Strip

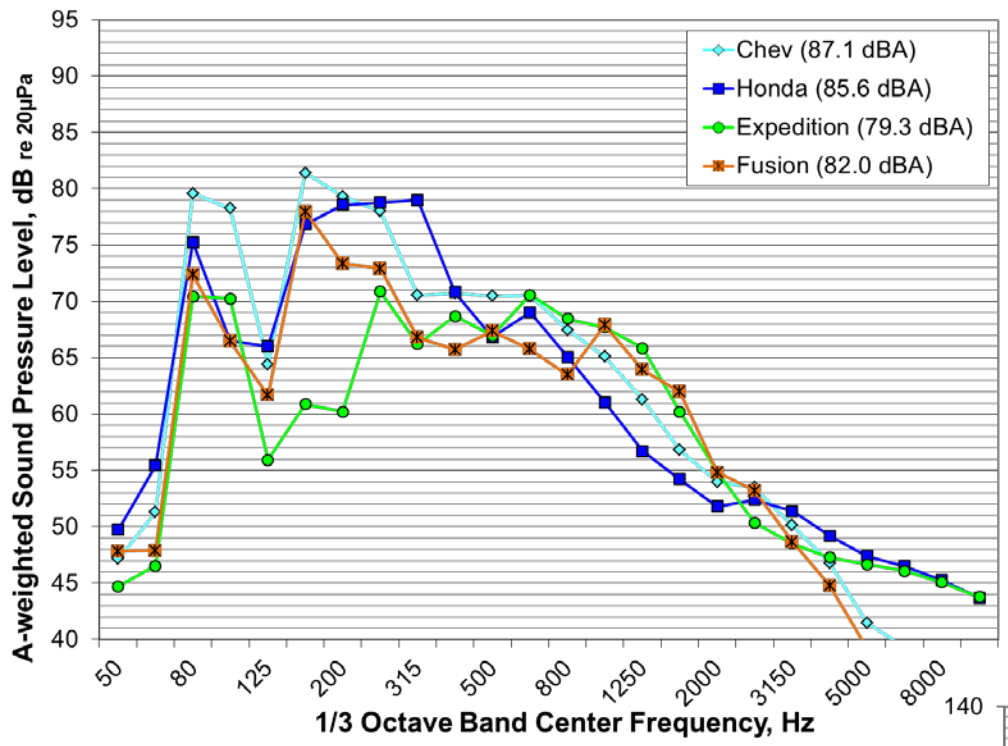


Interior Noise

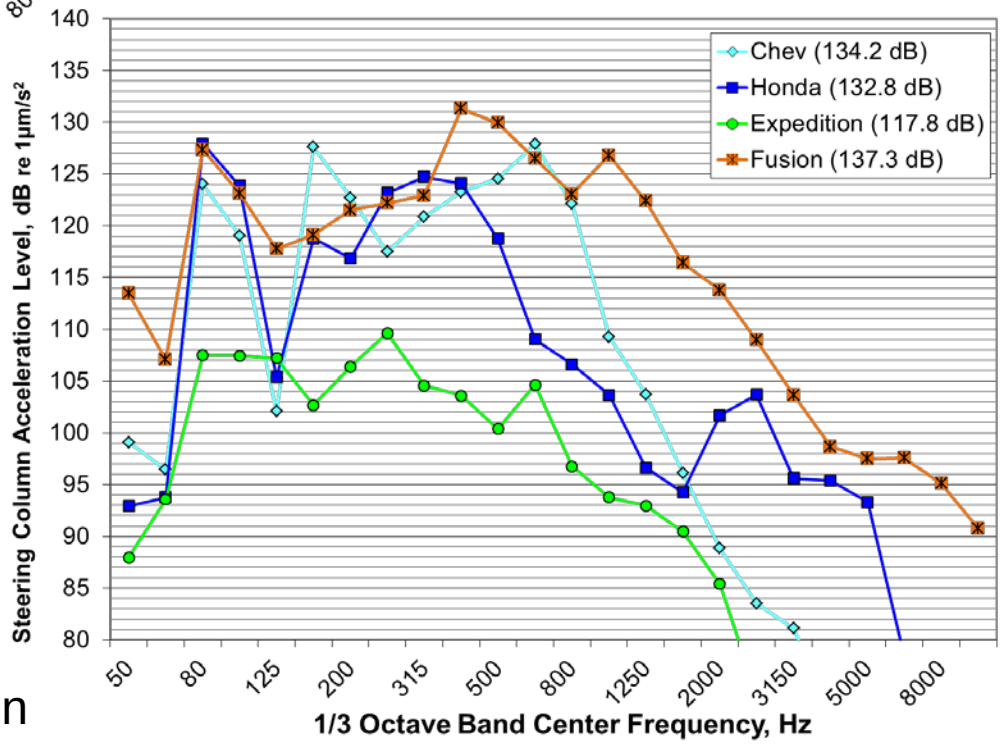


Steering Column Vibration

