Brake Pedal–Booster System Clunk Noise

Example using Percentile Frequency Method

Illustrating a simple way of displaying repeated measurements in Sound Quality Projects to identify objectionable impacts caused by poorly controlled product operation from the sounds of a properly function product.

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Background (1)

- Structured approaches for product improvement such as the Red X Strategies, Design-of-Experiments (DOE) and the Taguchi Method depend heavily on developing statistics using an effective measuring system to distinguish product variations that can range from the best-of-the-best (BOB) to the worst-of-the-worst (WOW).
- None of these structured approaches offer any direction about actually making measurements. They assume that the knowledge for making appropriate measurements exists. In spite of this short coming, these approaches do provide some statistical techniques (focused on repeatability and reproducibility) for determining if a measurement system is effective provided its output can be reduced to a single number for each test.

Background (2)

- Use of these approaches for Sound Quality work has been limited by the lack of measurement techniques that reduce the three dimensional information of complicated sounds (i.e. loudness, frequency, time) to a single number that agrees with human perception of the sound.
- Often attempts to use existing but antiquated single number N&V measures have been found not to be effective. Lacking an objective measure system necessitates using as a last resort, subjective sensory scoring which is fraught with many repeatability and reproducibility problems.
- While the following example does not produce the single number measures needed by the structured product improvement methods, it does demonstrate how the Percentile Frequency method was better able to objectively differentiate characteristics of the best-of-the-best (BOB) from the worst-of-the-worst (WOW) than the conventional color spectrogram.

Problem Statement

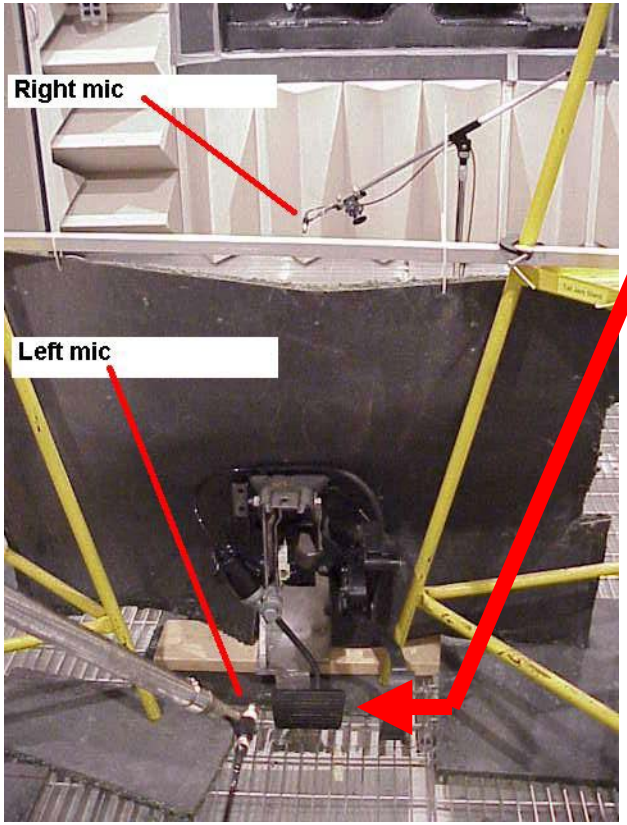
Objectionable Clunk Noise from Brake Pedal – Booster System

- Brake Pedal manually actuated (by foot) then suddenly released in a side-step fashion produces a “Clunk” noise.
- Some Brake Pedal – Booster part combinations produce “Clunk” noises that are more objectionable than others.
- Project team wanted to use Red X Methodologies for product improvement.
  - Team had subjectively identified a BOB and WOW for further investigation.
  - Team lacked single number measure for “Clunk” noise.
  - Team lacked time and resources to develop desired single number measure.
  - Team wanted to compare capabilities of Percentile Frequency method to more traditional methods (color spectrogram).

Test Setup

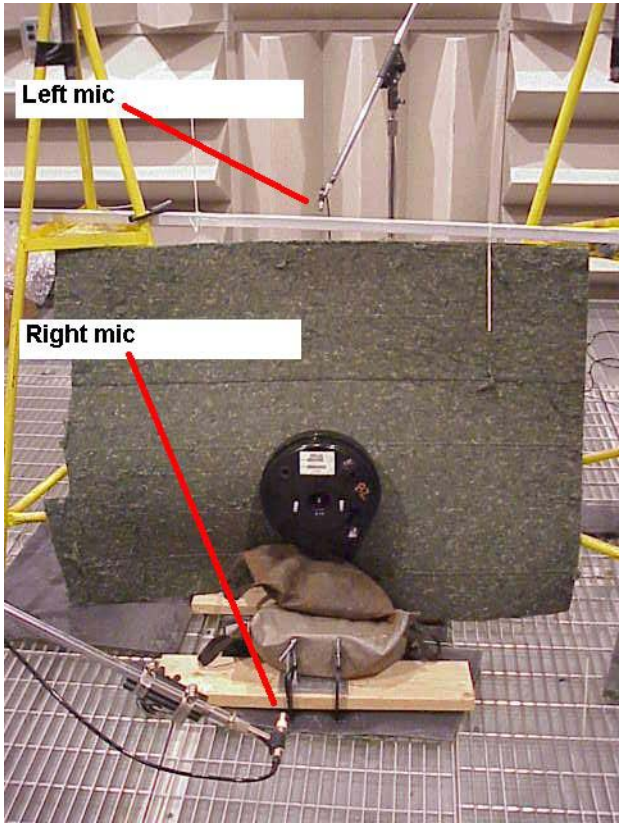
Brake Booster Clunk Noise Test in Anechoic Room
Two Channel Recording using Measuring Mics

Pedal-side view



Brake Pedal Manually Actuated (by foot) then Suddenly Released in a Side-step Fashion to Produce "Clunk" Noise

