QRTV-08-03

NHTSA-Volpe Phase 3 Research

Test Procedure Development, Preliminary Data, & Sound Parameters

NHTSA Quieter Vehicles Team

October 18th, 2011

PEDESTRIAN ALERT SOUND SYSTEM (PASS) TESTING

FOUR HYBRID-ELECTRIC OR ELECTRIC VEHICLES WITH PASS

VS.

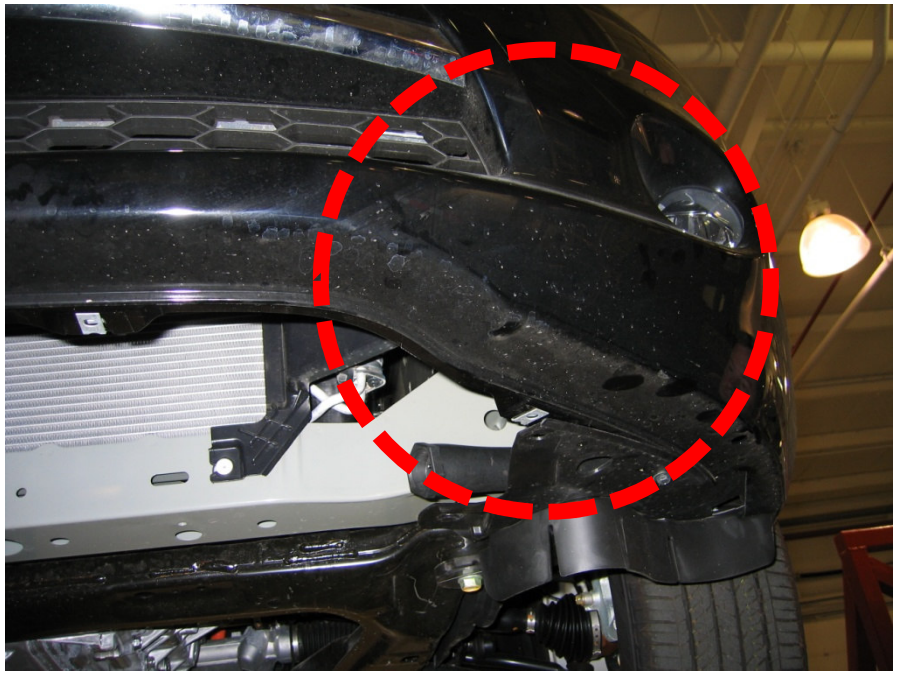
FOUR PEER INTERNAL COMBUSTION ENGINE VEHICLES

Phase 3 Testing Overview

- Goal is to support the NHTSA rulemaking effort for PSEA by developing a test procedure with accompanying performance specifications
- Completed Outdoor Testing on ISO 10844:1994 Noise Pad
  - June to October, 2011 (Data is preliminary)
- Production Vehicles with Pedestrian Alert Sound(s)
  - Nissan Leaf Electric Vehicle (EV) / Nissan Versa 1.8L SL Hatchback ICE Peer
- Prototype Vehicles with Pedestrian Alert Sound(s)
  - Prototype 1 Hybrid Electric Vehicle (HEV) & ICE Peer
  - Prototype 2 Hybrid Electric Vehicle (HEV) & ICE Peer
  - Prototype 3 Hybrid Electric Vehicle (HEV) & ICE Peer
- All HEVs & EVs were measured in electric propulsion mode (e.g., ICE off)
- Seven separate test scenarios used for each vehicle

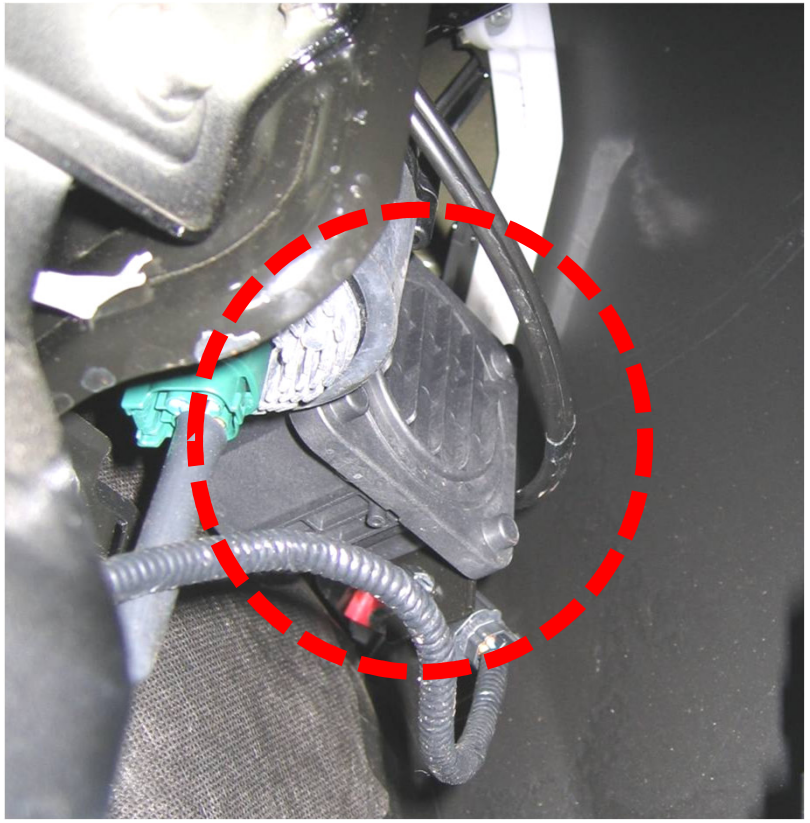
Pedestrian Alert Sound System (PASS)

PASS Speaker Location – Nissan Leaf EV



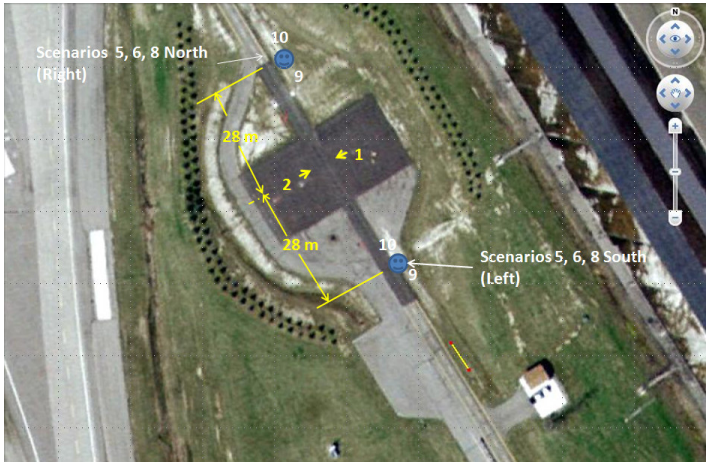
Behind front bumper, driver's side, above wheel-well housing.