Interior Noise & Steering Column Vibration for Ground Strips



Interior Noise



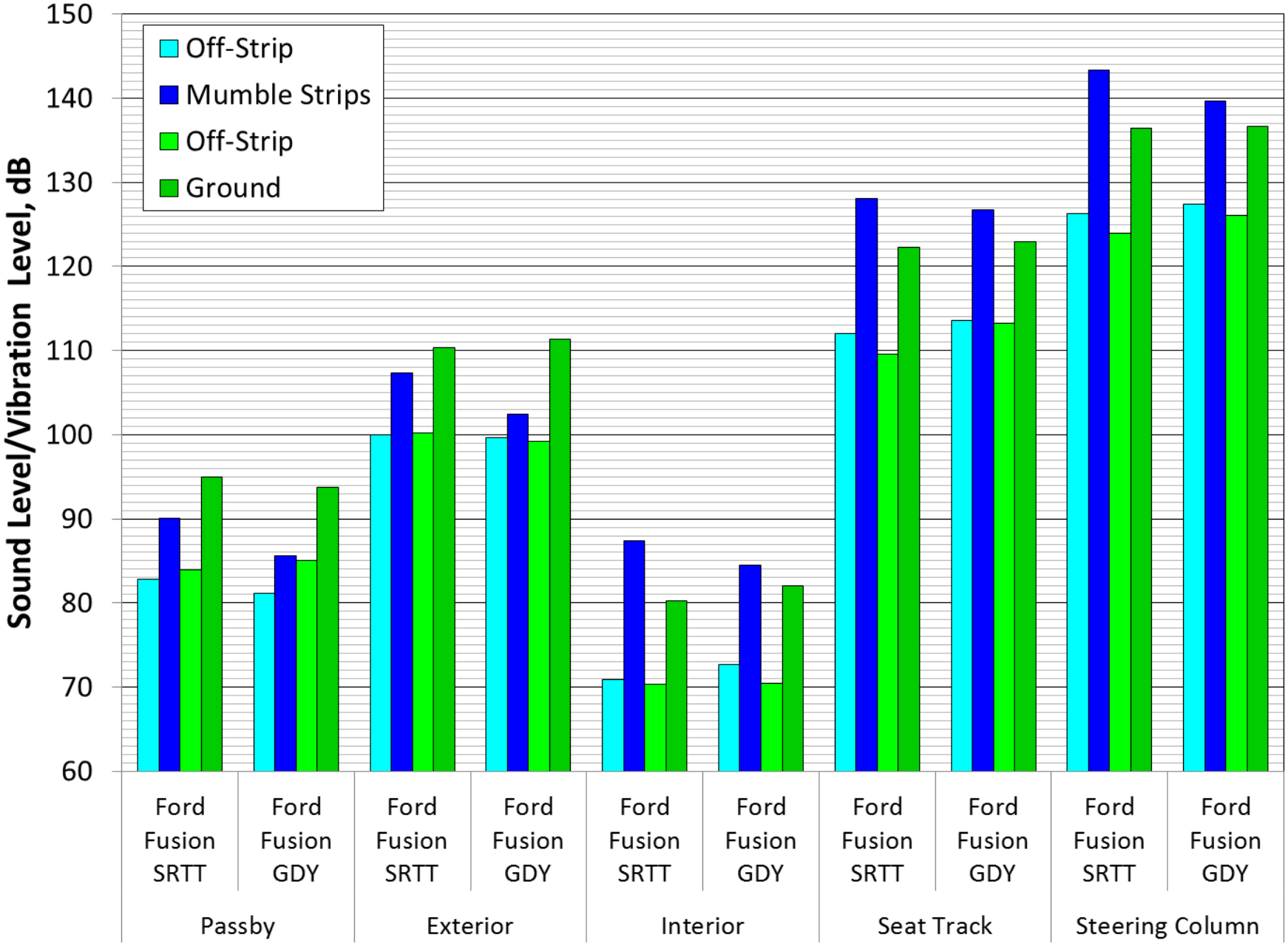
