The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRB
TRANSPORTATION RESEARCH BOARD

TRB WEBINAR PROGRAM

Highway Rumble Strips: Approaches to Balancing Public Safety and Community Noise

Tuesday, March 28, 2017
2:00-3:30 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Discuss how to balance the issues of public safety and community noise with highway rumble strips. The presenters will focus on the practices relative to installation of rumble strips in a manner that will minimize community noise.

Learning Objectives

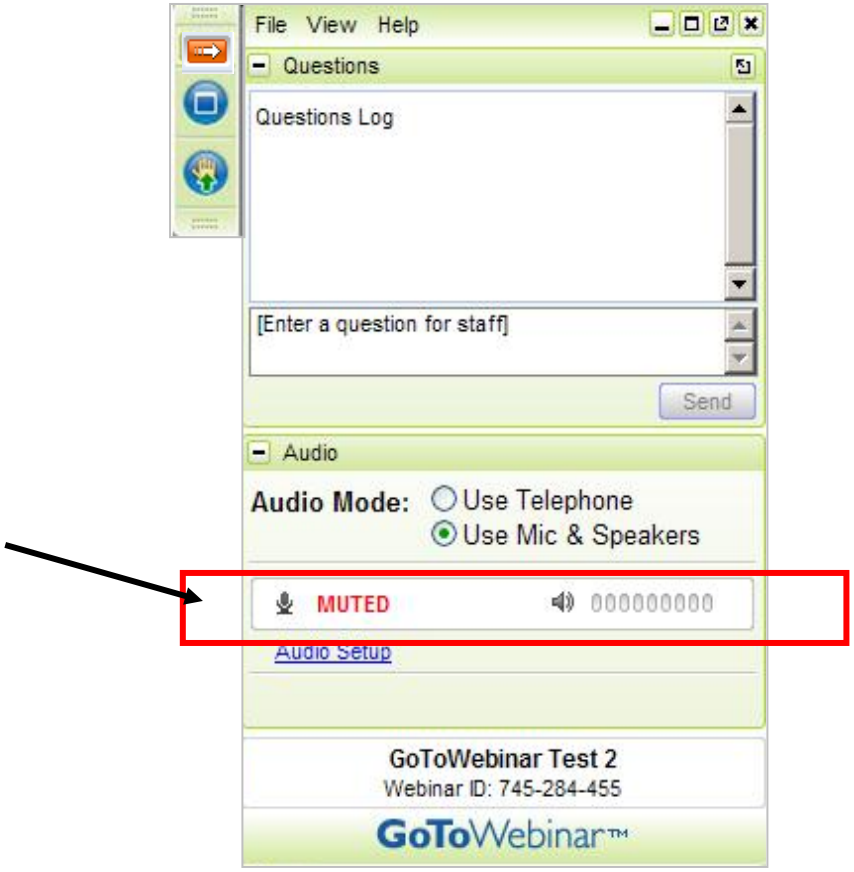
At the end of this webinar, you will be able to:

- Understand how rumble strips enhance traffic safety
- Describe approaches to install rumble strips in ways to potentially minimize community noise
- Identify methods to quantify noise levels and operator disturbance

PDH Certificate Information

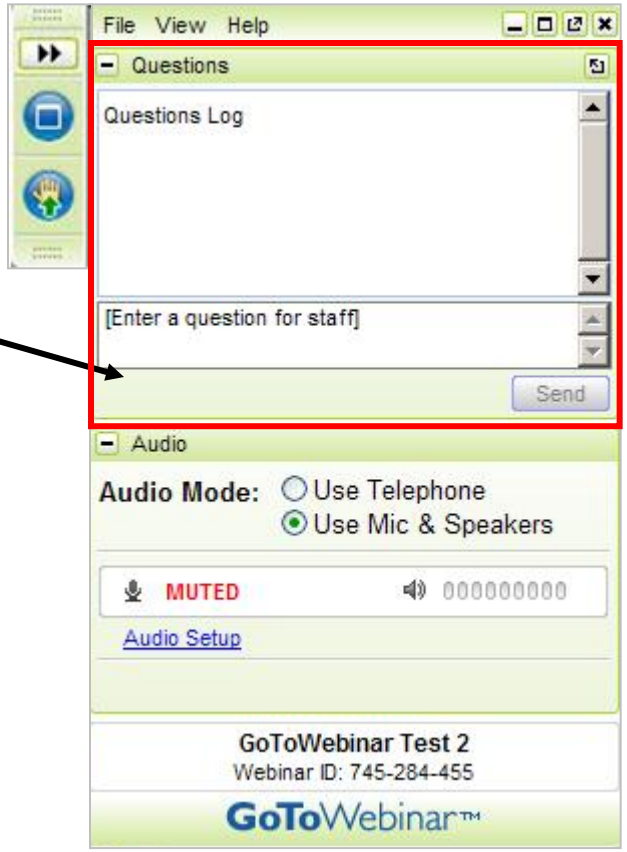
- This webinar is valued at 1.5 Professional Development Hours (PDH)
- Instructions on retrieving your certificate will be found in your webinar reminder and follow-up emails
- You must register and attend as an individual to receive a PDH certificate
- TRB will report your hours within one week
- Questions? Contact Reggie Gillum at RGillum@nas.edu

All Attendees Are Muted



Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



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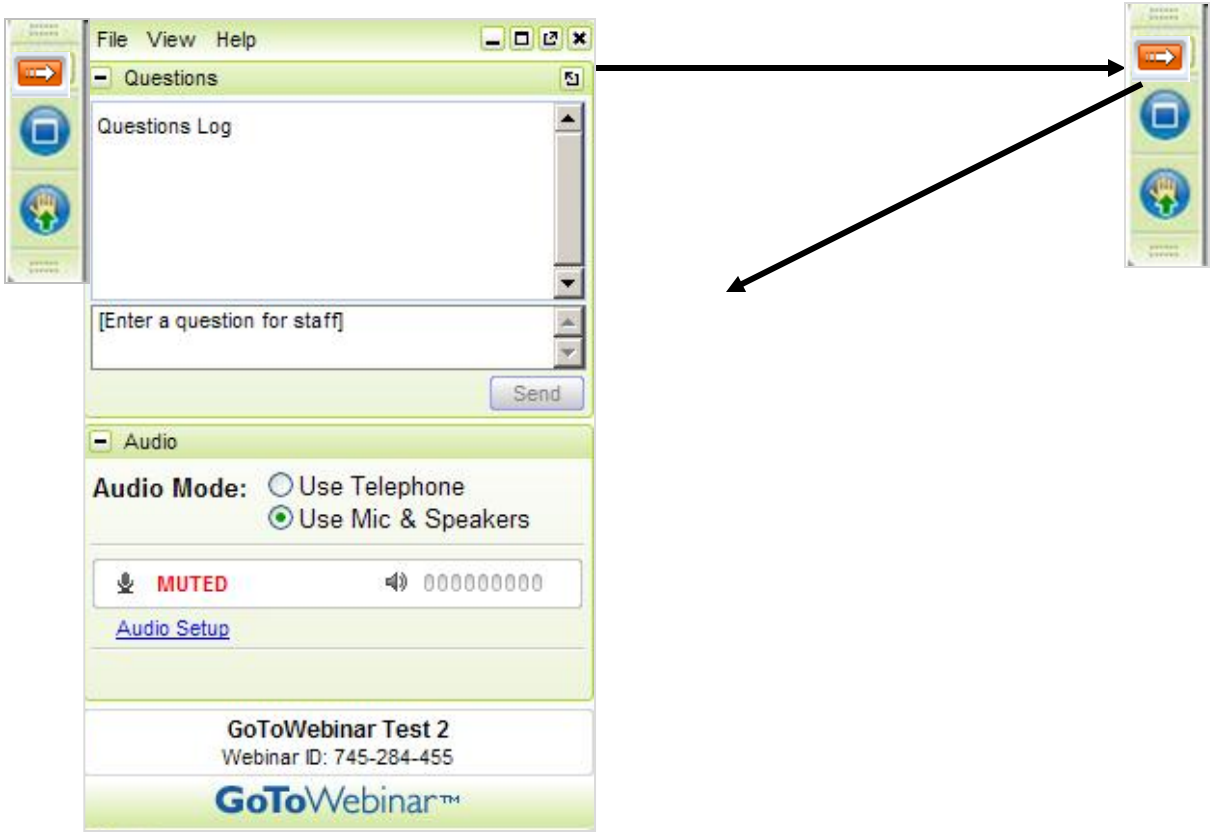
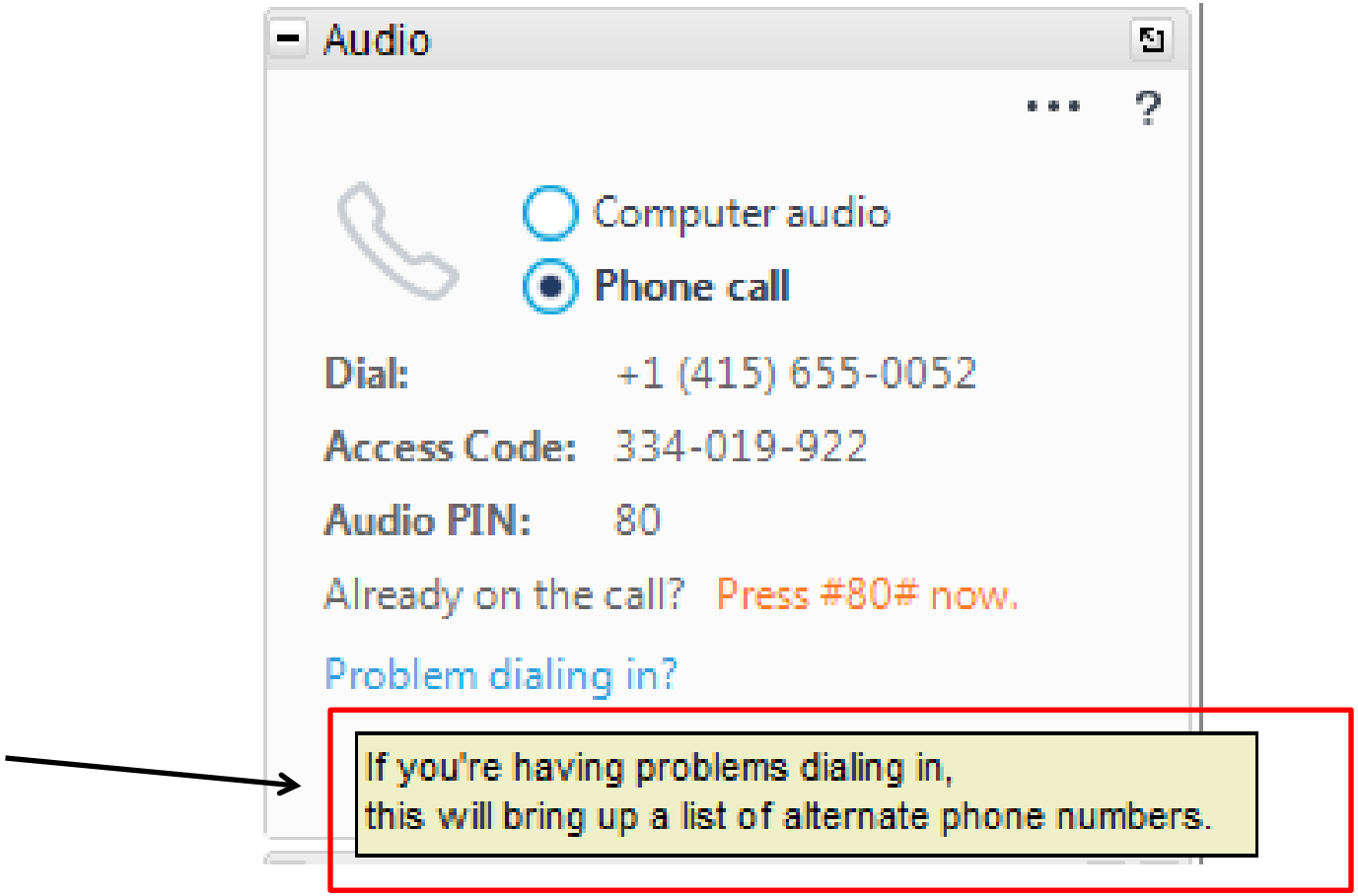


Having Trouble Logging On?



Panelists Presentations

http://onlinepubs.trb.org/onlinepubs/webinars/170328.pdf

After the webinar, you will receive a follow-up email containing a link to the recording

Today's Participants

- Judith Rochat, *ATS Consulting,* jrochat@atsconsulting.com
- Cathy Satterfield, *Federal Highway Administration,* Cathy.Satterfield@dot.gov
- Bruce Rymer, *California Department of Transportation,* bruce_rymer@dot.ca.gov
- Paul Donavan, *Illingworth & Rodkin Inc.*, pdonavan@illingworthrodkin.com

ATSConsulting
acoustics, transportation + strategy

ILLINGWORTH & RODKIN, INC.
Acoustics • Air Quality

U.S.Department of Transportation
Federal Highway Administration

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Get Involved with TRB

- Getting involved is free!
- Join a Standing Committee (http://bit.ly/2jYRrF6)
  - ADC40 (Transportation-Related Noise and Vibration)
- Become a Friend of a Committee (http://bit.ly/TRBcommittees)
  - Best way to become a member
  - Ultimate networking opportunity
- For more information: www.mytrb.org
  - Create your account
  - Update your profile

97th TRB Annual Meeting: January 7-11, 2018

Highway Rumble Strips: Approaches to Balancing Public Safety and Community Noise

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Transportation Research Board Webinar – Tuesday, March 28, 2017
TRB ADC40 Committee, Transportation-Related Noise and Vibration

Outline

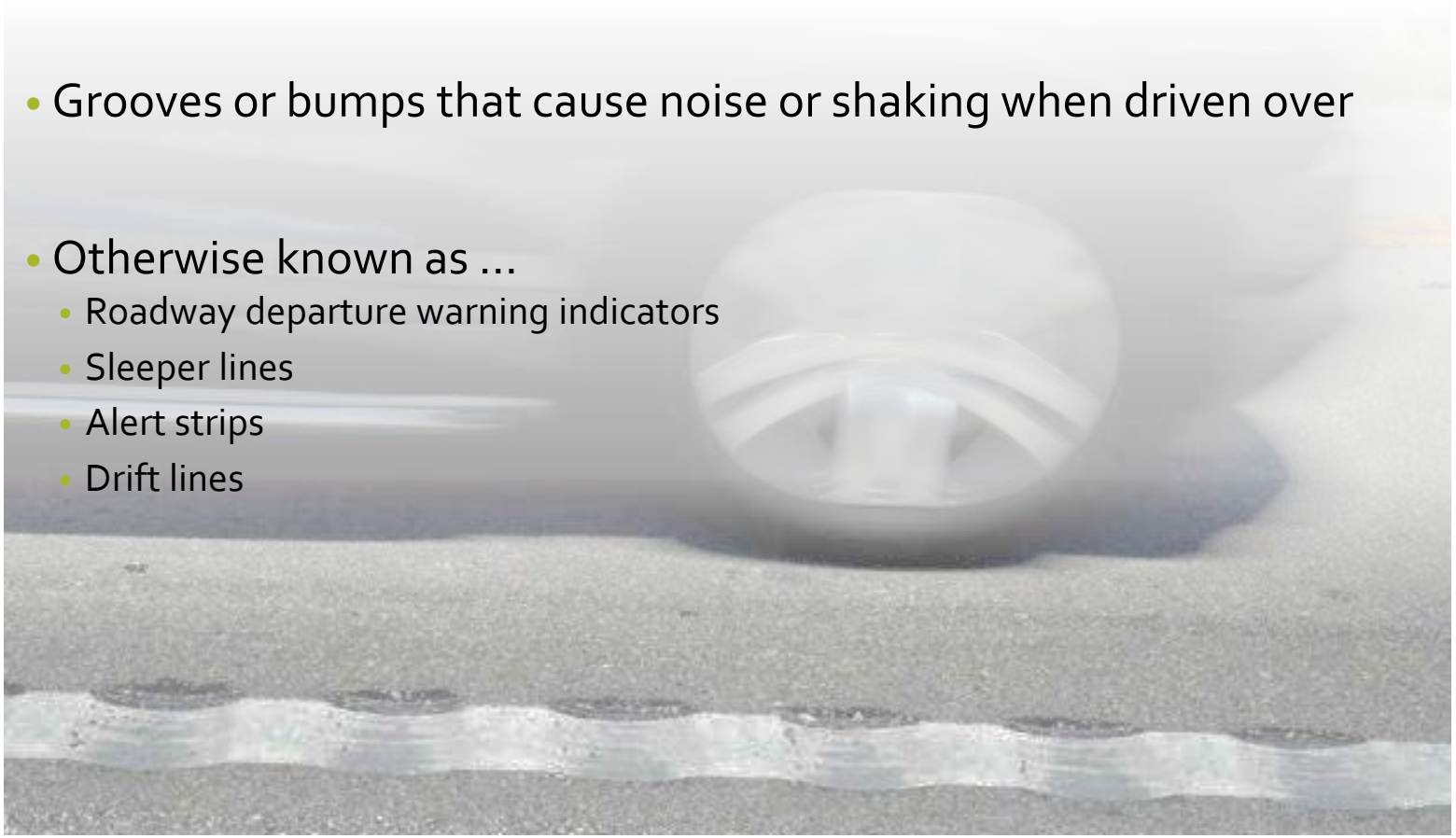
- Introduction
- Federal Highway Administration (FHWA)'s rumble strip program
- California Department of Transportation (Caltrans)'s experience with rumble strips
- Quantifying noise and operator disturbance from rumble strips
- Question and answer session

Learning Objectives

- Understand how rumble strips enhance safety
- Describe approaches to install rumble strips in ways to potentially minimize community noise
- Identify methods to quantify noise levels and operator disturbance

What's a rumble strip?

- A safety feature to alert inattentive drivers
- Grooves or bumps that cause noise or shaking when driven over
- Otherwise known as …
  - Roadway departure warning indicators
  - Sleeper lines
  - Alert strips
  - Drift lines



Types of rumble strips

milled

rolled

formed

raised

- Rumble strips can successfully decrease vehicle collisions or run-off-the-road crashes
- Main applications: centerline and shoulder

Rumble strip side effects

- Traditional designs + numerous vehicle strikes

  = NOISY

  … can lead to annoyed and possibly sleep-deprived neighbors

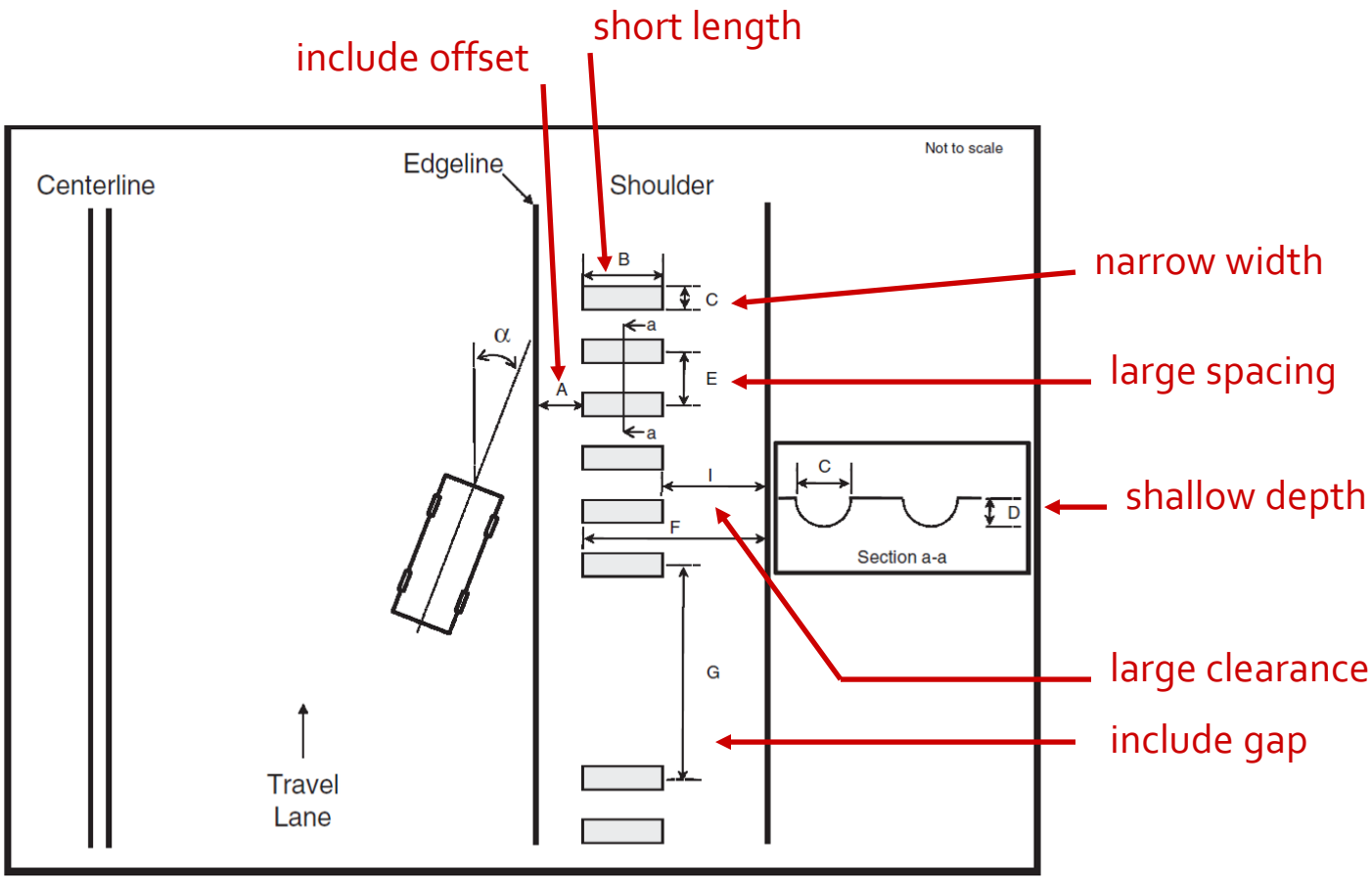
- Challenge for bicycle safety

National Park Service report

- Roadway Departure Warning Indicators: Synthesis of Noise and Bicycle Research
  - Natural Resource Technical Report 2013/780
  - Work completed in 2011

- Literature review findings
  - No consistent noise measurement technique
  - Limited literature in relation to *wayside* noise
  - Can extract/glean low-noise parameters for traditional and experimental rumble strip types

Design elements to minimize noise and maximize bicycle safety



Graphic: J Rochat, "Motorcycle noise and quieter pavement research in recreational areas," TRB ADC40 summer meeting 2012; based on NPS report

Suggested low-noise parameters

- Traditional type: rectangular

Length (in)	Depth (in)	Spacing (in)	Width (in)	Offset (ft)		Gap (ft)
				Outward from edge of lane	Inward from edge of pavement	
≤ 8	0.25	24	8	1	4	12 for every 60