PASS Speaker – Nissan Leaf EV



Outdoor Pass-by Noise Measurement Equipment

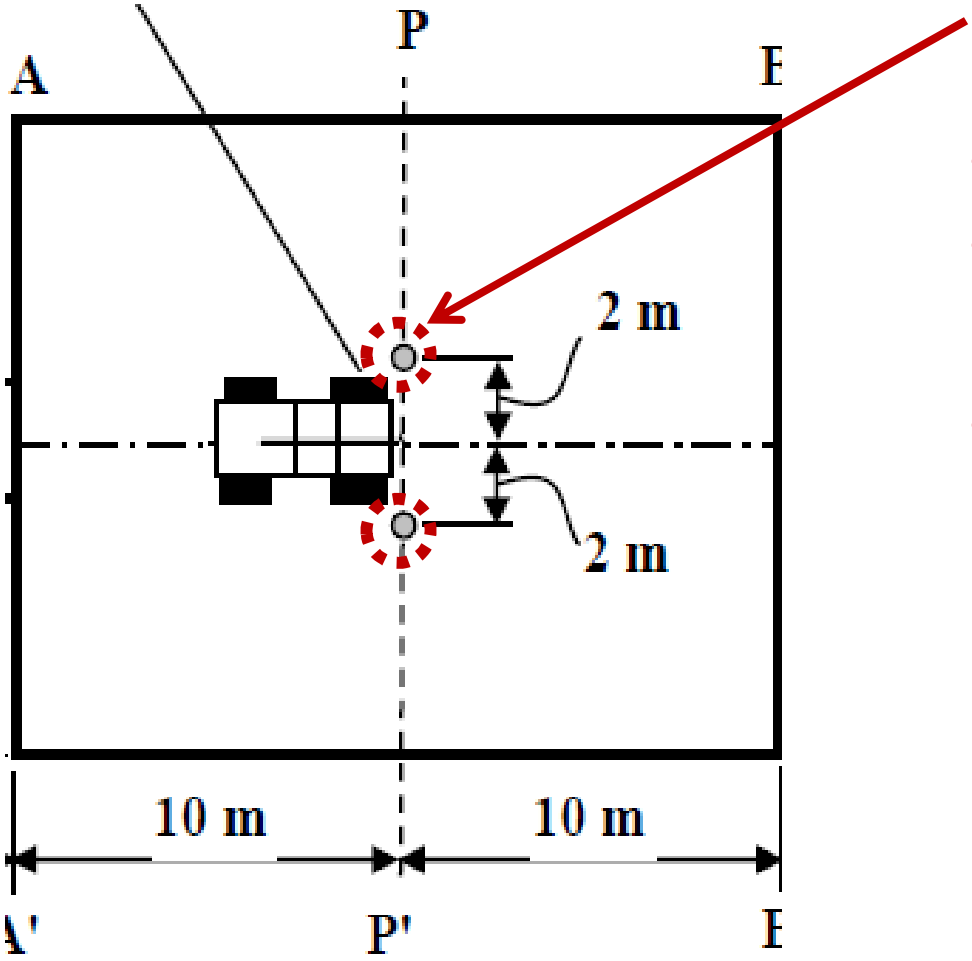
ISO 10844 Noise Pad & Pass-by Noise Measurement System



Two Microphones & Light Traps

SAE J2889-1: "*MEASUREMENT OF MINIMUM NOISE EMITTED BY ROAD VEHICLES*," ISSUED 2011-SEPT-21

Scenario A - SAE J2889-1 "Stopped Condition"



Graphic: SAE J2889-1 with overlays

- **Two microphones at a line P-P'**
  - Microphones 2.0-m from centerline, 1.2-m in height
- **Vehicle stopped**
- **For front engine vehicles**
  - Front end of vehicle at microphone line
- **Four measurement minimum**
  - 10 second measurement
  - Maximum A-weighted sound pressure level for each microphone is corrected for background noise level
  - Corrected results are averaged for each side of the vehicle
  - Reported value is the lower value of the two sides

Initial Results – Scenario A (0 km/h), Front Plane, Pass "On"

Vehicle	Sound at Idle? (Yes/No)	Volume Level Set by Manufacturer (Yes/No)	0 km/h (dBA)
Nissan Leaf EV	*Reverse Gear Only*	*Yes*	*(58) – Reverse Beeper*
Nissan Versa ICE	Yes	N/A	49
		Difference = PASS - ICE	*(+9) – Reverse Beeper*
Prototype 1 HEV	*No*	*N/A*	*N/A*
Prototype 1 ICE Peer	Yes	N/A	53
		Difference = PASS - ICE	N/A
Prototype 2 HEV	*Yes*	*No (Adjustable)*	*(Adjustable Range 46-68)*
Prototype 2 ICE Peer	Yes	N/A	50
		Difference = PASS - ICE	N/A
Prototype 3 HEV	*No*	*N/A*	*N/A*
Prototype 3 ICE Peer	Yes	N/A	54
		Difference = PASS - ICE	N/A
		EV/HEV Average	***N/A***
		ICE Average	**51.5**

None of the four HEV/EVs tested had a parked or forward-gear idle sound at a fixed noise level to evaluate with SAE J2889.

Scenario B- SAE J2889-1 "Slow Speed Cruise" (10 km/h), Pass "On"

