Changes in sound due to noise barrier reflections

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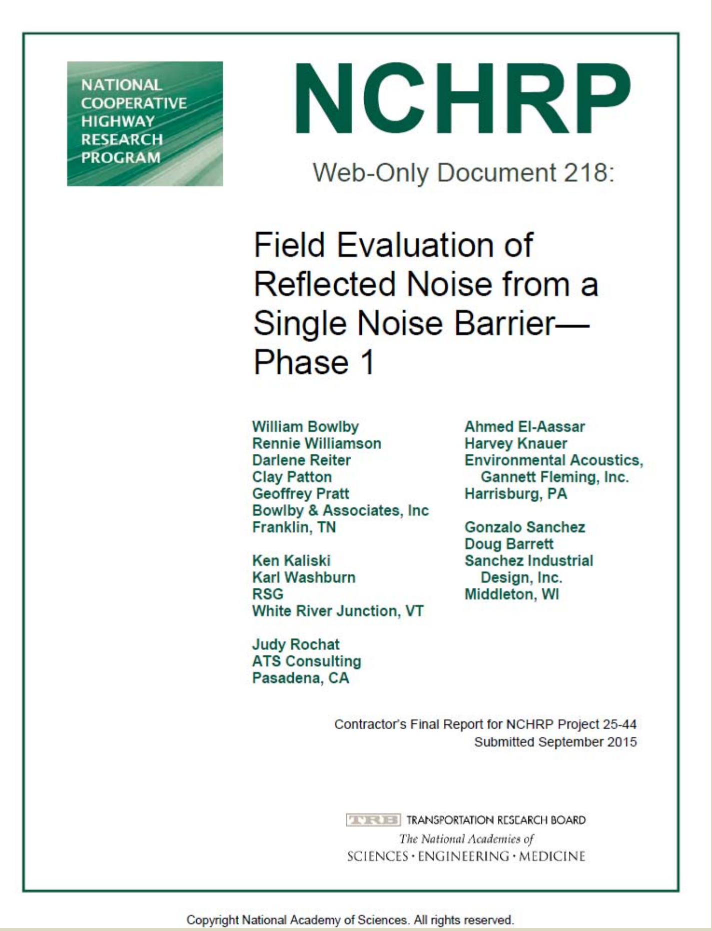
NCHRP Project No. 25-44

- Two main objectives:
  - Determine spectral noise level characteristics in the presence of a single noise barrier on the opposite side of the road
  - Summarize results to help understand actual and perceived effects of a barrier

- Phase 1: barriers with reflective surfaces
  - Sound levels higher in presence of barrier
  - Frequency-specific differences varied by site
  - Greater effects farther from road and higher above ground


NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP

Web-Only Document 218:

Field Evaluation of Reflected Noise from a Single Noise Barrier—Phase 1

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Contractor's Final Report for NCHRP Project 25-44
Submitted September 2015

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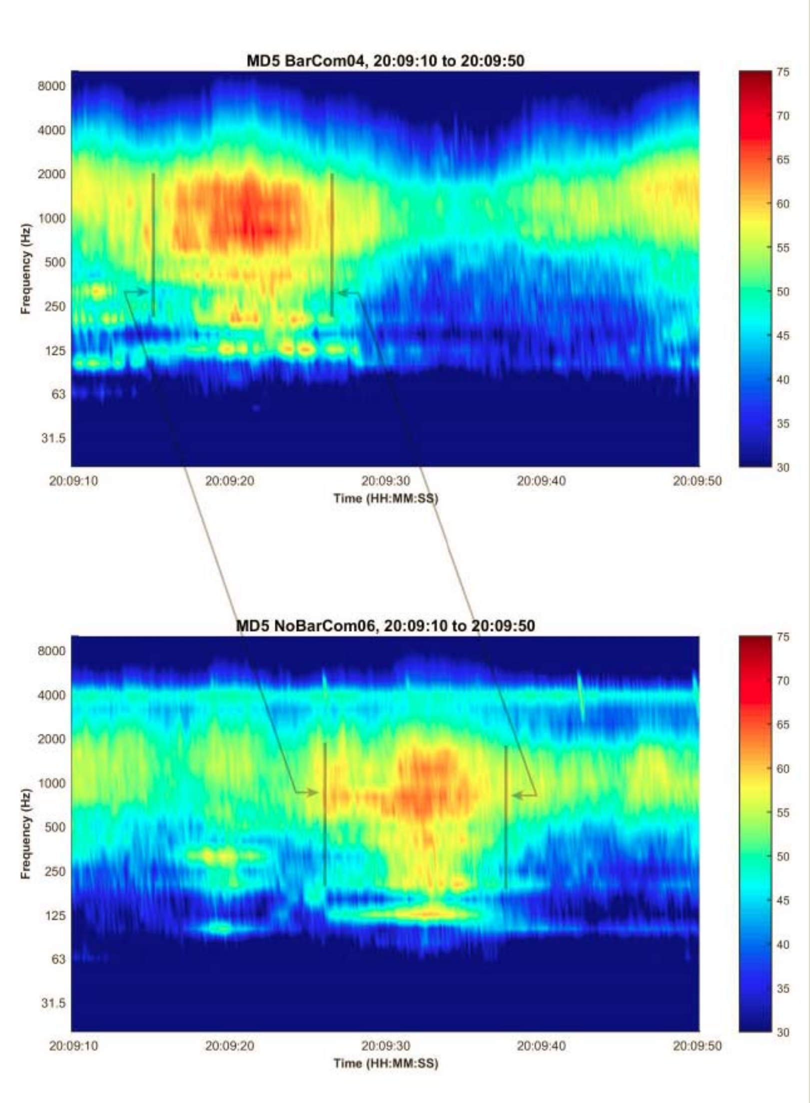
- Phase 2: barriers with absorptive surfaces (in progress)
  - Interim report submitted
  - Final analysis to compare results for reflective and absorptive barriers