- Experimental type: sinusoidal

Wavelength (in)	Peak-to-peak depth (in)	Length (in)	Offset (ft)		Gap (ft)
			Outward from edge of lane	Inward from edge of pavement	
Road speed/37*	0.16, 0.28**	tire width?	1	4	12 for every 60

*It is suggested that 14 in. may be ideal regardless of speed
**Both providing low-noise outcomes

Other considerations

- Interior noise/vibration must effectively warn drivers
  - Literature shows 4-10 dB increase in sound level required

    NOTE: This is relative to standard pavement; if the highway pavement is loud, rumble strips would need to provide a higher absolute sound level
  - Sinusoidal single-frequency oscillation provides vehicle movement feedback

- Bicycle safety
  - Need adequate riding space in shoulder (4 ft from edge of pavement)
  - Need gaps for exiting and entering bicyclists (12 ft gap for every 60 ft of rumble strip)

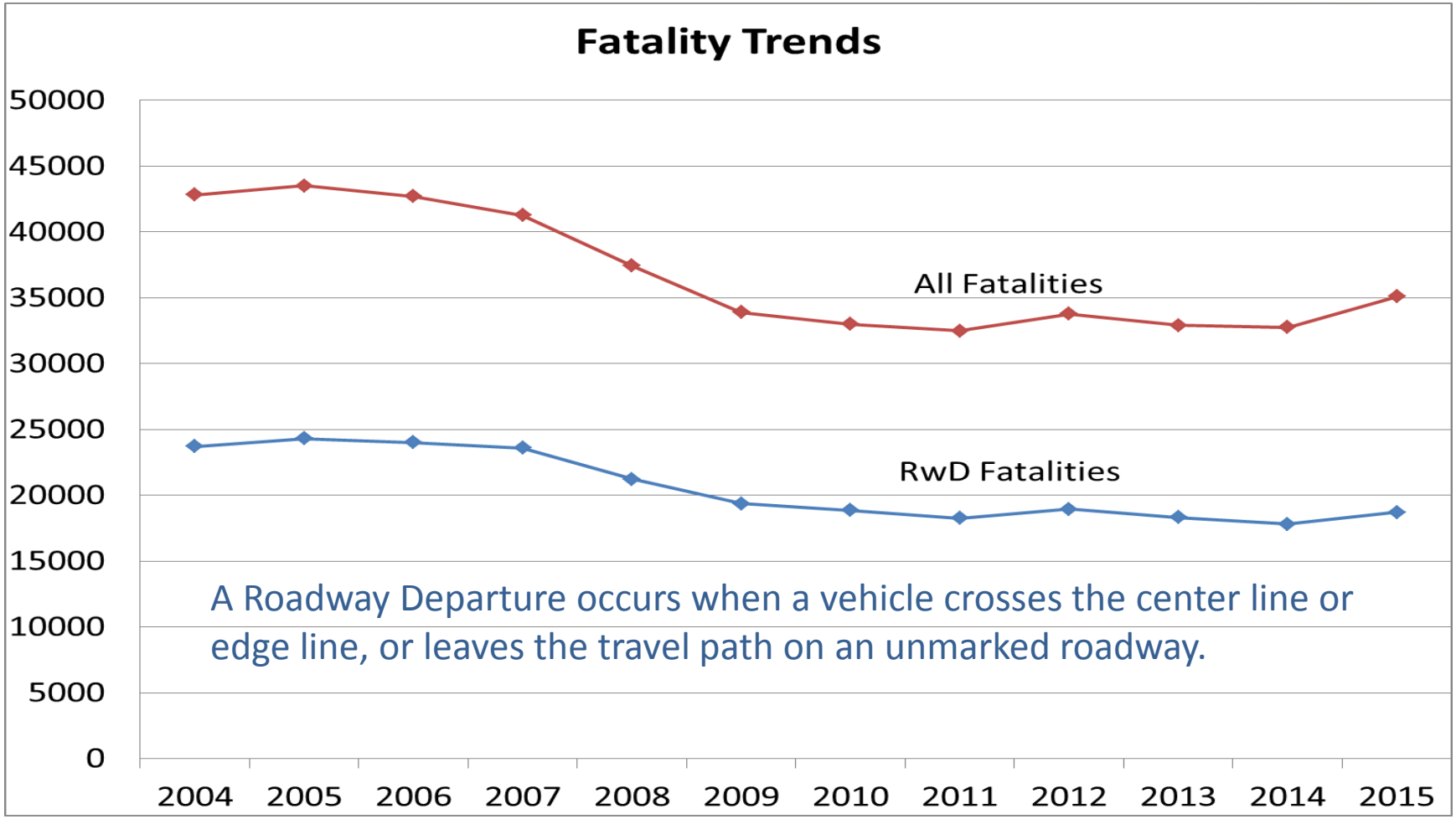
FHWA Rumble Strip Implementation Efforts

Cathy Satterfield

FHWA Office of Safety

Crash Trends

2015 Fatalities: 35,092 (↑2,348)
2014 RwD Fatalities: 17,791 (↑ 877)

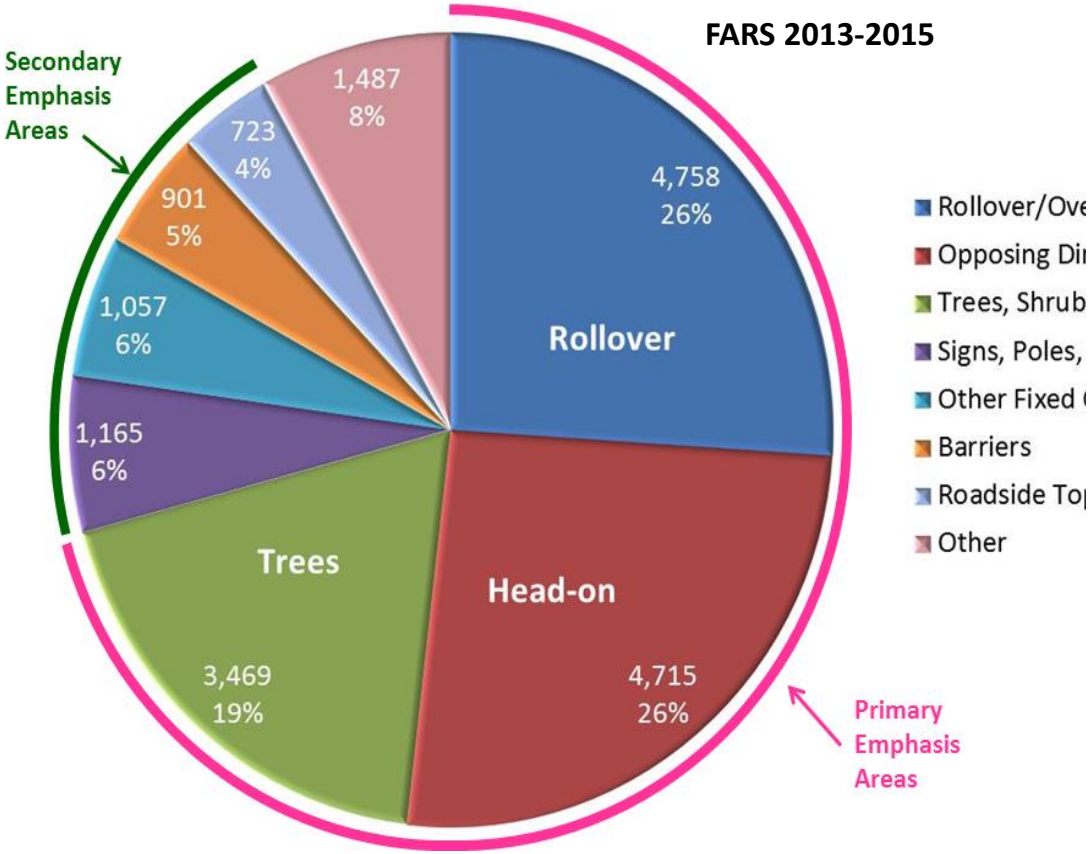


Roadway Departure Emphasis Areas

18,275 RwD Fatalities
54% of all traffic fatalities
(3-year average)

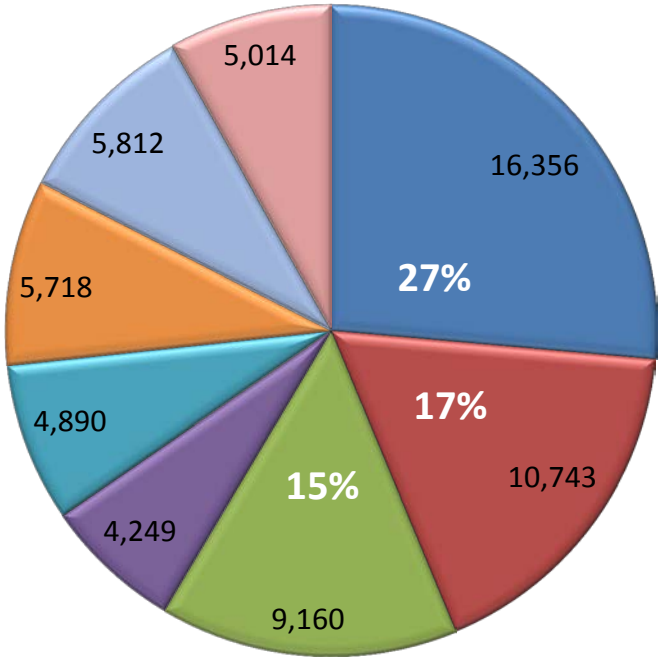
RwD Fatalities

FARS 2013-2015



RwD Serious Injuries

(GES 2011-2013)



Objectives and Methods

Objectives

1. Keep vehicles on the road, in their lane
2. Provide opportunities to come to safe re-entry or stop after a roadway departure
3. Reduce the severity of crashes that occur

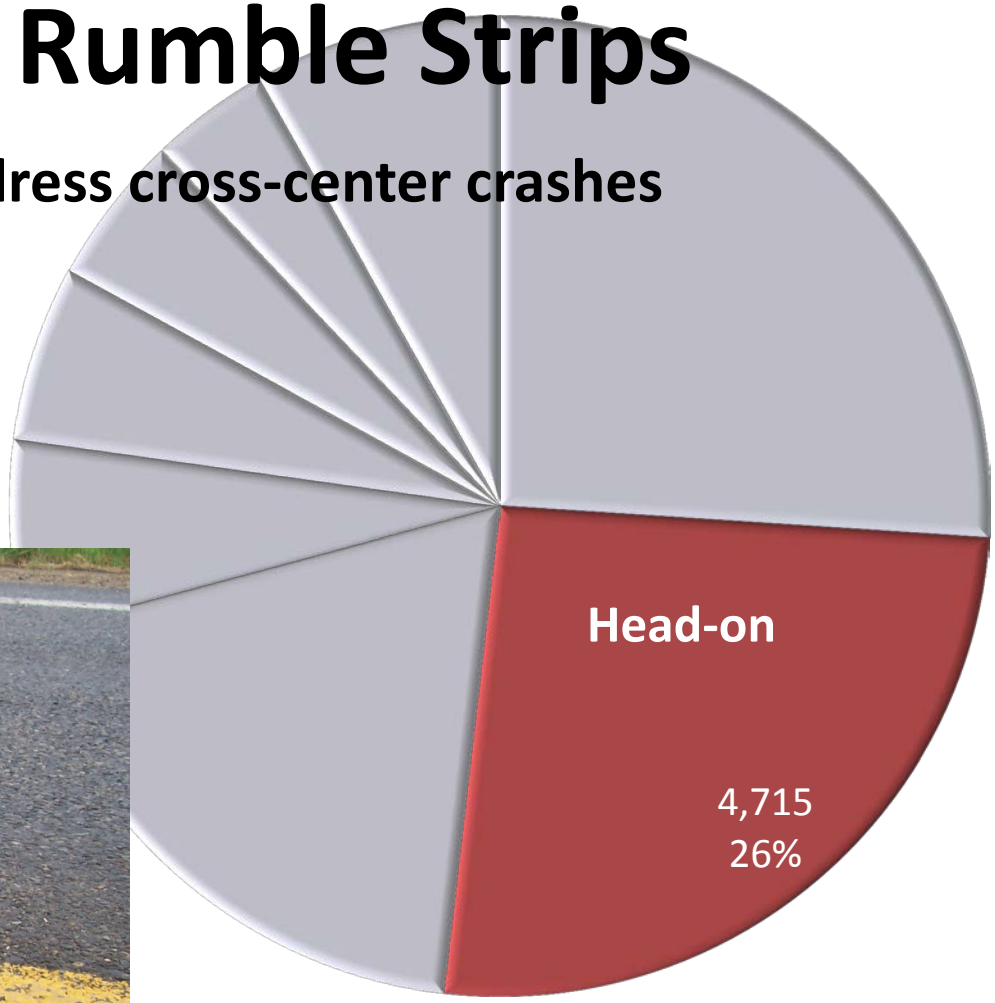
Methods

- "Hot Spot" Improvements
- Systemic Safety Improvements
- Comprehensive Improvements
  - Engineering
  - Enforcement
  - Education (behavior modification)
  - EMS

Center Line Rumble Strips

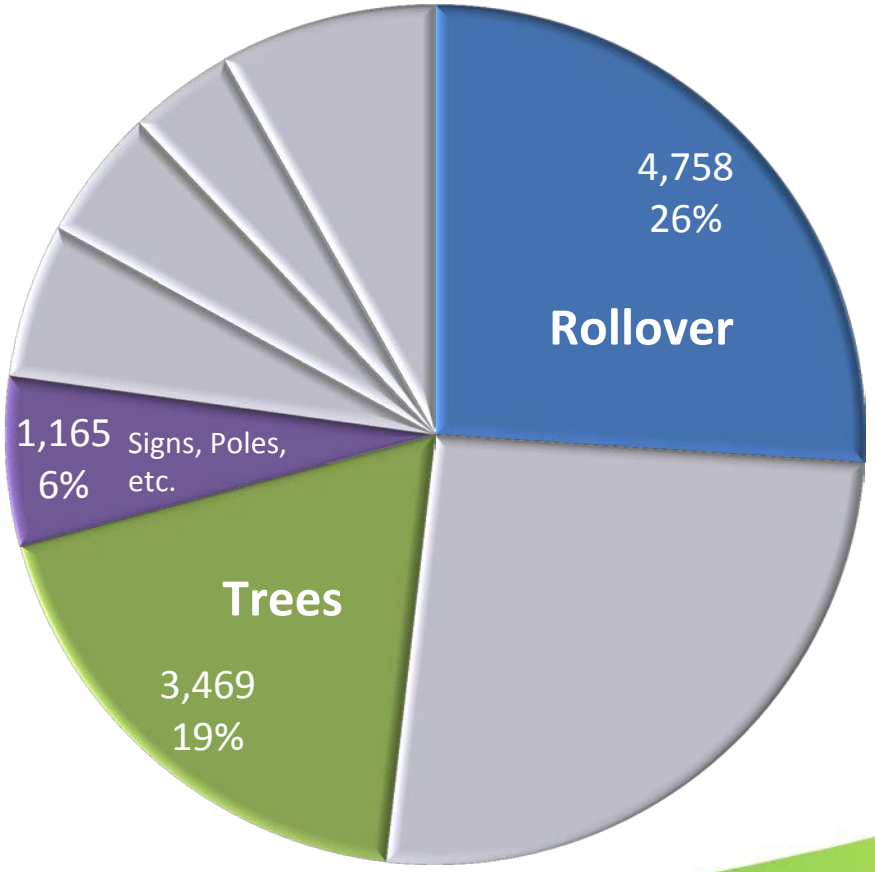
Few countermeasures address cross-center crashes

Crash Reduction: 44.5% of fatal and injury head-ons (for rural 2-lane roads)

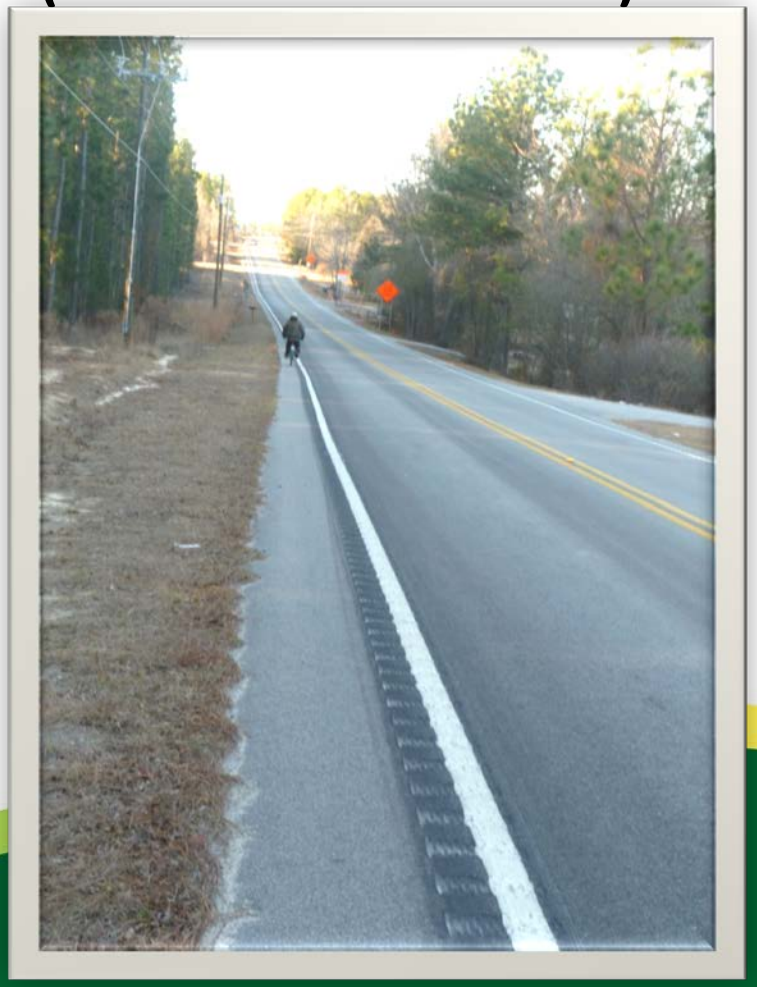


Edge Line or Shoulder Rumble Strips

Addresses two emphasis areas



Crash Reduction: 36.4% of fatal and injury SVRORs (for rural 2-lane roads)



Edge and Center Rumbles

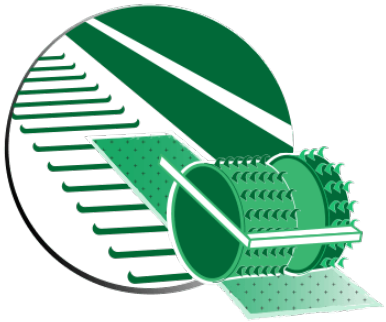
Crash Reductions on Rural 2-lane Roads
Total: 20%
Injury: 23%
ROR: 26%
Opp Dir: 30%

Why not put rumble strips on all roads?

- NOISE

- BICYCLE ACCOMMODATION

- PAVEMENT/DURABILITY



Flexibilities in Rumble Design to address Noise Issues:

- Shoulder rather than Edge Line
- Increasing Offset in curves and/or truck corridors
- Discontinue at intersections and major driveways
- Discontinuing in “Urban Areas”
  - Many states use speed limit as surrogate
  - Housing or driveway density
- Experimental
  - Adjust spacing
  - Sinusoidal design

Mitigating Rumble Strip Noise

Maintaining Alerting Noise and Vibration

- Measurement accuracy and range
- Comparing Noise/Vibration from various Studies
- Predictive Models
- Safety Studies

Measuring External Noise

- Measurement
  - Methods
  - Equipment
- Comparing Studies
- Models?

RESEARCH NEEDS?

Rumble Strip Resources

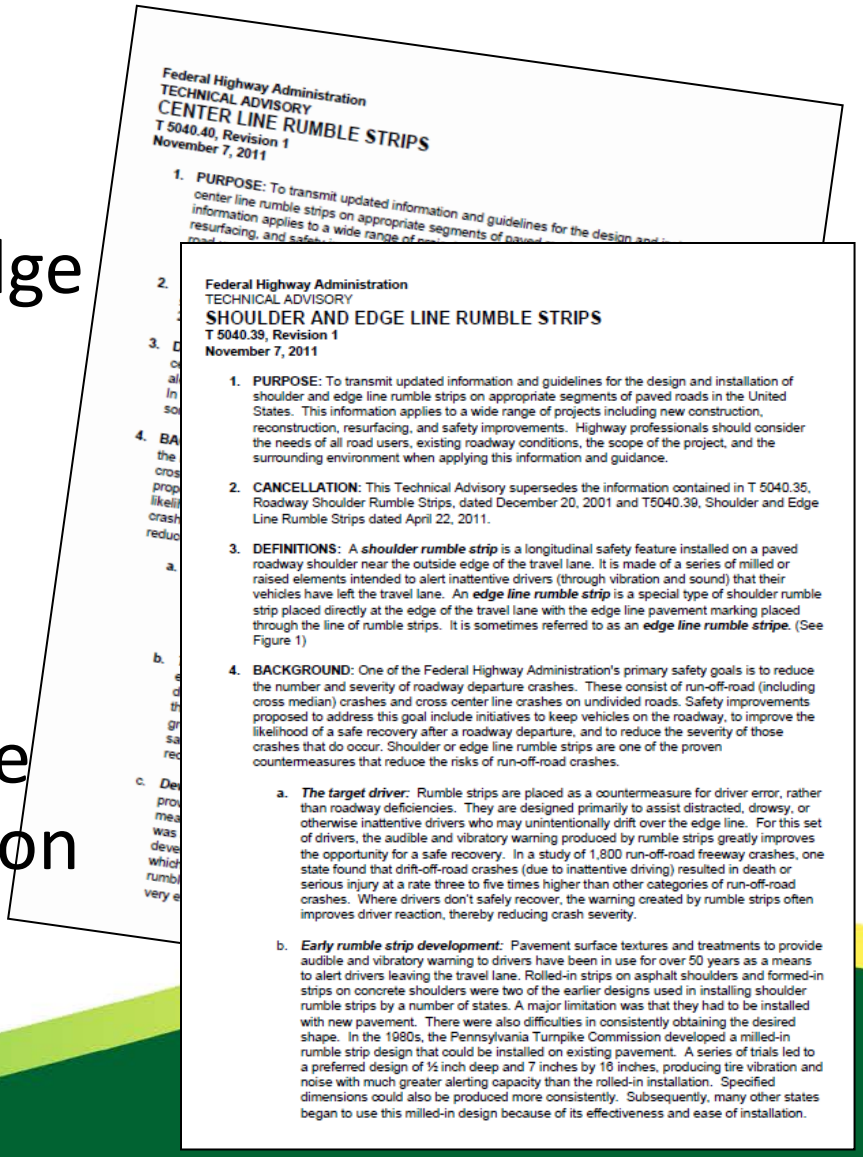
FHWA GUIDANCE

Technical Advisories

- TA 5040.39 Shoulder and Edge Line Rumble Strips
- TA 5040.40 Center Line Rumble Strips

RESEARCH

- NCHRP Report 641 Guidance for the Design and Application of Shoulder and Center Line Rumble Strips



Federal Highway Administration
TECHNICAL ADVISORY
CENTER LINE RUMBLE STRIPS
T 5040.40, Revision 1
November 7, 2011

1. PURPOSE: To transmit updated information and guidelines for the design and

Federal Highway Administration
TECHNICAL ADVISORY
SHOULDER AND EDGE LINE RUMBLE STRIPS
T 5040.39, Revision 1
November 7, 2011

1. **PURPOSE:** To transmit updated information and guidelines for the design and installation of shoulder and edge line rumble strips on appropriate segments of paved roads in the United States. This information applies to a wide range of projects including new construction, reconstruction, resurfacing, and safety improvements. Highway professionals should consider the needs of all road users, existing roadway conditions, the scope of the project, and the surrounding environment when applying this information and guidance.

