Case Study: Truck Noise Sources

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Project No. 08-56 "Truck Noise-Source Mapping"

Workshop "Measuring Tire-Pavement Noise"
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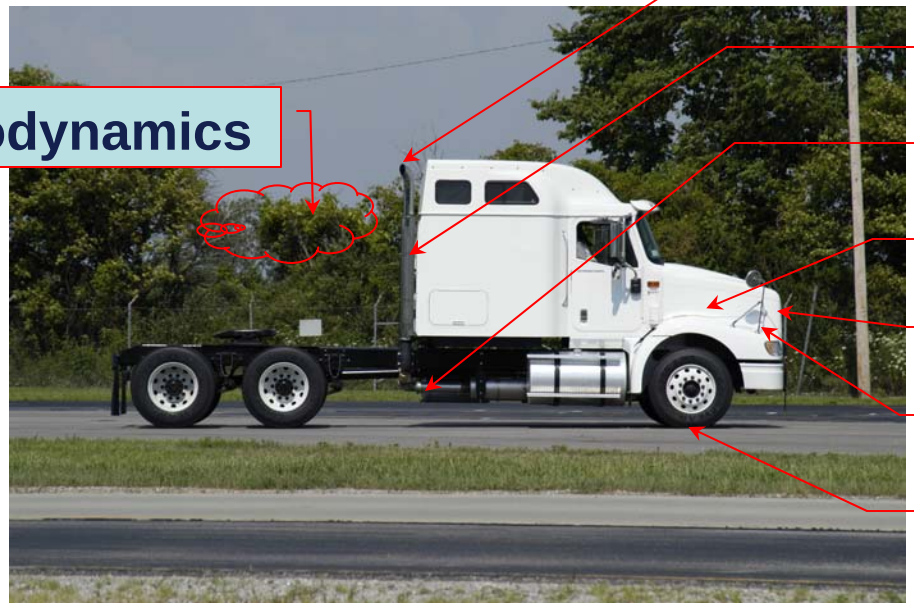
Truck Noise-Source Mapping

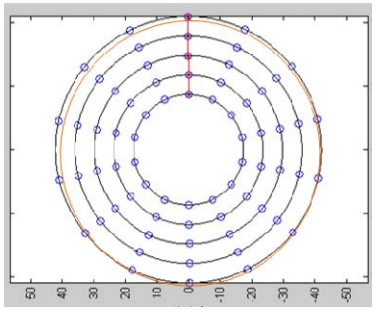
- NCHRP Project No. 08-56
- Completed April 2009
- Objective: Use noise mapping techniques to localize, identify, and quantify noise sources on typical trucks under actual roadway conditions
- Scope: Design, development, experimental demonstration, and validation of practical technology for truck noise source localization and (particularly) vertical distribution
- Presentation Purpose:
  - Review study results with
  - Emphasis on tire-pavement noise generation

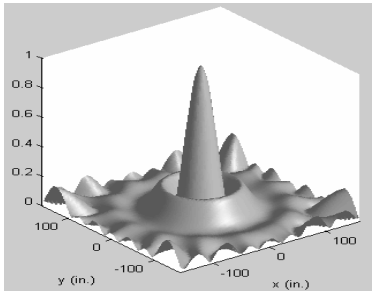
Truck Noise Sources

- Heavy trucks are significant contributors to overall traffic noise levels (~+10 dB vs. light vehicles)
- Major noise sources on trucks:



Acoustic Beam Forming Technique



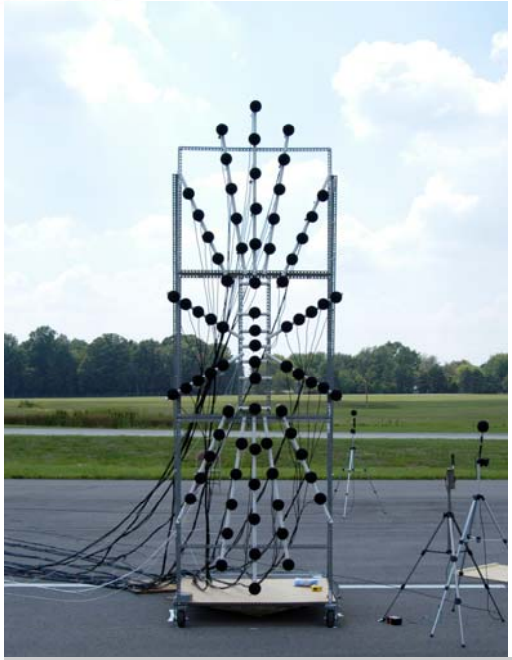


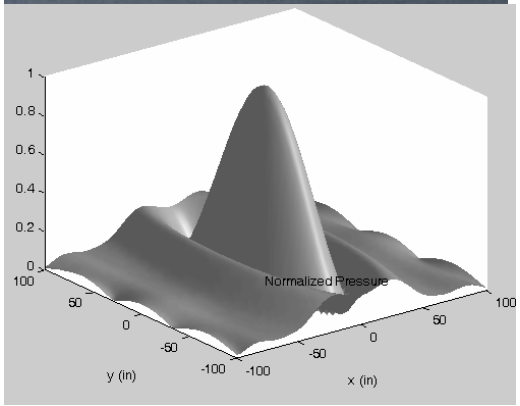
- A single microphone is non-directional
- A sound intensity probe (OBSI) is a simple array of two microphones
- A complex array of microphones with a phase delay for each signal is an acoustical antenna with a directivity pattern
- Sound from test object is measured at a number of mics and calculations are repeated for a large number of angles to obtain a full map
- Advantages:
  - Measurements in far field
  - Use in uncontrolled situations
  - No special test vehicles

Experimental Microphone Array

70+ microphone elliptical array designed and constructed:

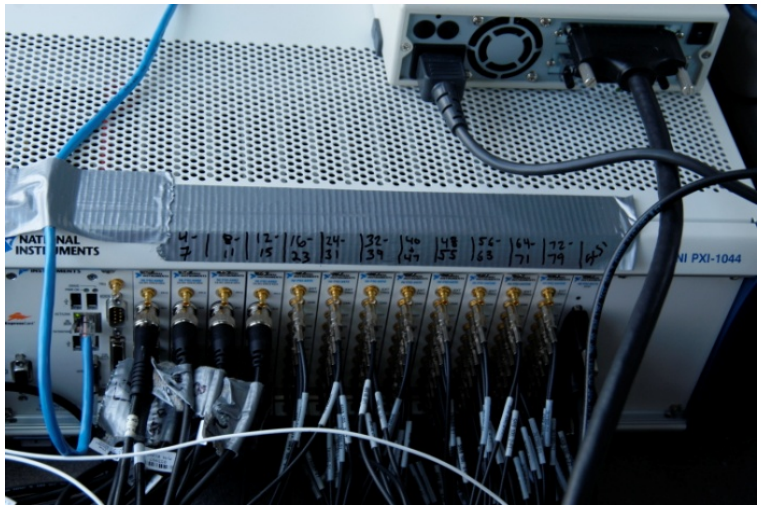
- width 4 ft; height 12 ft; aspect ratio of 1.7
- 3 metal frame sections mounted vertically on four-wheel metal base
- 14 PVC pipe spokes each holding 5 mics
- additional mics easily integrated (7 in the array center)
- PCB ¼-inch electret microphones with ICP® preamplifiers and windscreens
- Excellent side lobe suppression of ~ -14 dB at 250 to 2250 Hz and ~ -11 dB at 8000 Hz
- The post-processing algorithm incorporates a cross-spectral density (CSD) method with spherical divergence, source tracking and Doppler shift correction