Steering Column Vibration

Ford Fusion Test Tires

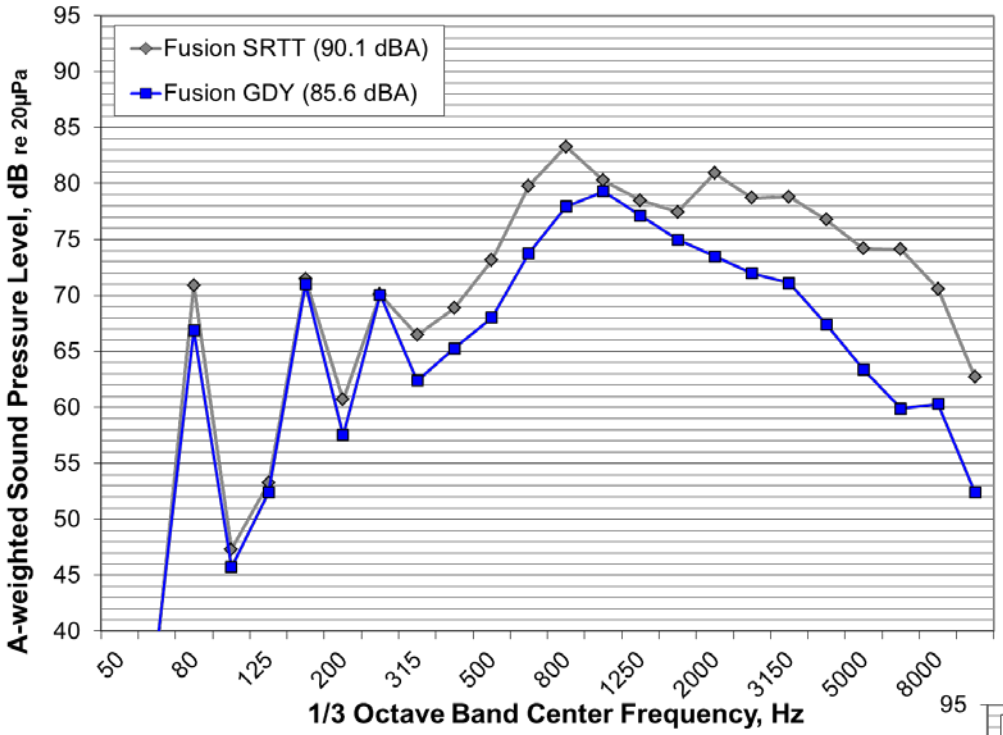
SRTT (Uniroyal)

Eagle LS2 (Goodyear)