- Part of analysis includes spectrograms (spectral content as a function of time)
  - Generated for both highway traffic and individual vehicle pass-by events
  - Allows for visual examination of barrier effects
  - Phase 1 showed barrier-reflected noise caused …
    - sound levels to increase over a broad range of frequencies
    - higher sound levels to be sustained for a longer period of time

Example vehicle pass-by event

with barrier

no barrier



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Difference spectrograms

- Subtle differences are key to comparing reflective and absorptive barriers

- Method developed to visualize subtle differences: difference spectrograms
  - Compares same vehicle passing through barrier site and no barrier site
  - Maximum sound level for each site aligned after applying 3-second averaging to data
  - Once aligned, 1-second averaging applied
  - Difference between barrier and no barrier data for each 1/3-octave band used to create difference spectrogram

- Preliminary results applying this method presented today

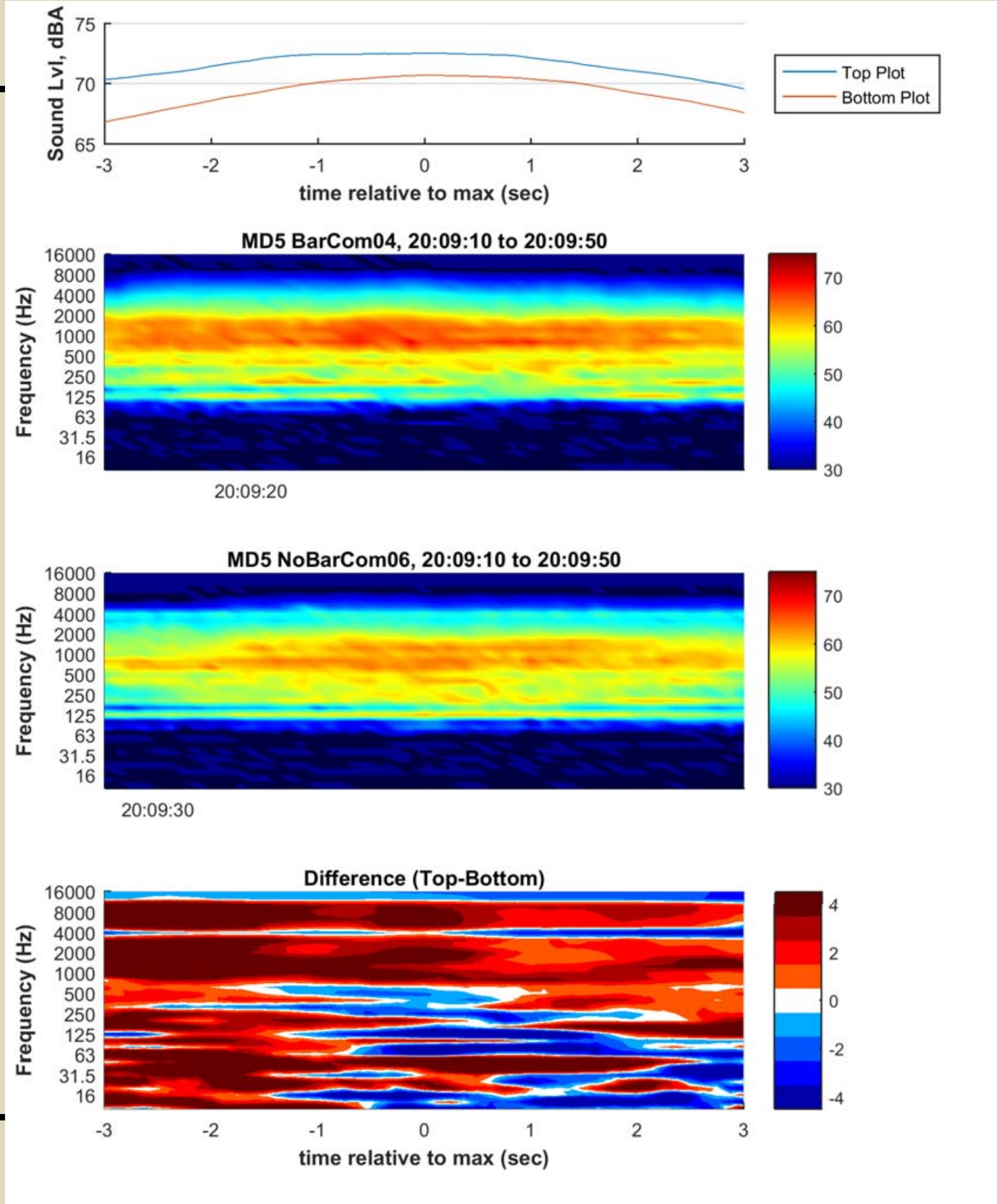
Example process

Align maxima

Barrier event spectrogram

No barrier event spectrogram

Difference spectrogram
red = barrier louder
white = no difference
blue = no barrier louder



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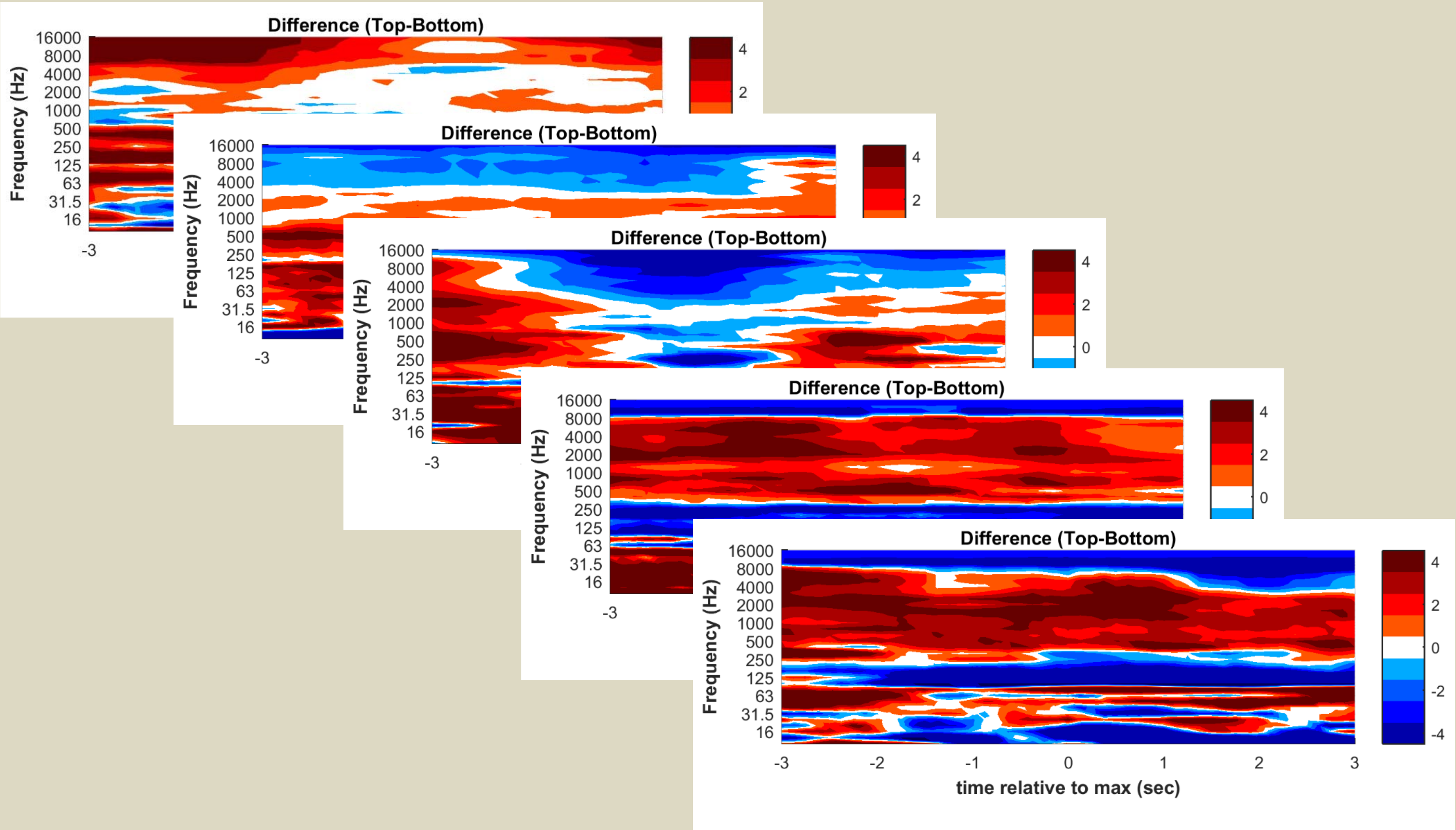
Difference plots