1000 Hz

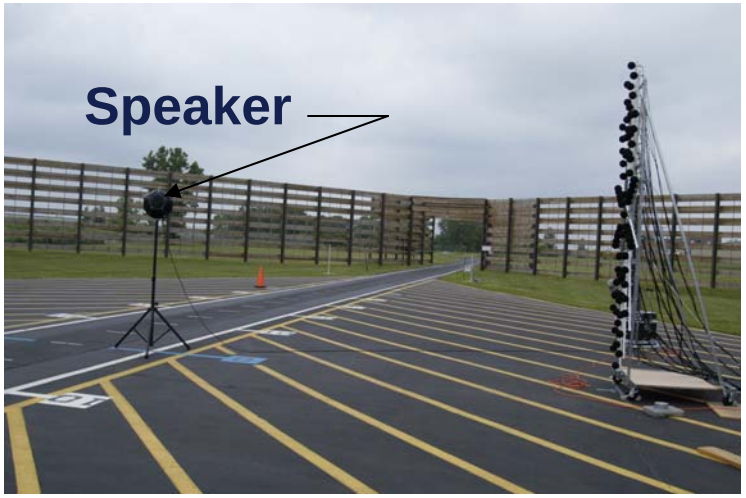
Data Acquisition System



- National Instruments Model PXI-1044 embedded controller chassis for 80 digital data channels
- Software for running the system in real time and transferring data from PXI to a laptop computer for post-processing
- GPS-based time code generator for data synchronization
- 2 pairs of photo cells to register truck pass-bys
- Vehicle tracking system for determining the truck speed (during controlled tests)

Proof-of-Concept Testing

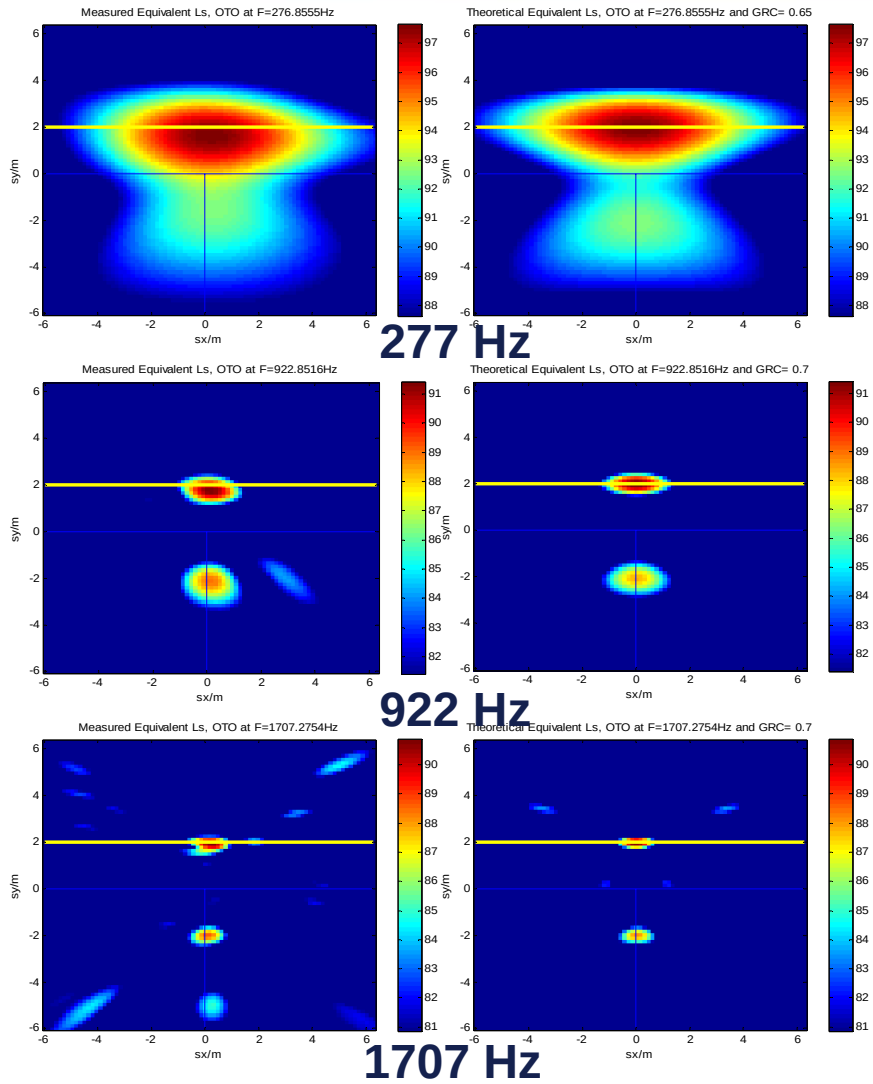
International Truck and Engine Corp., Fort Wayne, IN



Array calibration using omni-directional speaker at low-speed pass-by sound pad (truck speed up to 35 mph)

1-mile long multiple-lane loop for endurance truck testing up to 50 mph

Microphone Array Calibration



10 dB

Measured **Calculated**

- Images of measured and calculated omni-directional source emission:
  - source elevation 6 ft
  - array stand-off at road side 20 ft
- Additional speaker positions were used to test array steering off the array axis

