NIST
National Institute of Standards and Technology
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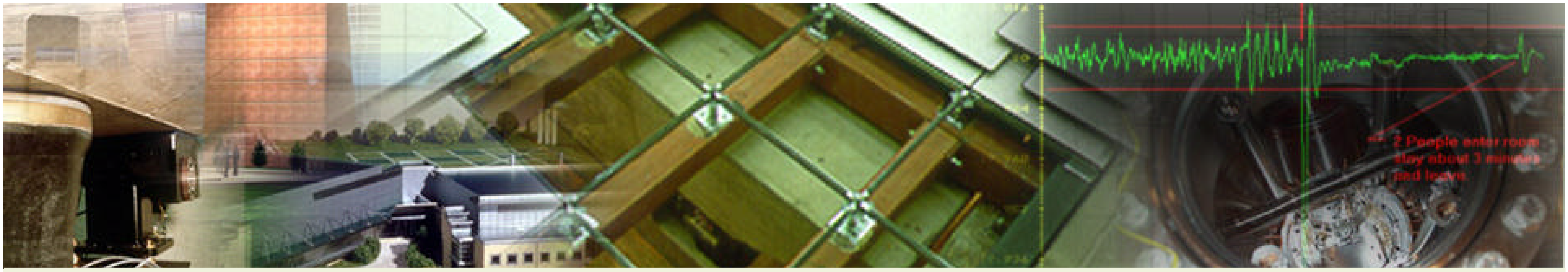
COLIN GORDON & ASSOCIATES
[vibration / acoustics]



Building Design for Advanced Technology Instruments Sensitive to Acoustic Noise

Michael Gendreau
Colin Gordon & Associates

Presentation Outline

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- High technology research and manufacturing instruments respond to internal vibration that can be excited by the external acoustic environment. The degree to which this occurs depends on many factors, but primarily the correspondence between the resonance characteristics of the instrument and the frequency content of the acoustic environment in which it operates. Adverse acoustic environments, such as those often found in operating laboratories, can affect the threshold of resolution achievable by the instrument.

- This presentation will include:
  - a review of the basic terminology and criteria used in the acoustical design of advanced technology facilities,
  - discussion of the mechanisms by which acoustic noise can interfere with instruments, and
  - details of what the building contributes in terms of sources of noise (internal and external) and protection from those sources

I. Acoustics Terminology Review

There is a lot more to even *basic* acoustics than can presented in a short time. In this section of the presentation, I have tried to focus on the parameters that seem to be most important in defining room criteria and equipment specifications with respect to acoustic noise.

- Presentation concerned with "acoustical" phenomena – impact via the air medium (as opposed to the same phenomena propagated via structures, which is vibration)
- Pressure versus power
  - Noise is pressure fluctuation in air, it is to pressure variations that ears and machine components respond
- Decibels (dB)
  - Logarithmic scale necessary due to large dynamic range (12 orders of magnitude for human hearing)
  - Reference units
    - Pressure: dB re 20 micropascals
    - Power: dB re 1 picowatt
- Types of noise
  - Tonal versus Broadband