Graphic: SAE J2889-1 with overlays

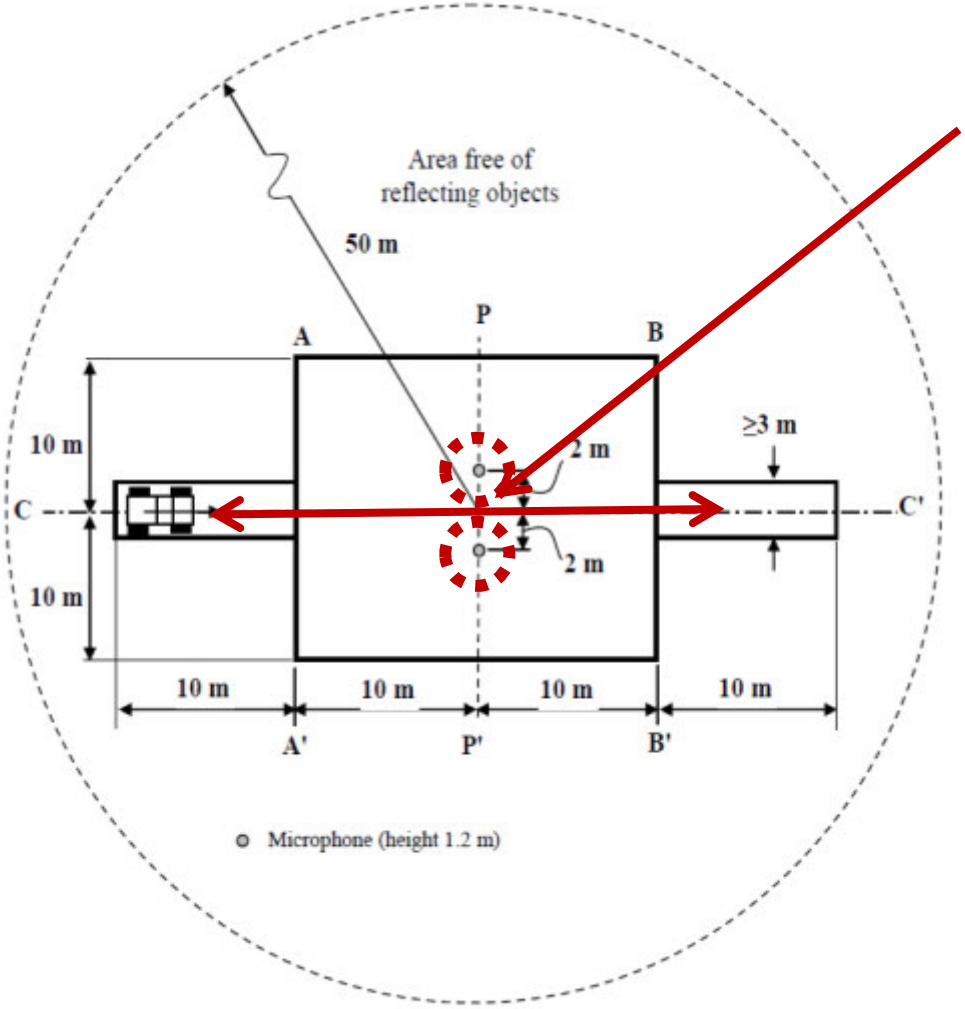


FIGURE 1 – TEST SITE DIMENSIONS – SHADED AREA IS THE MINIMUM AREA TO BE COVERED WITH A SURFACE COMPLYING WITH ISO 10844

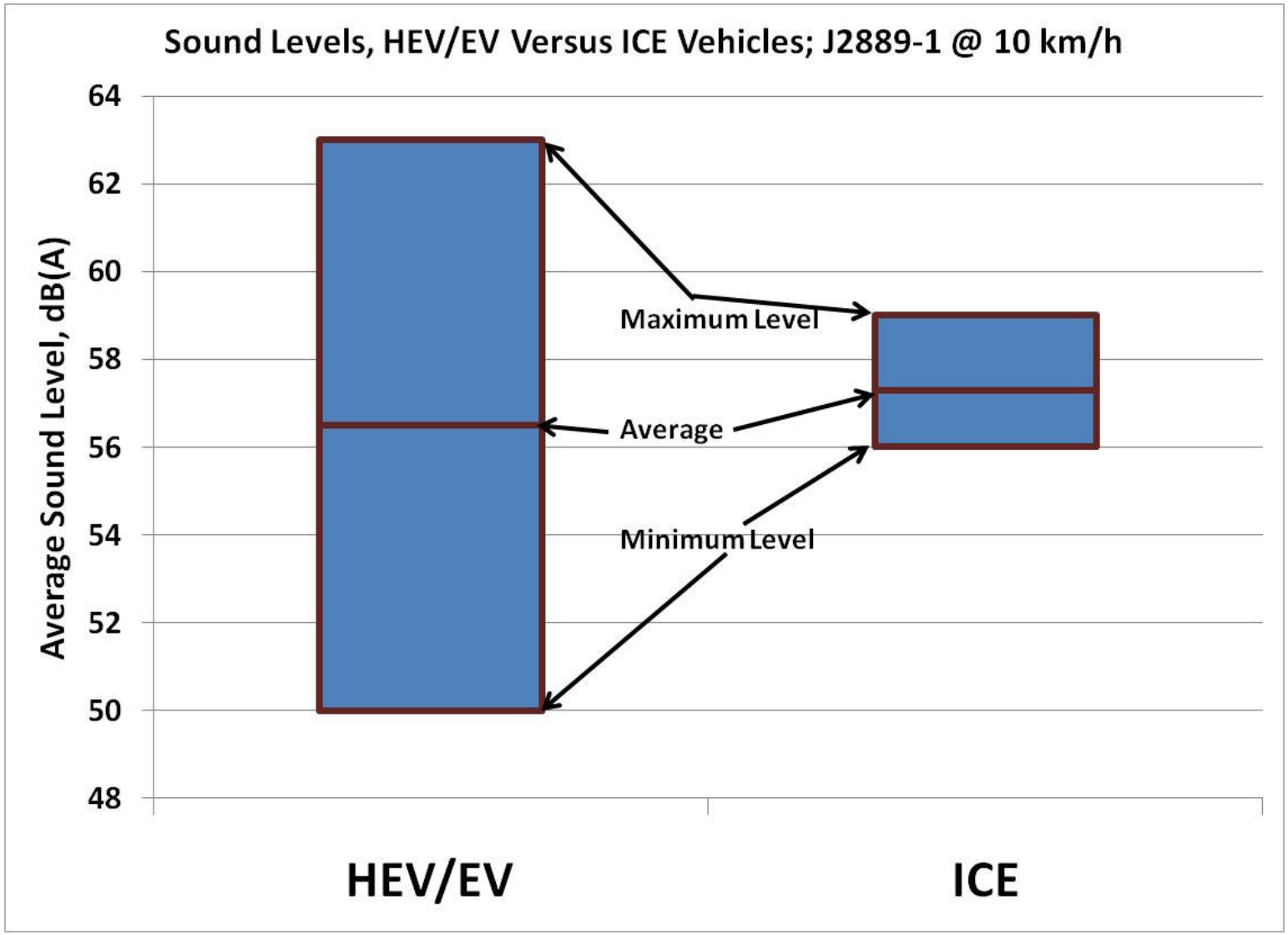
- **Two microphones at a line P-P'**
  - **Microphones 2.0-m from centerline, 1.2-m in height**
- **Vehicle Pass-by**
  - **10 km/h (+/- 1 km/h)**
- **Four measurement minimum**
  - **Maximum A-weighted sound pressure level for each microphone is corrected for background noise level**
  - **Corrected results are averaged for each side of the vehicle**
  - **Reported value is the lower value of the two sides**

Initial Results – Scenario B (10 km/h), PASS "On"

Vehicle	Volume Level Set by Manufacturer (Yes/No)	10 km/h (dBA)
Nissan Leaf EV	Yes	50
Nissan Versa ICE	N/A	56
	Difference = PASS - ICE	-6
Prototype 1 HEV	Yes	56
Prototype 1 ICE Peer	N/A	57
	Difference = PASS - ICE	-1
Prototype 2 HEV	*No (Adjustable)*	*(Range 51-68)*
Prototype 2 ICE Peer	N/A	57
	Difference = PASS - ICE	N/A
Prototype 3 HEV	Yes	63
Prototype 3 ICE Peer	N/A	59
	Difference = PASS - ICE	4
	EV/HEV Average	**56.5**
	ICE Average	**57.3**

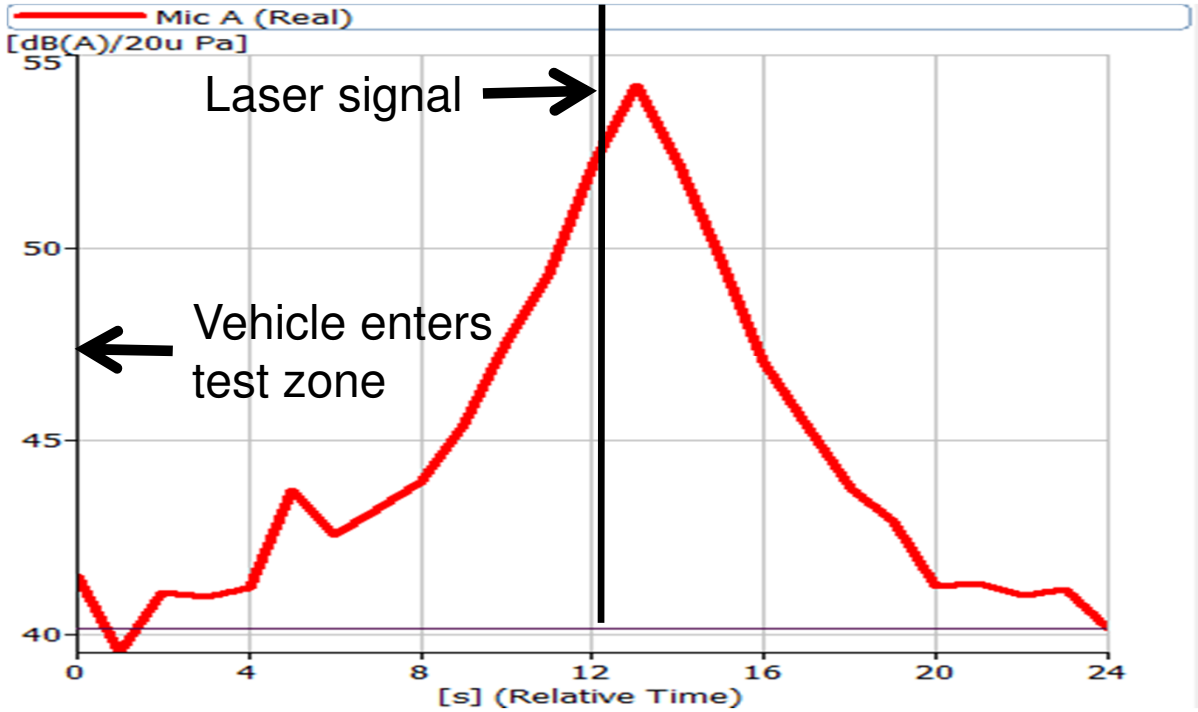
The 10 km/h pass-by level of the HEV/EVs ranged from **10% quieter to 7% louder** than their ICE peers.