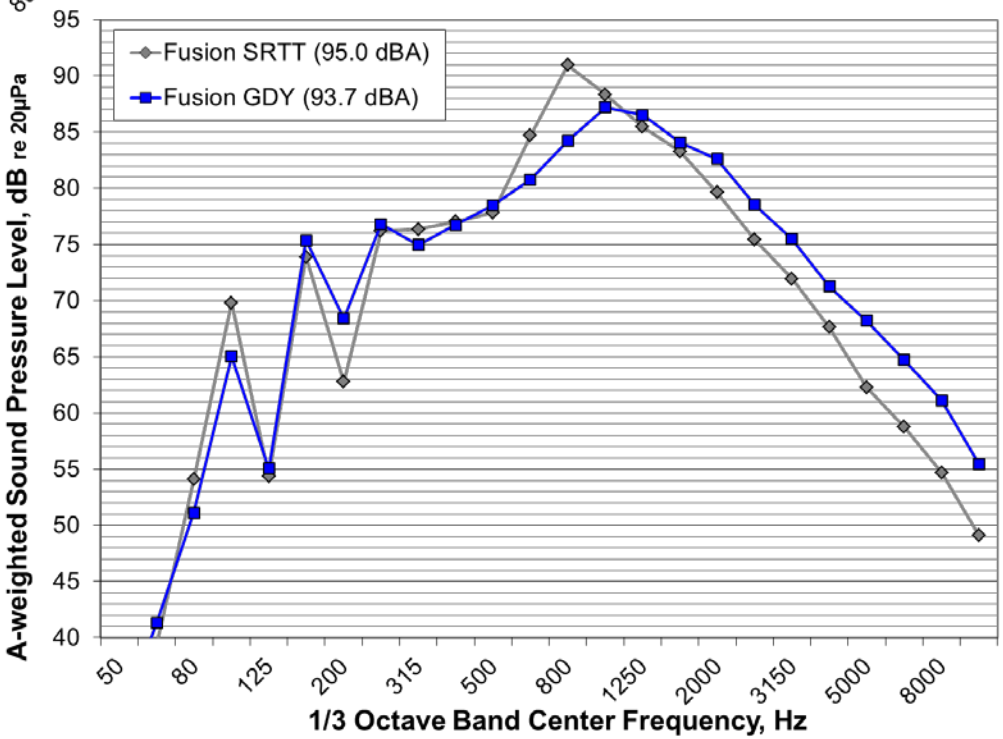
Comparison of Tires – Ford Fusion



Pass-by Noise with Different Tires

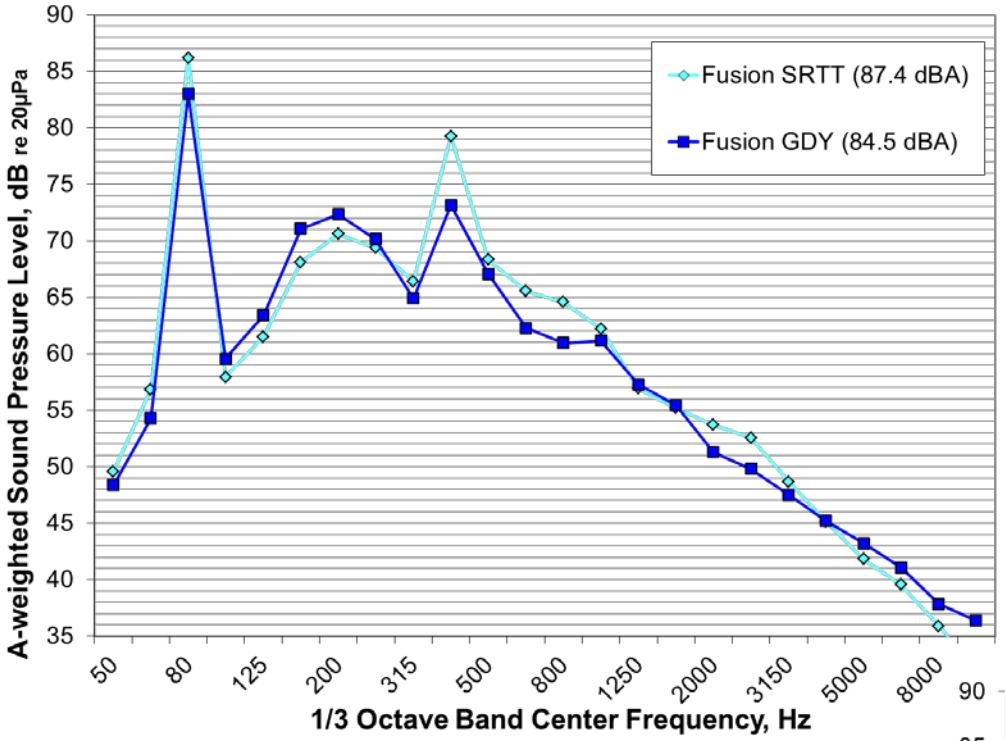


Mumble Strips

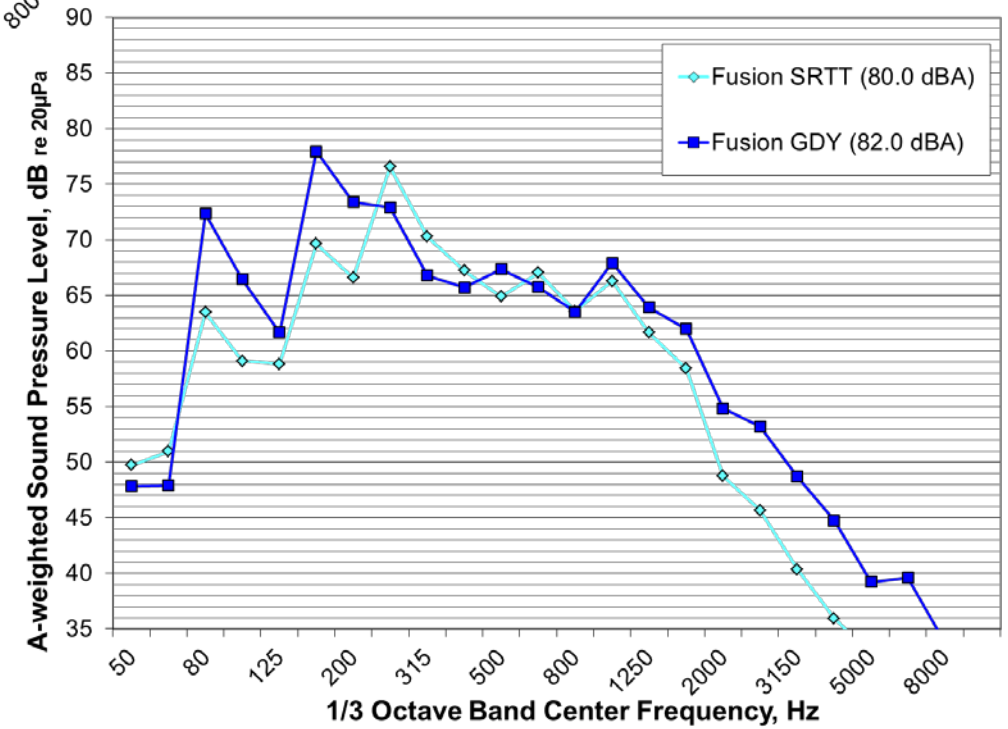