Booster-side view



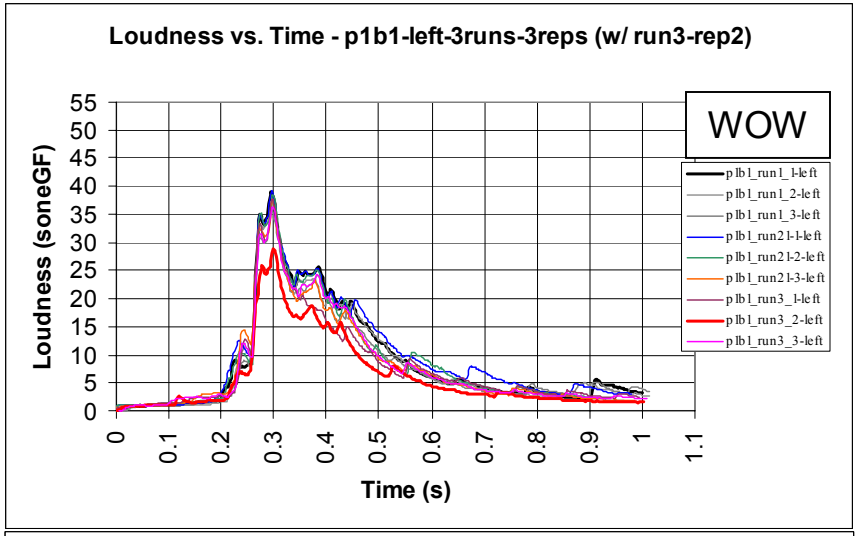
Results Presented are Analyses of "Left mic" Recording Only (pedal-side)

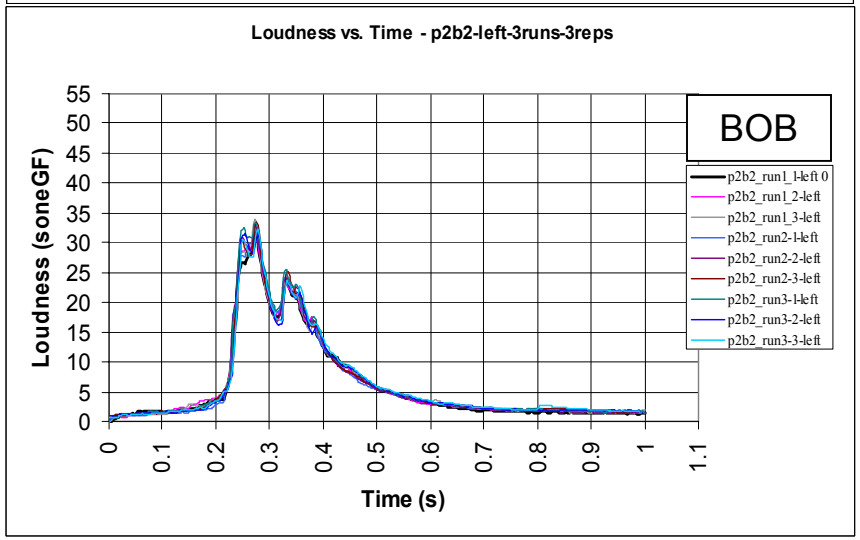
Data Analysis Plan

- Analyze for Zwicker Loudness Time History (Nhist)
- Analyze for Zwicker Specific Loudness Time History (spNhist)
  - Display: Colored Spectrograms
  - Analyze and Display: Percentile Frequency curves
- Assess Measurement Repeatability & Reproducibility
- Look for Evidence of Product Variations
  - Can results distinguish BOB and WOW?

Repeatability and Reproducibility

Overlaid Loudness Time Histories (Nhist)





P1b1:
Pedal 1 and Booster 1 (WOW)
Disassemble/Reassemble (3)
Operation Repetitions (3)
(WOW due to Multiple Impacts)

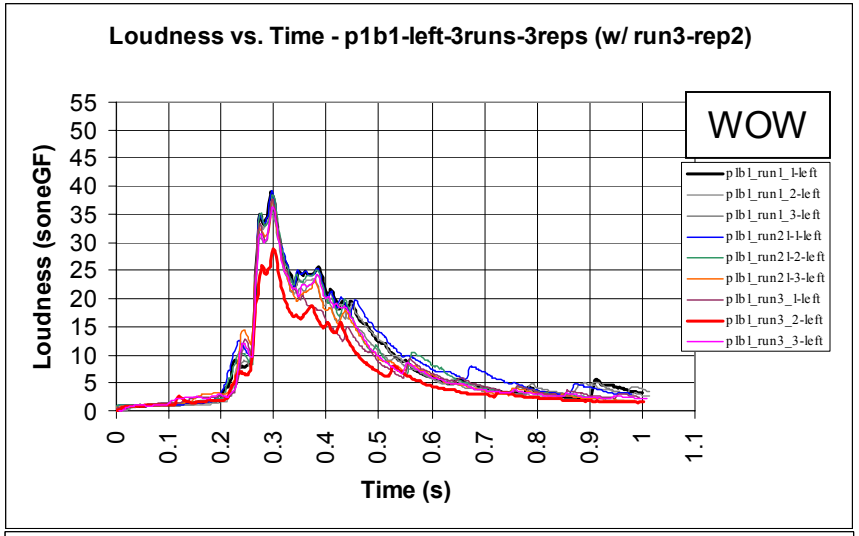
NOTE: P1b1-run3-rep2 (heavy red line) omitted from later study for inconsistent manual actuation based on Loudness Time History