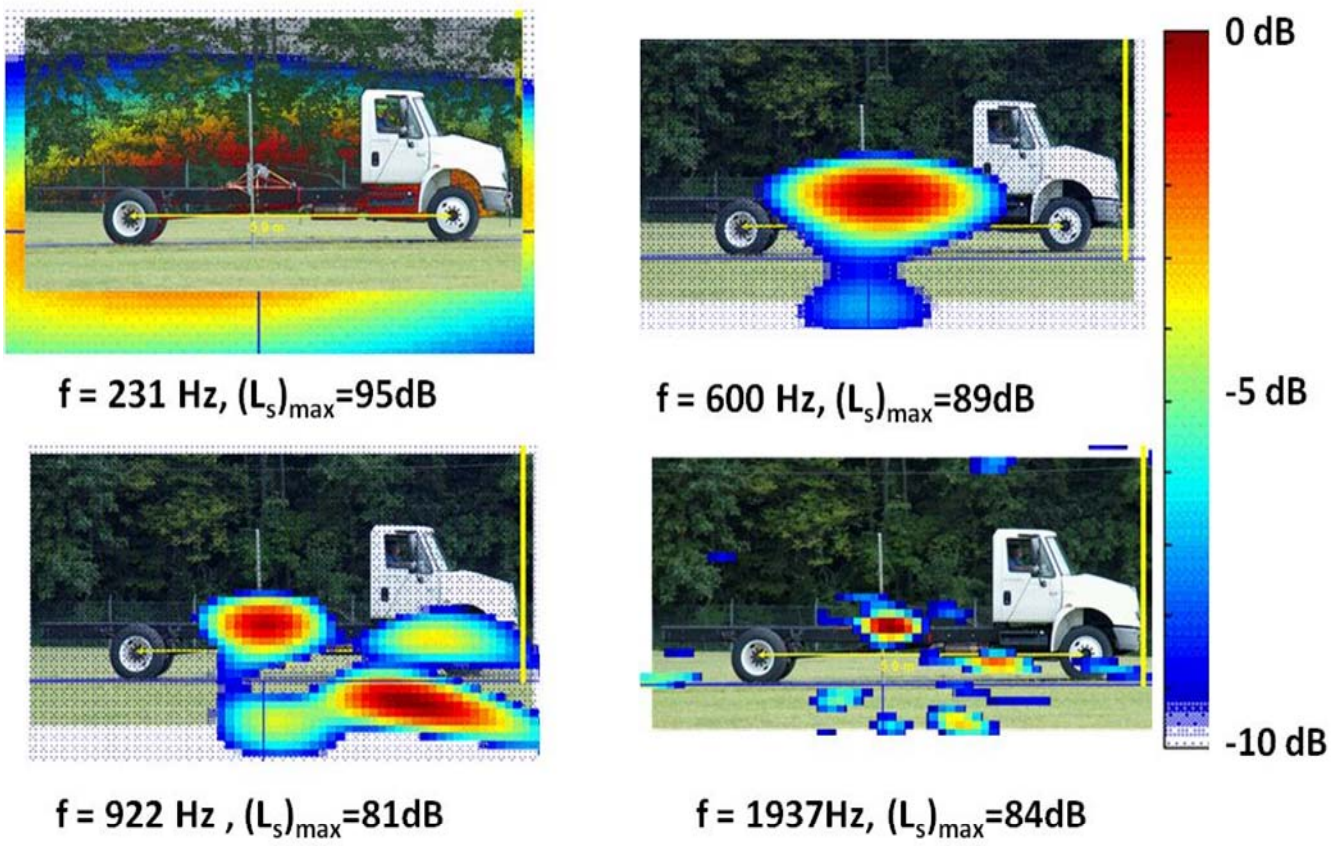
Truck Pass-by Tests

Low-speed track

Endurance track

All trucks by International®

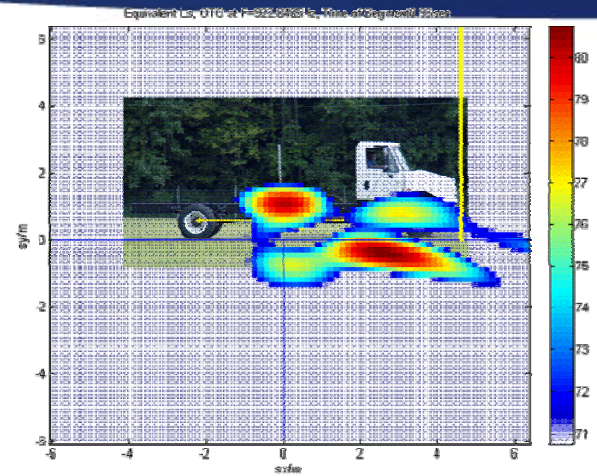
Stationary Truck 4400 with Speaker



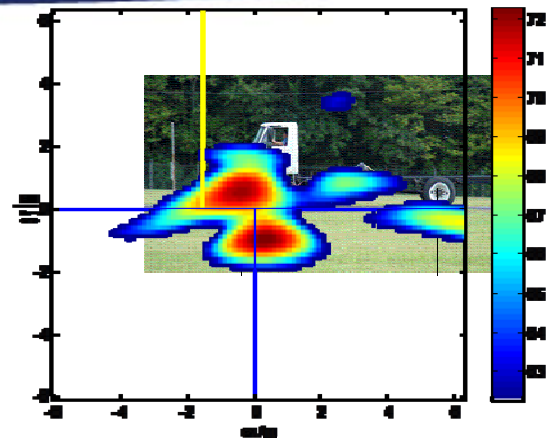
Engine at 2000rpm

- Spherical source unambiguously disclosed.
- Reflected path from road surface.
- Engine noise apparent by both direct and reflected paths above 900 Hz.

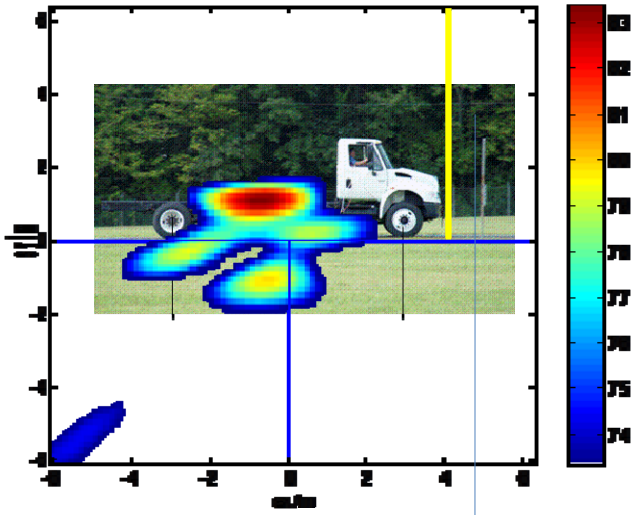
Stationary and Moving Truck 4400 with Speaker



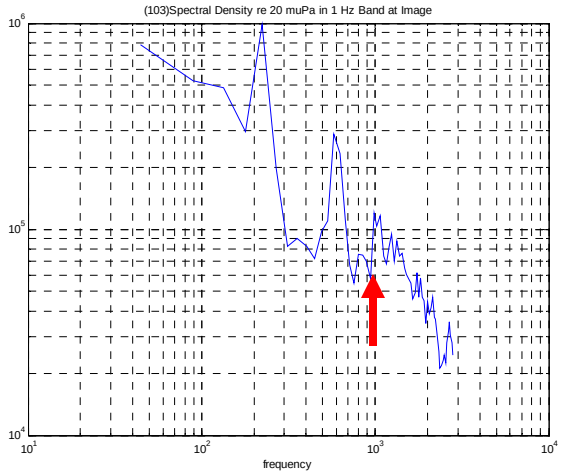
Stationary; Engine 2000 RPM; 922 Hz



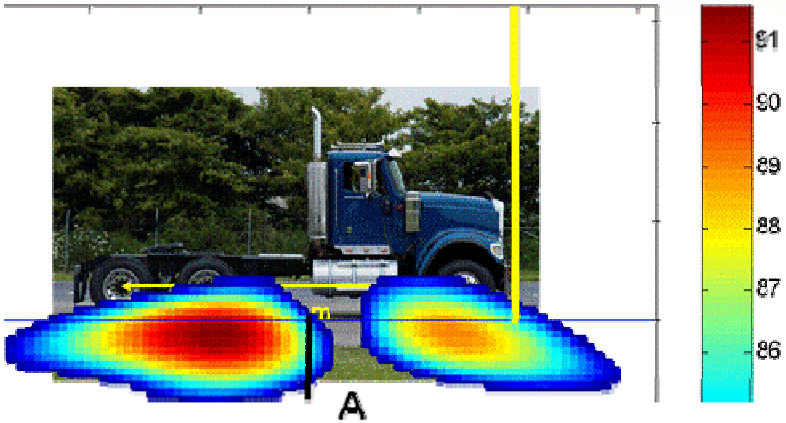
25 mph; Engine 2000 RPM; No Speaker; 988 Hz