Ground Strips

Interior Noise with Different Tires

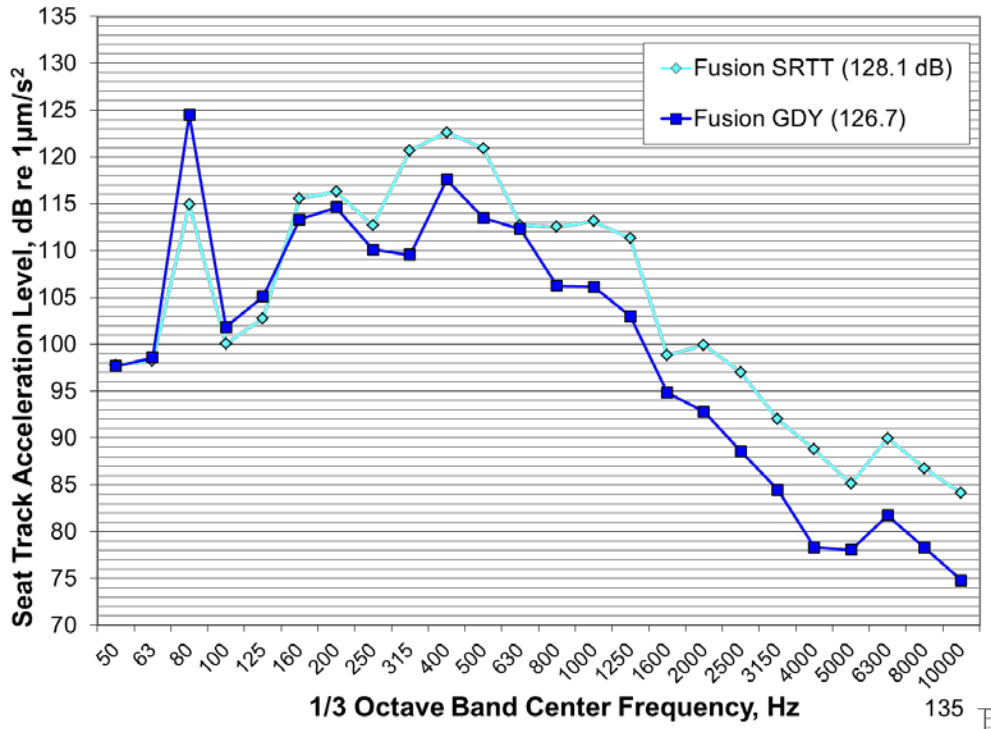


Mumble Strips

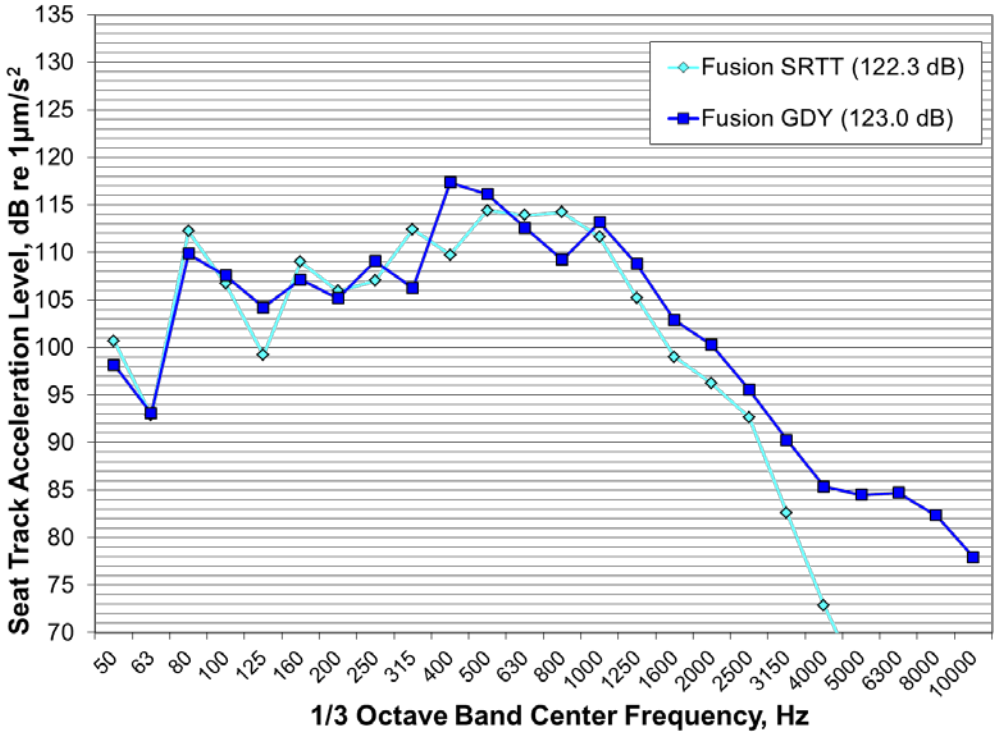


Ground Strips

Seat Track Vibration with Different Tires