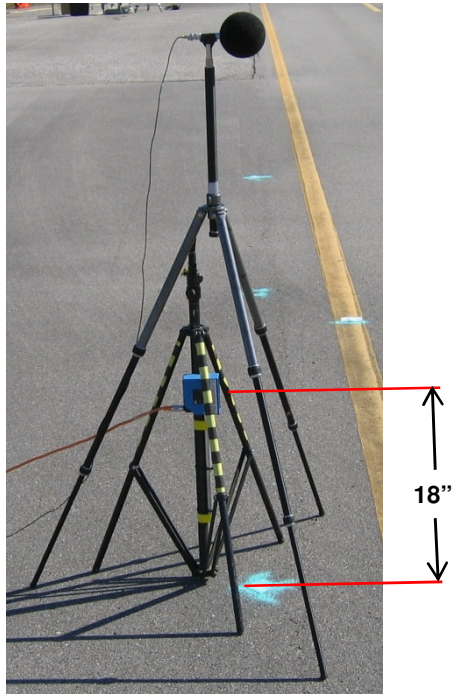
Initial Results – Scenario B (10 km/h)



Maximum Sound Level and Sound Level at P-P' Line

- **Laser device added at the P-P' line at center of bumper height specification (FMVSS 49CFR Part 581: 16" to 20")**
- **J2889-1 measurement at 10 km/h was compared to the value for the same microphone when the front plane of vehicle has reached the P-P' line**

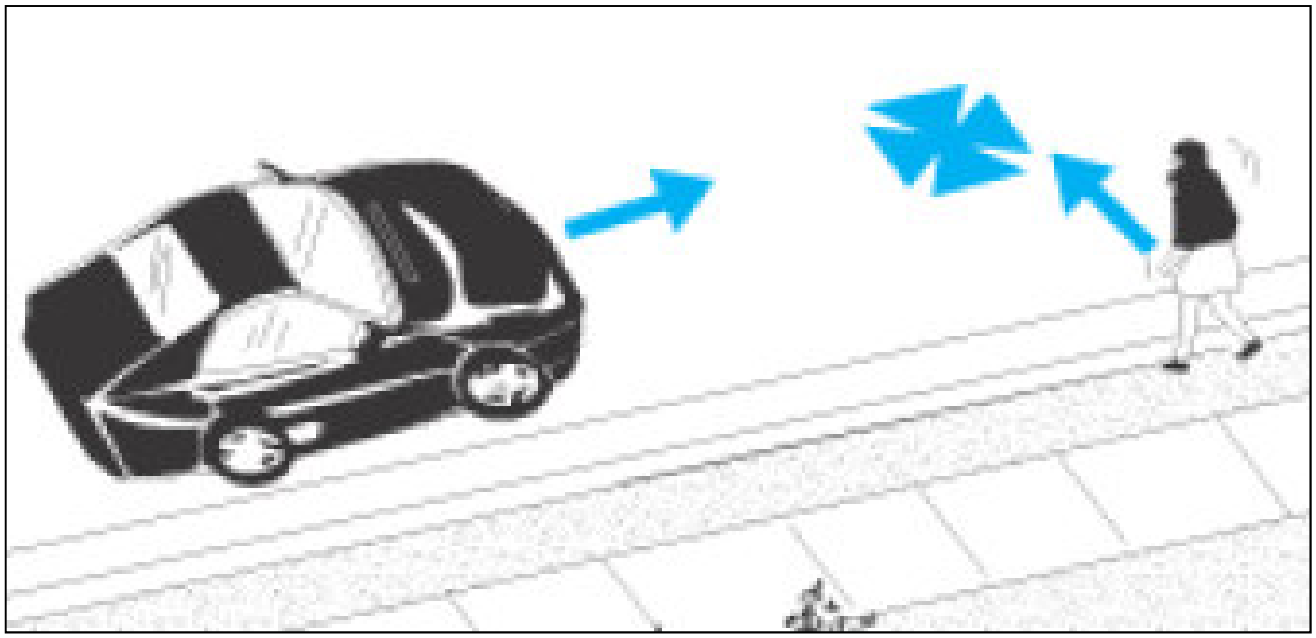




The maximum sound level recorded may be up to 0.7 seconds **after** the front plane of the vehicle crosses the microphone P-P' line for some vehicles.

ADDITIONAL ON-ROAD SCENARIOS

Pedestrian crossing roadway



Graphic: *Evaluation of the Miami-Dade Pedestrian Safety Demonstration Project,* June 2008, NHTSA