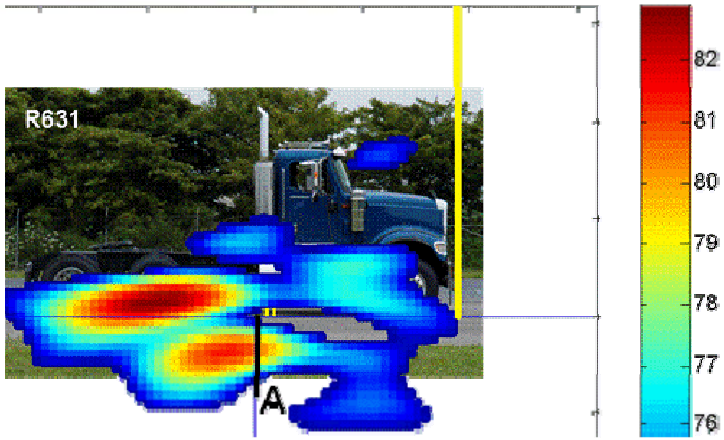
25 mph; Engine 2000 RPM; 922 Hz



Truck 5900 at 50 mph

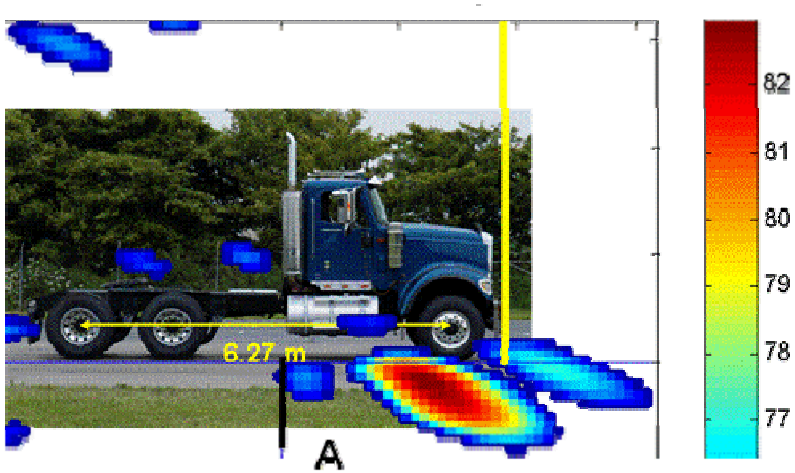


695 Hz

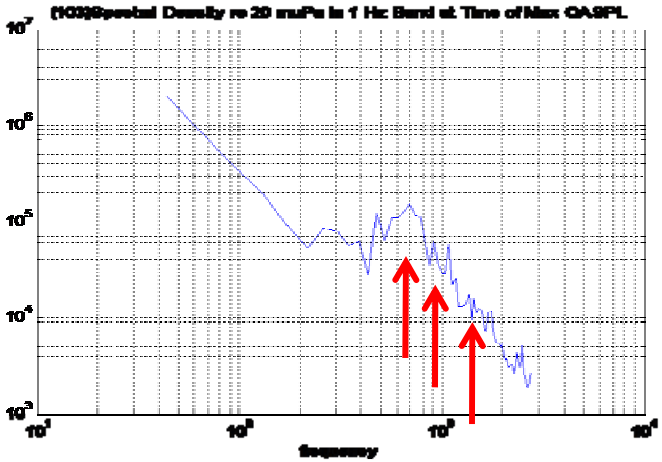


868 Hz

Engine at 1400 rpm



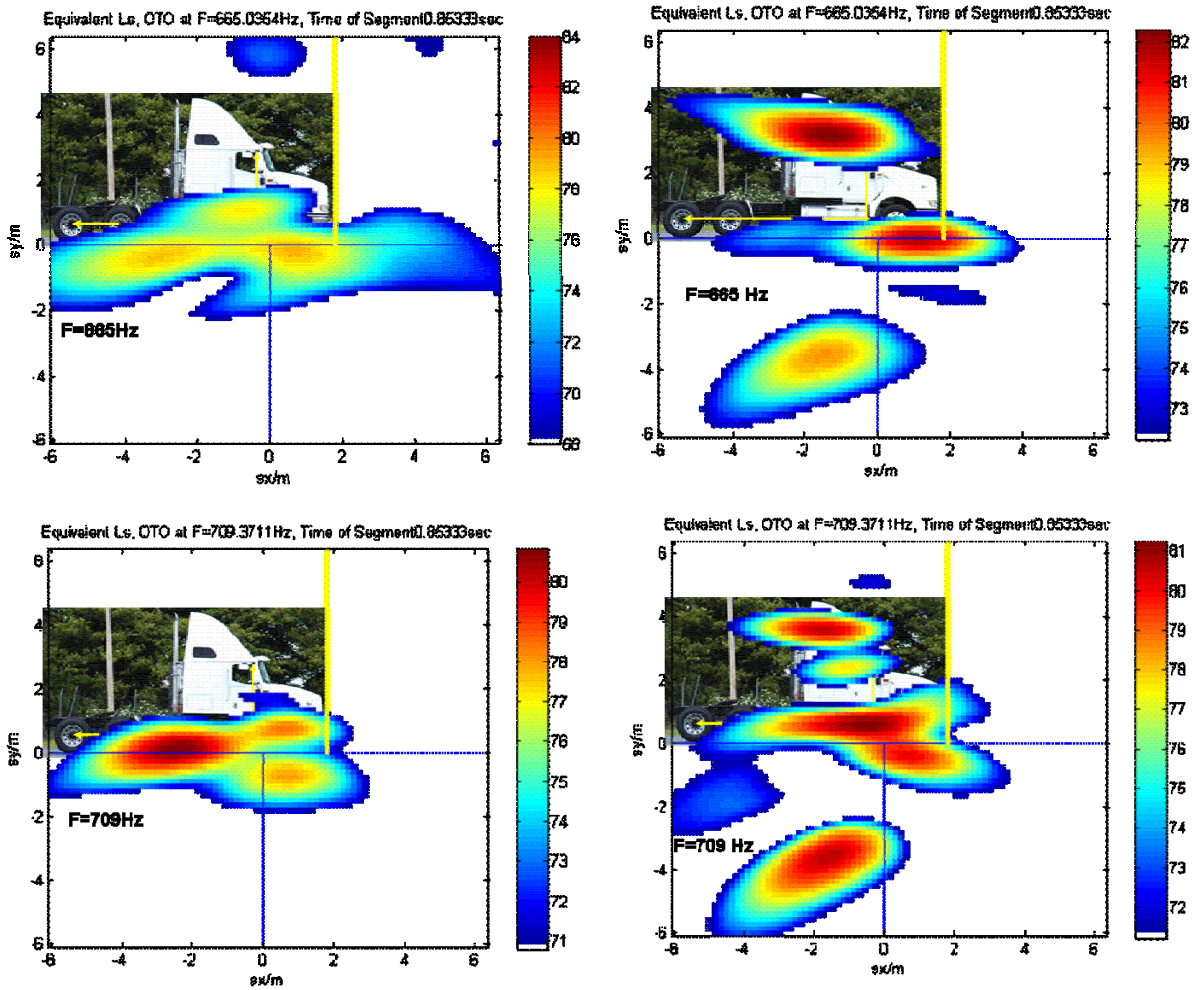
1346 Hz



Truck 9200 at 35 mph: Exhaust with and without Muffler

665 Hz

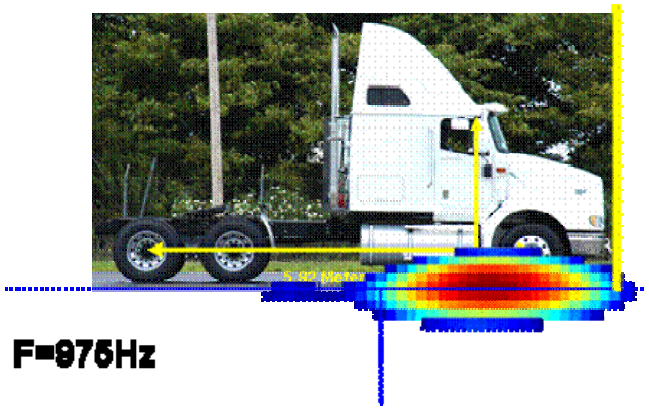
709 Hz



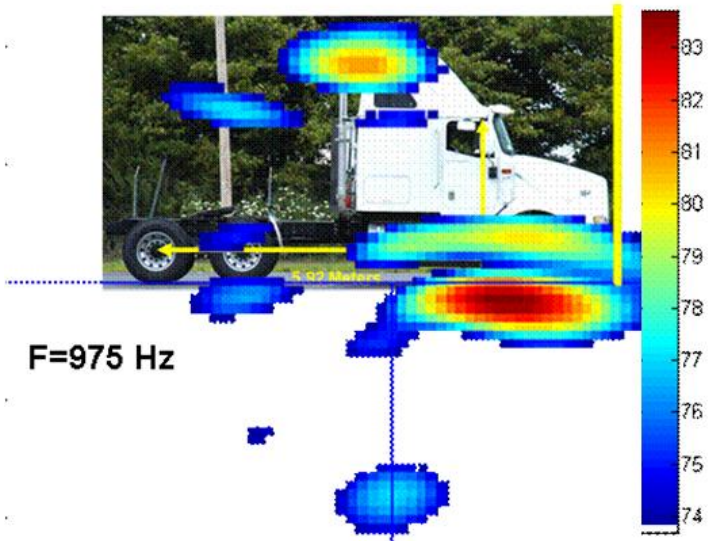
Muffler Intact **Muffler Removed**

- Tire sound from rear tires at and just below road surface.