Mumble Strips



Ground Strips

Speed Dependence

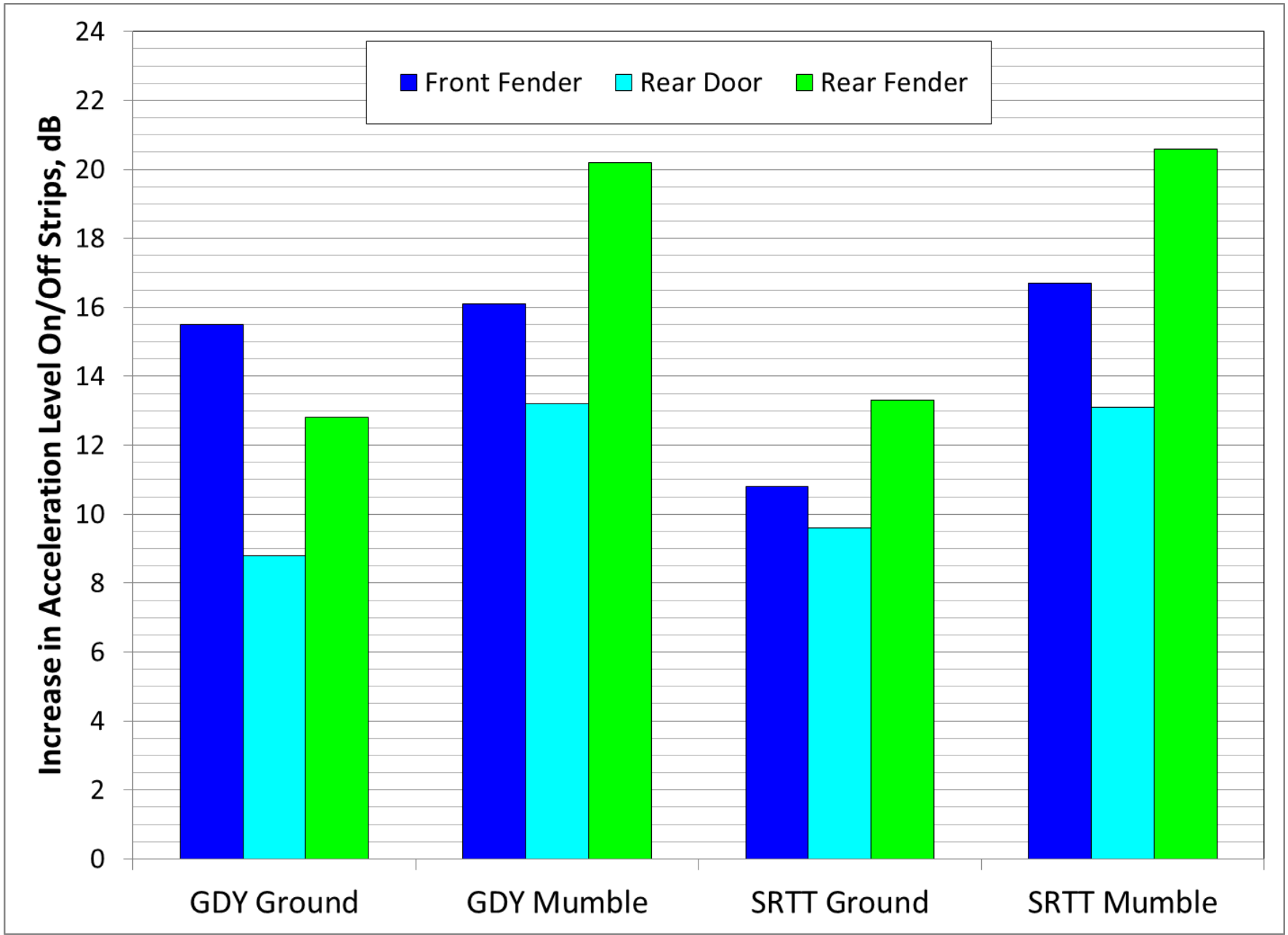
- Performed on Malibu
  - At 20, 40, & 60 mph
  - All data types except pass-by
  - On mumble and ground rumble strips
- Findings
  - Interior disturbance remained adequate at all speeds (noise & vibration)
  - Exterior mumble strip noise consistently lower than ground rumble strips
  - Repetition rate (frequency) shifted with speed as expected