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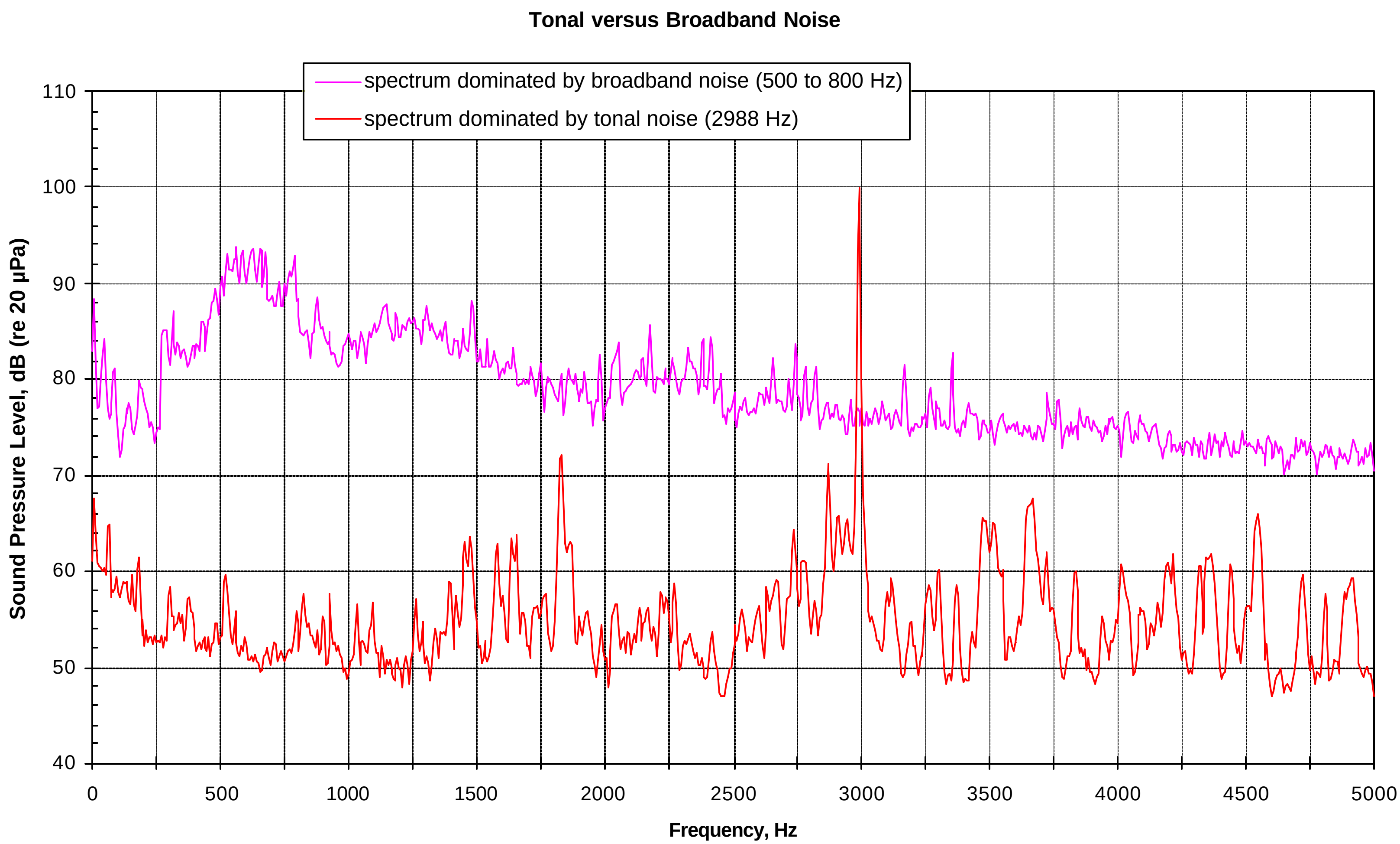
I. Acoustics Review (3)
Types of Noise



- Measurement methodologies

  Bandwidth

  - Constant (e.g., “narrowband”)
  - Proportional (e.g., 1/10, 1/3, and 1/1 octave band)
  - Overall

  Common Noise Level Representations

  - Average
    - L_{eq}, L_n
    - Linear versus Exponential Averaging
  - Maximum
    - L_{max}, L_{peak}, etc.

  Time Averaging Characteristics

  - Standard
    - Slow (1000ms)
    - Fast (125ms)
    - Impulse (35ms)
  - Other

  Measurement Position

  - Stationary (may be best for time domain)
  - Space-average (usually best for frequency domain, average or maximum)