2. **CANCELLATION:** This Technical Advisory supersedes the information contained in T 5040.35, Roadway Shoulder Rumble Strips, dated December 20, 2001 and T5040.39, Shoulder and Edge Line Rumble Strips dated April 22, 2011.

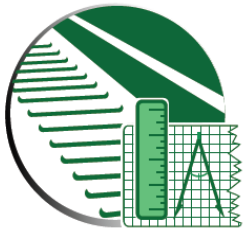
3. **DEFINITIONS:** A ***shoulder rumble strip*** is a longitudinal safety feature installed on a paved roadway shoulder near the outside edge of the travel lane. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane. An ***edge line rumble strip*** is a special type of shoulder rumble strip placed directly at the edge of the travel lane with the edge line pavement marking placed through the line of rumble strips. It is sometimes referred to as an ***edge line rumble stripe***. (See Figure 1)

4. **BACKGROUND:** One of the Federal Highway Administration's primary safety goals is to reduce the number and severity of roadway departure crashes. These consist of run-off-road (including cross median) crashes and cross center line crashes on undivided roads. Safety improvements proposed to address this goal include initiatives to keep vehicles on the roadway, to improve the likelihood of a safe recovery after a roadway departure, and to reduce the severity of those crashes that do occur. Shoulder or edge line rumble strips are one of the proven countermeasures that reduce the risks of run-off-road crashes.

   a. ***The target driver:*** Rumble strips are placed as a countermeasure for driver error, rather than roadway deficiencies. They are designed primarily to assist distracted, drowsy, or otherwise inattentive drivers who may unintentionally drift over the edge line. For this set of drivers, the audible and vibratory warning produced by rumble strips greatly improves the opportunity for a safe recovery. In a study of 1,800 run-off-road freeway crashes, one state found that drift-off-road crashes (due to inattentive driving) resulted in death or serious injury at a rate three to five times higher than other categories of run-off-road crashes. Where drivers don't safely recover, the warning created by rumble strips often improves driver reaction, thereby reducing crash severity.

   b. ***Early rumble strip development:*** Pavement surface textures and treatments to provide audible and vibratory warning to drivers have been in use for over 50 years as a means to alert drivers leaving the travel lane. Rolled-in strips on asphalt shoulders and formed-in strips on concrete shoulders were two of the earlier designs used in installing shoulder rumble strips by a number of states. A major limitation was that they had to be installed with new pavement. There were also difficulties in consistently obtaining the desired shape. In the 1980s, the Pennsylvania Turnpike Commission developed a milled-in rumble strip design that could be installed on existing pavement. A series of trials led to a preferred design of ½ inch deep and 7 inches by 16 inches, producing tire vibration and noise with much greater alerting capacity than the rolled-in installation. Specified dimensions could also be produced more consistently. Subsequently, many other states began to use this milled-in design because of its effectiveness and ease of installation.

Newer Resources Focus on Two Lane Roads



- Updated Website
- Comprehensive FAQs
- Implementation Guides and Fact Sheets
  - Noise
  - Bicycles
  - Pavement/Maintenance
- Decision Support Guide

Rumble Strip Implementation on Two-Lane, Two-Way Roads

We welcome your comments!

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(708) 283-3552

Adam Alexander
Office of Environment
Adam.Alexander@dot.gov
(202) 366-6799

FHWA Rumble Strip Website:
http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/

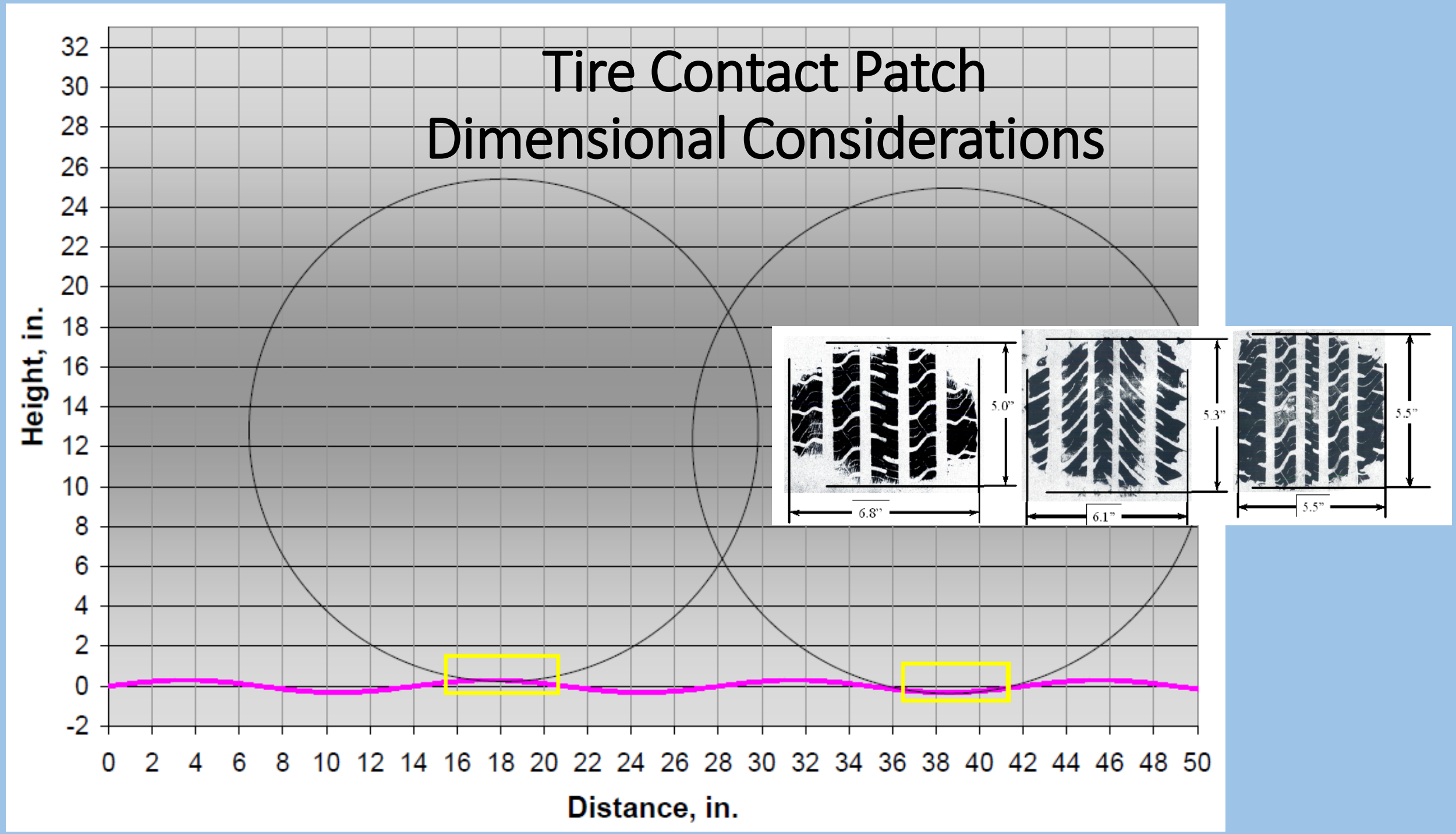
Bruce Rymer
Senior Engineer
Division of Environmental Analysis
California Department of Transportation
Sacramento, CA

Rumble Strip Design Needs

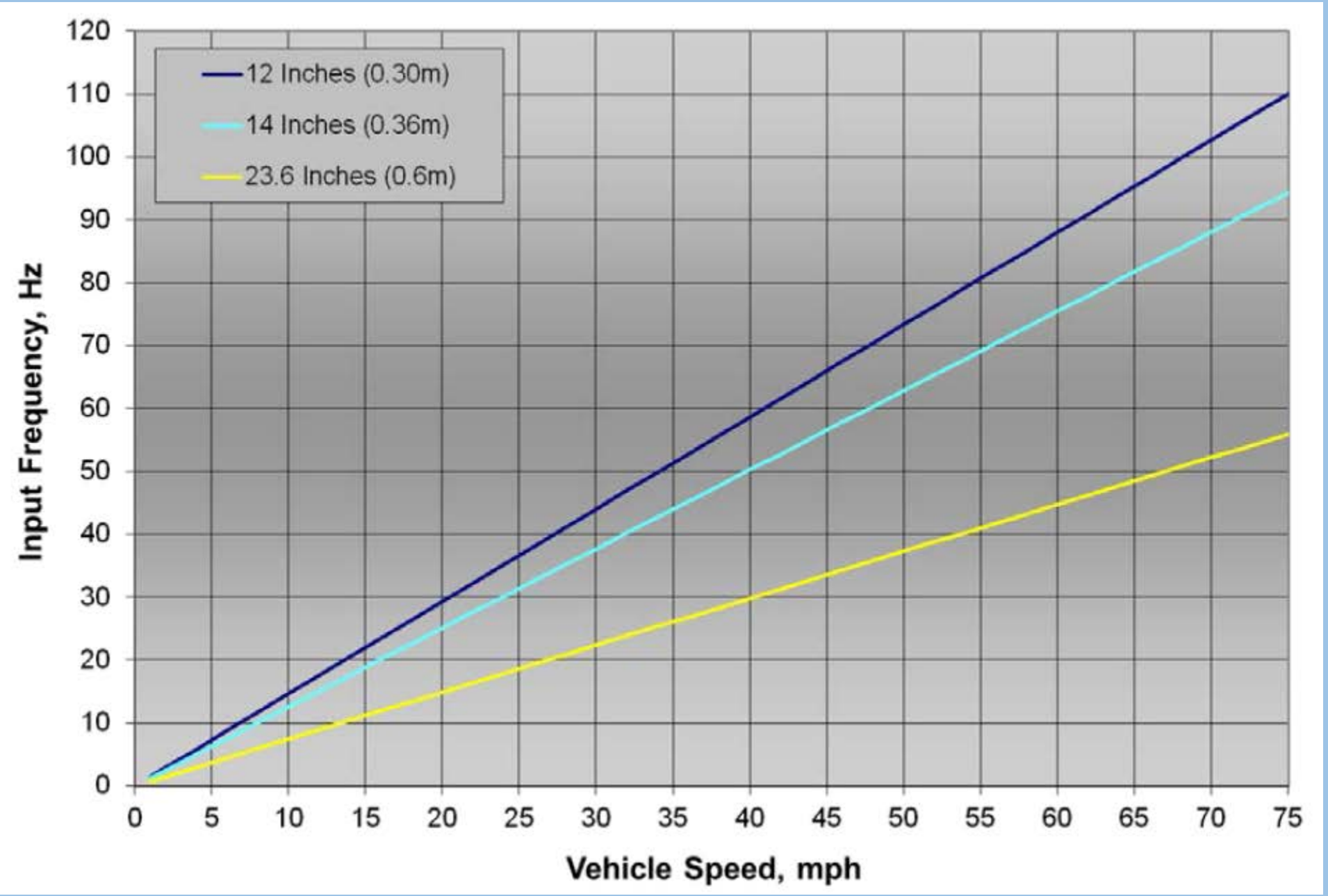
- Maintain or Increase Interior Sound & Vibration Levels
- Lower Roadside Noise Levels
- Bicycle Friendly
- Fit Within Roadway Cross Section
- Limit Depth of Material Removal
- Cost effective
- Easy to Construct

SAFETY

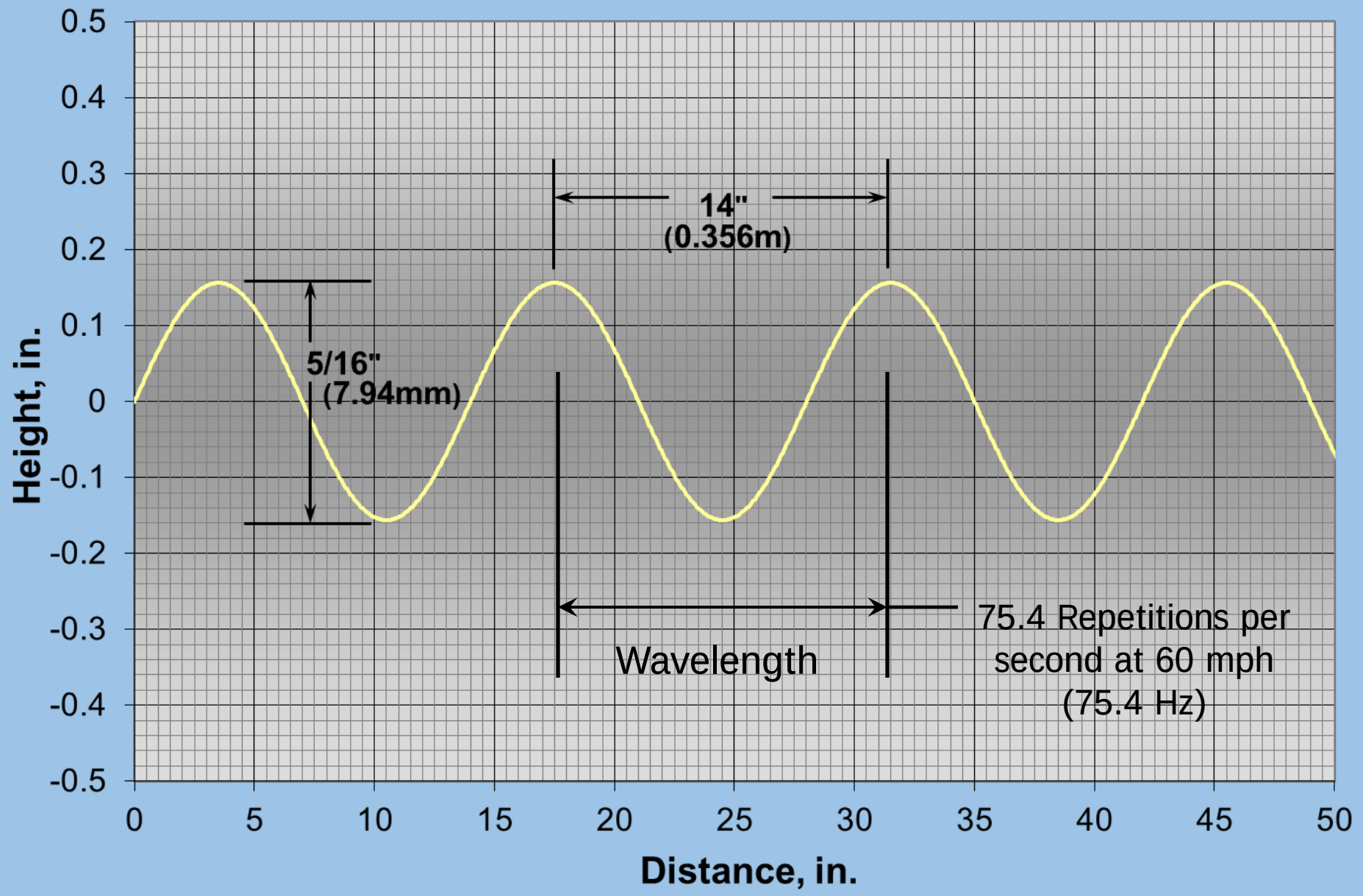
Tire Contact Patch Dimensional Considerations



Forcing Frequency



Recommended Design



Warning Strips Evaluated

"Mumble" strip:
14" O.C., sinusoidal profile,
p-p depth 5/16"

Conventional ground rumble strip:
12" O.C., 5/16 depth, 5" edge to edge

4" Dia Dots:
12" O.C.,
5/8 – 13/16" tall

Test Vehicles

- Chevrolet Malibu
- Honda Civic
- Ford Expedition
- Ford Fusion
- International 4 Yard Dump Truck

- 20 mph, 40 mph, 60 mph
- On & Off Rumble Strips
- Some tire swaps
- Two separate measurement studies