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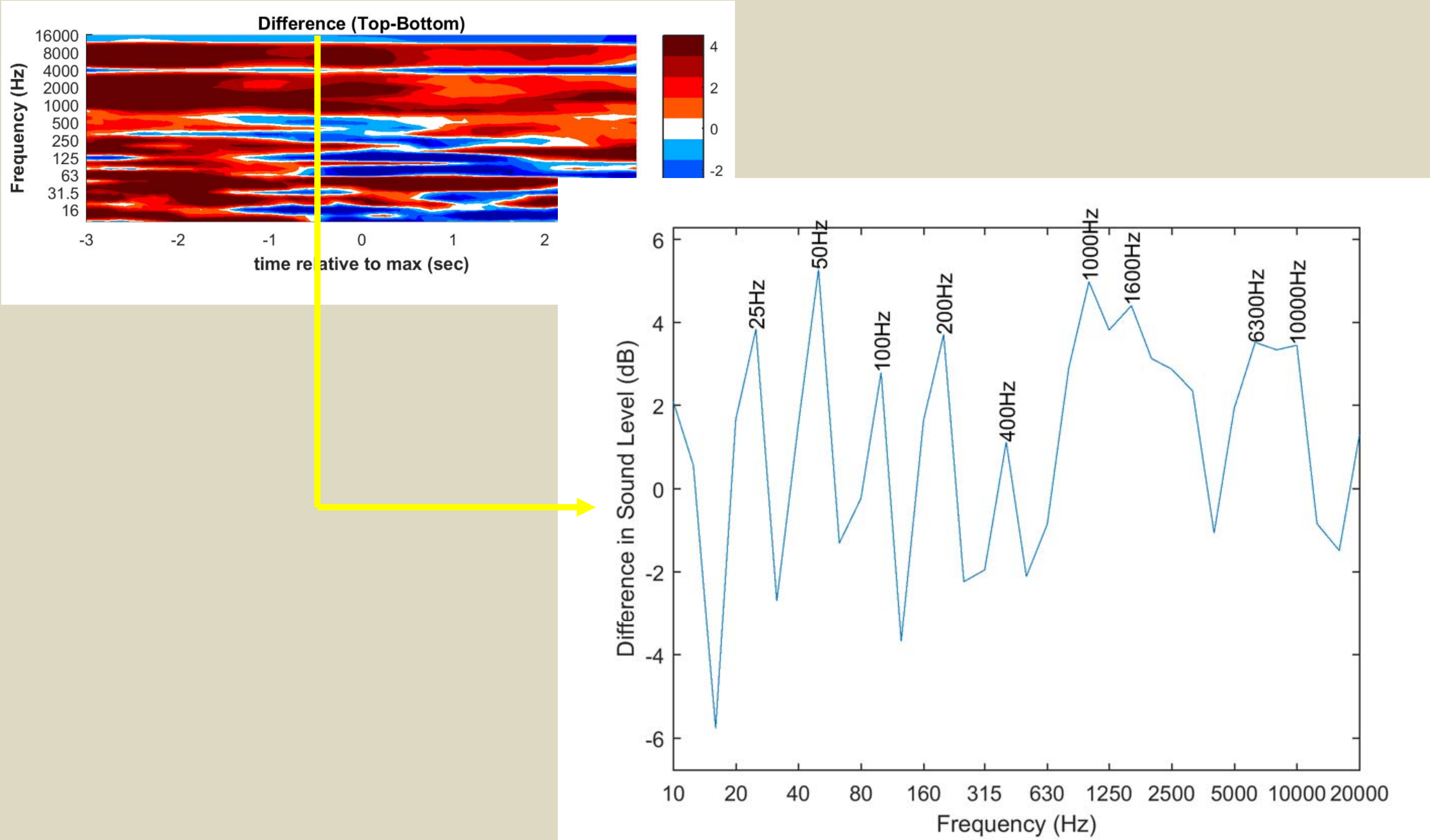
"Hot lines" frequencies