- Engine sound with clear ground reflection.
- Sources at exhaust opening excite cross-modes of open-backed fairing at cab roof.
- Strong ground path.

Truck 9200 at 35 mph – Cont'd



Muffler Intact



Muffler Removed

- A common (and dominant!) path for sound from the engine compartment is by ground reflection.
- The above-cab flow fairing can amplify and re-radiate exhaust sound.
- Tire noise sources appear at and slightly below road surface.

Roadside Testing Along US-301 in MD

Data Acquisition

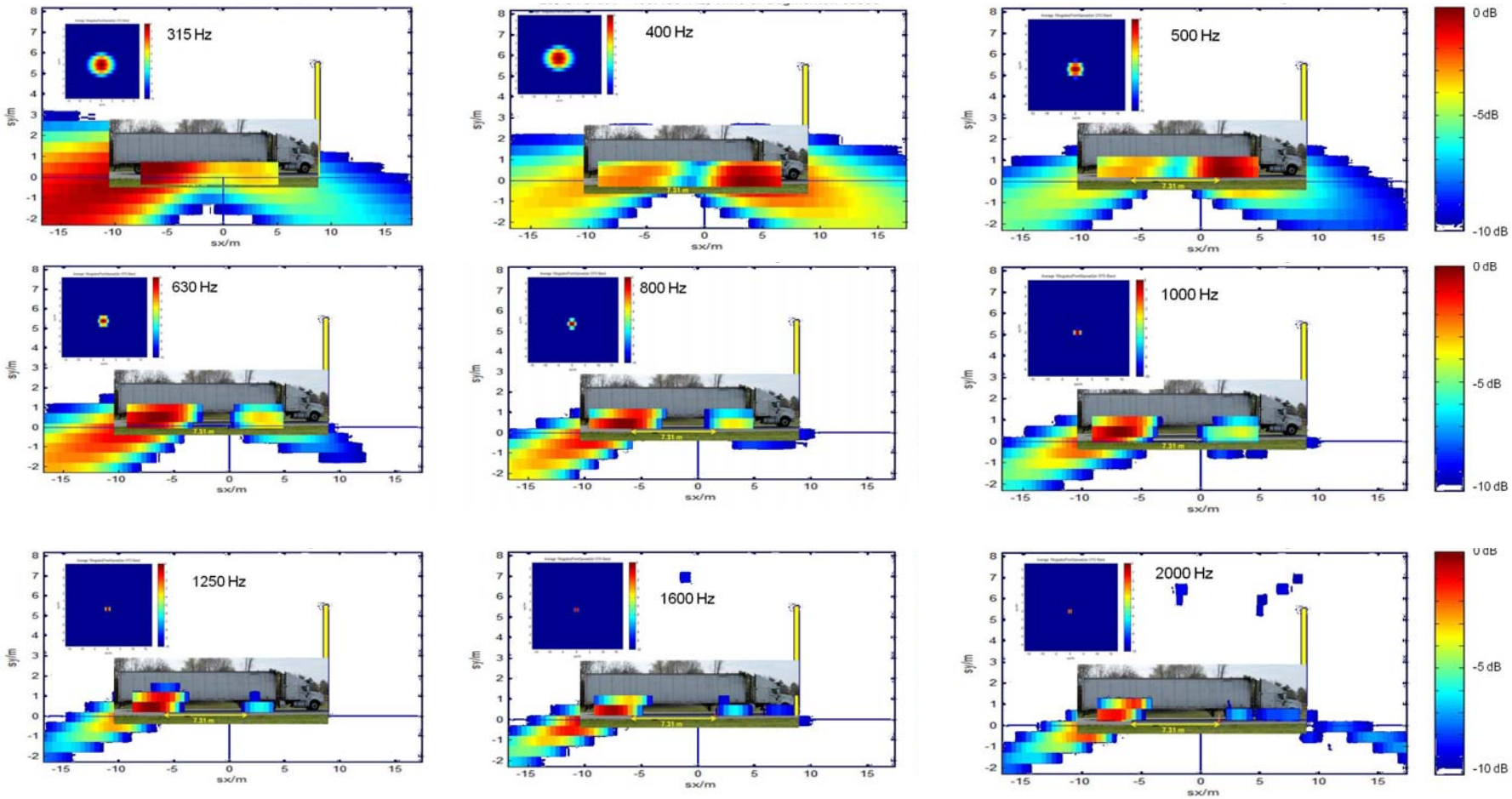
Array (77 mics)