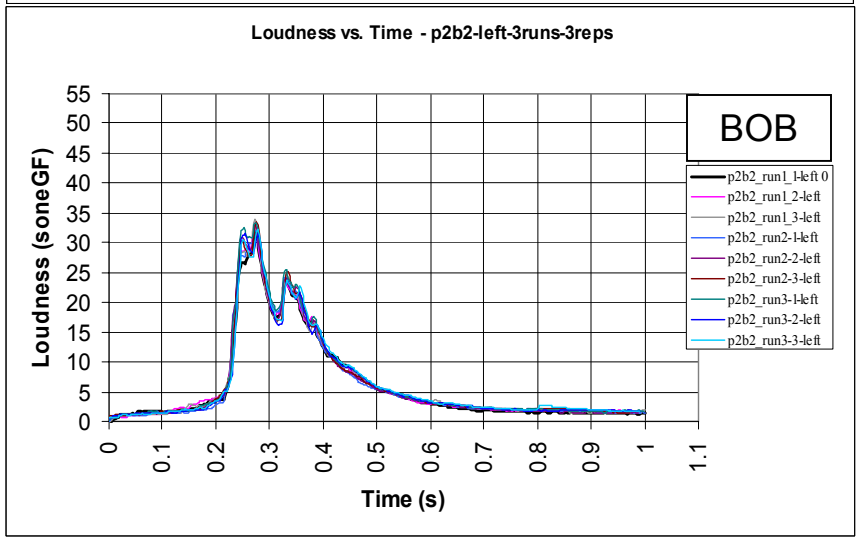
P2b2:
Pedal 2 and Booster 2 (BOB)
Disassemble/Reassemble (3)
Operation Repetitions (3)

NOTE: Loudness Time History (Nhist) synchronized for Brake Clunk Event between ~0.2s and ~0.4s

Repeatability and Reproducibility

Overlaid Loudness Time Histories (Nhist)

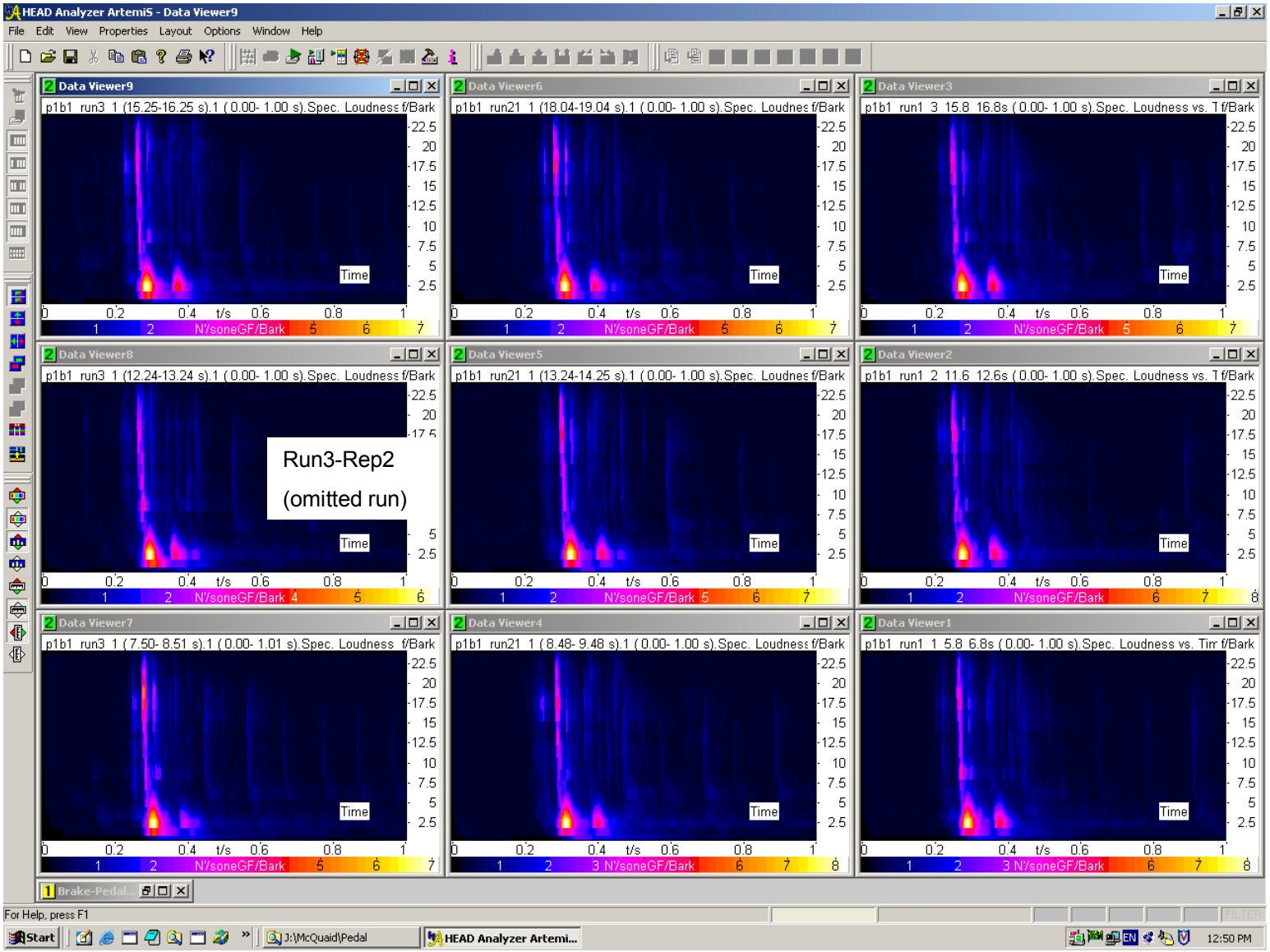




Loudness Time Histories (Nhist) for both BOB and WOW appear to have reasonably good Repeatability and Reproducibility which may be surprising given that the pedal actuation method was solely by human foot. WOW data appears to have more “Jitter” than BOB but differences in the traces are not very large. (For steady-state sounds, a 7% to 10% change in sones is needed for average human hearing to detect a change in loudness.)