Chevrolet Malibu

Honda Civic

Ford Expedition

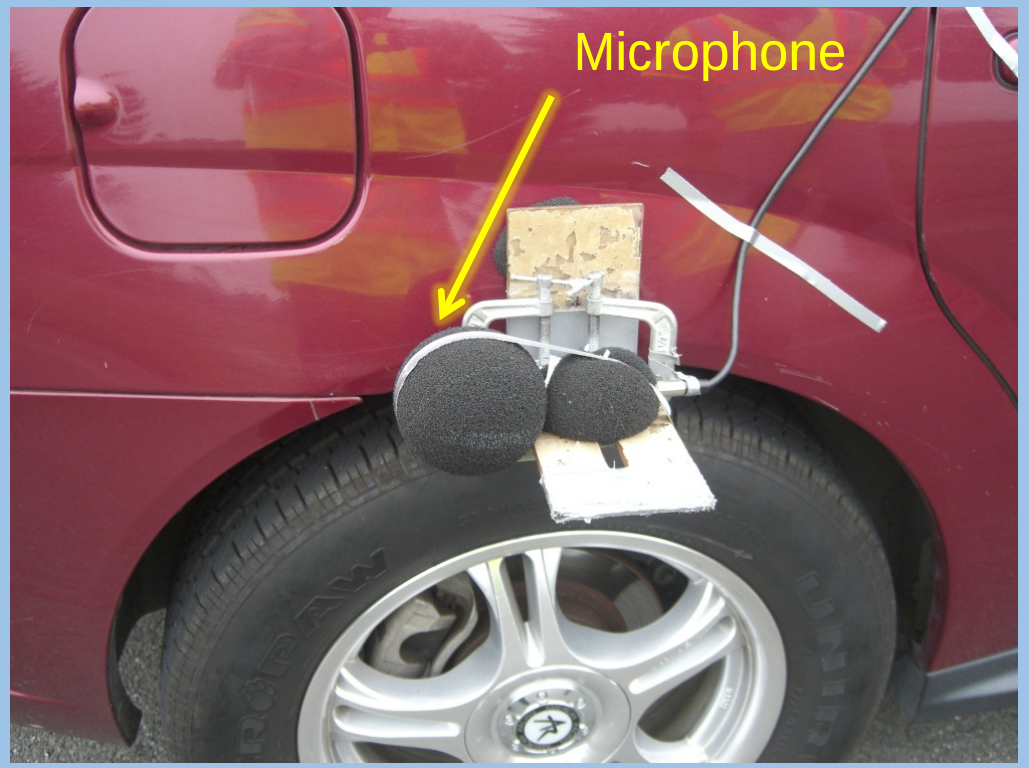
Ford Fusion

International four-yard dump Truck

Exterior Noise Measurements

Pass-by Noise

25 ft 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

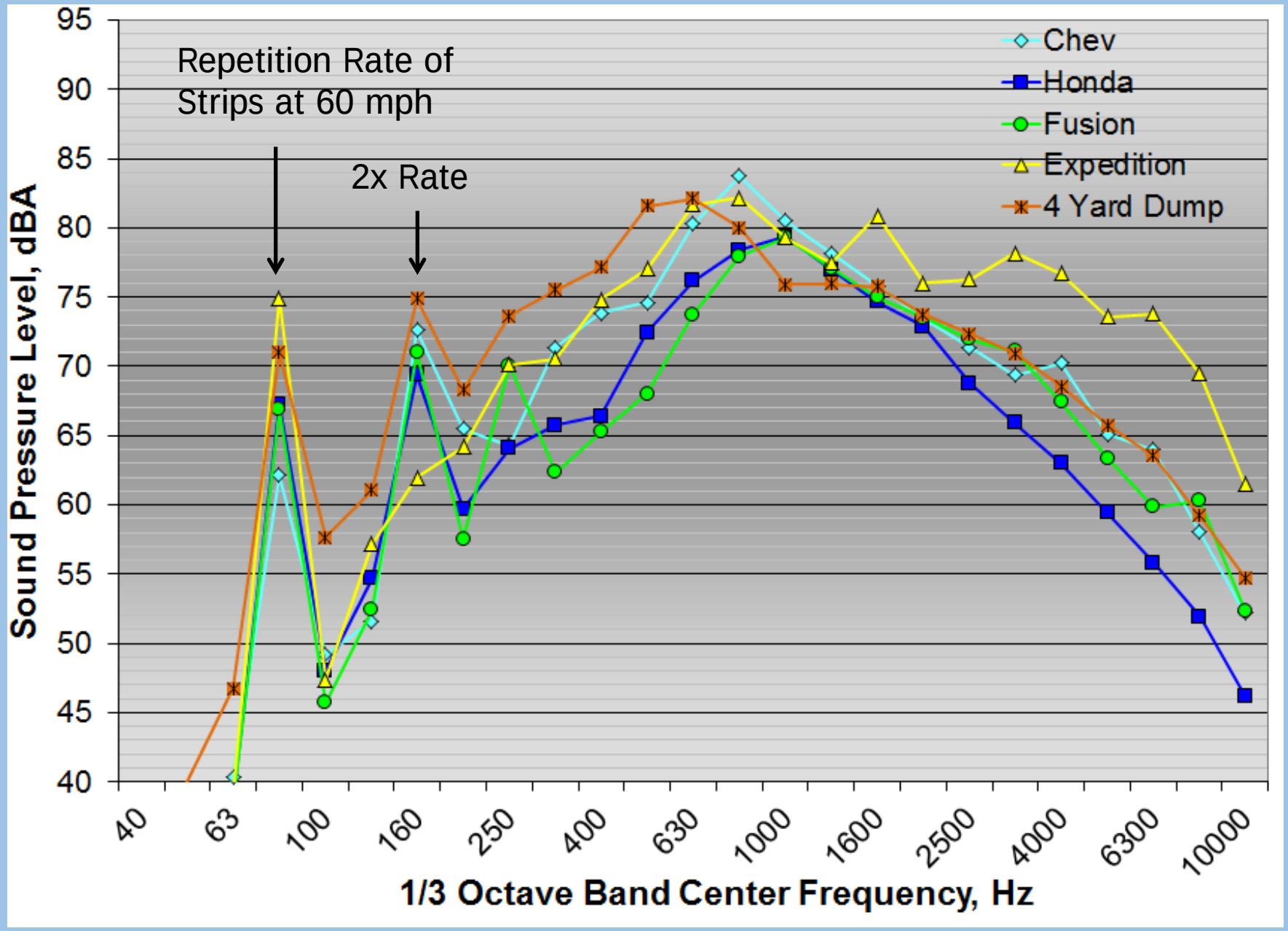
Seat Track

Right front passenger seat track rail – measures vehicle structural response

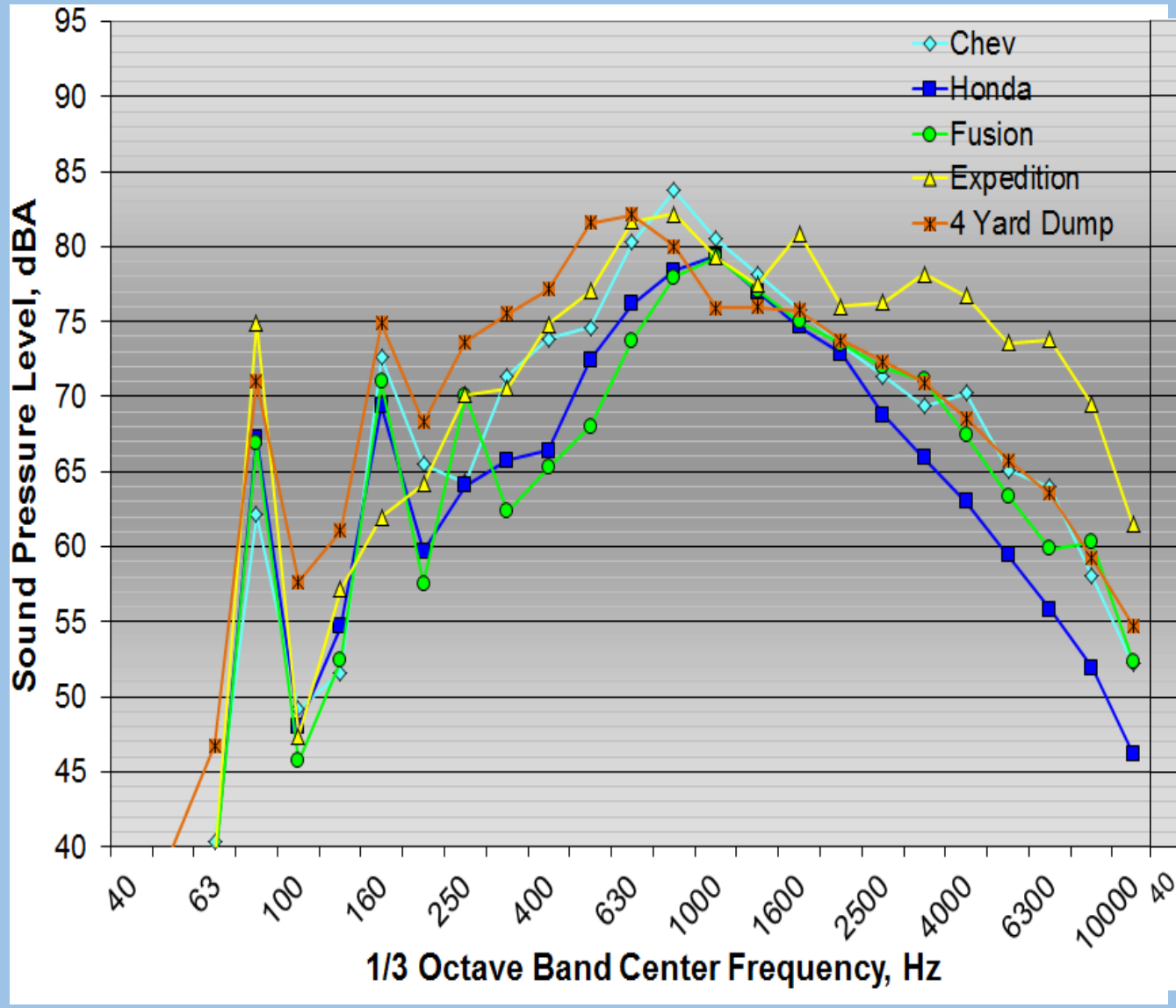
Steering Column

Indicates input to driver's hands on the steering wheel

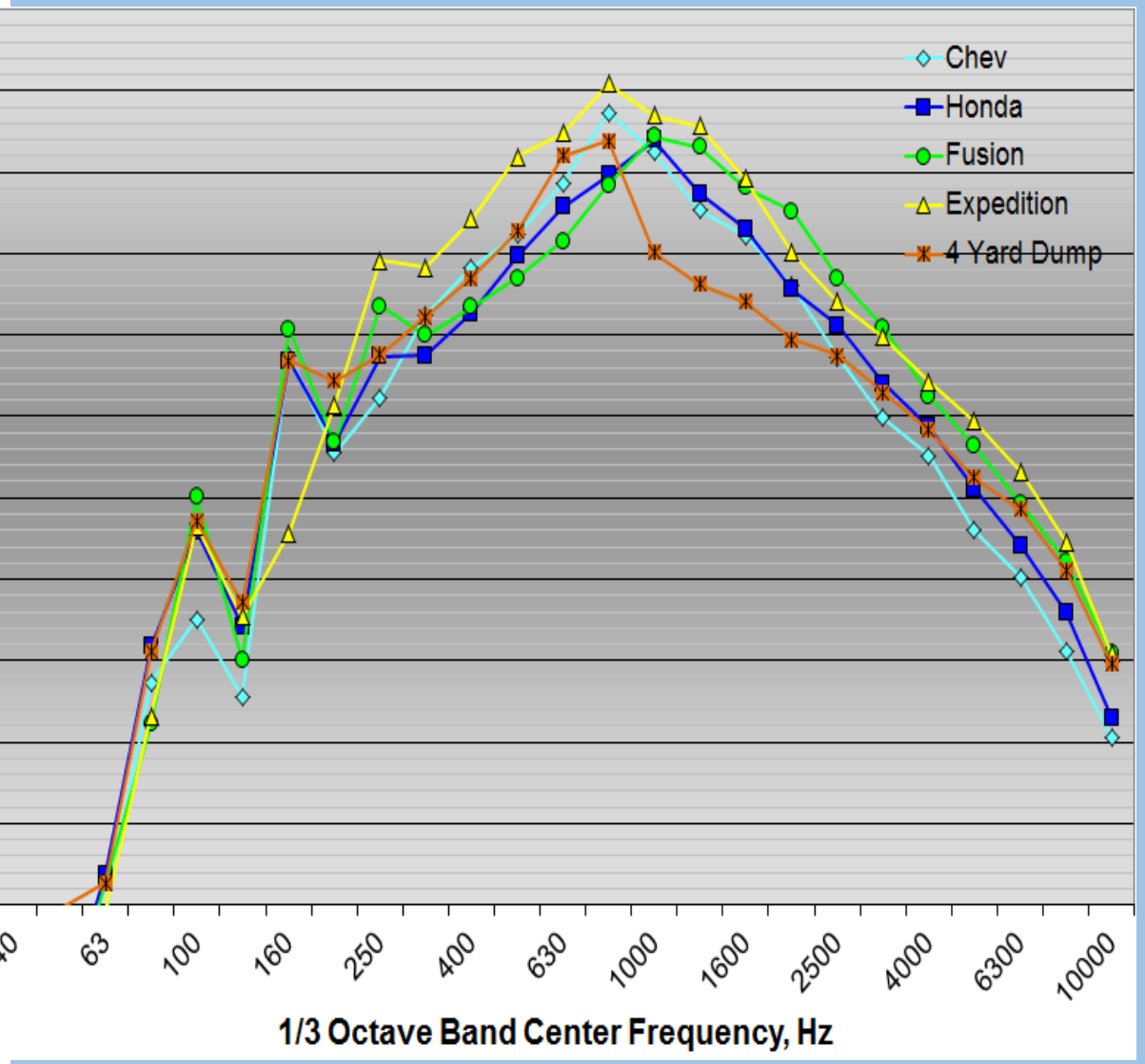
Pass-by Noise on Mumble Strips



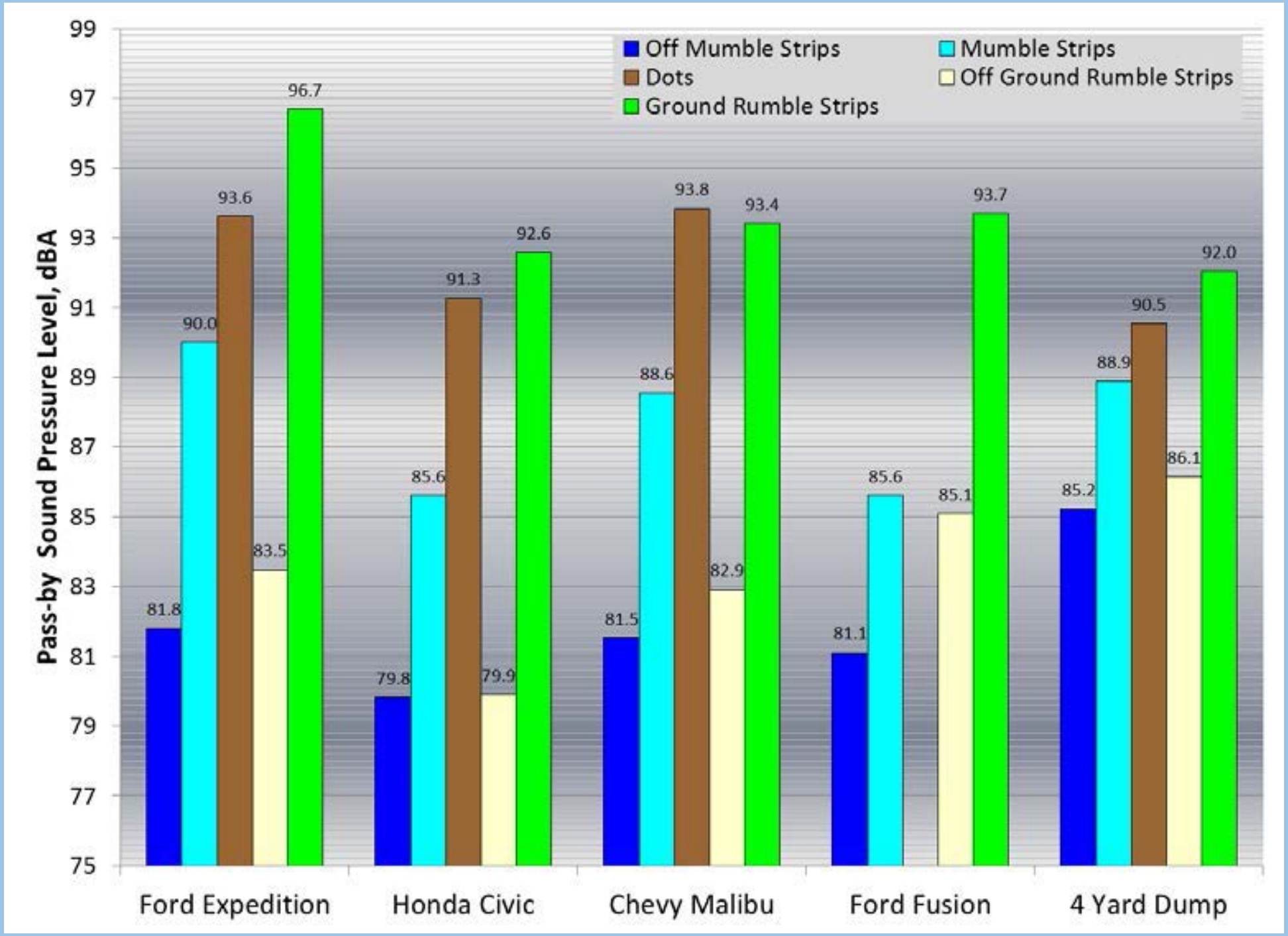
Mumble & Ground Strip Pass-by Noise



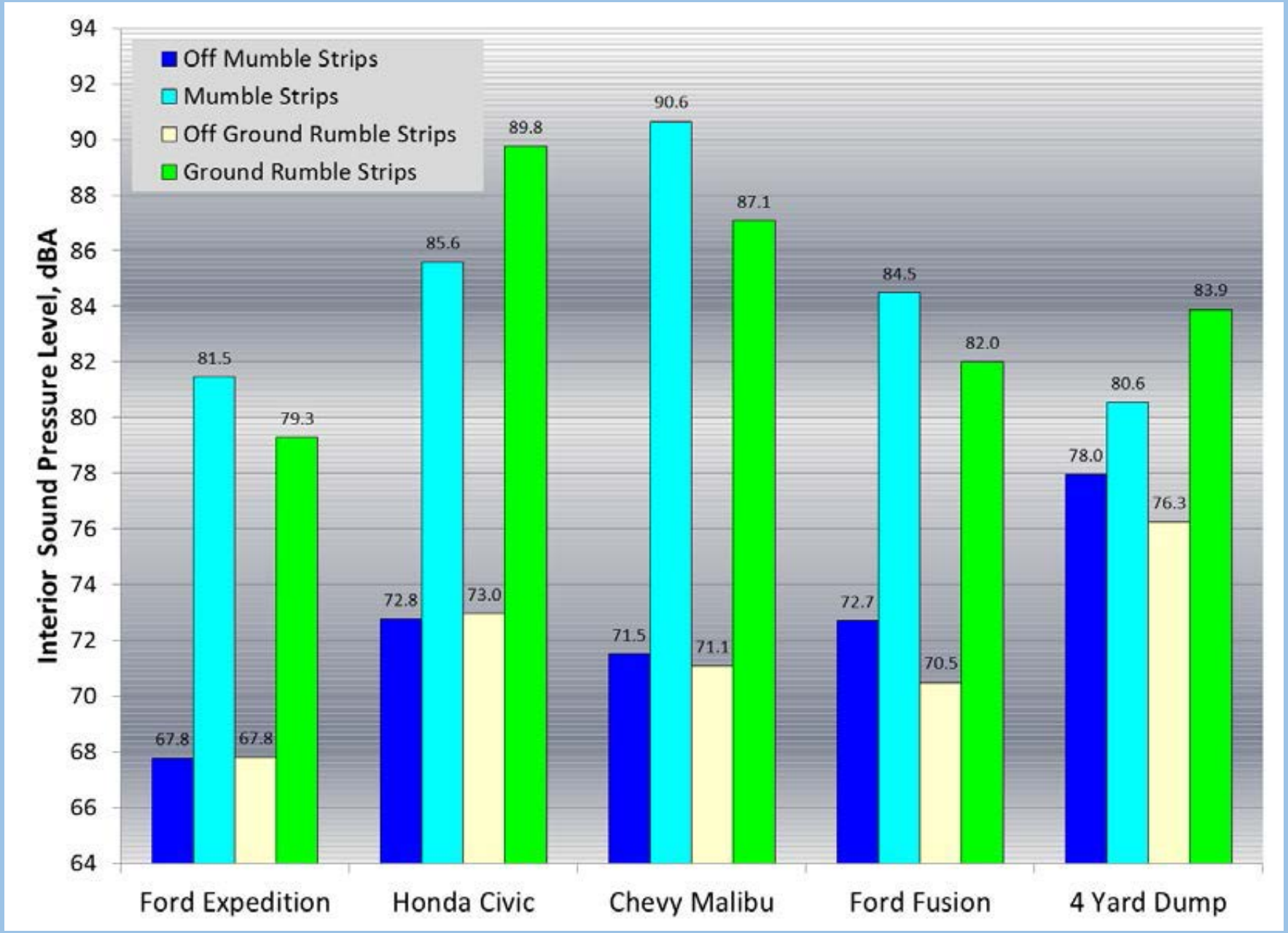
Mumble Strip



Ground Strip

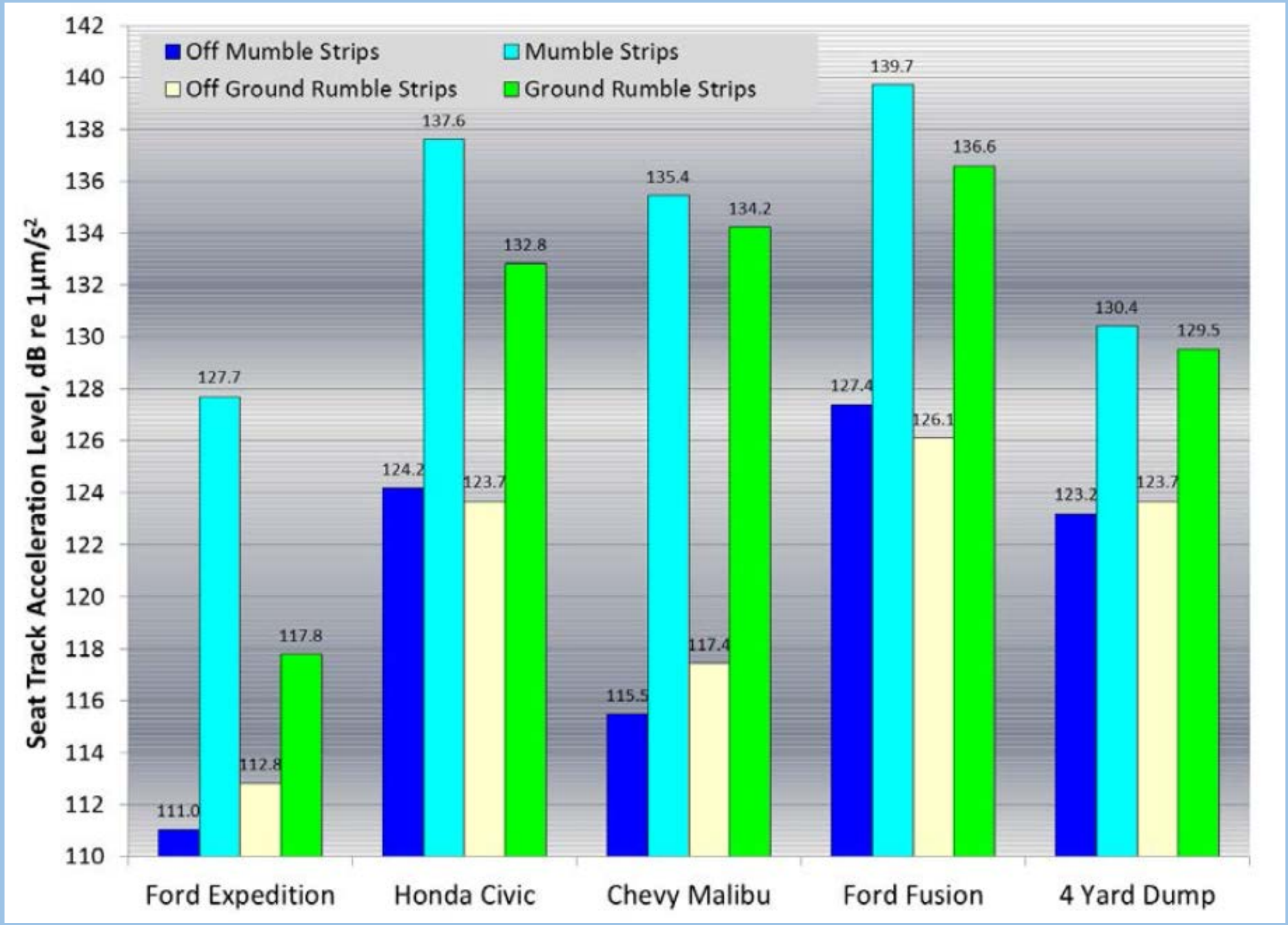

Off Mumble Strips
Mumble Strips
Dots
Off Ground Rumble Strips
Ground Rumble Strips
Pass-by Sound Pressure Level, dBA
99
97
95
93
91
89
87
85
83
81
79
77
75
81.8
90.0
93.6
83.5
96.7
79.8
85.6
91.3
79.9
92.6
81.5
88.6
93.8
82.9
93.4
81.1
85.6
85.1
93.7
85.2
88.9
90.5
86.1
92.0
Ford Expedition
Honda Civic
Chevy Malibu
Ford Fusion
4 Yard Dump