Cal. Source

Photocells

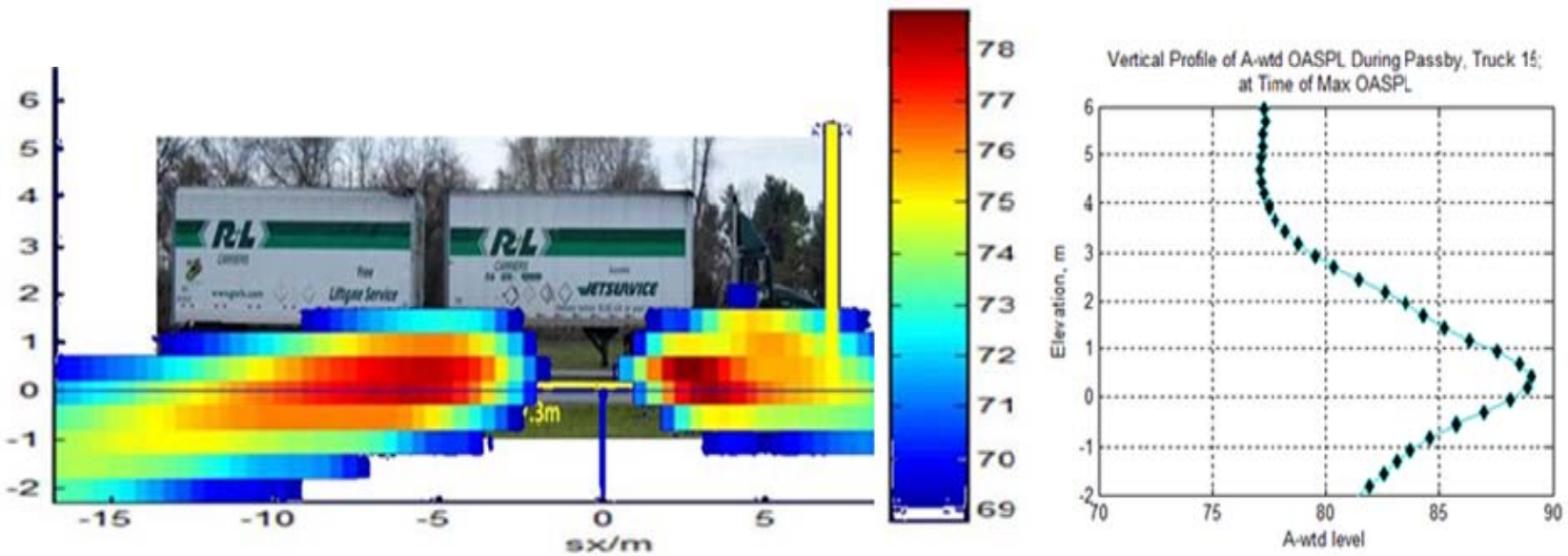
- Components for measurement shown during deployment
- 100 vehicle pass-bys recorded in one day