RESULTS: Repeatability and Reproducibility
P1b1 Specific Loudness Time Histories (spNhist) (WOW)

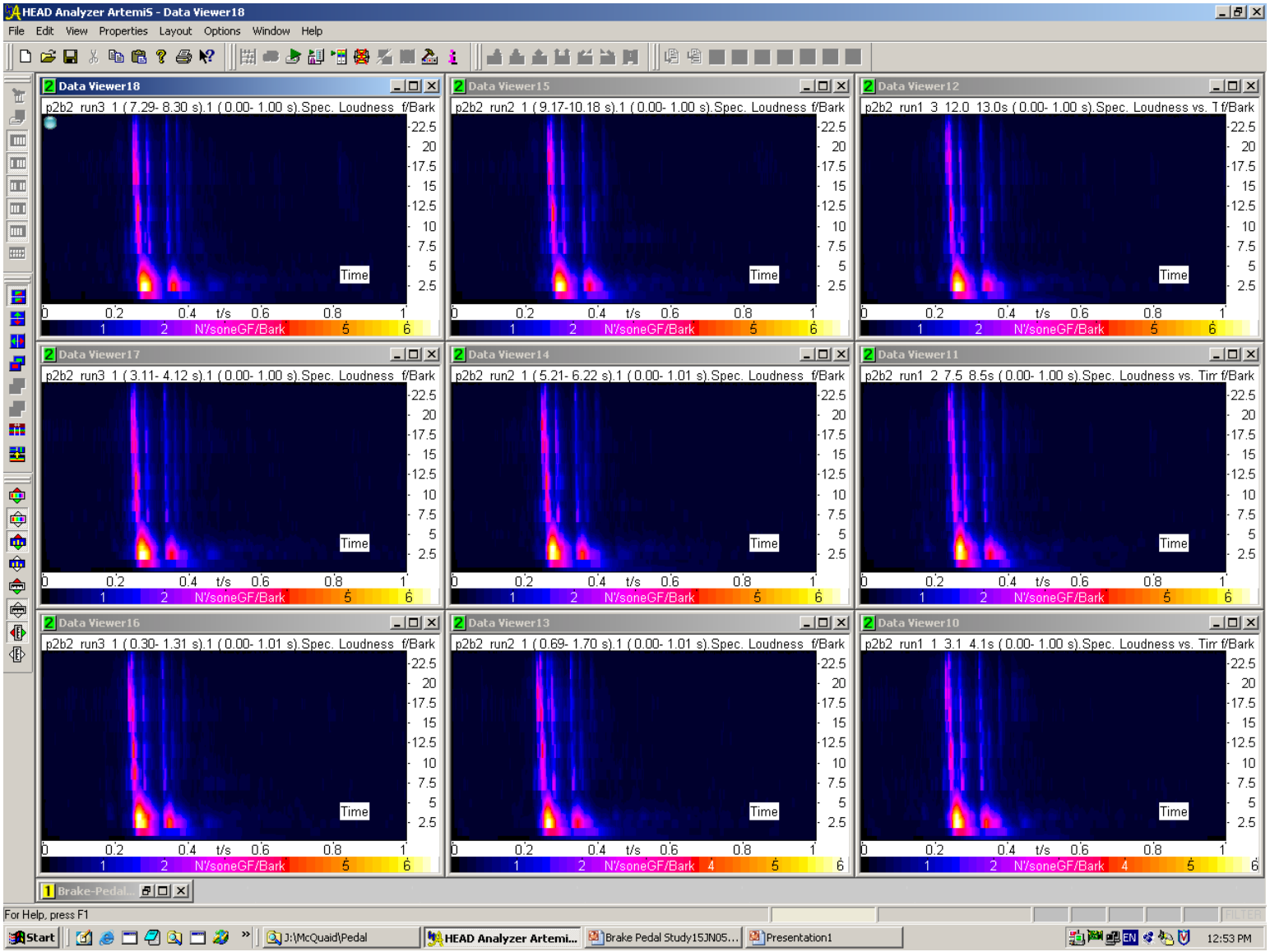
Specific Loudness Time History (color spectrogram)



No Event Synchronization

RESULTS: Repeatability and Reproducibility
P2b2 Specific Loudness Time History (spNhist) (BOB)

Specific Loudness Time History (color spectrogram)



No Event Synchronization

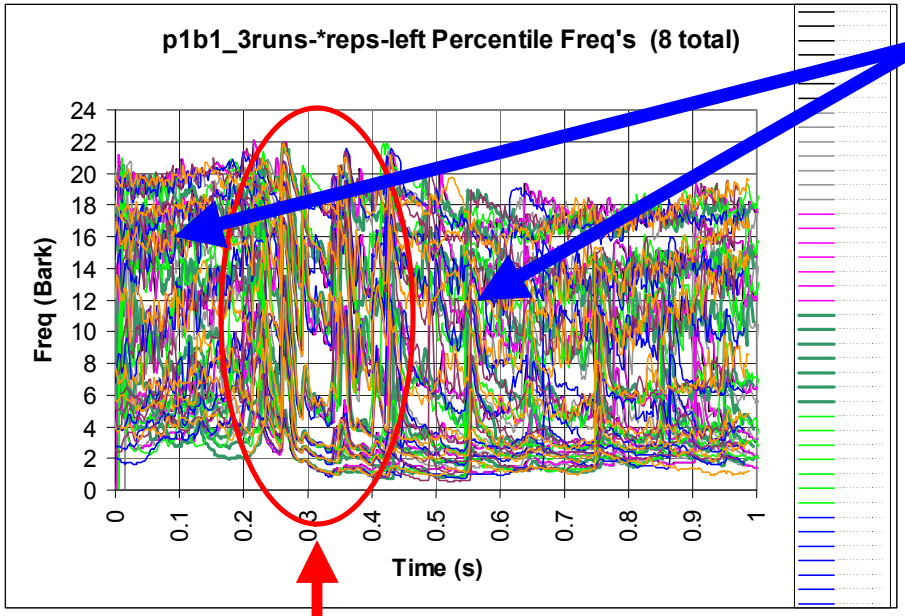
Repeatability and Reproducibility
Specific Loudness Time History (spNhist)

- As a group, the sets of 9 color spectrograms of Specific Loudness Time Histories are difficult to visually compare. But for both BOB and WOW they appear to have reasonably good Repeatability and Reproducibility at least in the early part of the event.