Scenario C - SAE J2889-1 @ 10, 20 & 30 km/h

Graphic: SAE J2889-1 with overlays

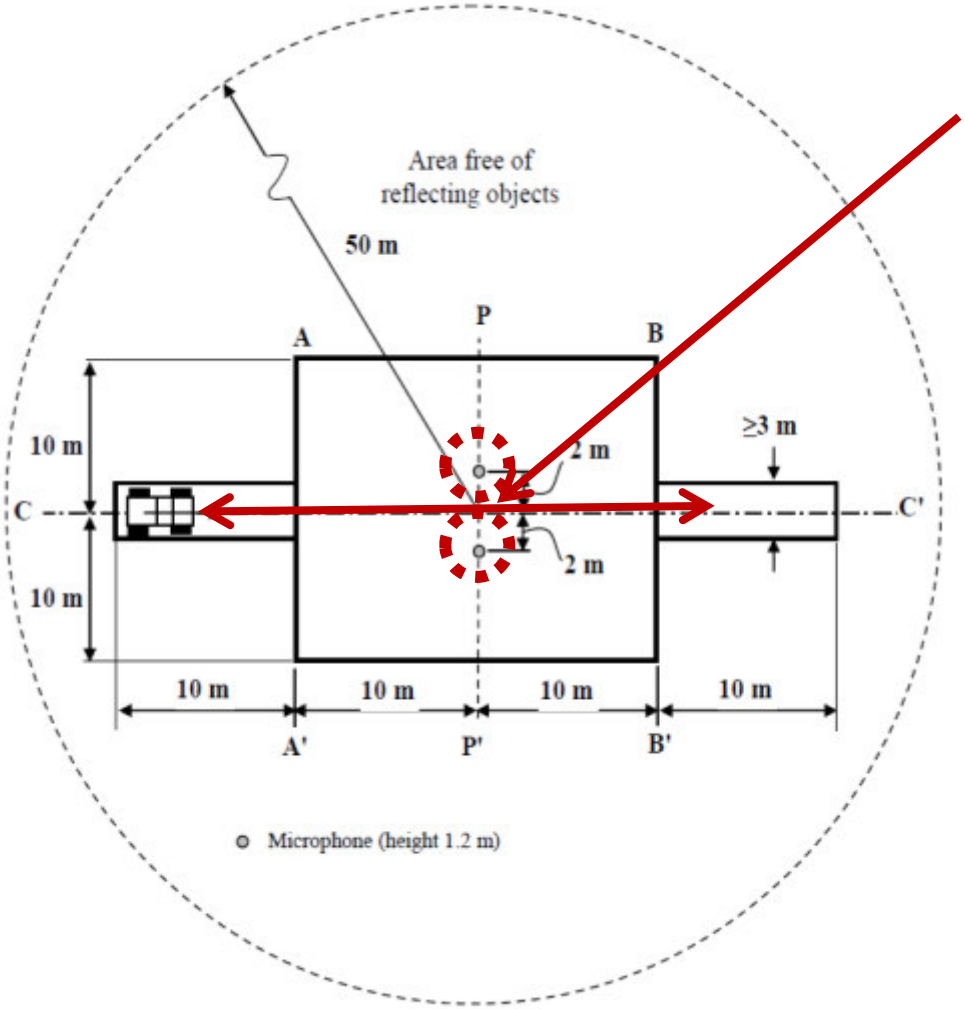


FIGURE 1 – TEST SITE DIMENSIONS – SHADED AREA IS THE MINIMUM AREA TO BE COVERED WITH A SURFACE COMPLYING WITH ISO 10844

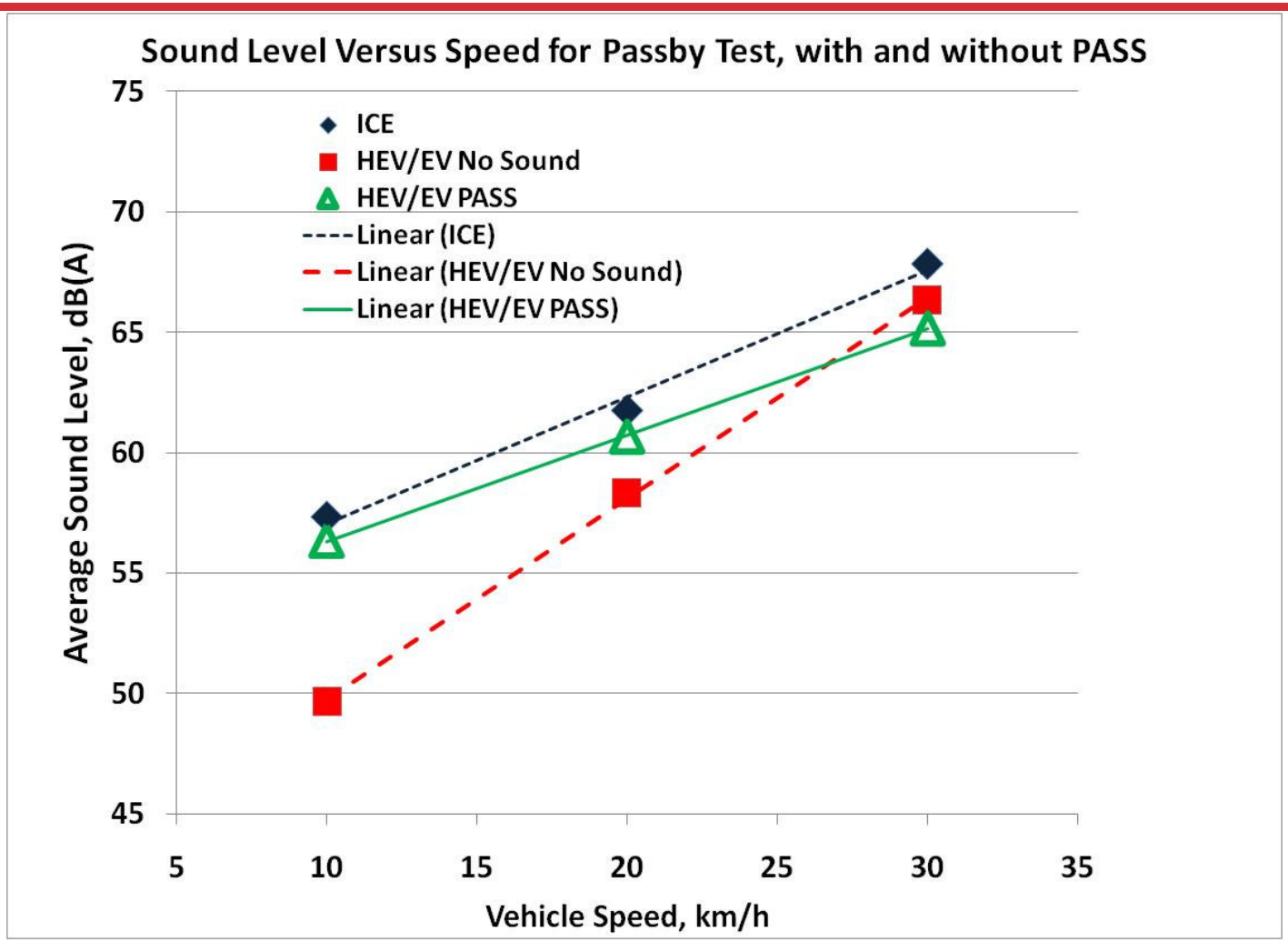
- **Vehicle Pass-by**
  - **Added 20 & 30 km/h Scenarios**
  - **Tested HEV/EV vehicles with and without alert sound**
  - **Help identify speed at which tire, aerodynamic, etc. noise is dominant (cross-over speed)**

Initial Results – Scenario C – Crossover Speed

Vehicle	10 km/h (dBA)	20 km/h (dBA)	30 km/h (dBA)
Nissan Leaf EV – No sound	49	57	64
Nissan Versa ICE	56	62	68
Difference = ICE – EV No Sound	**7**	**5**	**4**
Prototype 2 HEV – No sound	*51*	*60*	*71*
Prototype 2 ICE Peer	57	61	67.5
Difference = ICE – HEV No Sound	**6**	**1**	**-3.5**
Prototype 3 HEV – No sound	49	58	64
Prototype 3 ICE Peer	59	63	68
Difference = ICE – HEV No Sound	**10**	**5**	**4**
Average Difference	**8 dBA**	**4 dBA**	**1.5 dBA**

Two of the three HEV/EVs tested with PASS "Off" did not exceed ICE sound levels at 10, 20, & 30 km/h.

Scenario C – Crossover Speed



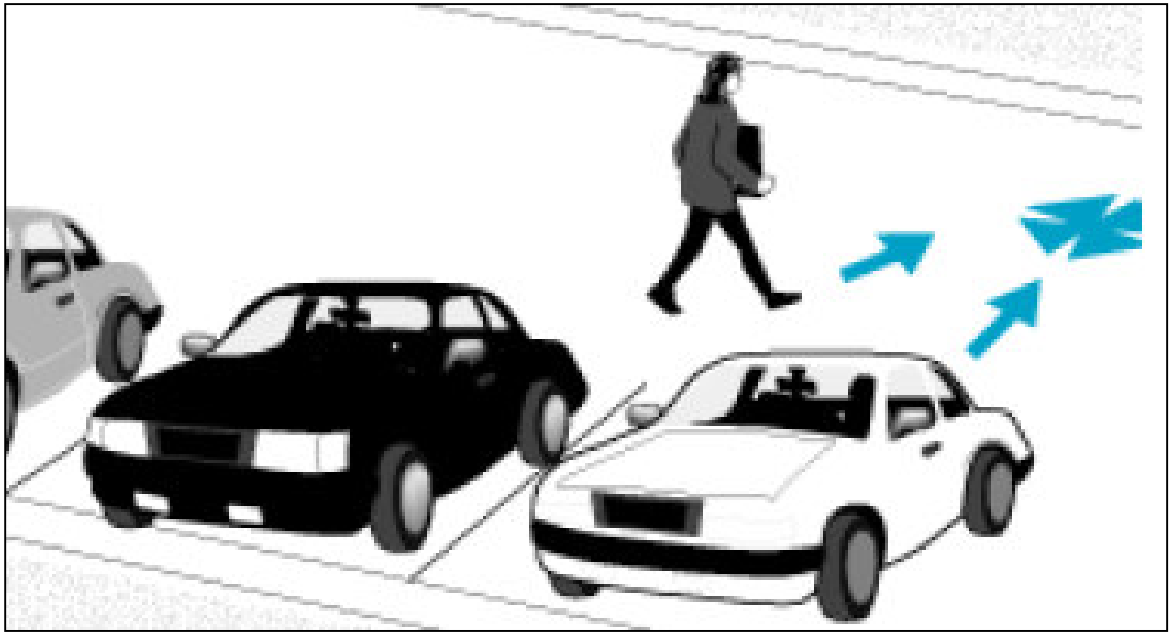
Initial Results – Scenario C – PASS "ON" 20 & 30 km/h