Rumble Strip Tire Noise Sound Intensity

- Severe vibration problems
- Remedied with isolated mounts & holders
- Measurement shows intensity is all negative & not coming from tire
- Body panel vibration measured & suspected source of noise

Panel Vibration Measurements

Panel Vibration On/Off Strips



Summary/Conclusions

- The sinusoidal profile rumble strip reduces pass-by noise while maintaining a comparable level of operator input
- The noise & vibration response to rumble strips varies with different vehicles/tires
- The difference in level on & off strips shows the most promise for setting rumble strip performance requirements
- On-board exterior noise measurements not particularly useful

The End


THANK YOU
FOR
DRIVING SAFELY
STAY BACK!
3500DX
ENERGY ABSORPTION
Caltrans

Rumble Strip Considerations

Positive Aspects

- Reduces frequency & severity of lane & roadway departures
- Can produce 20 to 50% reduction in collisions

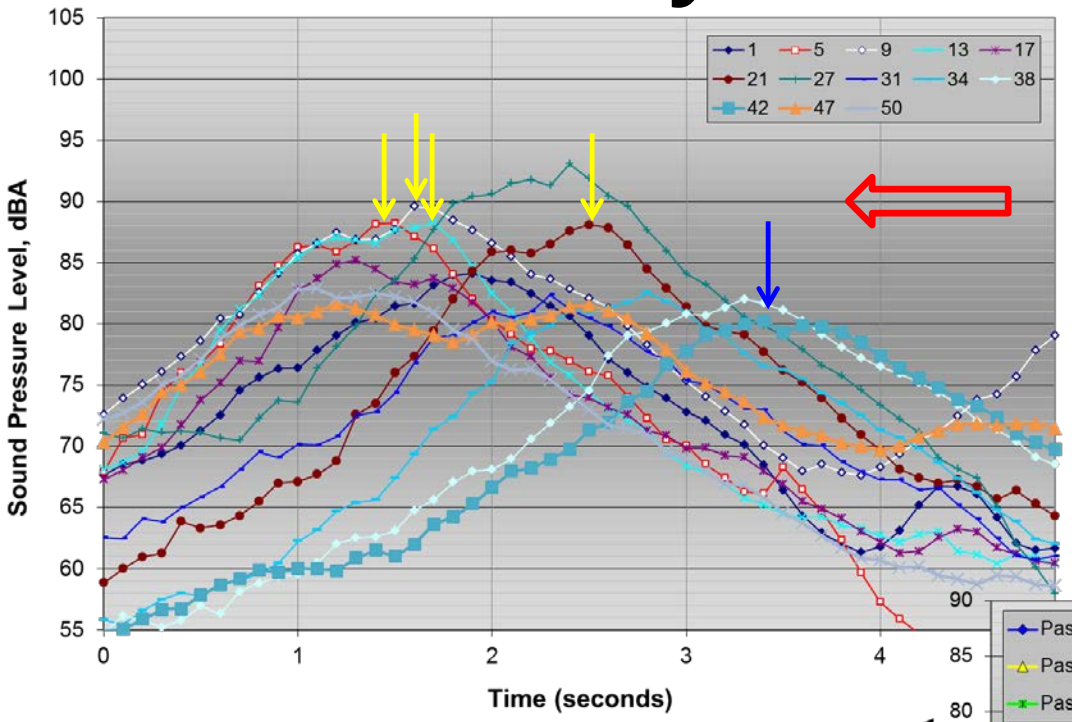
Negative Aspects

- Exterior noise – community, agency, habitats
- Bicyclists – fatigue & loss of control

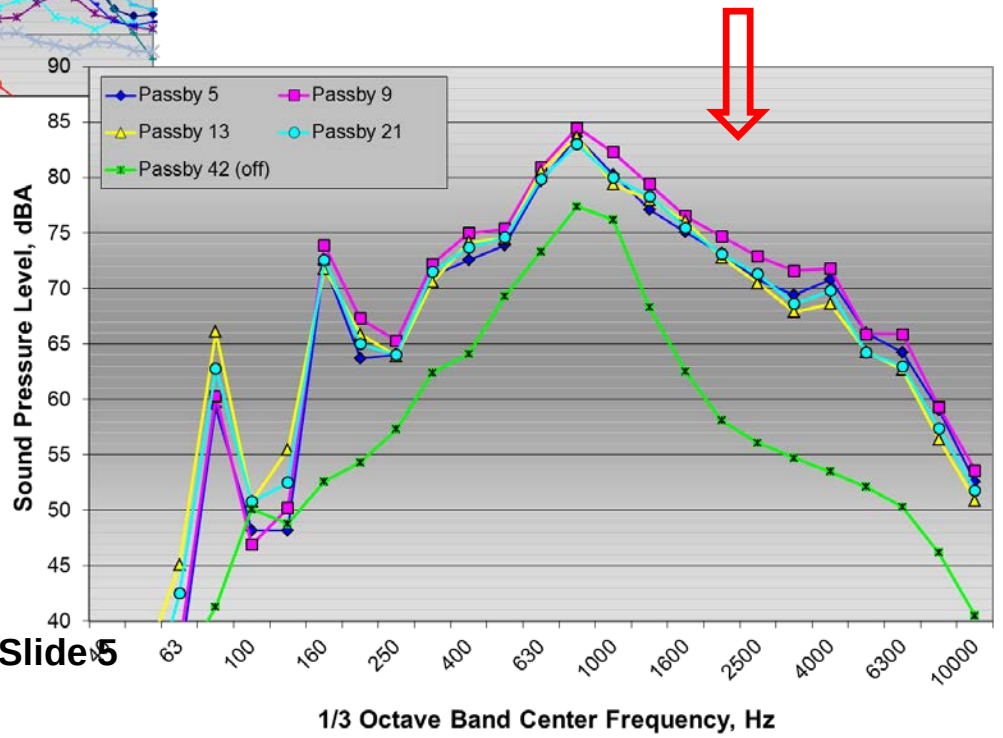
FHWA Initiative

- Encourage more use of rumble strips
- Possibly set standards of amount of operator warning

Pass-by Data Processing



- Select maximum levels on & off strips
- Select typical pass-by for vehicle off the strips (e.g. 42)
- Average on the strip pass-bys to get ⅓ octave spectra & compare to off strip spectra



Consideration for Wavelength

- Minimize lower forcing frequencies, below ~40 Hz to avoid larger vehicle modes and suspension modes
- Maximize forcing frequencies in the range from 40 Hz to 200 Hz where vehicle system vibration modes generate interior noise and vibration
- Avoid forcing frequencies above 200 Hz where exterior sound radiation from tire begins