RESULTS: Repeatability and Reproducibility

8 Sets of Percentile Frequency Summaries of Specific Loudness Time Histories

P1b1 %-ile Freq (WOW)



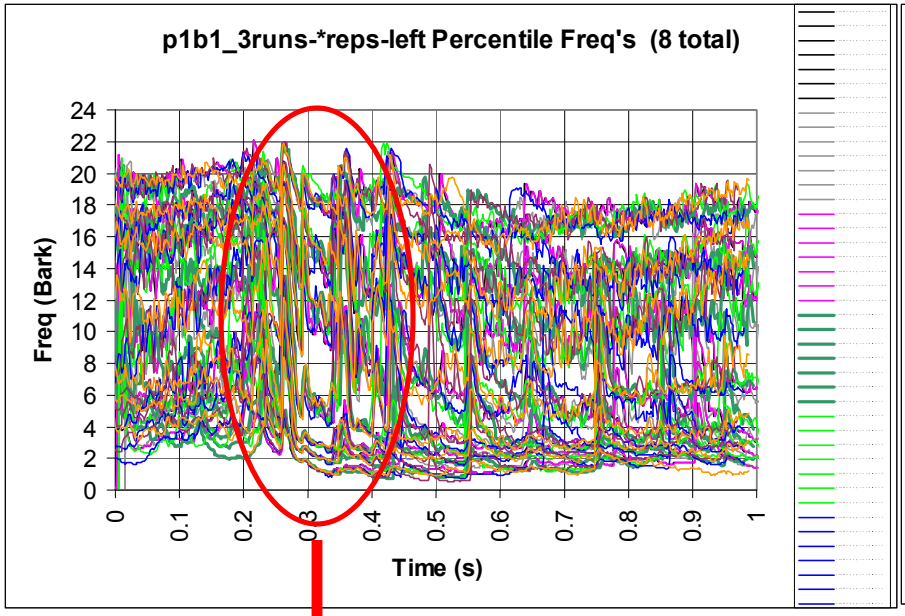
The 8 sets of overlaid Percentile Frequency Curves of the background noise in the room (i.e. before and after the “Clunk” Noise Event) are displayed as a tangle of lines, characteristic of random (unstructured) noise. Only the “Clunk” Noise Event exhibits a structure in the curves that can be observed in more detail by expanding the time scale and focusing on the event as demonstrated on the next slide.

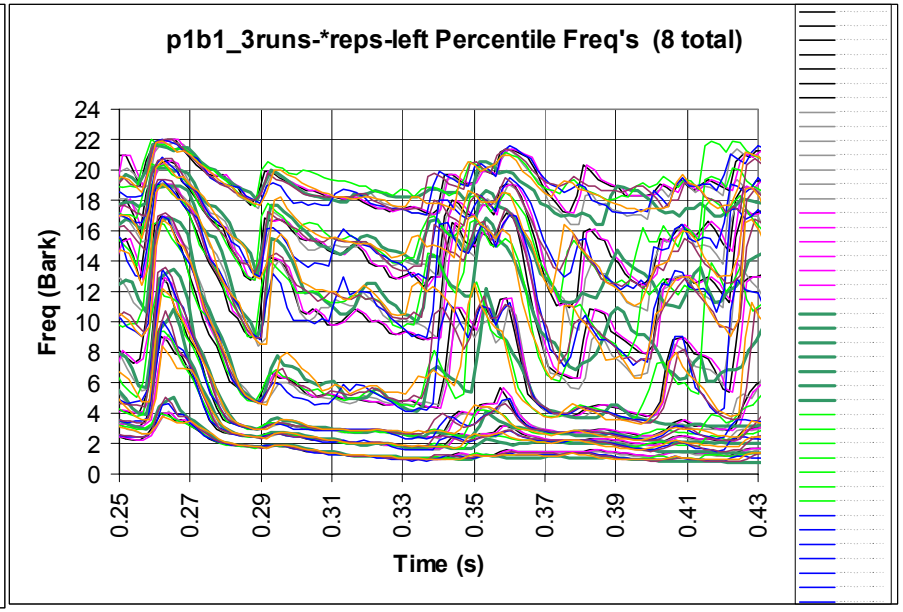
“Clunk” Noise Event

P1b1-3runs-3reps (8 total – run3-rep2 omitted for inconsistent manual actuation)

NOTE: %-ile Freq synchronized for Brake Clunk Event between ~0.2s and ~0.4s

RESULTS: Repeatability and Reproducibility
P1b1 %-ile Freq (WOW)