Truck ID060 Source Image Maps

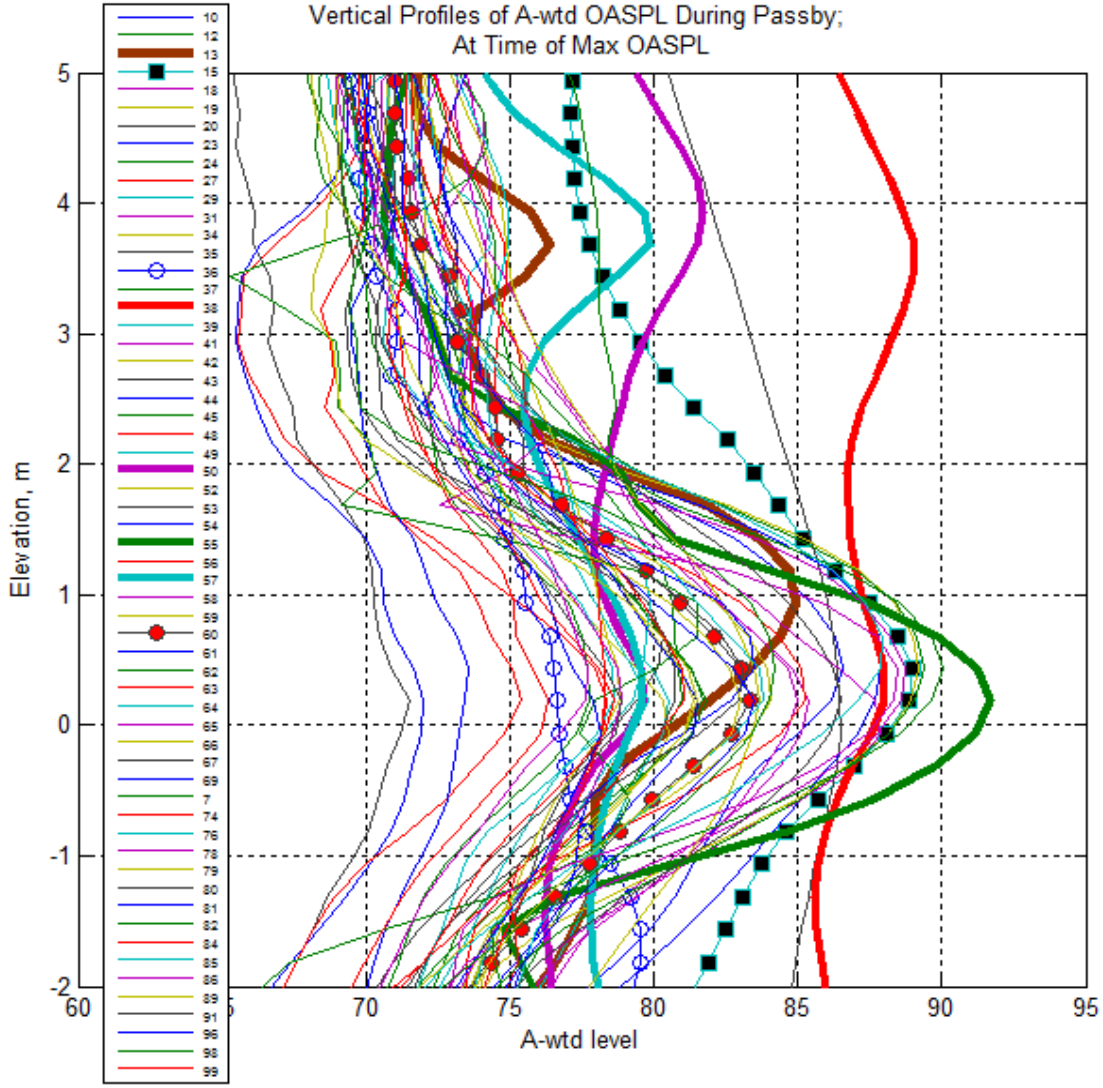


Tractor drive axel tires vs. trailer tires: different tire patterns

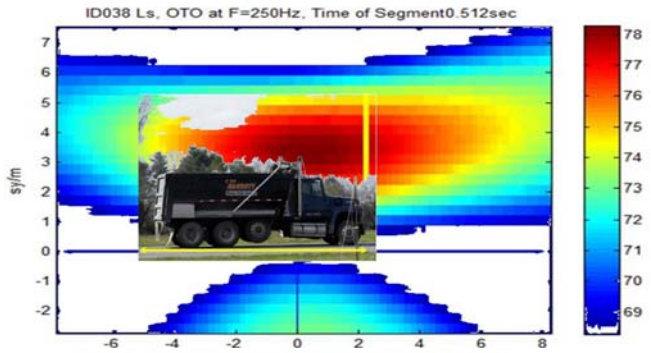
Truck ID015: Typical Source Image and Vertical Distribution



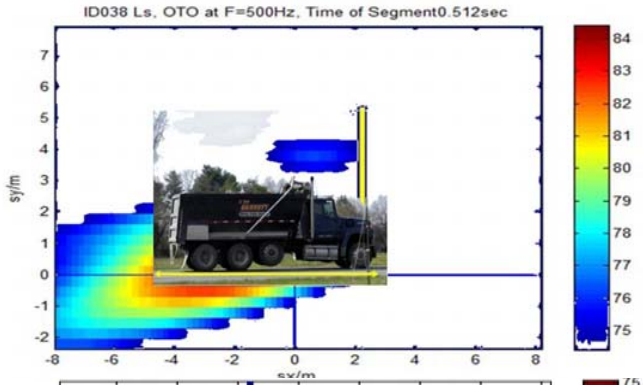
Vertical Distribution of A-wtd OASPL for 59 Heavy Trucks



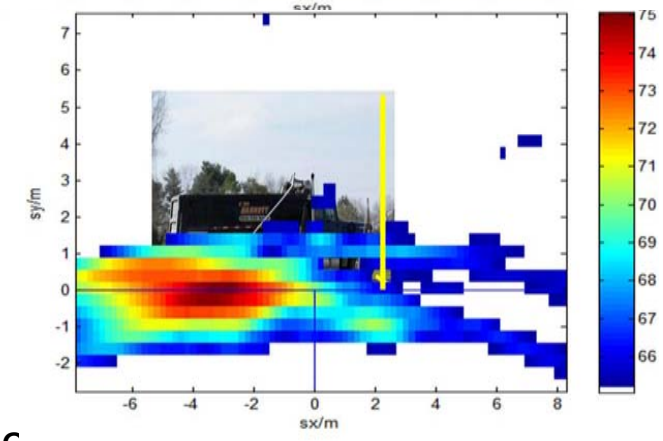
Truck ID038 (Dump Truck)