Vehicle	Volume Level Set by Manufacturer (Yes/No)	10 km/h (dBA)	20 km/h (dBA)	30 km/h (dBA)
Nissan Leaf EV	Yes	50	57	64
Nissan Versa ICE	N/A	56	62	68
	Difference = PASS - ICE	-6	-5	-4
Prototype 1 HEV	Yes	56	61	66.5
Prototype 1 ICE Peer	N/A	57	61	N/A
	Difference = PASS - ICE	-1	0	N/A
Prototype 2 HEV	*No (Adjustable)*	*(Range 46-68)*	-	-
Prototype 2 ICE Peer	N/A	57	61	67.5
	Difference = PASS - ICE	*N/A*	*N/A*	*N/A*
Prototype 3 HEV	N/A	63	64	65
Prototype 3 ICE Peer	N/A	59	63	68
	Difference = PASS - ICE	4	1	-3
	EV/HEV Average	**56.5**	**60.7**	**65.2**
	ICE Average	**56.3**	**62.0**	**67.8**

The 20 & 30 km/h pass-by values of the three HEV/EVs with PASS "On" were on average 2% & 4% lower than their ICE peers.

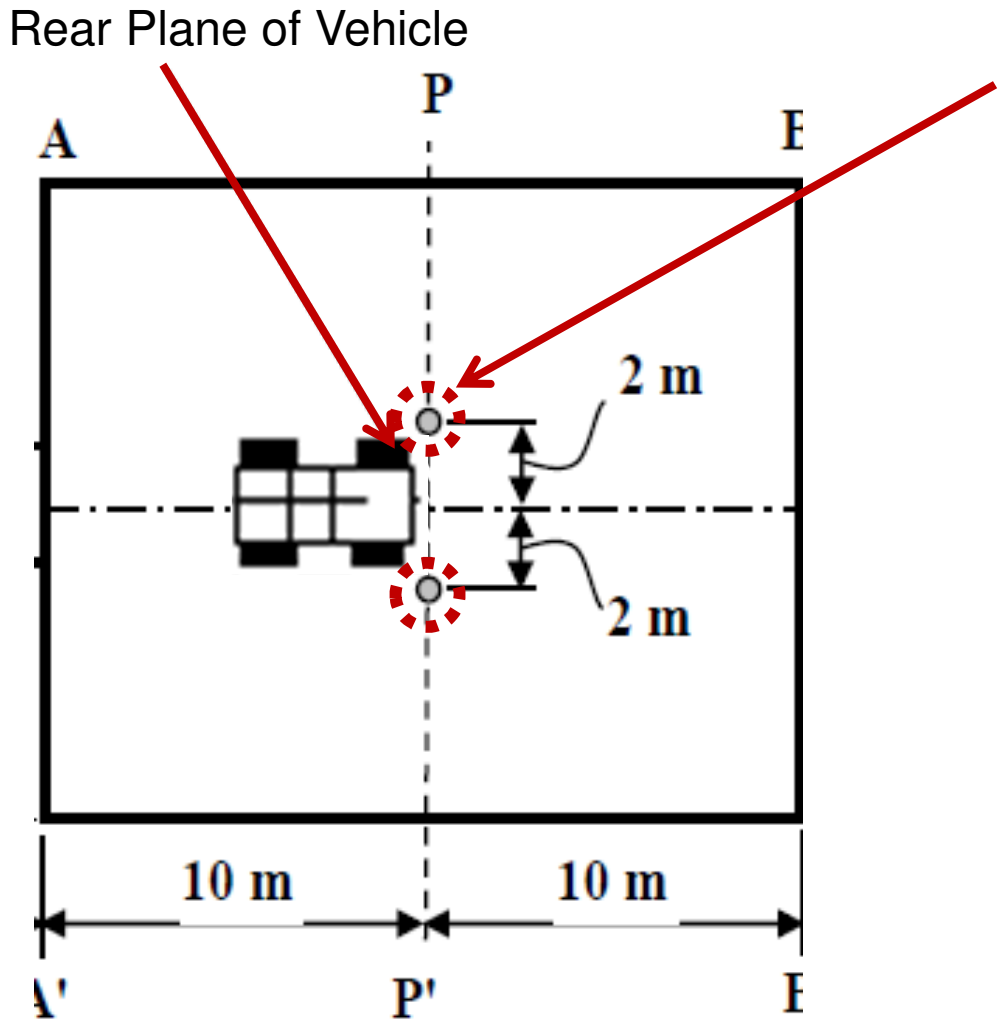
NON-ROAD SCENARIOS

Parking lot, driveway, private road, alley, sidewalk, service station, yard, etc.



Graphic: *Evaluation of the Miami-Dade Pedestrian Safety Demonstration Project,* June 2008, NHTSA