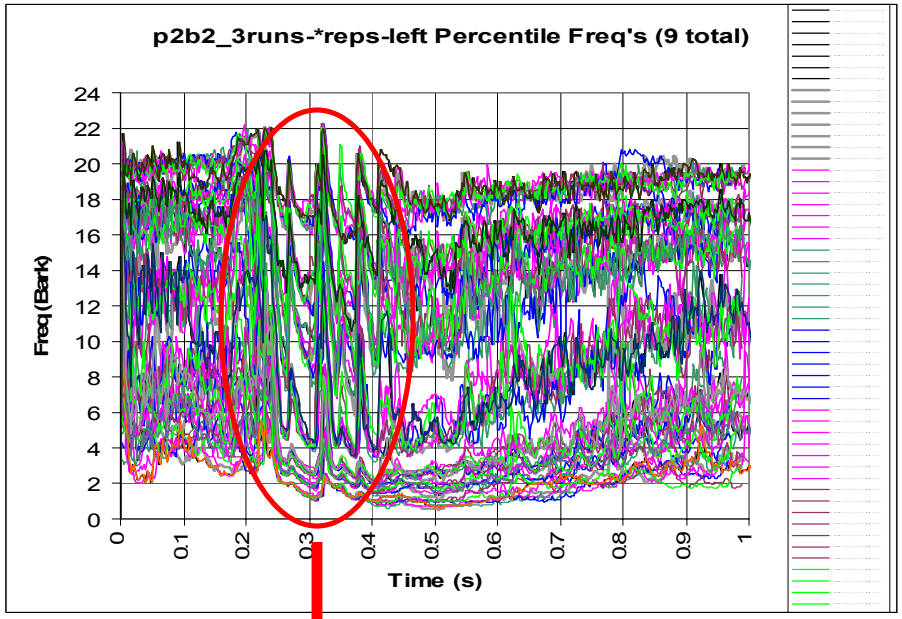
Expanded Time Scale

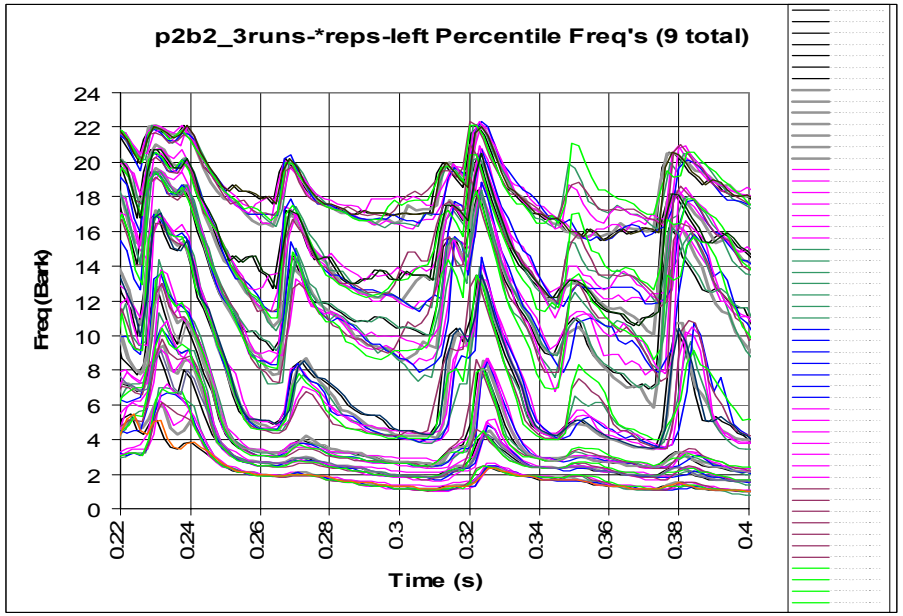
P1b1-3runs-3reps (8 total – run3-rep2 omitted for inconsistent manual actuation)

8 Sets of Percentile Frequency Summaries of Specific Loudness Time Histories

NOTE: %-ile Freq curves synchronized for Brake Clunk Event between ~0.2s and ~0.4s

RESULTS: Repeatability and Reproducibility
P2b2 %-ile Freq (BOB)





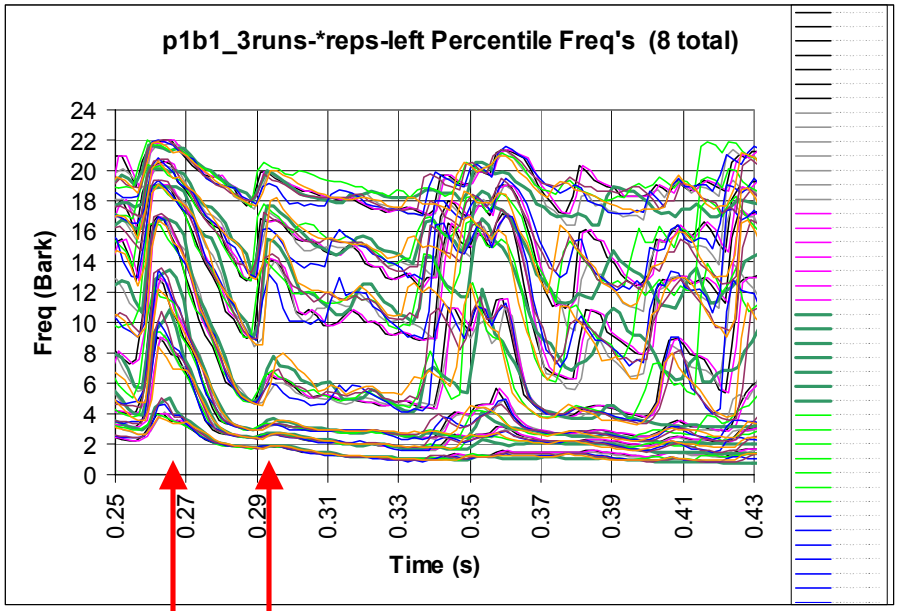
Expanded Time Scale

P2b2-3runs-3reps (9 total)