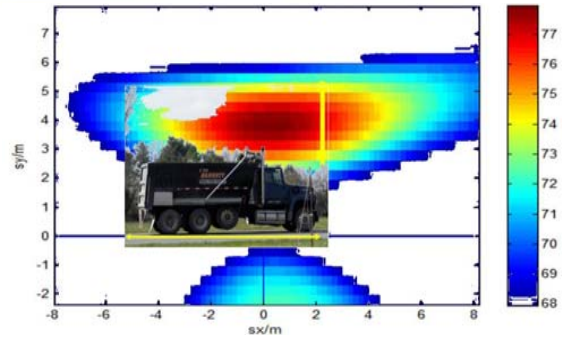
250 Hz



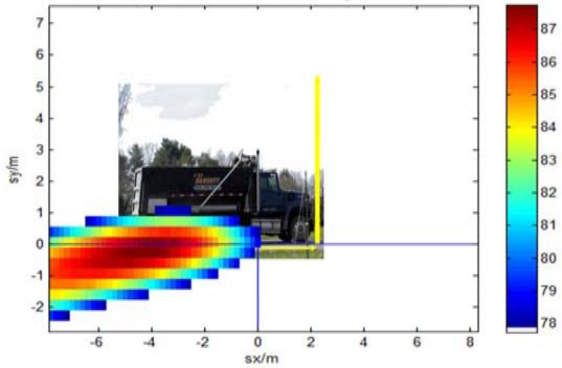
500 Hz



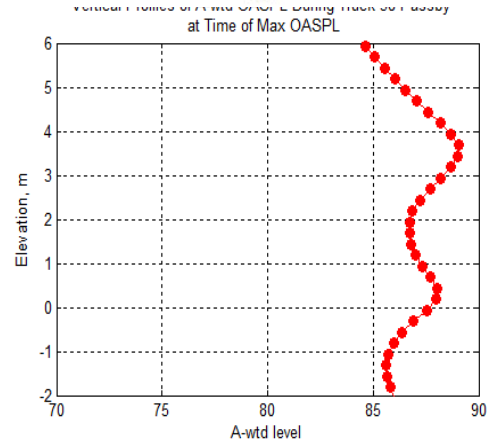
1250 Hz



315 Hz



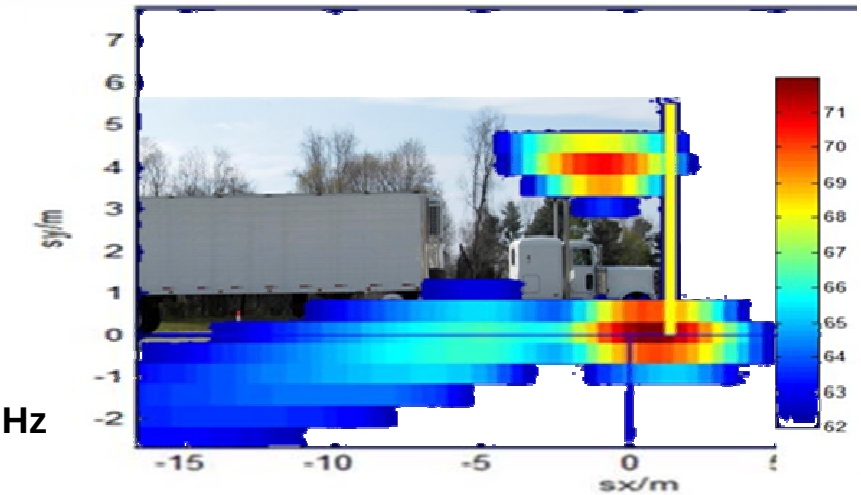
630 Hz

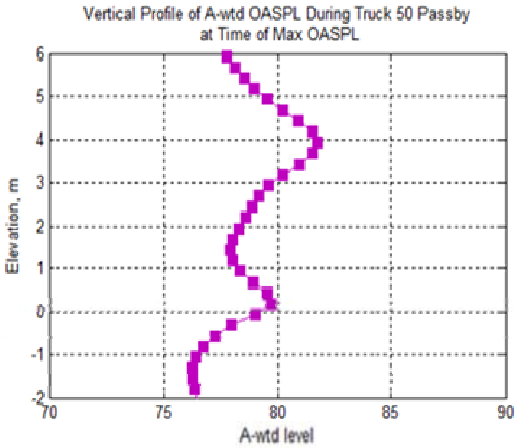


A-wtd OASPL

Truck ID050

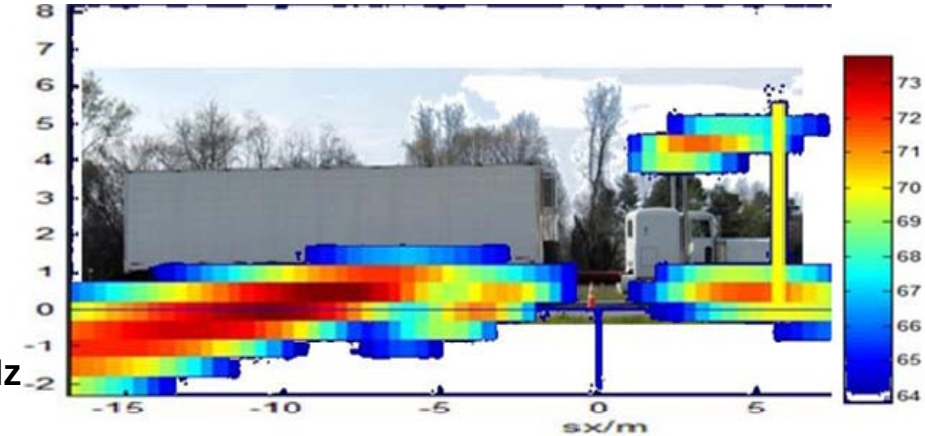
630 Hz



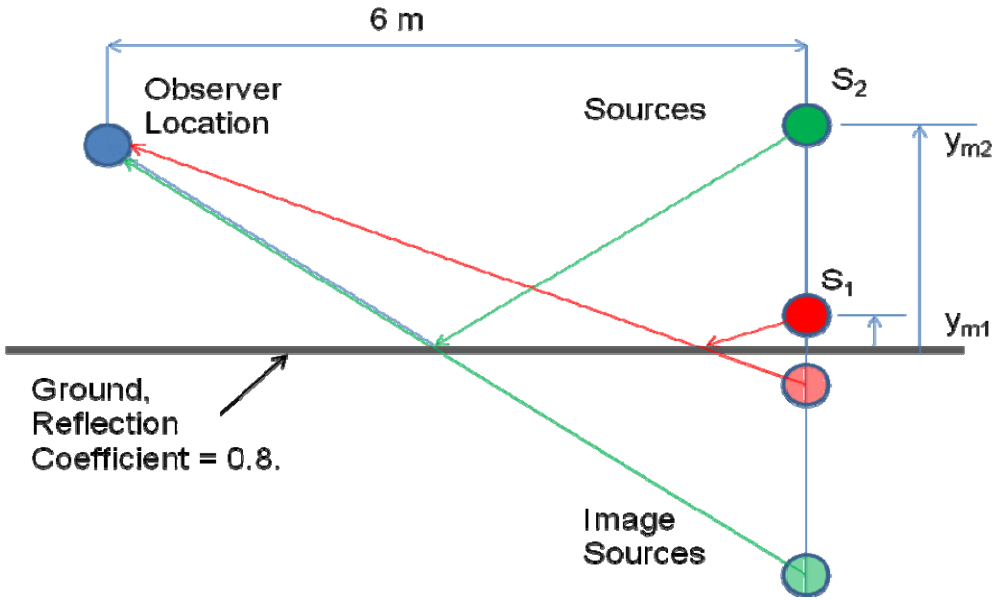


A-wtd OASPL

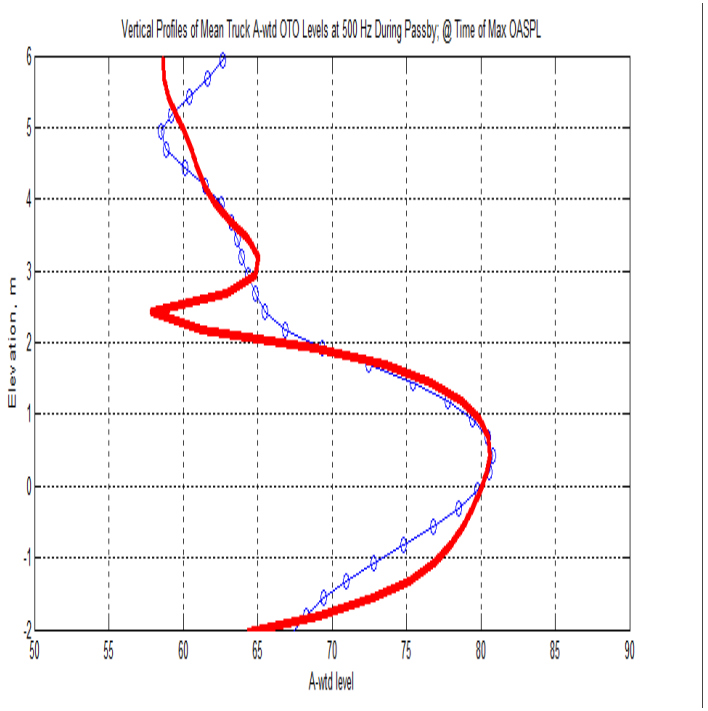
1000 Hz



Truck Noise-Source Modeling



Simulation geometry



Simulated vertical distribution (red) vs. measured distribution (blue) (max A-wtd levels at 500 Hz)

Conclusions

- Tire-pavement noise was dominant for most trucks
- A small proportion of heavy trucks showed significant noise sources at the vertical exhaust stack
- Results have been applied to barrier height analysis using TNM (Inter-Noise 2009, Ottawa, Canada)
- Potential areas for follow-up research and application include:
  - nation-wide measurements for a wider range of pavements and terrains with simplified microphone array
  - traffic noise prediction model updates using noise source distributions for different vehicle types from this and follow-up studies
  - measurement and analysis of abatement measures for trucks, automobiles, buses, motorcycles, and other noise sources, such as construction equipment, etc.

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Thank you.

Questions?