Scenario D - Modified SAE J2889-1 “Stopped Condition” - Rear



Graphic: SAE J2889-1 with overlays

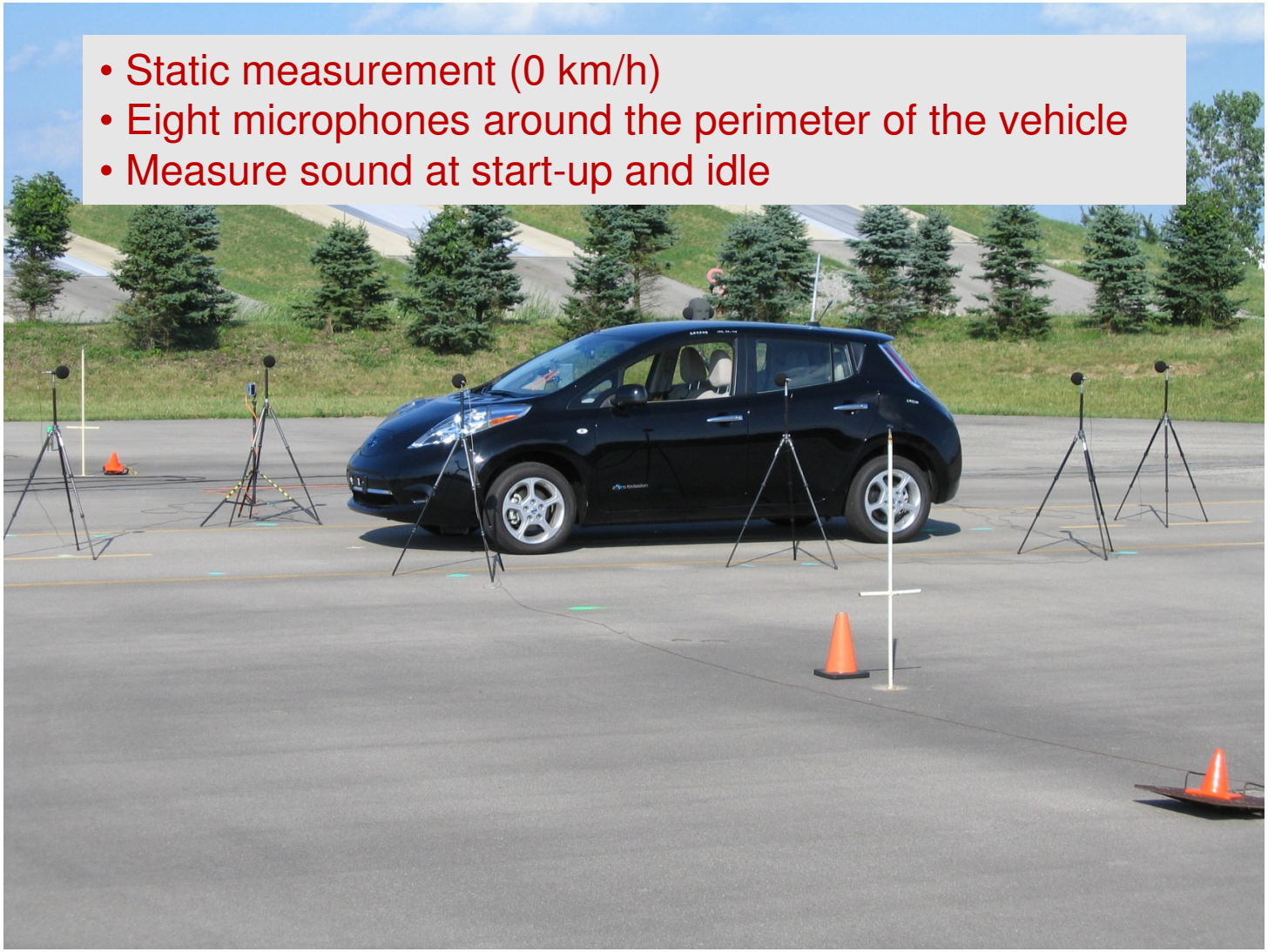
- **Two microphones at a line P-P’**
  - **Microphones 2.0-m from centerline, 1.2-m in height**
- **Vehicle stopped**
- **For front engine vehicles:**
  - **Rear plane of vehicle at microphone line (instead of front plane)**
  - **10 second measurement**

Initial Results – Scenario D (0 km/h), Rear Plane, PASS "On"

Vehicle	Sound at Idle? (Yes/No)	Volume Level Set by Manufacturer (Yes/No)	Front (dBA)	Rear (dBA)	Difference = Rear – Front (dBA)
Nissan Leaf EV	Reverse Gear Engaged (Only)	Yes	(58) – Reverse Beeper	(50) – Reverse Beeper	-8
Nissan Versa ICE	Yes	N/A	49	47	-2
Prototype 1 HEV	*No*	*N/A*	*N/A*	*N/A*	*N/A*
Prototype 1 ICE Peer	Yes	N/A	52	48	-4
Prototype 2 HEV	*Yes*	*No (Adjustable)*	*(Adjustable Range 46-68)*	*(Adjustable Range 41-53)*	*(Range -5 to -15)*
Prototype 2 ICE Peer	Yes	N/A	50	48	-2
Prototype 3 HEV	*No*	*N/A*	*N/A*	*N/A*	*N/A*
Prototype 3 ICE Peer	Yes	N/A	54	53	-1
		EV/HEV Average	**N/A**	**N/A**	**N/A**
		ICE Average	**51.3**	**49**	**-2.3**

There was an average drop off in static sound levels for ICEs **from front to rear planes** of 2.3 dBA. PASS speaker had **8 dBA drop-off**.

Scenario E – 360-Degree Static Sound Directivity



Initial Results – Scenario E – 360-Degree Static Sound Directivity

Vehicle	Sound at Idle? (Yes/No)	Volume Level Set by Manufacturer (Yes/No)	Center Front (dBA)	Center Rear (dBA)	Difference = Center Rear – Center Front (dBA)
Nissan Leaf EV	Reverse Gear Engaged (Only)	Yes	54	44	-10
Nissan Versa ICE	Yes	N/A	48	43	-5
Prototype 1 HEV	*No*	*N/A*	*N/A*	*N/A*	*N/A*
Prototype 1 ICE Peer	Yes	N/A	52	45	-7
Prototype 2 HEV	*Yes*	*No (Adjustable)*	*Adjustable (Range 46 – 65)*	*Adjustable (Range 40 – 52)*	*(Range -6 to -13)*
Prototype 2 ICE Peer	Yes	N/A	*50*	*47*	*-3*
Prototype 3 HEV	*No*	*N/A*	*N/A*	*N/A*	*N/A*
Prototype 3 ICE Peer	Yes	N/A	53	50	-3
		EV/HEV Average	**N/A**	**N/A**	**N/A**
		ICE Average	**50.8**	**46.3**	**-4.5**

There was an average drop off in static sound levels for ICEs from center front to center rear of 4.5 dBA. Pass Speaker had 10 dBA drop-off.

Scenario F – Acceleration From Stop Sound Recordings

- Vehicle front or rear plane stopped 2 meters prior to P-P' Line
- Binaural head 4 meters from centerline at P-P' Line
- Vehicle accelerates forward or reverse ~ 0.1g
- Measurement stopped at P-P' Line

Initial Results – Scenario F – Acceleration From Stop, PASS "On"

Vehicle	Volume Level Set by Manufacturer (Yes/No)	Peak Forward Acceleration (dBA)	Peak Rearward Acceleration (dBA)	Difference = Rearward – Forward (dBA)
Nissan Leaf EV*	Yes	*N/A*	55	*N/A*
Nissan Versa ICE	N/A	55	55	0
Prototype 1 HEV	*N/A*	*57*	*57*	*0*
Prototype 1 ICE Peer	N/A	60	58	-2
Prototype 2 HEV	*No (Adjustable)*	*N/A*	*N/A*	*N/A*
Prototype 2 ICE Peer	N/A	60	58	-2
Prototype 3 HEV	*N/A*	*61*	*58*	*-3*
Prototype 3 ICE Peer	N/A	56	54	-2
EV/HEV Average		**58**	**57**	**-1.5**
ICE Average		**59**	**56**	**-1.5**

* Beeper on Nissan Leaf operates in reverse gear only

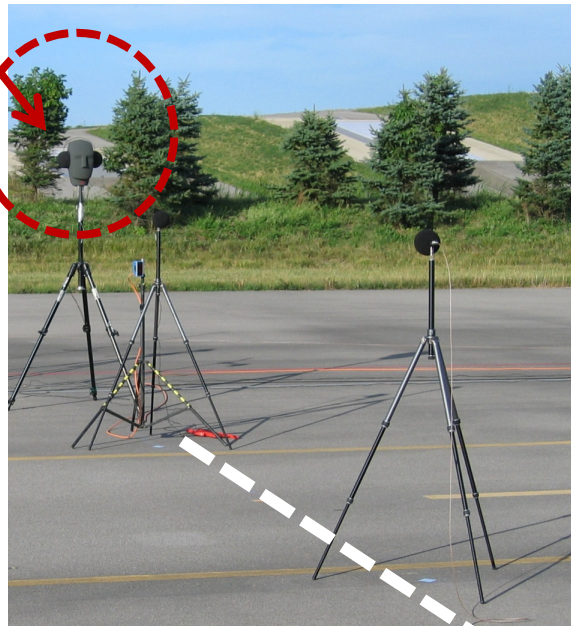
For HEV/EVs & ICEs - Peak rearward accelerations were about 1.5 dBA quieter than peak forward accelerations.