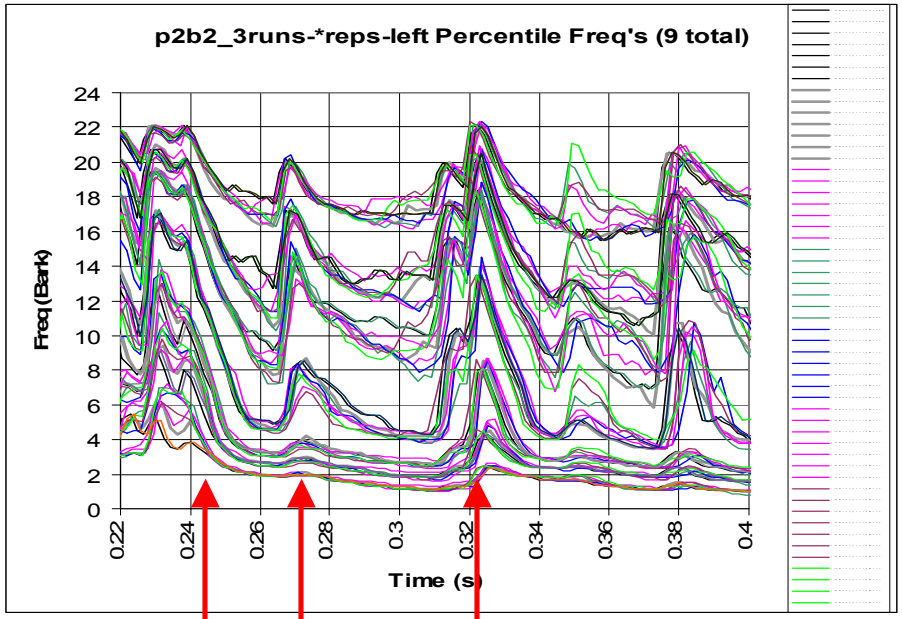
9 Sets of Percentile Frequency Summaries of Specific Loudness Time Histories

NOTE: %-ile Freq curves synchronized for Brake Clunk Event between ~0.2s and ~0.4s

Repeatability and Reproducibility
%-ile Freq



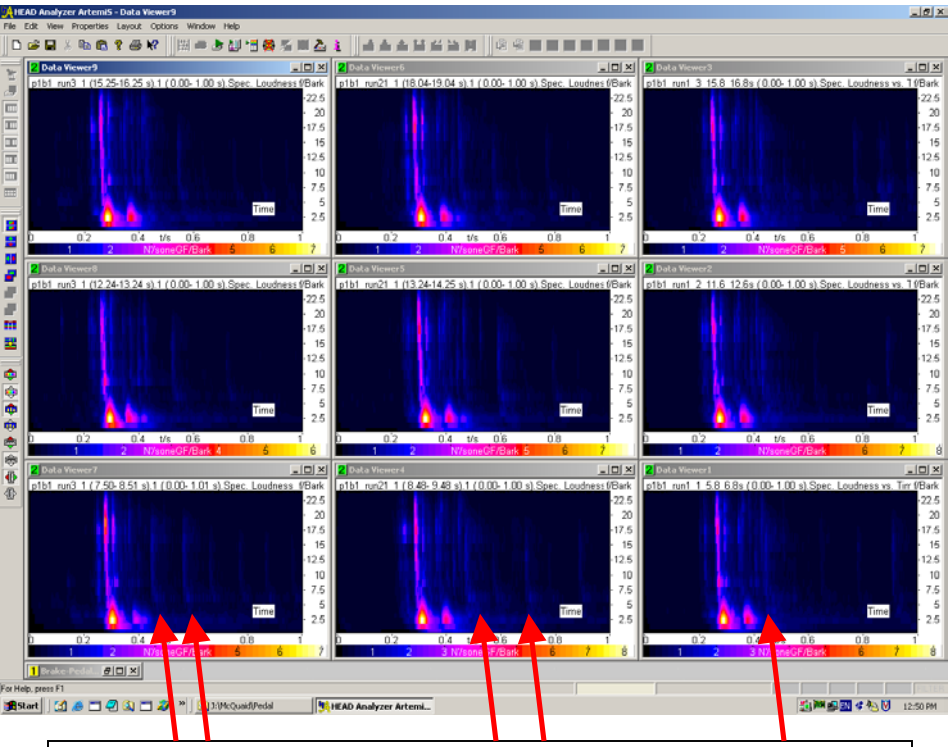
P1b1 %-ile Freq (WOW)



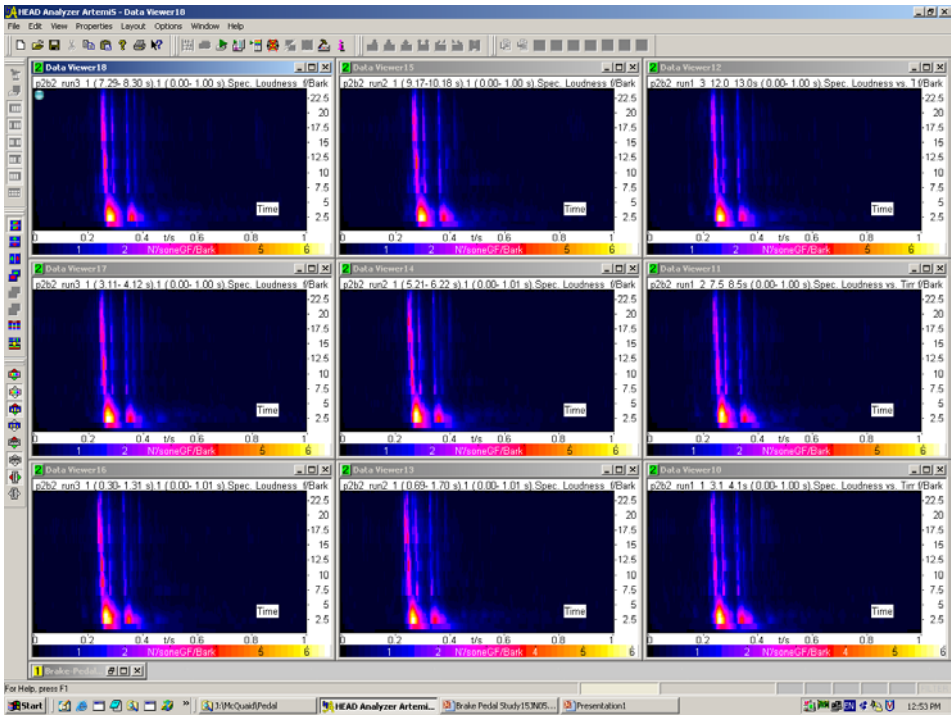
P2b2 %-ile Freq (BOB)

The 8-9 sets of Percentile Frequency curves overlay fairly well especially early in the event which supports the conclusion that Repeatability and Reproducibility are reasonably good.