Interior Sound Levels



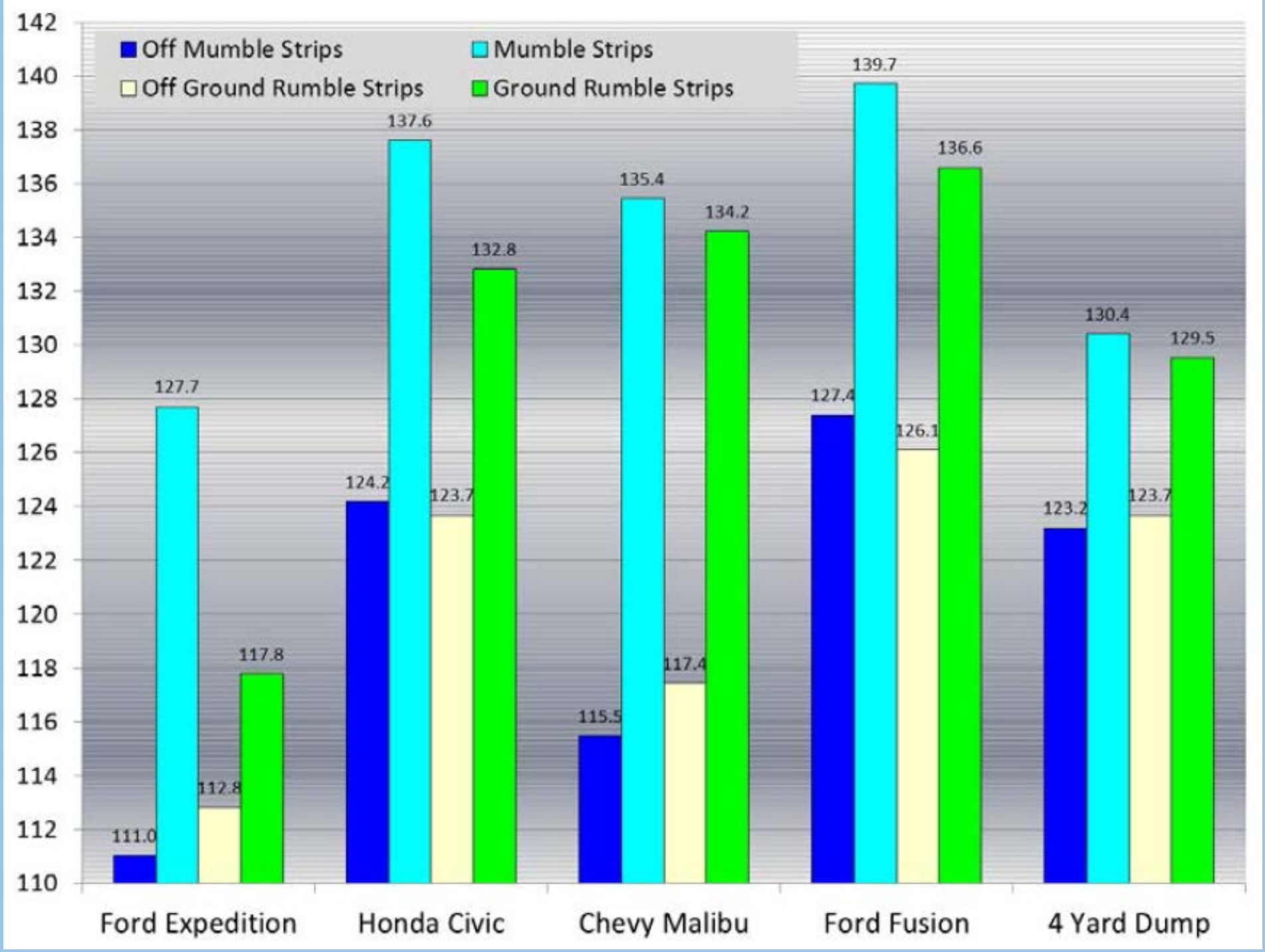
Seat Track Acceleration

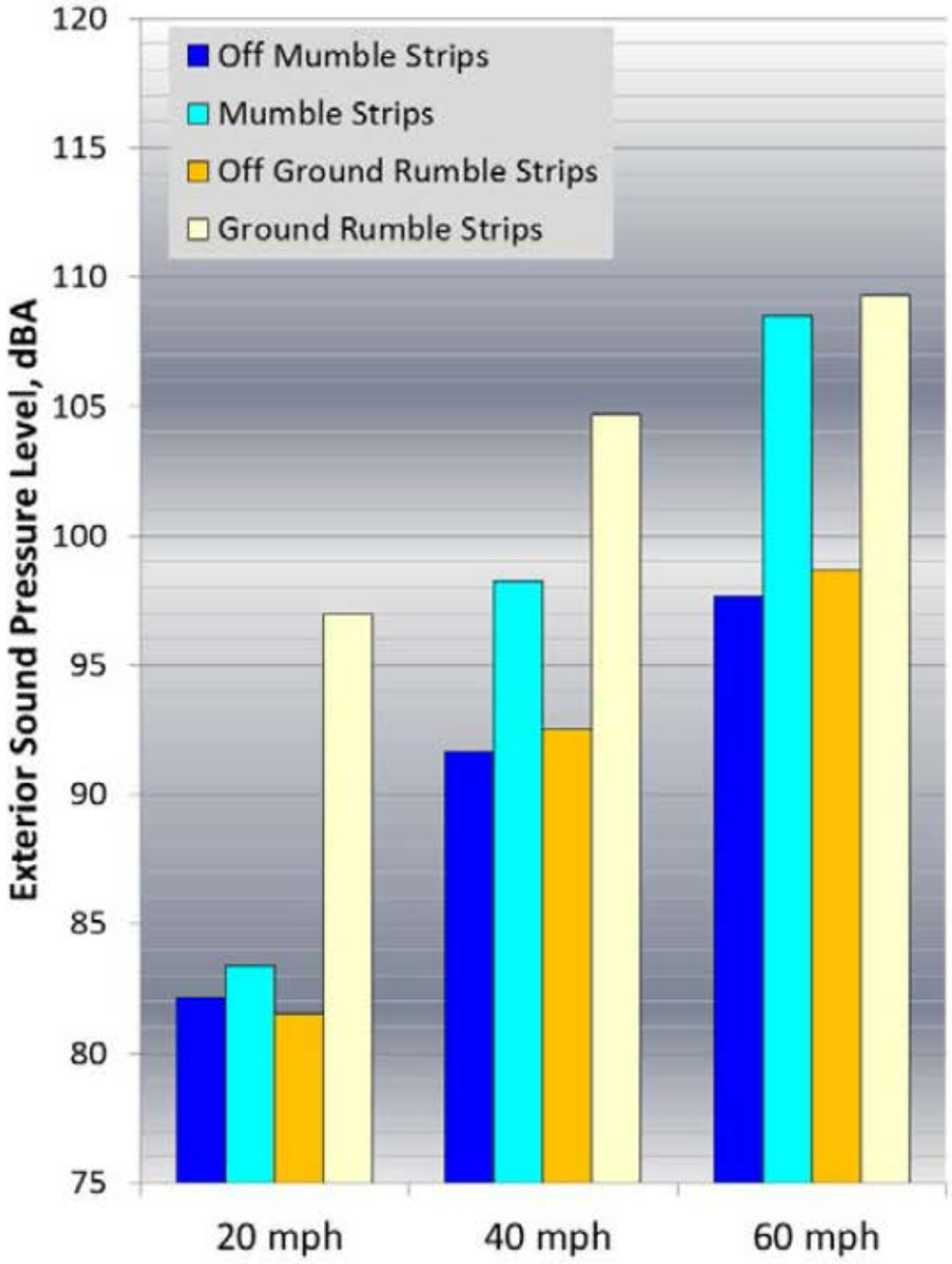
in dB re 1µm/m2

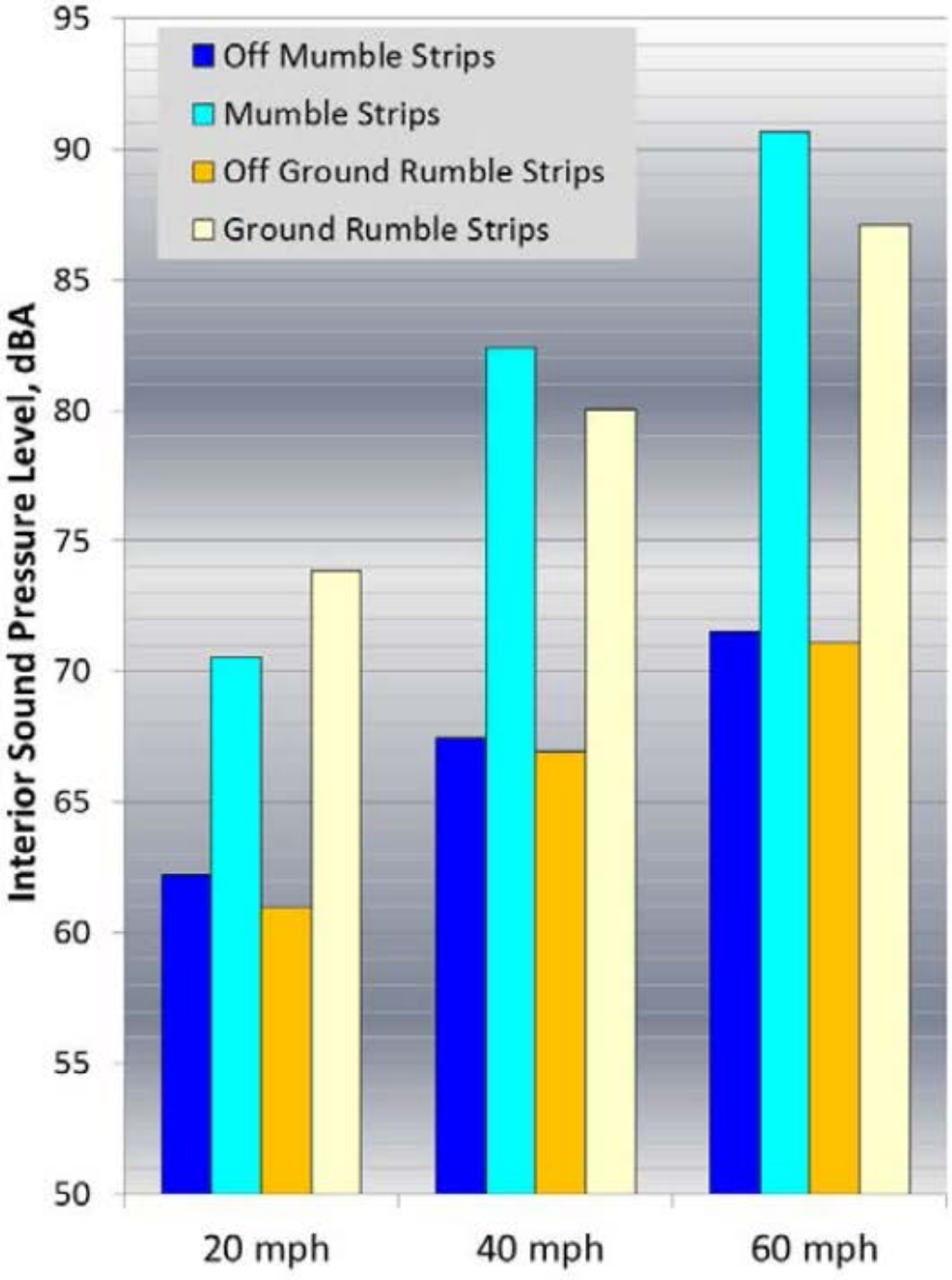


Steering Column Acceleration

in dB re 1µm/m2




Off Mumble Strips
Mumble Strips
Off Ground Rumble Strips
Ground Rumble Strips
Exterior Sound Pressure Level, dBA
120
115
110
105
100
95
90
85
80
75
20 mph
40 mph
60 mph


Off Mumble Strips
Mumble Strips
Off Ground Rumble Strips
Ground Rumble Strips
Interior Sound Pressure Level, dBA
95
90
85
80
75
70
65
60
55
50
20 mph
40 mph
60 mph

Conclusions & Summary

- *Mumble Strip achieved design goal*
  - *Lowered exterior noise*
  - *Provided sufficient driver input*
- *Interior N&V response varies w/ vehicle*
- *Performance maintained at other speeds*
- Mumble strip design could be modified
- ‘Flat topping’ sinusoidal pattern increases noise
- Haptic input doesn’t compete w/ interior audio systems
- *Develop acoustic guidance for locating near sensitive receptors*
- *Caltrans will finalize Mumble Strip Study & make available to public*

Quantifying Noise & Operator Disturbance from Rumble Strips

Paul Donavan

Illingworth & Rodkin, Inc.

Measurement Needs

Operator Warning

- Acoustic – interior noise
- Tactile input – through operator seat & steering wheel

Exterior Noise

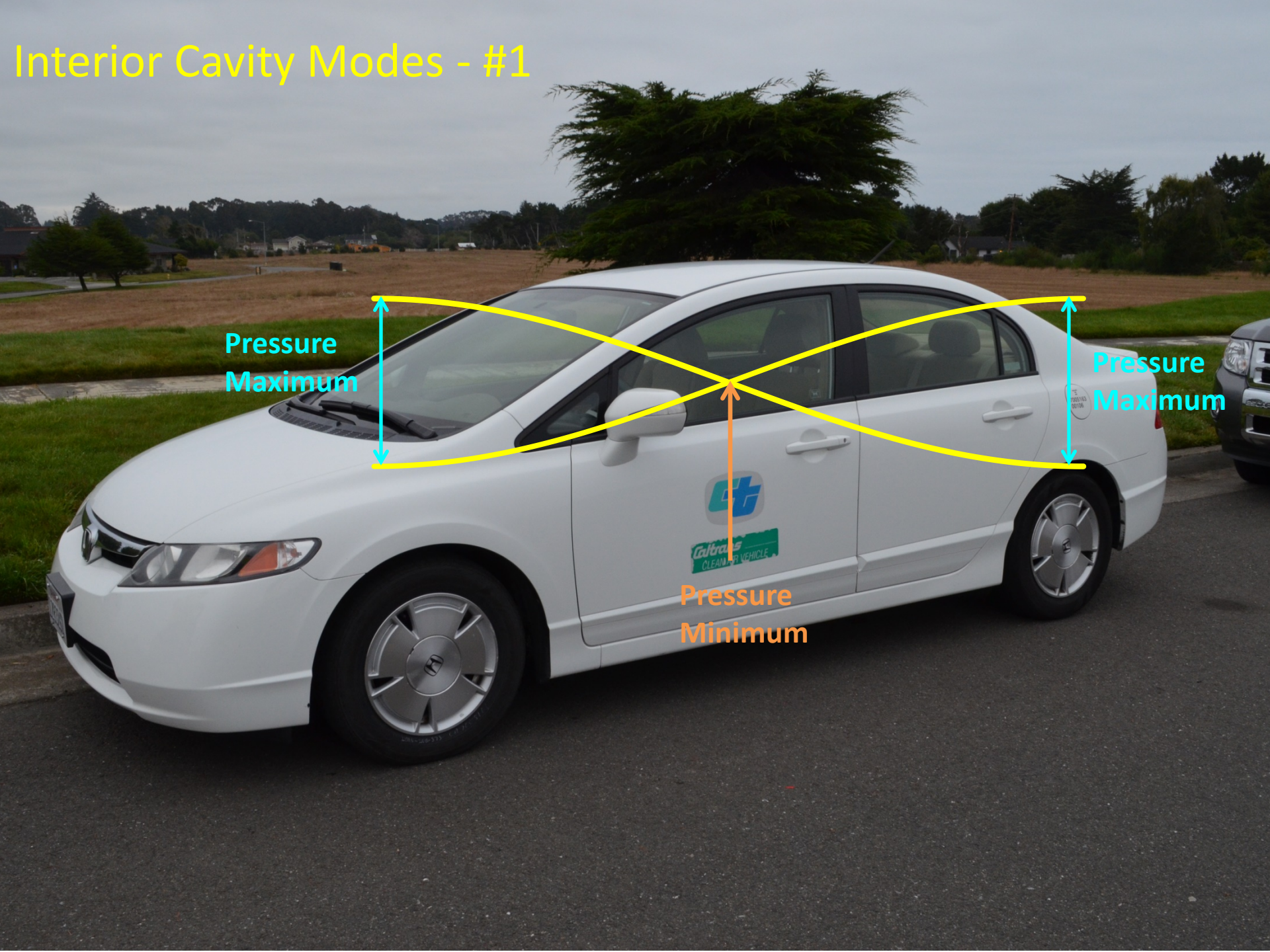
- Statistical Independent Pass-by (SIP)
- Surrogate exterior measurement

On & Off Rumble Strips

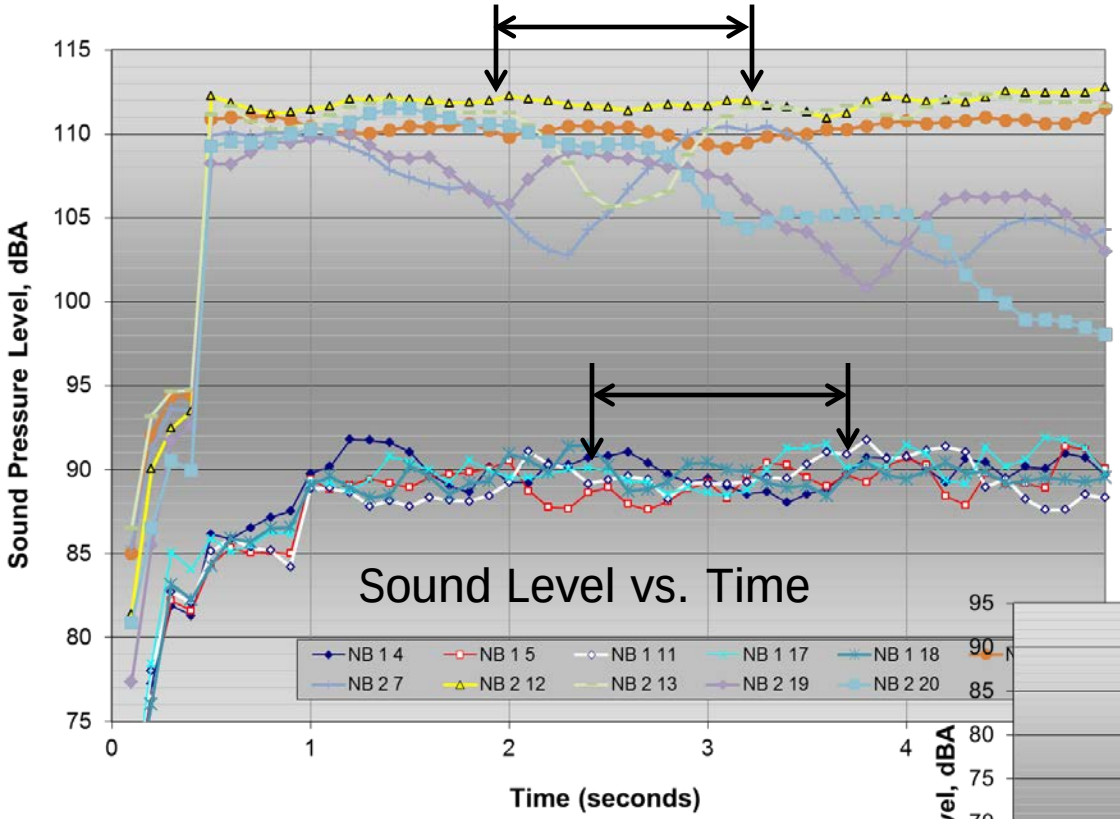
Interior Noise Measurement

- Ideally operator head location
- Use front passenger head
  - Avoids head reflection & shielding
  - No interference with the operator

Interior Cavity Modes - #1



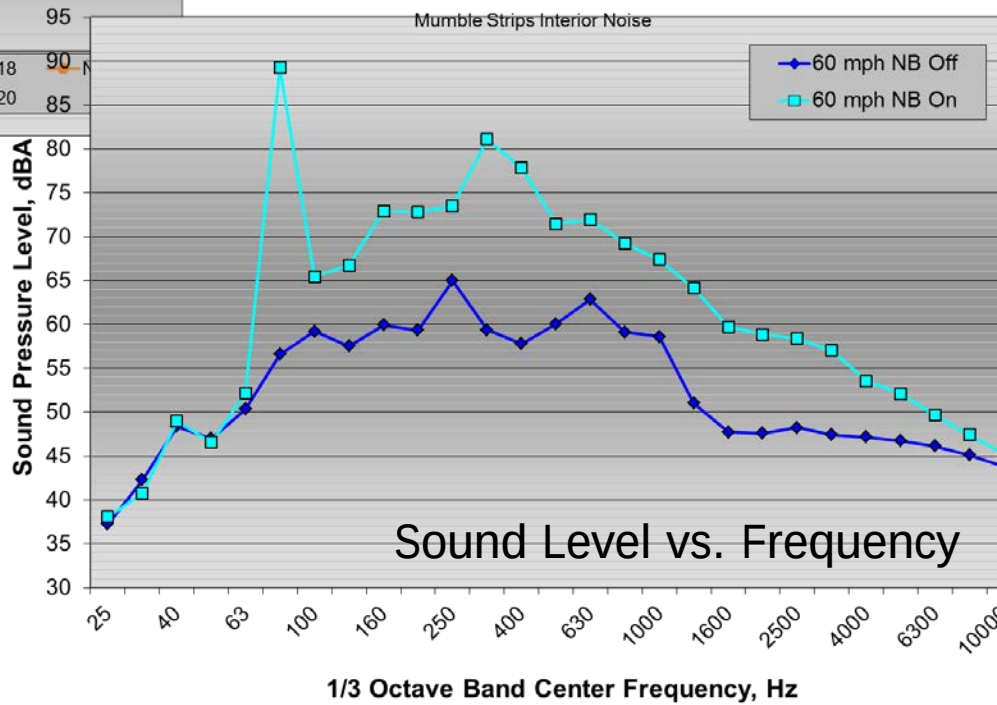
On-Board Data Processing



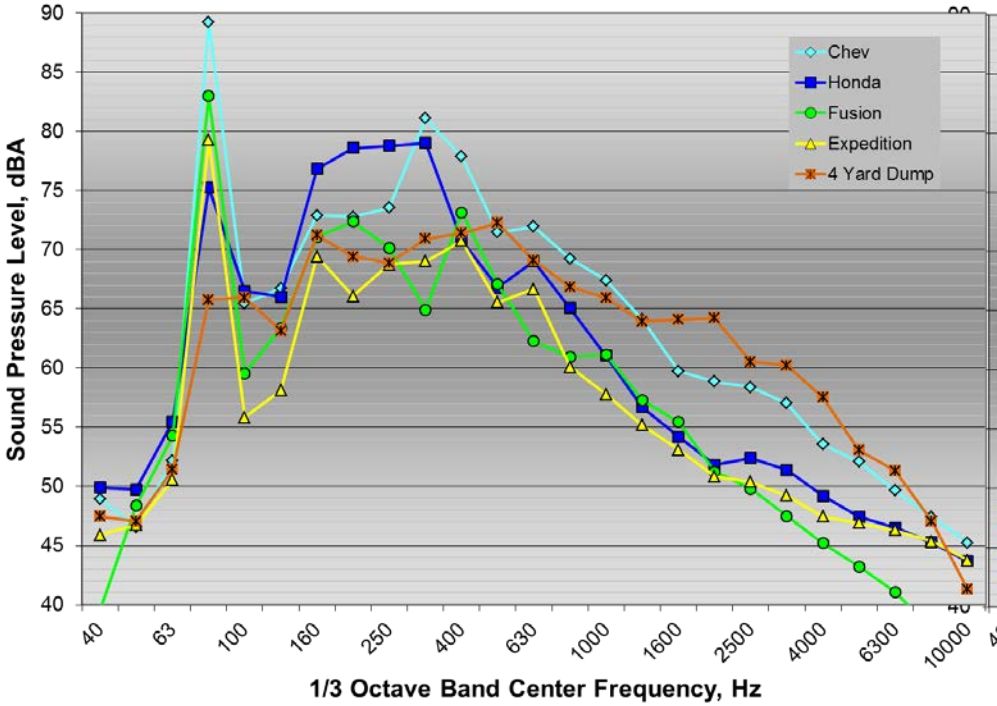
Select run & time block on strips

Select run & time block off strips

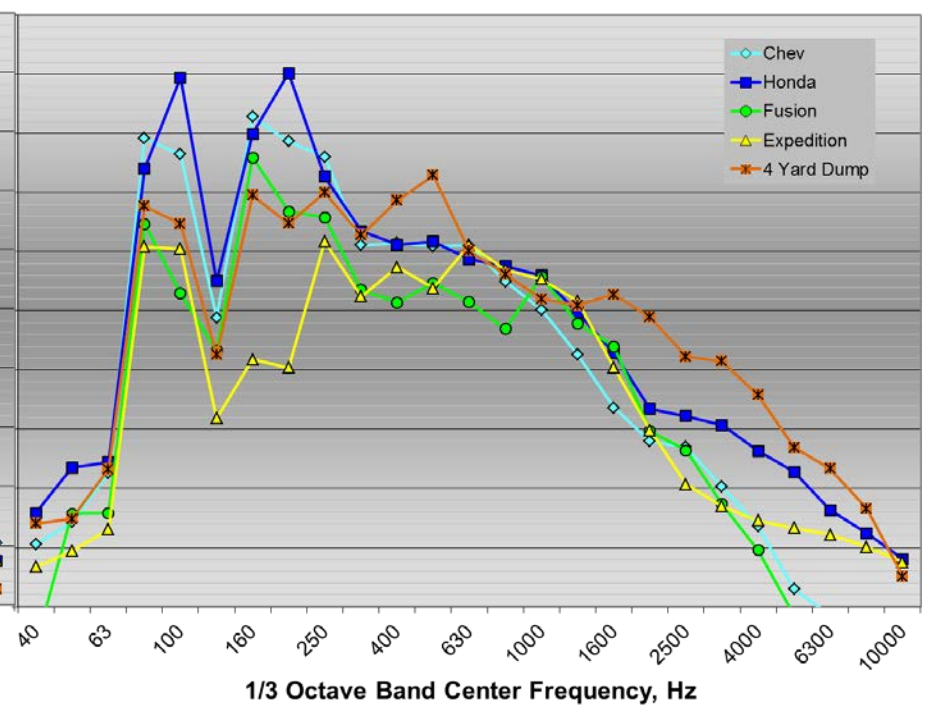
Average ⅓ octave band spectra in time blocks & compare on & off strips