Scenario G – Deceleration From 30 km/h Sound Recordings

- 2 microphones set at P-P' line
- Binaural head 4 meters from centerline at P-P' Line
- Vehicle passes light traps at **30 km/h and decelerates at 0.1g to 10 km/h at P-P' line**
- Measurement stopped at P-P' Line

Binaural Head

0.1g



Initial Results – Scenario G – Volpe Deceleration, PASS "On"

Vehicle	Volume Level Set by Manufacturer (Yes/No)	Volume at PP' Line (dBA)
Nissan Leaf EV	Yes	53
Nissan Versa ICE	N/A	55
Prototype 1 HEV	*N/A*	*55*
Prototype 1 ICE Peer	N/A	57
Prototype 2 HEV	*No (Adjustable)*	*Range 49 - 68*
Prototype 2 ICE Peer	N/A	56
Prototype 3 HEV	*N/A*	*62*
Prototype 3 ICE Peer	N/A	55
	EV/HEV Average	**54.7**
	ICE Average	**55.8**

30 to 10 km/h deceleration pass-by tests for HEV/EV Sound "ON" versus ICE peers were within 1 dBA.

DEVELOPMENT OF PARAMETERS FOR ALERTING SOUNDS

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National Transportation
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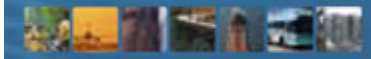
A Federal Center of Excellence



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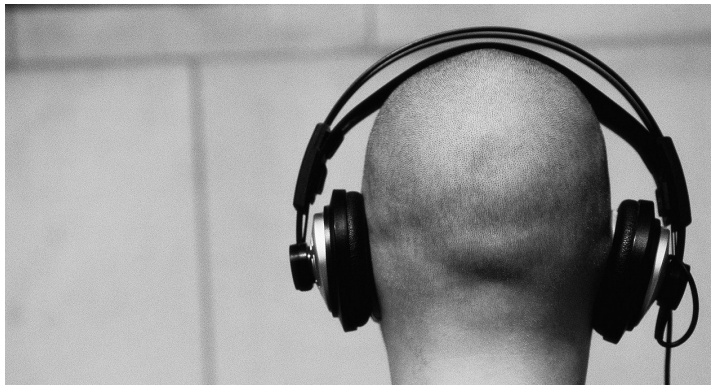
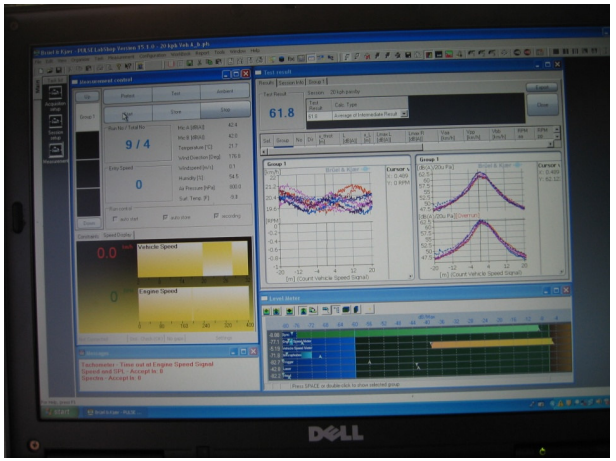


Parameters for Alerting Sounds

- **Considerations**
  - Identify acoustic parameters that would aid in detectability
  - Identify acoustic parameters that would aid in recognition
  - Apply to ICE-like and ‘other’ sounds
  - Objective and practical



- **Expected Outcome**
  - Performance Parameters, for example:
    - Overall level
    - Frequency range
    - Number of tonal components, level for tonal components
    - Amplitude and frequency modulation
    - Pitch and amplitude shifting in proportion to vehicle speed
    - Directivity

Parameters for Alerting Sounds

- **Activities**
  - Establish baseline sound level(s) = target values for loudness considering ambient of 55 and 60 dBA
    - (Assumptions: (a) alerting sounds should be as detectable as current ICEs;
    - (b) sounds with equal Loudness will be equally detectable)
  - Identify acoustic parameters (and criteria) for a sound to be recognizable and detectable
    - broadband noise/random noise and tonal components
  - Generate sounds with acoustic parameters identified above (using sound simulation program in MATLAB®)
  - Examine synthesized sounds
    - detectability models and engineering judgment
  - Refine acoustic parameters and criteria

Data, Methods, & Goals

Question(s)	Data/Input	Method(s)	Goal
What level(s)? What frequencies?	•Phase 1 Data •SAE-type data for ICEs: • Phase 2 (n=9) • OICA (n=24) • VRTC (n=4)	•Stat analysis •Moore's Loudness model with ambient	•Time for pedestrian to make decision •Overall level/Loudness •Spectra content
Parameters that would aid in detectability	•SAE-type data (VRTC) •Synthesized sounds	•Sound simulation •Moore's Loudness model with ambient	•Broadband/random noise •Tonal components (# and levels) • Amplitude and frequency modulation •Pitch shifting
Parameters that would aid in recognition	•SAE-type data (VRTC) •Synthesized sounds •Long duration pass-by recordings (VRTC)*	•Sound simulation •Engineering judgment	
Sound dispersion (front, side, back). Uniform? Sound louder in front of vehicle?	•Multiple microphone measurements (VRTC)	•Statistical analysis	•Directivity •Microphone location

* time permitting

Summary

- Phase 2 report has been published:
  http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811496.pdf
- None of the four HEV/EVs tested had a parked or forward-gear idle sound at a fixed noise level to evaluate with SAE J2889
- The 10 km/h pass-by level of the HEV/EVs ranged from 10% quieter to 7% louder than their ICE peers.
- The maximum sound level recorded may be up to 0.7 seconds after the front plane of the vehicle crosses the microphone P-P' line for some vehicles.
- Two of the three HEV/EVs tested with PASS "Off" did not exceed ICE sound levels at 10, 20, & 30 km/h.
- The 20 & 30 km/h pass-by values of the four HEV/EVs with PASS "On" were on average 2% & 4% lower than their ICE peers.
- There was an average drop-off in static sound levels for ICEs from front to rear planes of 2.3 dBA. The vehicle with PASS speaker had 8 dBA drop-off.
- There was an average drop-off in static sound levels for ICEs from center front to center rear of 4.5 dBA. The vehicle with Pass Speaker had 10 dBA drop-off.
- Peak rearward accelerations were about 1.5 dBA quieter than peak forward accelerations.
- 30 to 10 km/h deceleration pass-by tests for HEV/EV Sound "ON" versus ICE peers were within 1 dBA.
- VRTC is developing a test procedure for the regulation.
- Volpe is using test data to help develop parameters for alert sounds.

Issues

- **Outdoor Noise Testing**
  - Ambient conditions such as wind speed, temperature, precipitation, etc. difficult to achieve year-around, even day-to-day.
  - Automatic cooling fans & coolant pumps for electric batteries kick on and off unpredictably during warm weather testing (safety hazard to disconnect) and affect test noise levels
- **SAE J2889-1**
  - Allows credit for peak sound pressure level after front plane of vehicle is past P-P' microphone line (i.e., after vehicle has crossed the potential path of a frontal pedestrian)
  - Static sound levels for mid-engine and rear-engine vehicles measured with engine at P-P' microphone line rather than front plane of the vehicle (i.e., not from the perspective of a frontal pedestrian)
  - Large ambient test temperature window in standard means cooling fan and coolant pump activity states can vary significantly
  - Does not apply to (electric) motorcycle category
  - Pitch shifting test methods currently under development