BOB & WOW Compared



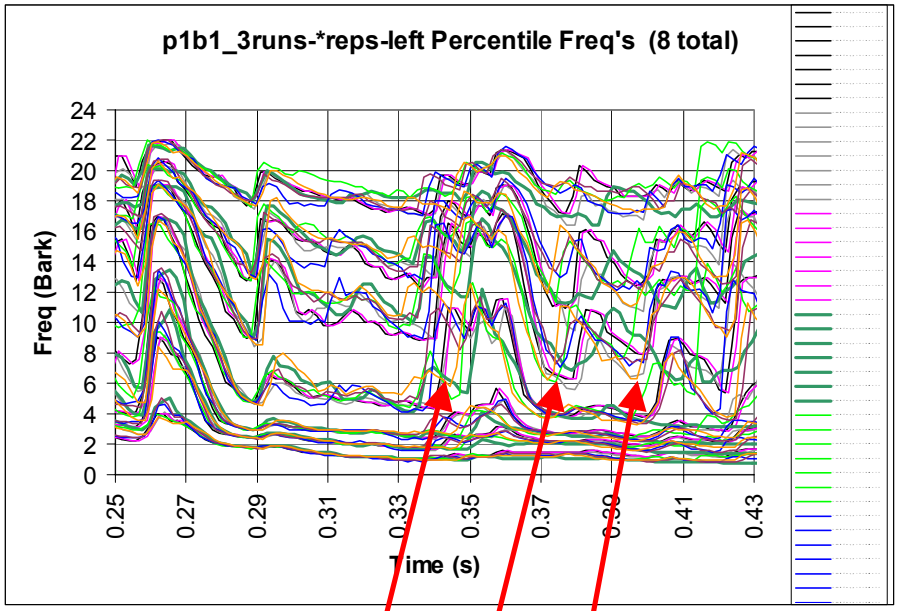
P1b1 spNhist (WOW)



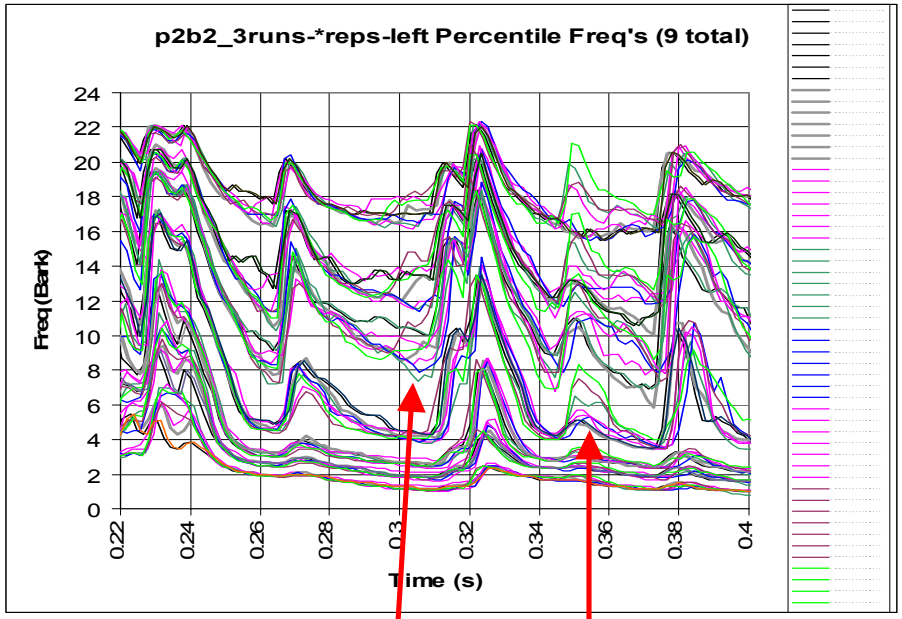
P2b2 spNhist (BOB)

Side by side, it is difficult to compare the two sets of 9 color spectrograms but it is still possible to see that WOW has more late occurring impacts (e.g. red arrows pointing to faint blue traces) than BOB. However, a way to further reduce that data to two spectrograms would be useful.

BOB & WOW Compared



P1b1 %-ile Freq (WOW)



P2b2 %-ile Freq (BOB)

Side by side, <u>two graphs</u> of overlaid Percentile Frequency curves are easier to compare than <u>eighteen</u> color spectrograms. Notice that WOW has more regions of its curves with large variations compared to BOB. This “Jitter” in the curves indicates that the parts of the WOW brake-booster system are creating more erratic impacts compared to BOB and are the probable cause of the objectionable “Clunk” noise. BOB also exhibits some erratic impacts that could be better controlled to help improve the product.

Summary

- The Percentile Frequency method is a data reduction tool that summarizes Zwicker Specific Loudness Time Histories.
- The overlaid Percentile Frequency curves of repeated measurements can identify the structured sound of product operation from the unstructured sound of background noise.
- Overlaying of Percentile Frequency curves from multiple tests allows easier visual assessment of Repeatability and Reproducibility.
- The Percentile Frequency method provides a relatively simple way of using repeated measurements in Sound Quality Projects to better identify objectionable impacts compared to color spectrograms.

End of Presentation