Mumble & Ground Strip Interior Noise



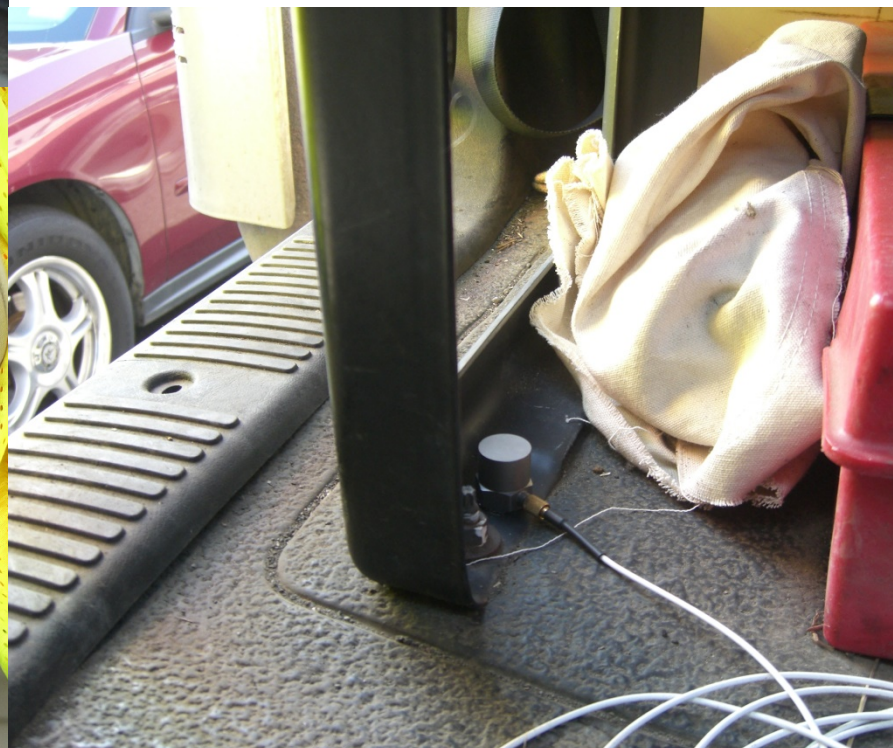
Mumble Strips



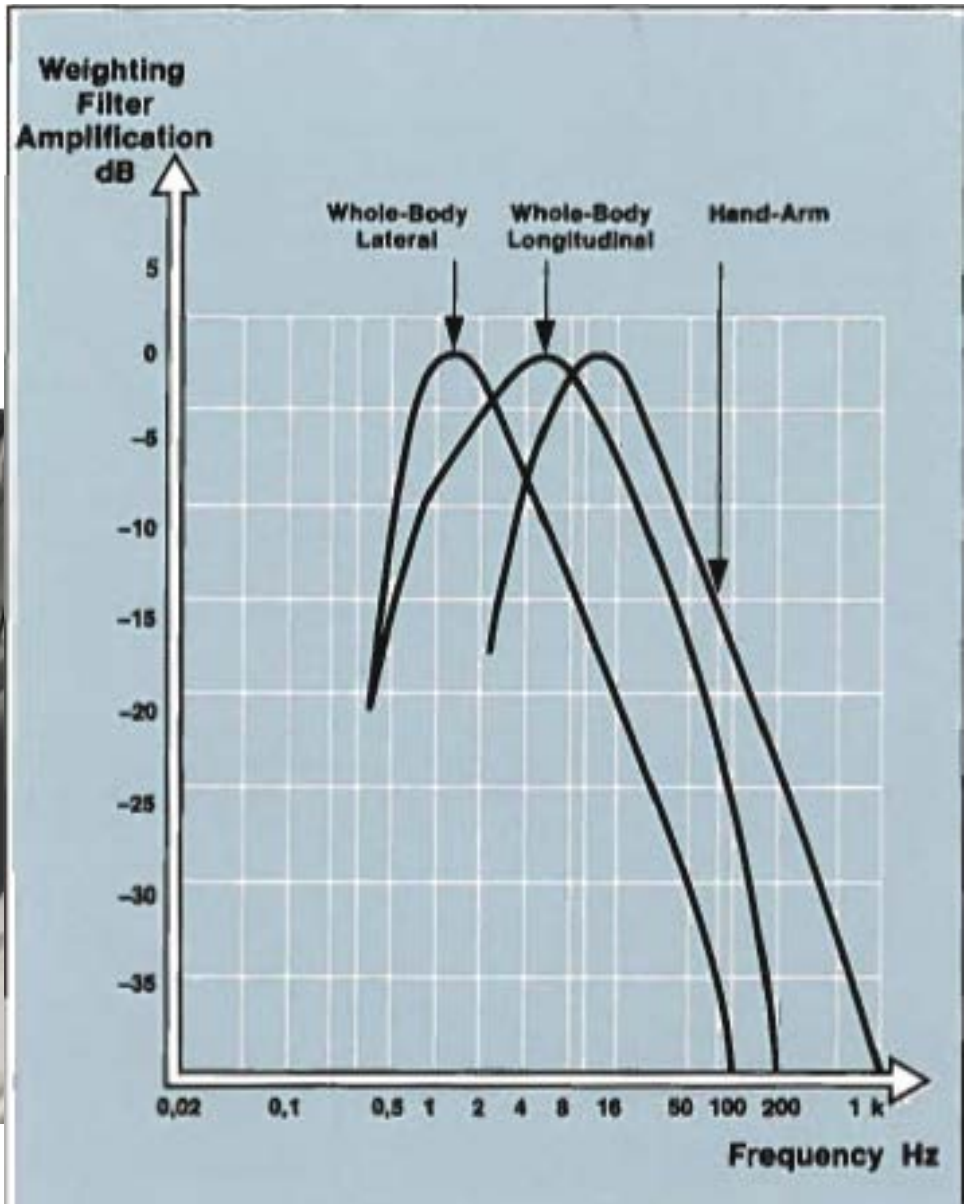
Ground Strips

Seat Track Acceleration

- Vertical axis primary input to seat
- Access to similar location can be an issue
- Outboard vs. inboard
- Passenger vs. Driver seat

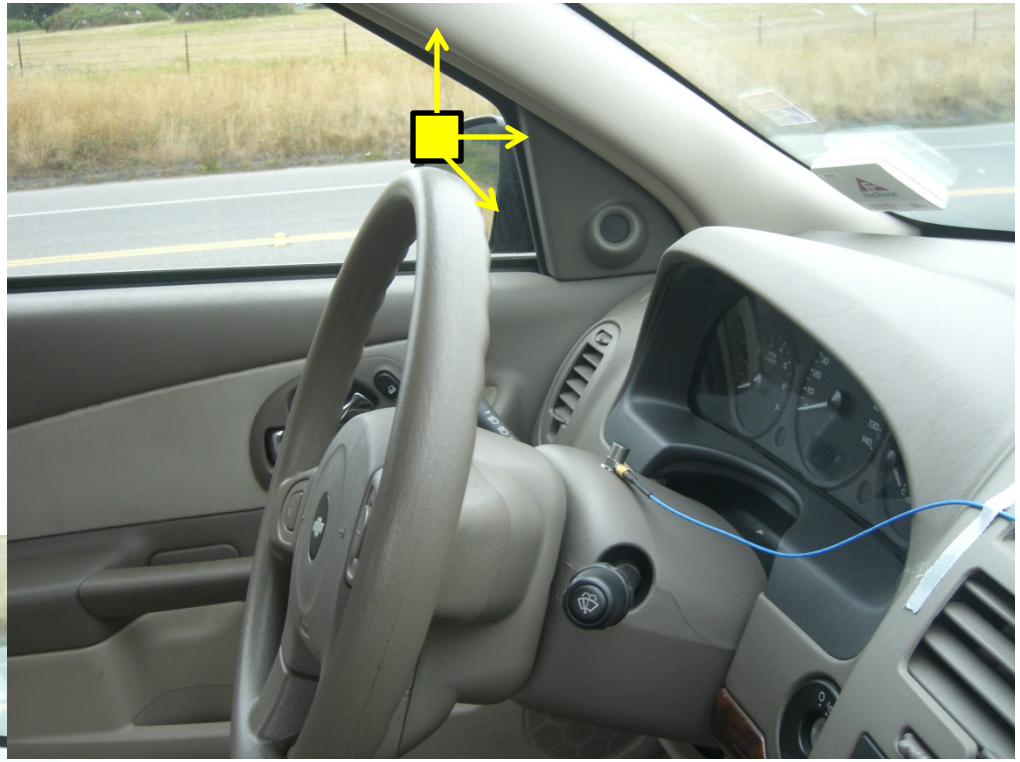


Alternative Seat Input Measurement Methods



Steering Column Accelerometer Locations

Steering Column Accelerometer Locations



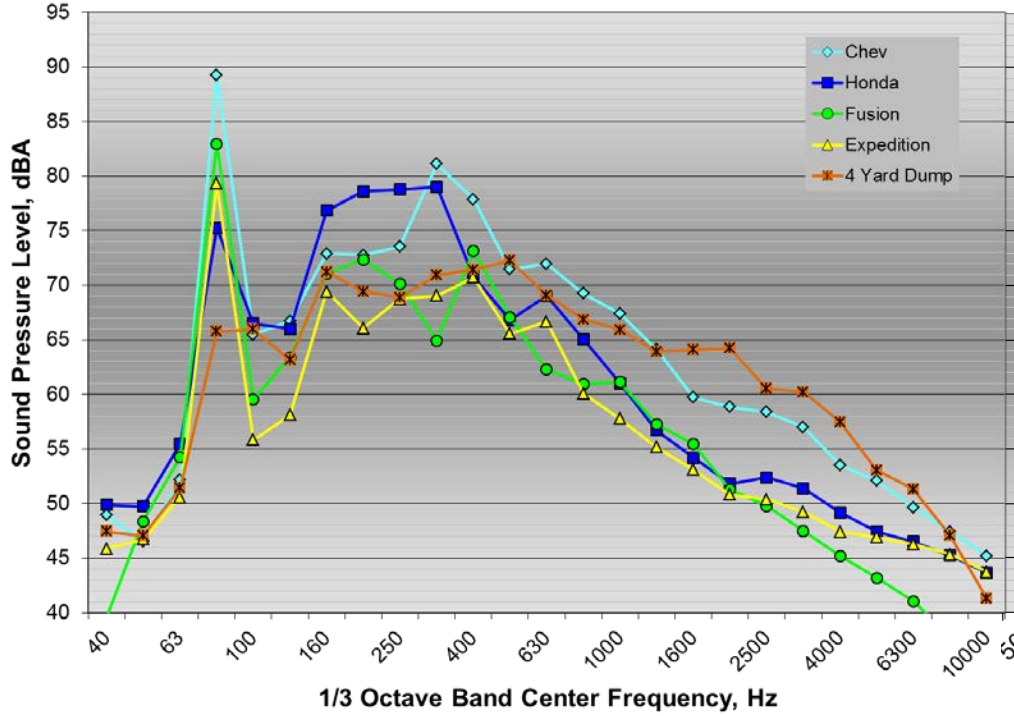
Expedient Location

- Easy to secure
- No interference with driver
- Measures response of steering column + plastic cover

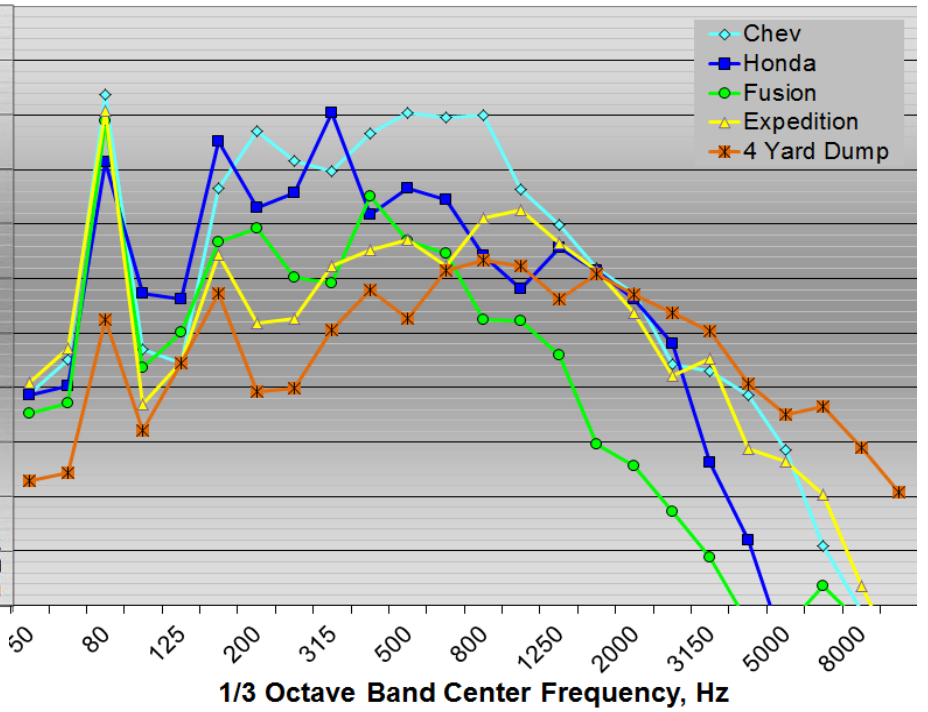
Idealized Location

- Mounted on steering wheel
- Measures on 3 axis
- Interferes with driving
- Needs secure mounting