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“Hot lines” relationship

- Peak difference frequencies are harmonically related, with few exceptions
  - Harmonic relationship: frequency is an integer multiple of base frequency

Site and event	Peak difference frequencies (Hz)	Harmonic relationships
MD-5 19:46	16, 20, 40, 80, 160, 400, 800, 1600, 12500	All except 16 are related to 20 Alternately, all except 20, 40, and 12500 are related to 16
MD-5 20:09	25, 50, 100, 200, 400, 1000, 1600, 6300, 10000	All are related to 25
I-90 14:41	16, 25, 31.5, 50, 63, 125, 250, 500, 1000, 2000, 3150, 5000, 8000	All except 16, 31.5, and 63 are related to 25
I-90 16:17	16, 25, 50, 63, 100, 250, 500, 2500	All except 16 and 63 are related to 25
SR-71 10:44	25, 50, 80, 315, 400, 630, 800, 2000, 2500, 6300, 8000, 12500	All except 80, 315, and 630 are related to 25
SR-71 12:10	25, 50, 80, 400, 1250, 2500	All except 80 are related to 25

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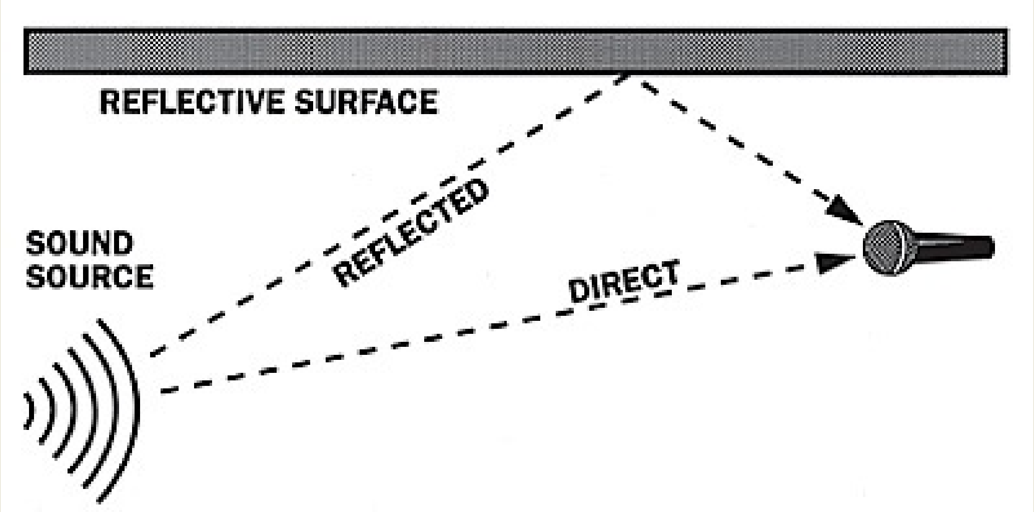
Why harmonic relationship?