Mumble Strip Interior Noise & Seat Track Acceleration

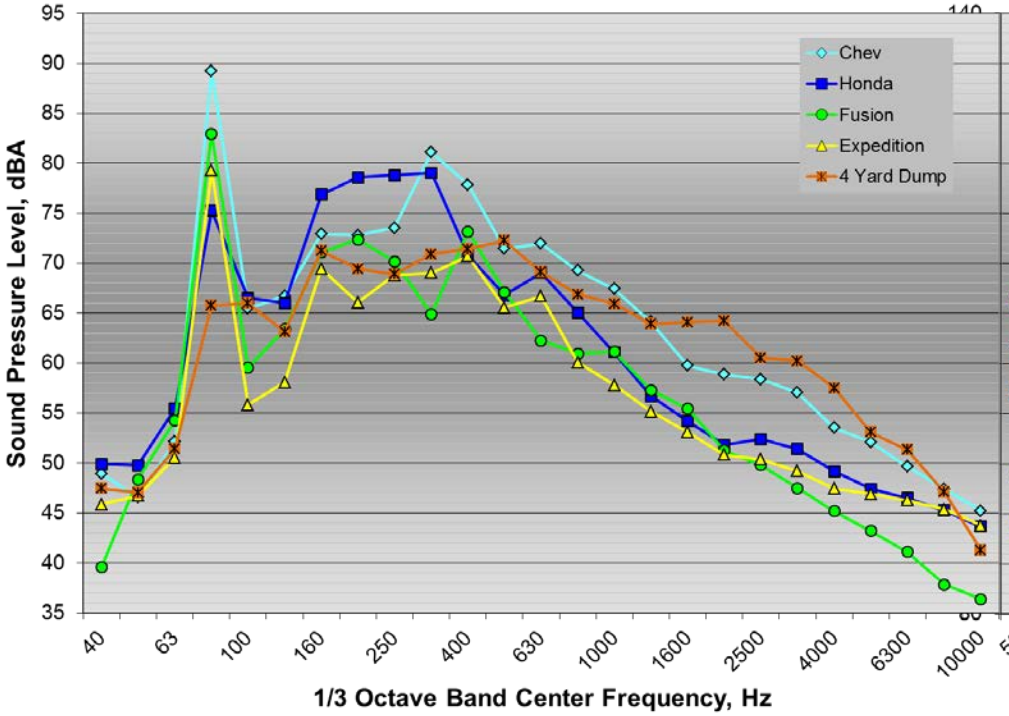


Interior Noise

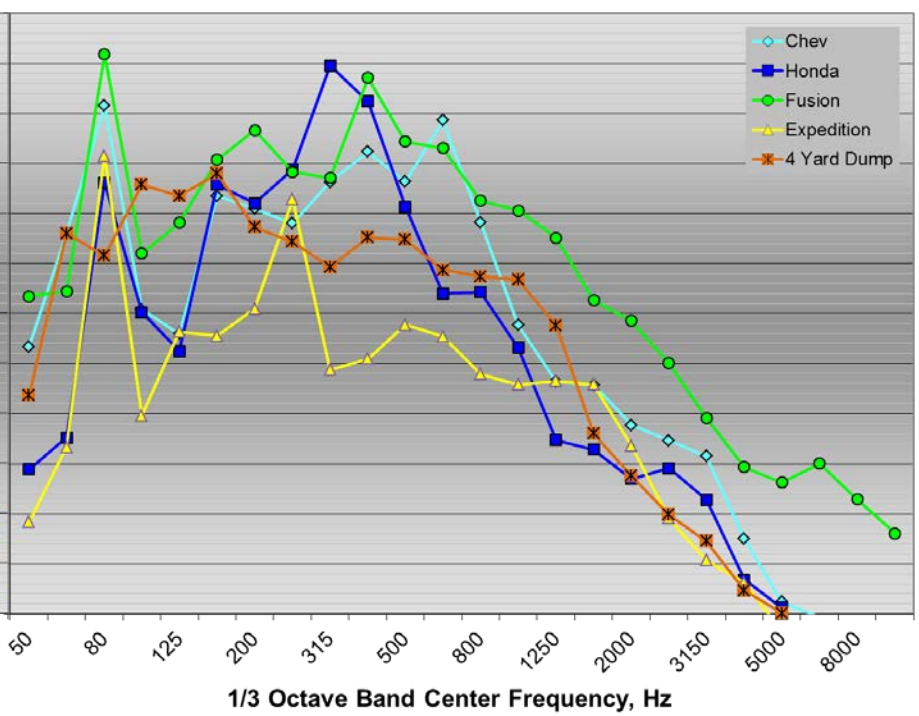


Seat Track Acceleration

Mumble Strip Interior Noise & Steering Column Acceleration

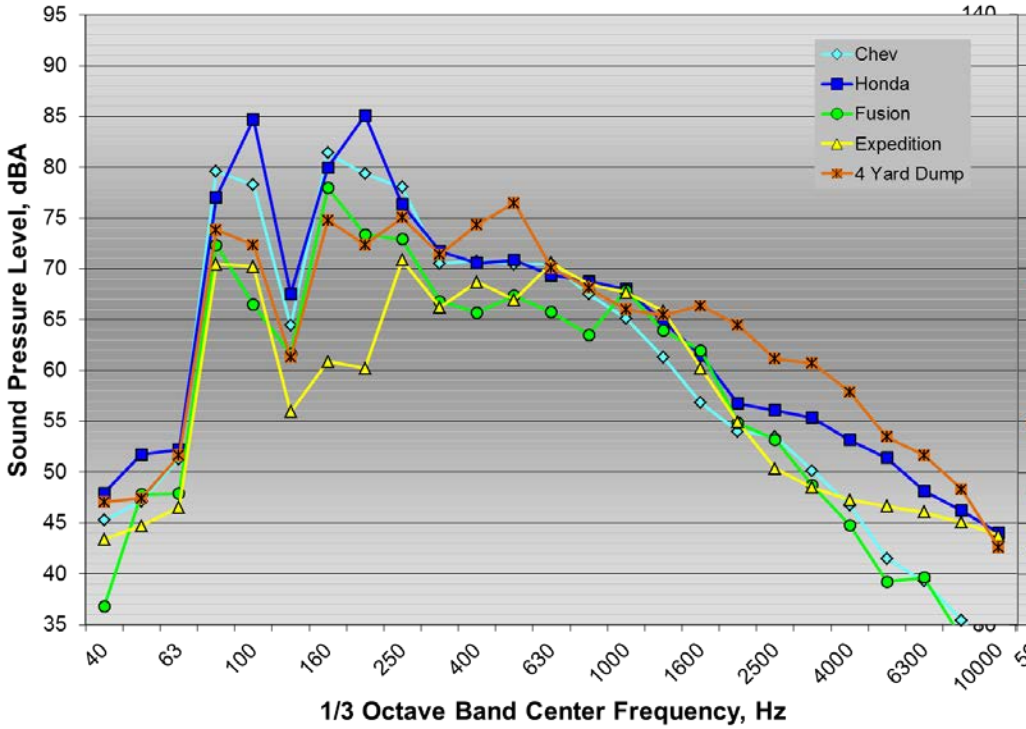


Interior Noise

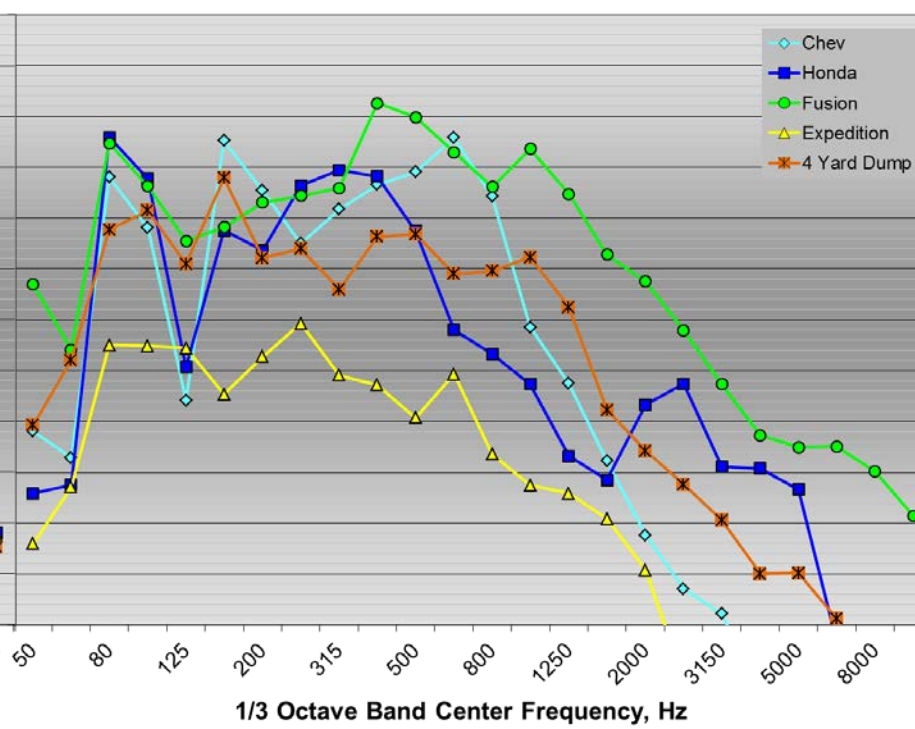


Steering Column Acceleration

Ground Rumble Strip Interior Noise & Steering Column Acceleration



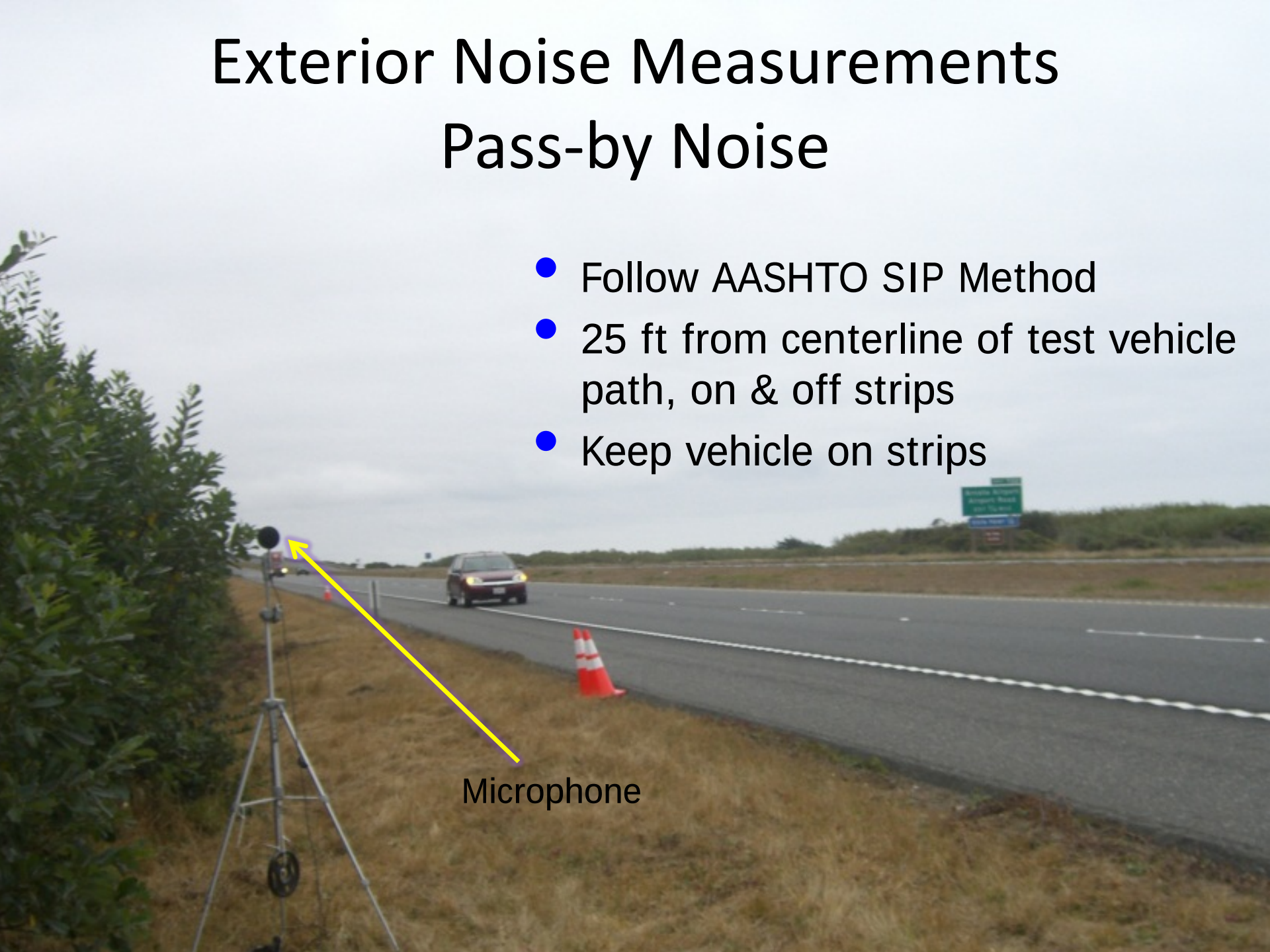
Interior Noise



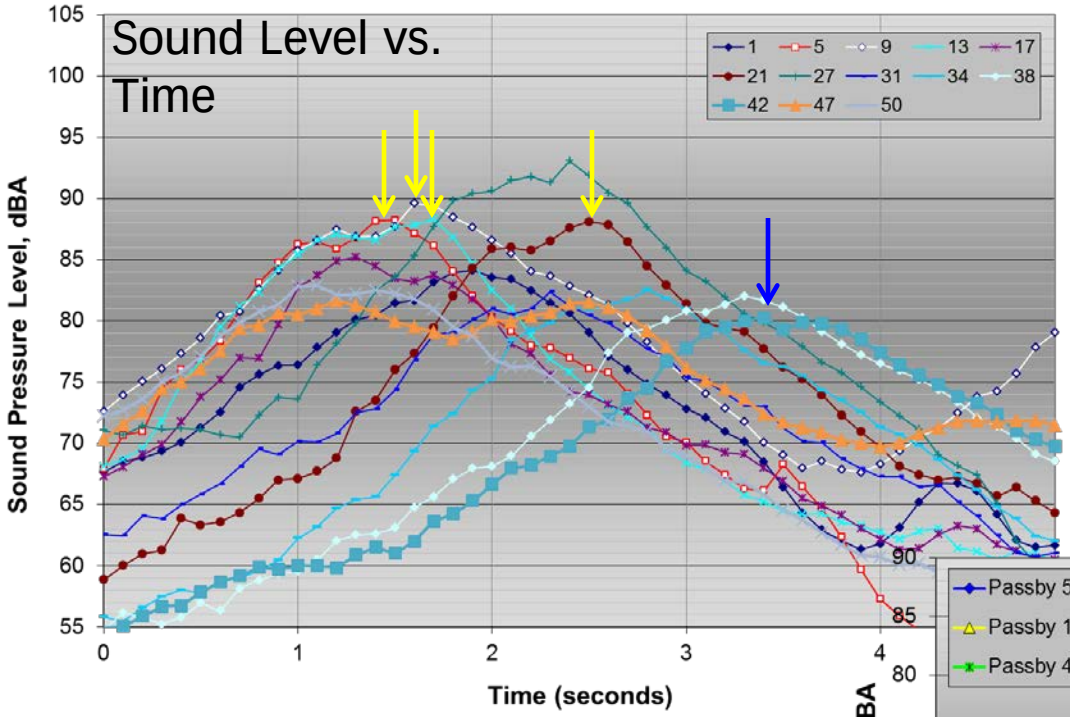
Steering Column Acceleration

Exterior Noise Measurements
Pass-by Noise

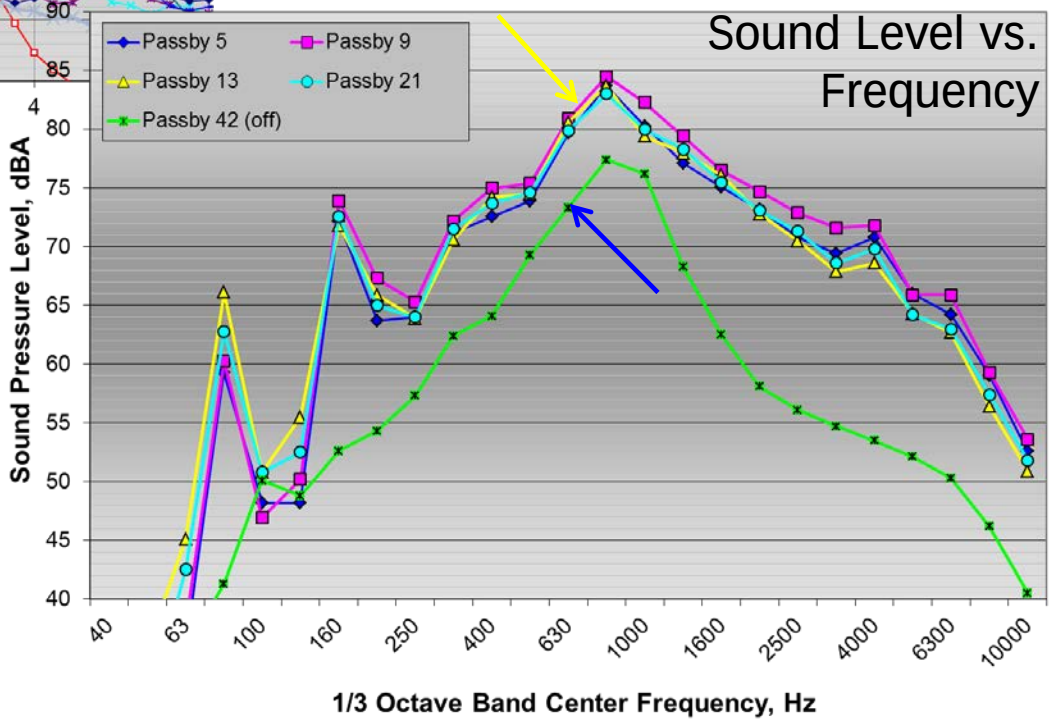
- Follow AASHTO SIP Method
- 25 ft from centerline of test vehicle path, on & off strips
- Keep vehicle on strips



Pass-by Data Processing

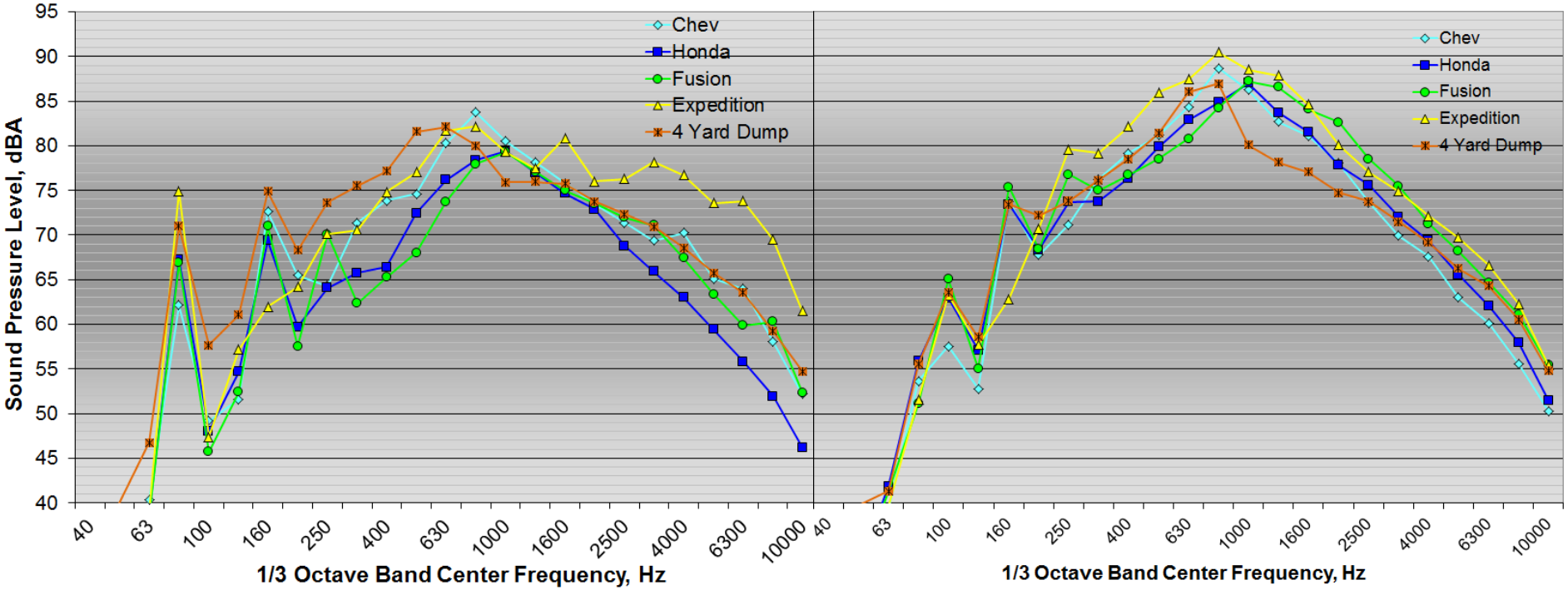


Select maximum levels on & off strips



Average maximum ⅓ octave band spectra on the strip & off

Mumble & Ground Strip Pass-by Noise



Mumble Strips

Ground Strips

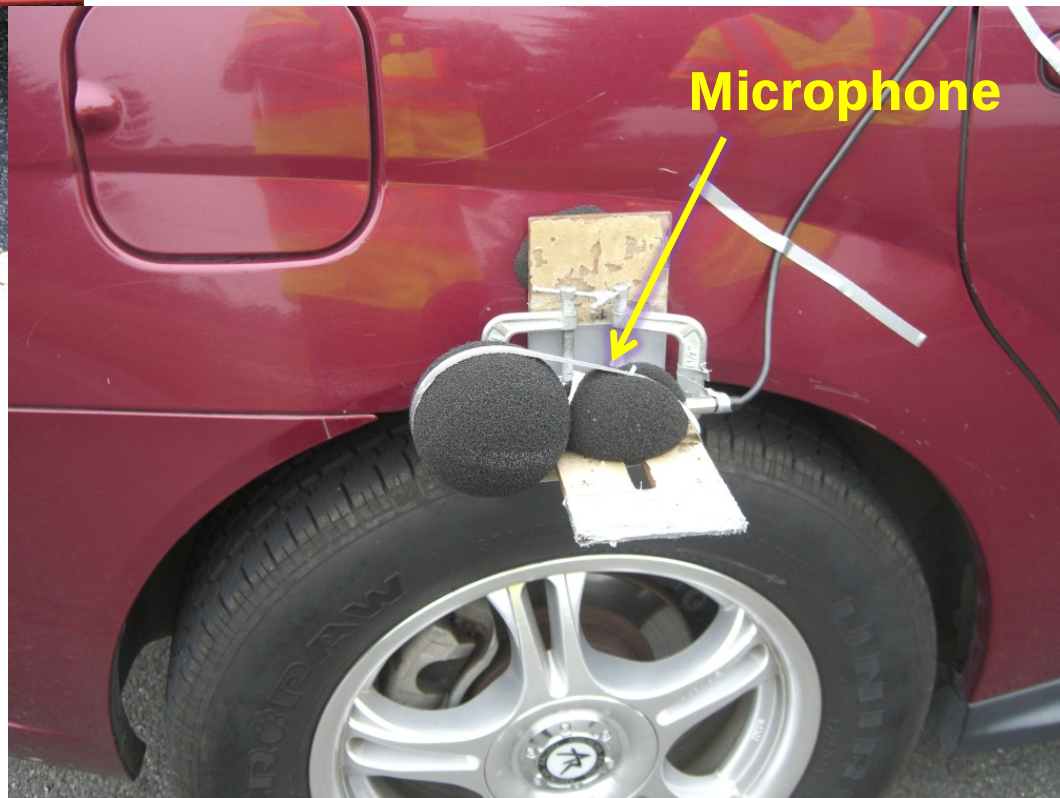
Surrogate Exterior Measurement

- Eliminate more time consuming pass-by measurements
- Conduct measurements all at the same
- Correlate surrogate to pass-by much like OBSI to pass-by

Exterior Noise Measurements

- Initial attempt using AASHTO OBSI
- Abandoned due to excessive probe vibration

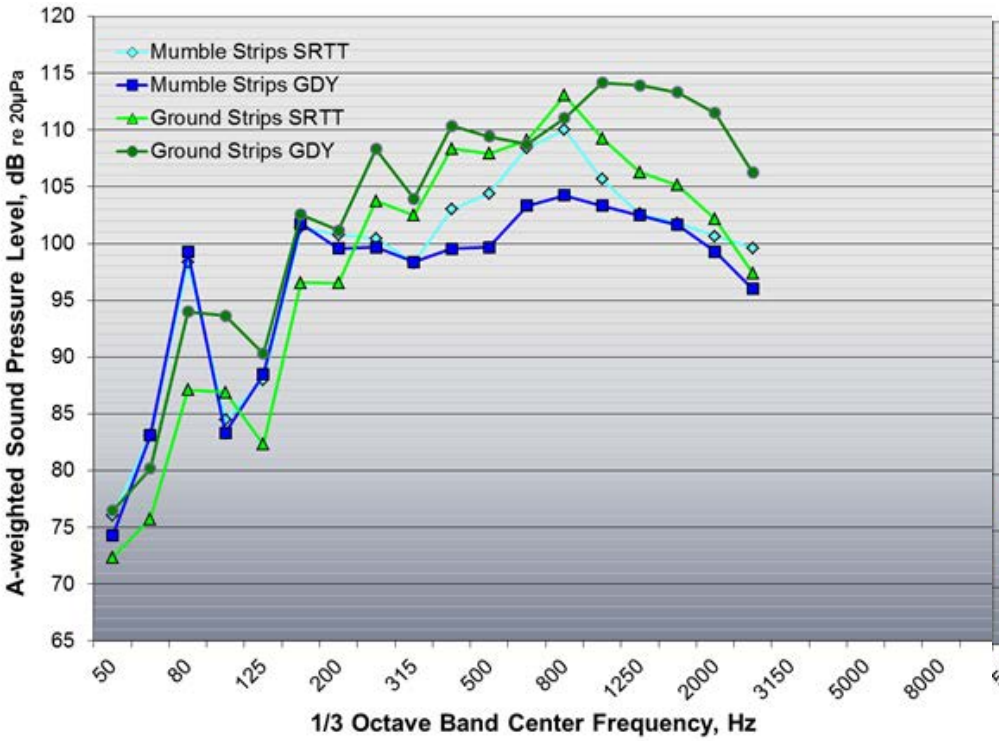
- Second (crude) attempt
- Sound pressure level above rear tire
- Provided acceptable signal to noise ratio



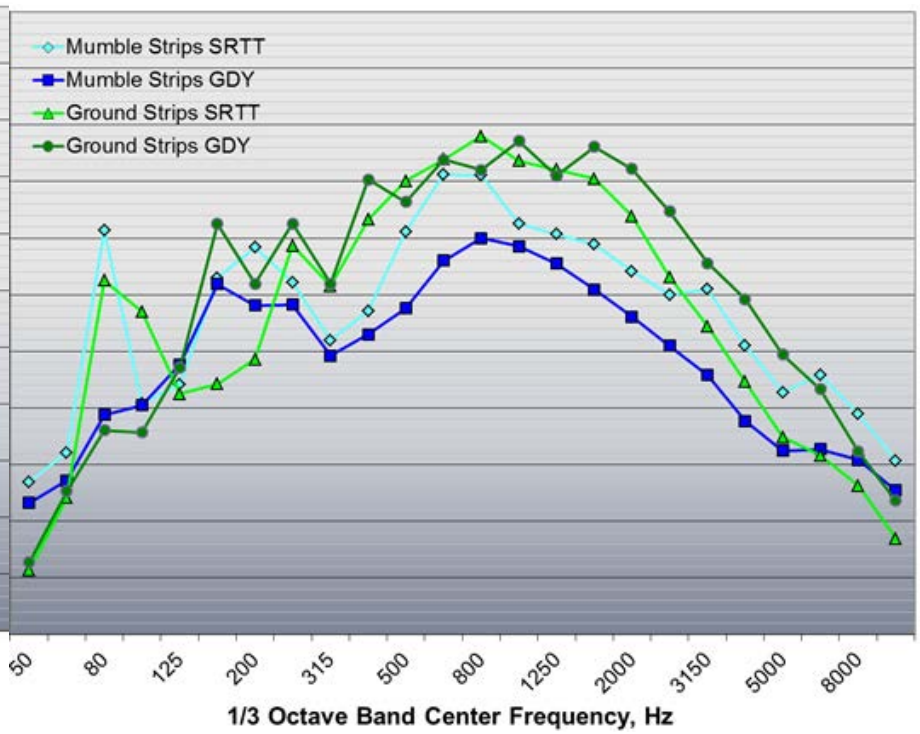
Rumble Strip Tire Noise
Sound Intensity

- Severe vibration problems initially
- Remedied with isolated mounts & holders
- Measurement shows intensity is all negative & not coming from tire
- Potential to use sound pressure level instead

OBSI Pressure & Exterior Noise – Fusion with SRTT & Goodyear Tires

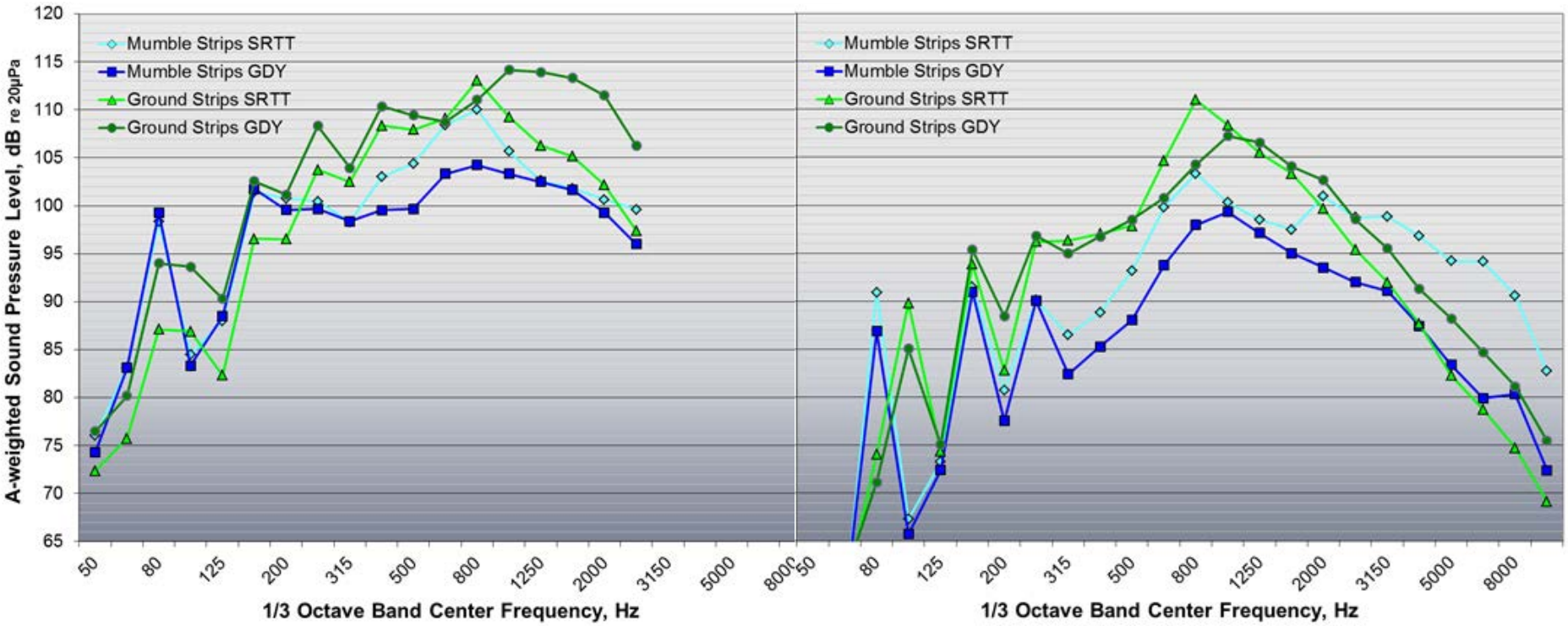


OBSI Sound Pressure Level



Exterior Noise Level

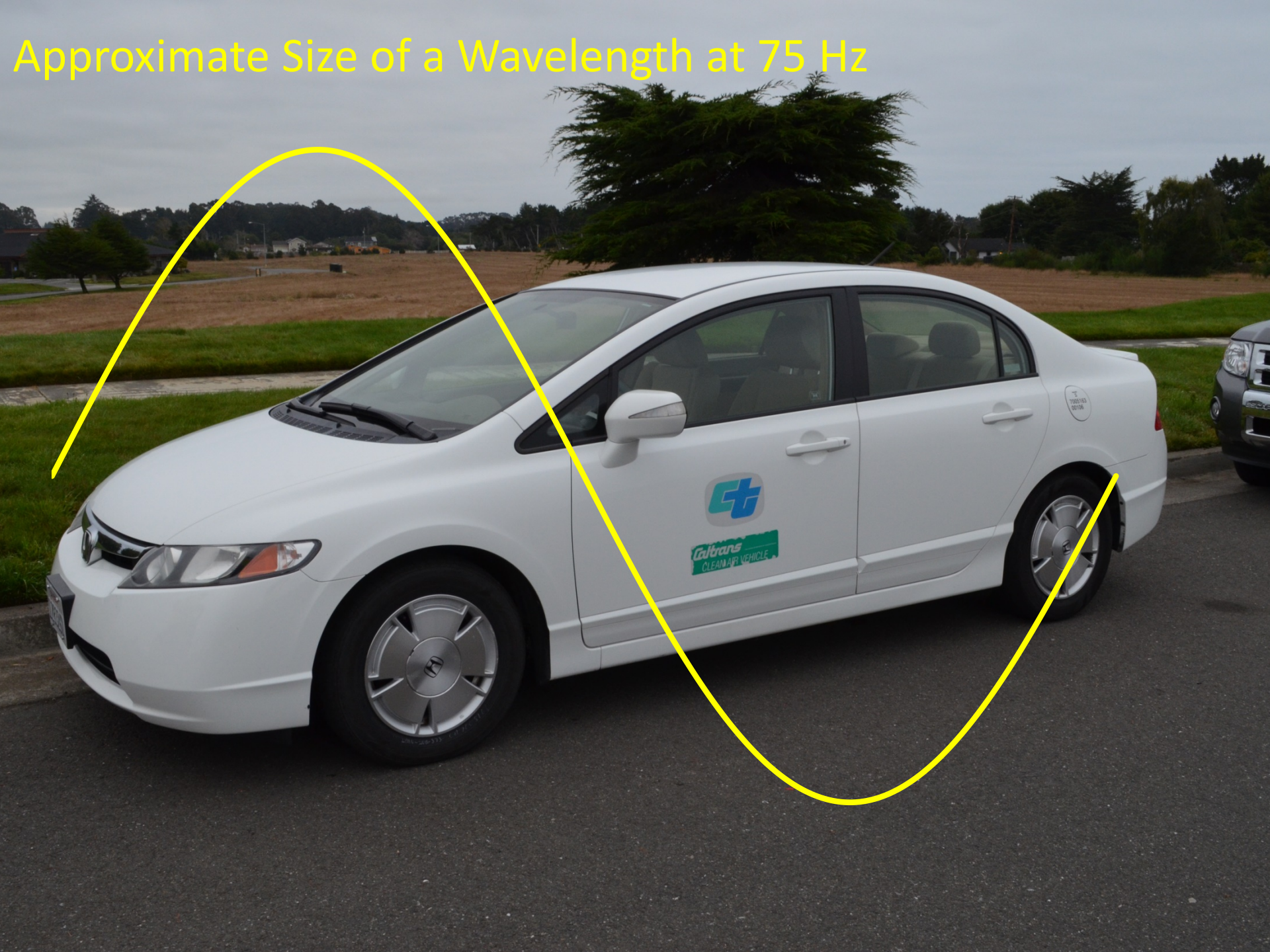
OBSI Pressure & Pass-by Noise – Fusion with SRTT & Goodyear Tires



OBSI Sound Pressure Level

Pass-by Noise Level

Approximate Size of a Wavelength at 75 Hz



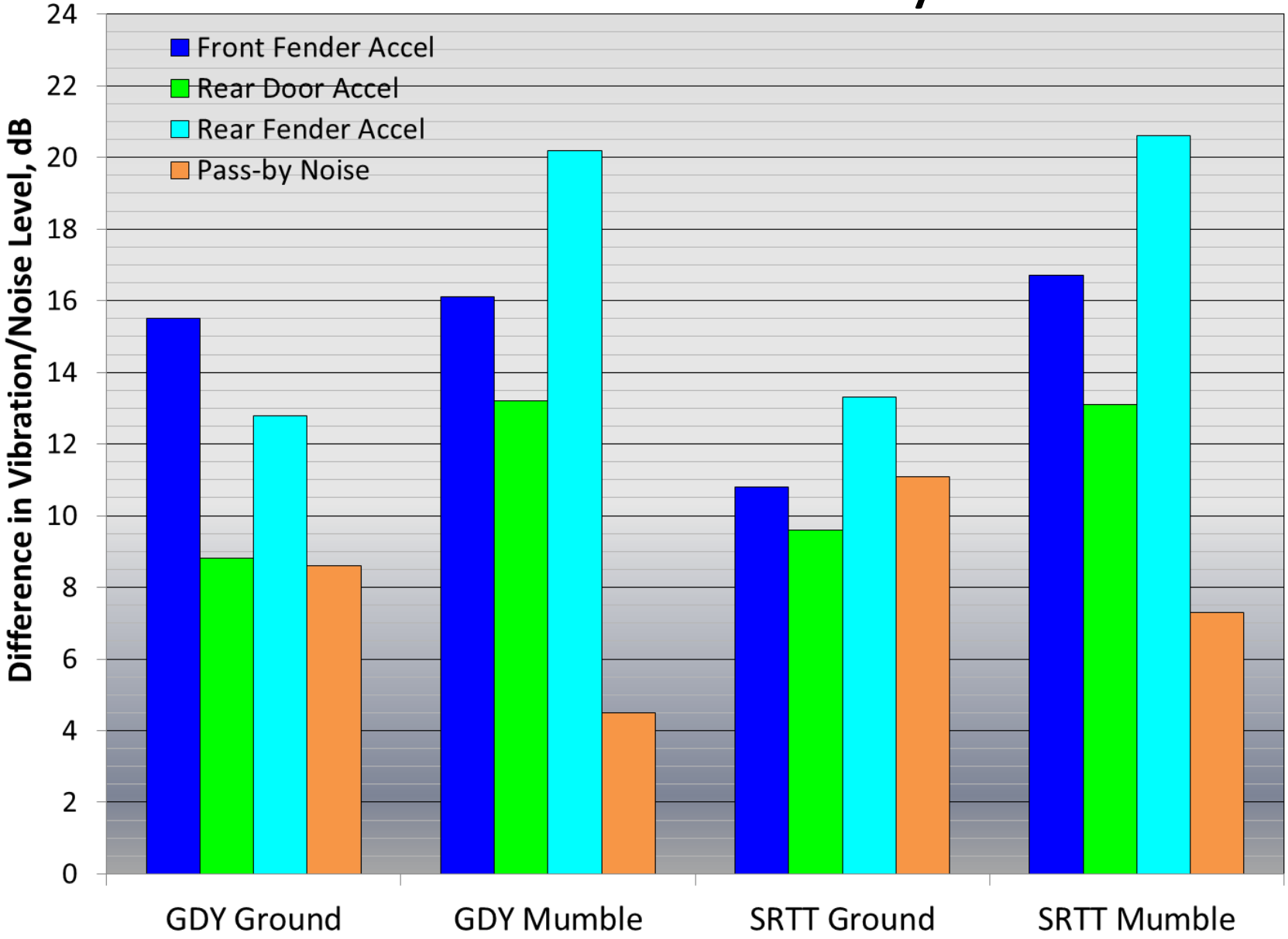
Panel Vibration Measurements

Front Fender

Rear Door

Rear Fender

Increase in Level On/Off Strips
Panel Vibration & Pass-by Noise

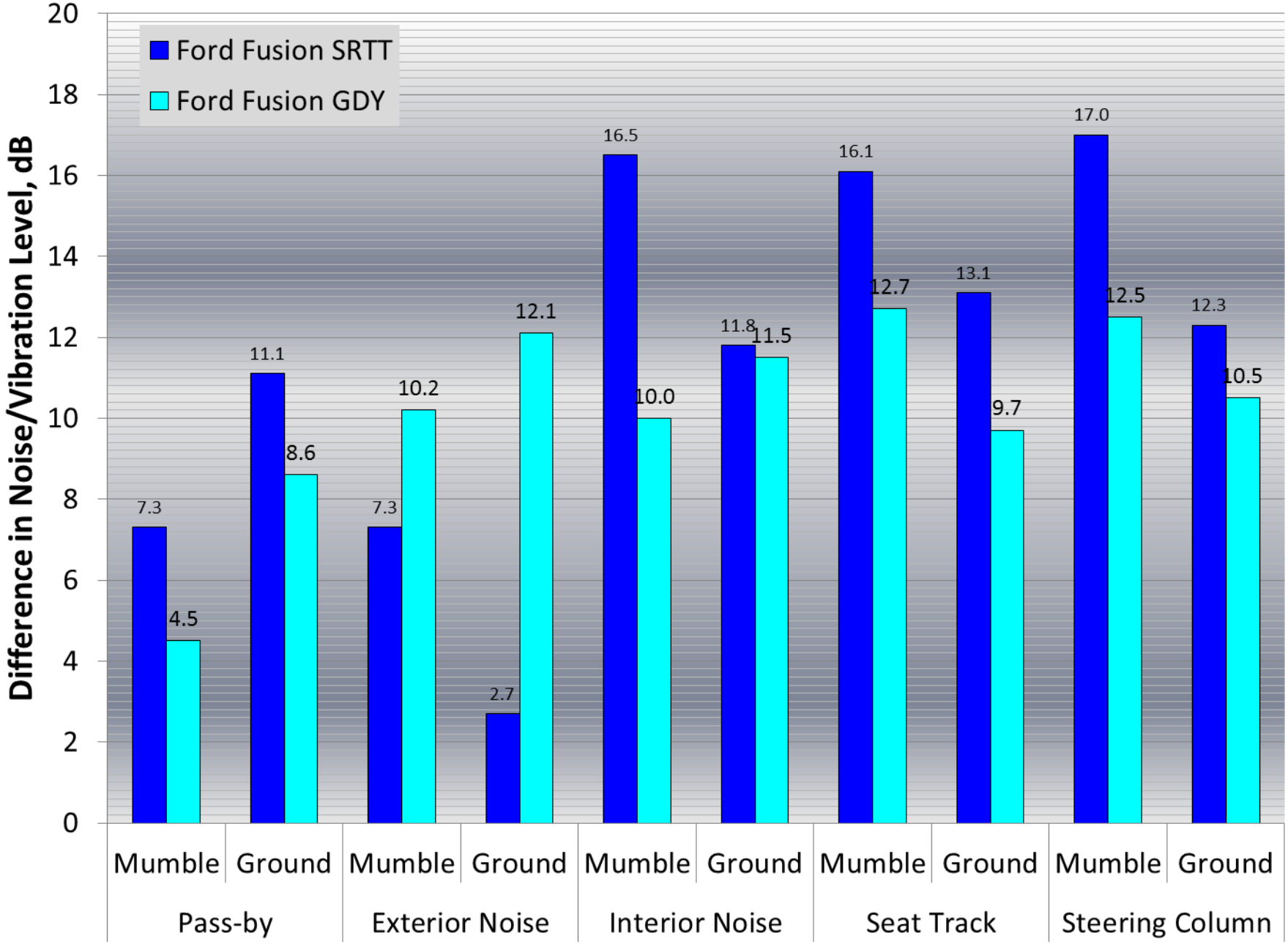


Ford Fusion Test Tires

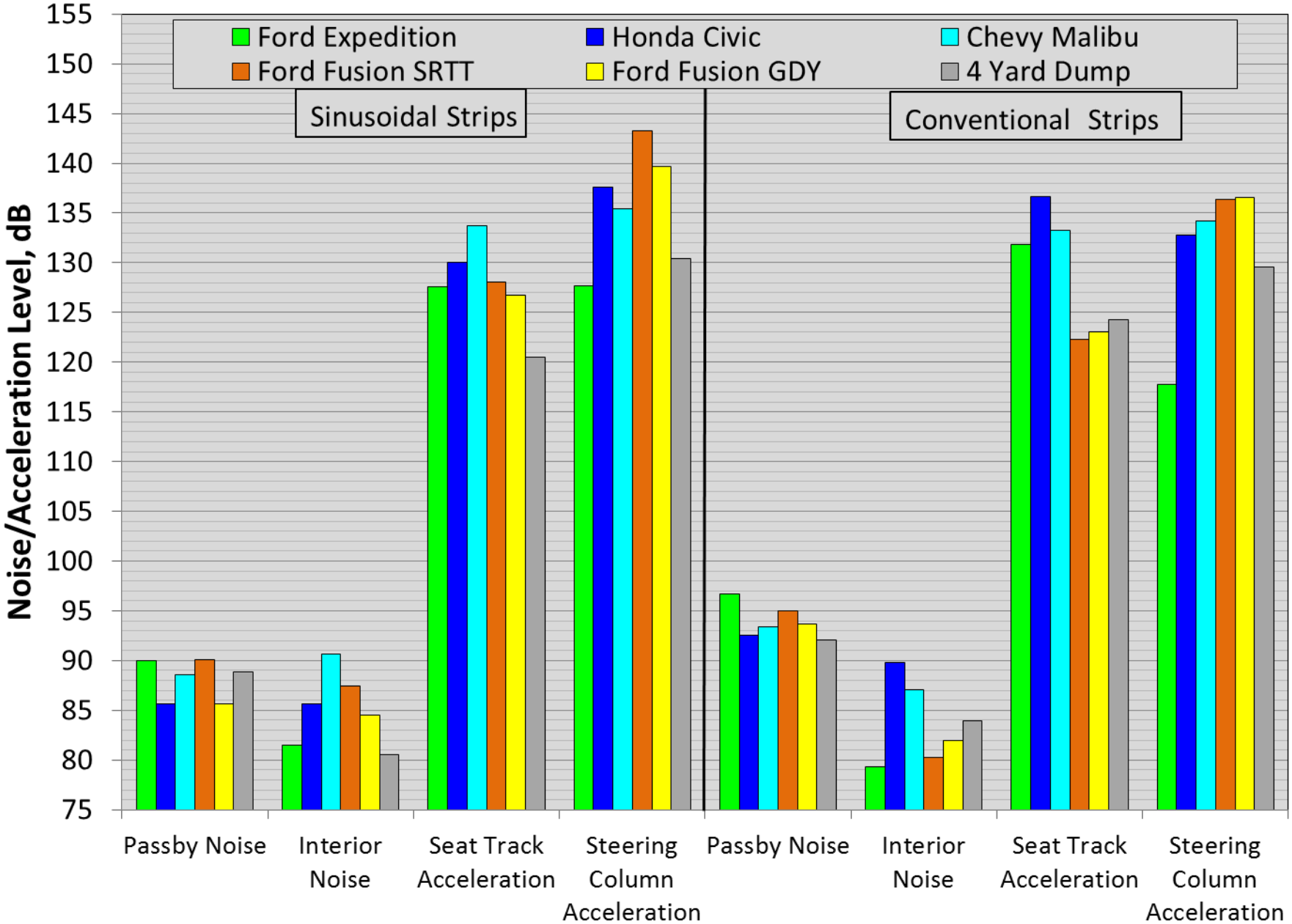
SRTT (Uniroyal)

Eagle LS2 (Goodyear)

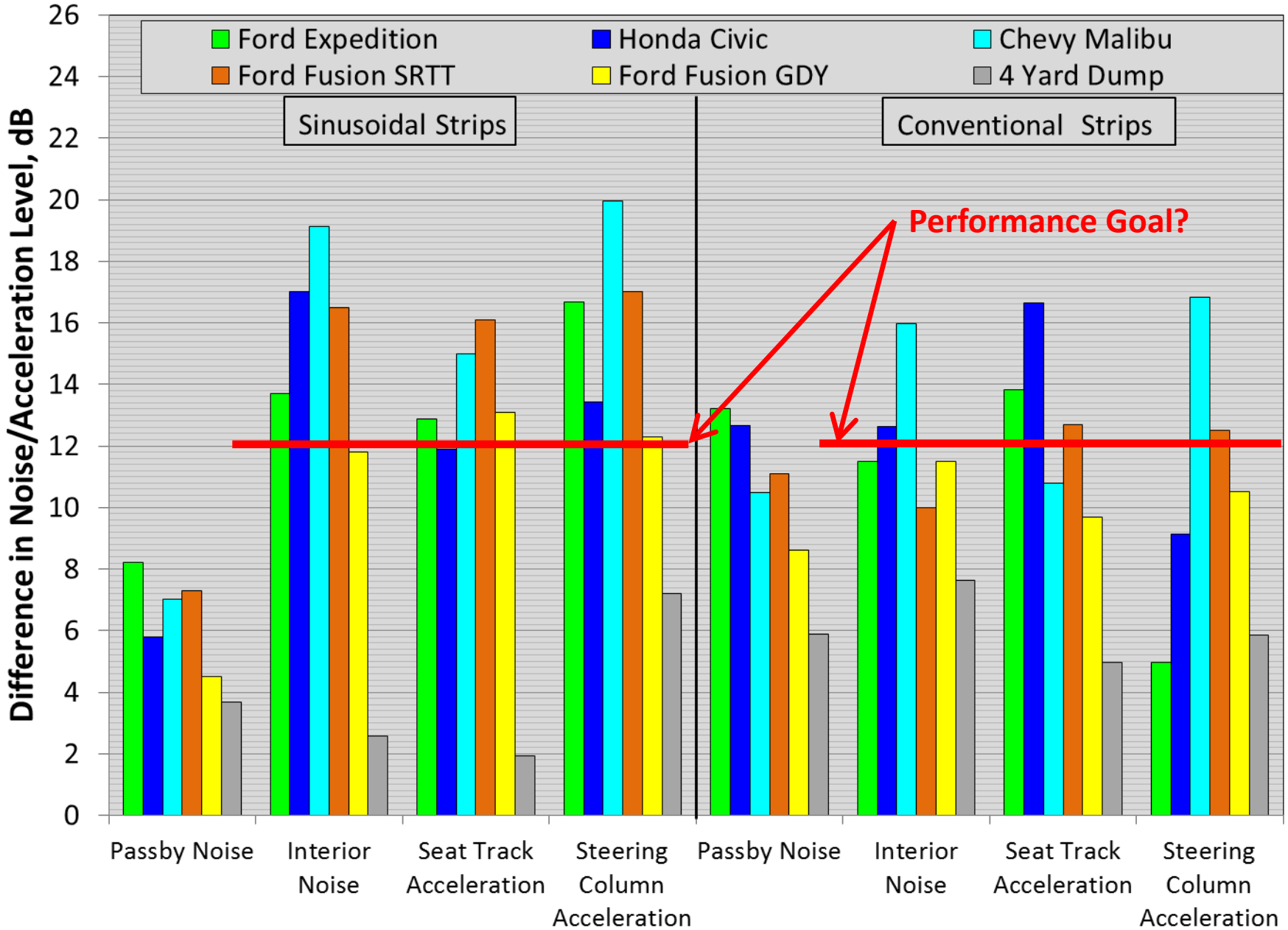
Comparison of Tires – Ford Fusion



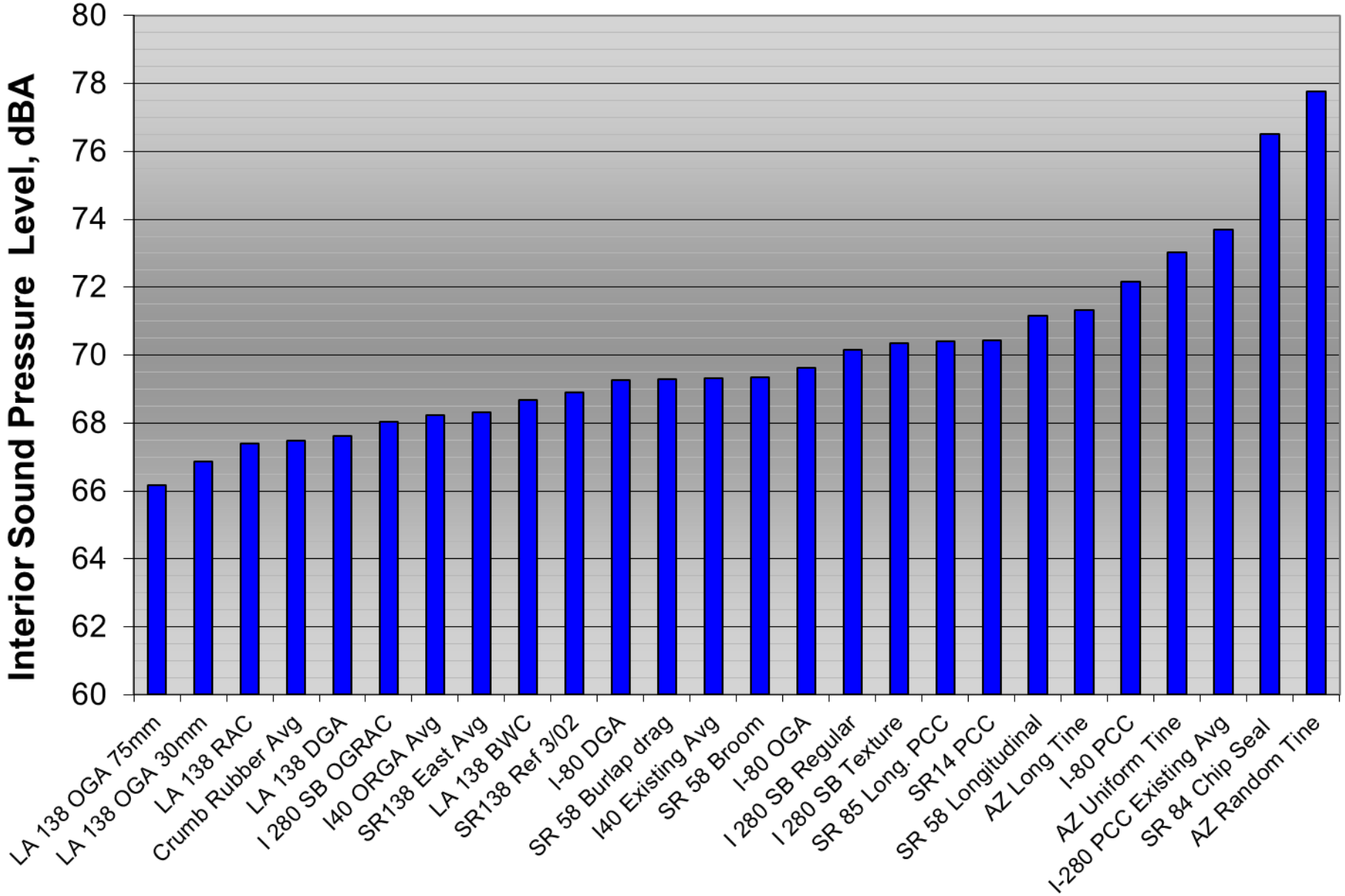
Overall Noise & Vibration Results



Difference in Noise & Vibration Levels On & Off Strips



Interior Noise Levels on Various Pavements



Rumble Strip Evaluations Issues

- Response to rumble strips varies with different vehicles and tires
- Validation of rumble designs requires both noise & vibration measurements
- Other vibration measurement methods should be evaluated
- No surrogate (yet) for pass-by measurements
- Setting rumble strip performance standards requires standardized evaluation methods