- Comb filtering
  - Effect created by direct-path sound wave combining with reflected-path sound wave
  - Reflected-path sound is delayed in time from direct path
  - Combination results in harmonically related peaks (constructive interference) and dips (destructive interference)



Perception of comb filtering

- Harmonically related peaks can result in perception of tonality

- Audio engineering (short delay times in recording studio)
  - Sounds metallic, boxy, or artificial
  - Can make higher frequencies sound odd or harsh

- Psychoacoustics
  - Effect dependent on delay time
    - Coloration of sound (change in timbre) with delays < 25 ms
    - Longer delays = rough character effect
    - Very long delay time = echo
  - Repetition pitch
    - (sound) + (repetition of sound with delay time T) = repetition pitch of 1/T (e.g., 10 ms delay results in repetition pitch of 1/0.010 = 100 Hz)

Comb filtered highway noise

- Effect dependent on vehicle/site geometry

- For this study, site geometries result in 8 to 200 ms time delays
  - Equates to 125 Hz and much lower repetition (base) frequencies
  - At max sound level, time delay greater than when vehicle up- or down-stream

- For single vehicle pass-by event, it is possible to perceive comb filtering effects as …
  - Coloration of sound as the vehicle approaches or recedes
  - Fuller sound or echo at the closest point of approach

Audio analysis

- Further analyzed effects using audio file

- Sound for a vehicle pass-by event delayed in time and added to original
  - Delay times ranged from 20 ms to 200 ms

- For a 20 ms delay, effect was obvious raspiness or buzziness

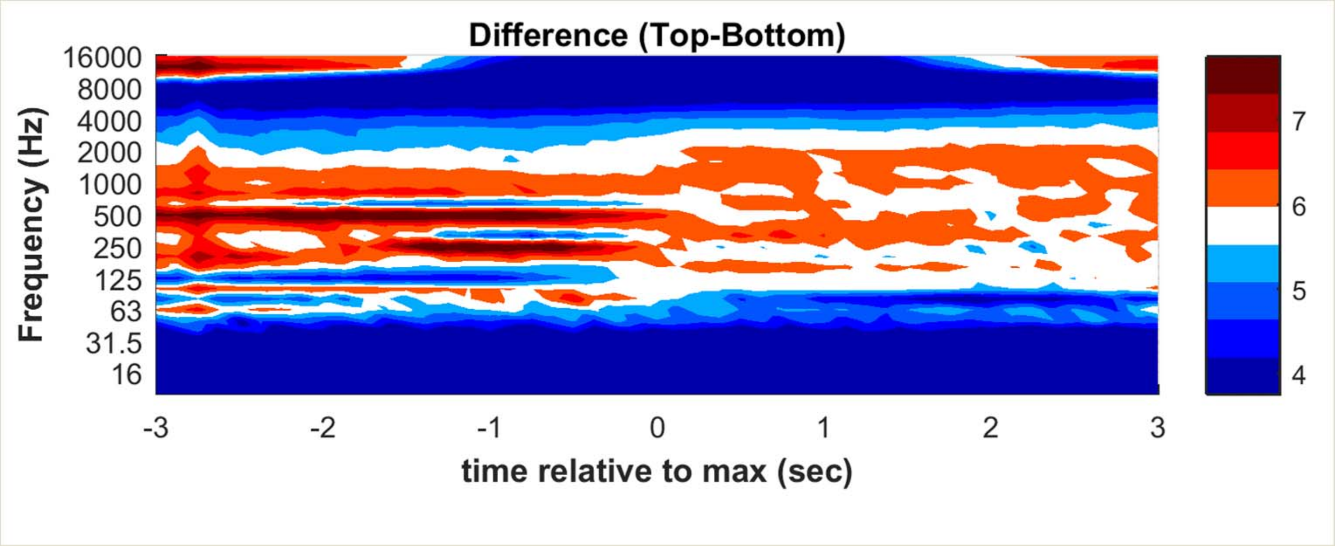
vehicle pass-by   vehicle pass-by, 20 ms delay added

- For sweeping time delay (20 ms to 100 ms to 20 ms), effect was raspiness/buzziness to full sound to raspiness/buzziness

vehicle pass-by, sweep delay added

Spectrogram differences for simulated effect

- Original audio compared to original plus barrier effect simulated by sweep delay
- Hot lines: 12.5, 20, 63, 100, 200, 500, 800, 1250, 12500 Hz
  - o All harmonically related to 12.5 Hz except 20 Hz



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Conclusions

- Evidence that comb filtering effects adding tonal qualities to received sound
  - Particularly in low to mid frequencies
  - Applies to distances near and far from road

- Effect may add raspiness/buzziness, particularly as vehicle is approaching/receding

- Based on highway geometry delay times, very low frequency repetition pitches may be introduced – perceived?

Questions?