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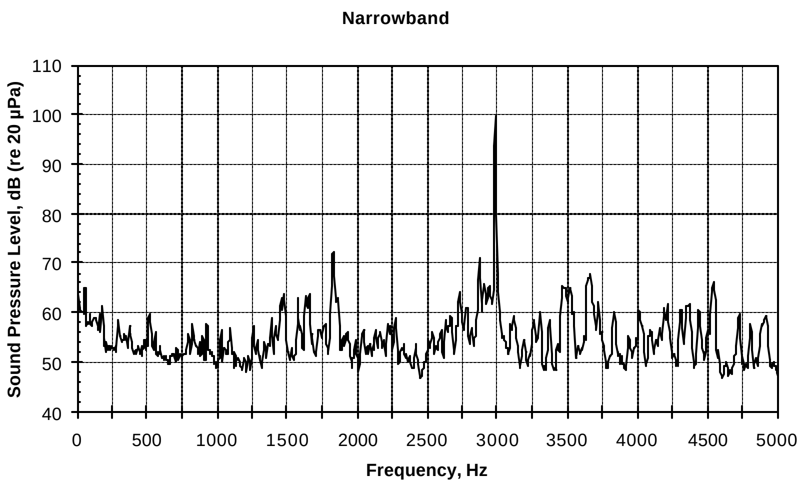
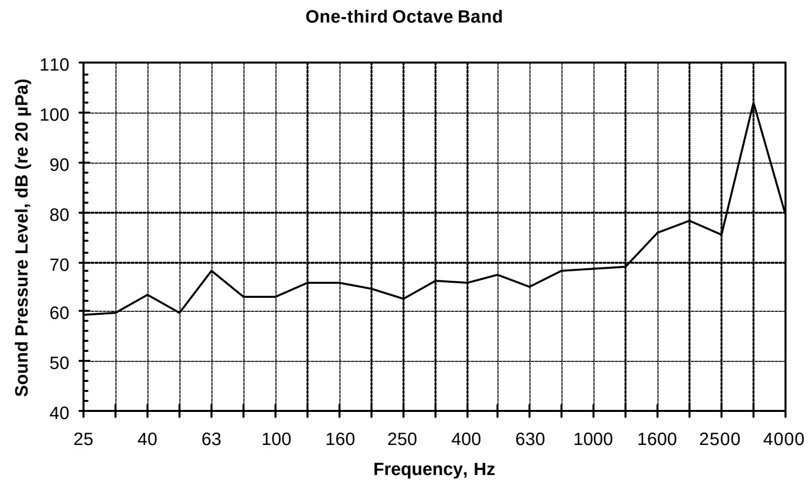
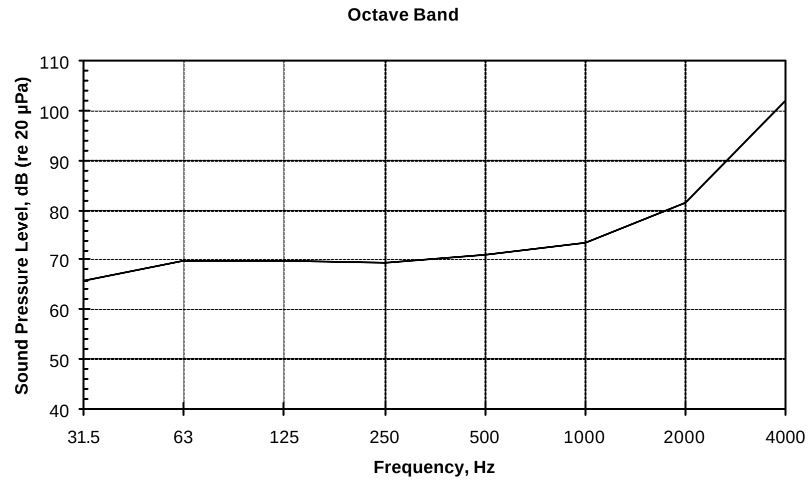
I. Acoustics Review (5)
Bandwidth



Overall (0 to 5000 Hz) = 102 dB





- Measurement methodologies

  Bandwidth
  - Constant (e.g., “narrowband”)
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  - Overall

  Common Noise Level Representations
  - Average

    L_{eq} (equivalent energy average rms), L_n (statistical centile levels)

    Linear versus Exponential Averaging
  - Maximum

    L_{max} (maximum rms), L_{peak} (greatest instantaneous sound pressure), etc.

  Time Averaging Characteristics
  - Standard

    Slow (1000ms)

    Fast (125ms)

    Impulse (35ms)
  - Other

  Measurement Position
  - Stationary (may be best for time domain)
  - Space-average (usually best for frequency domain, average or maximum)

- Measurement methodologies

  Bandwidth
  - Constant (e.g., “narrowband”)
  - Proportional (e.g., 1/10, 1/3, and 1/1 octave band)
  - Overall

  Common Noise Level Representations
  - Average

    L_{eq}, L_n

    Linear versus Exponential Averaging
  - Maximum

    L_{max}, L_{peak}, etc.

  Time Constant – Time Averaging Characteristics
  - Standard

    Slow (1000ms)

    Fast (125ms)

    Impulse (35ms)
  - Other

  Measurement Position
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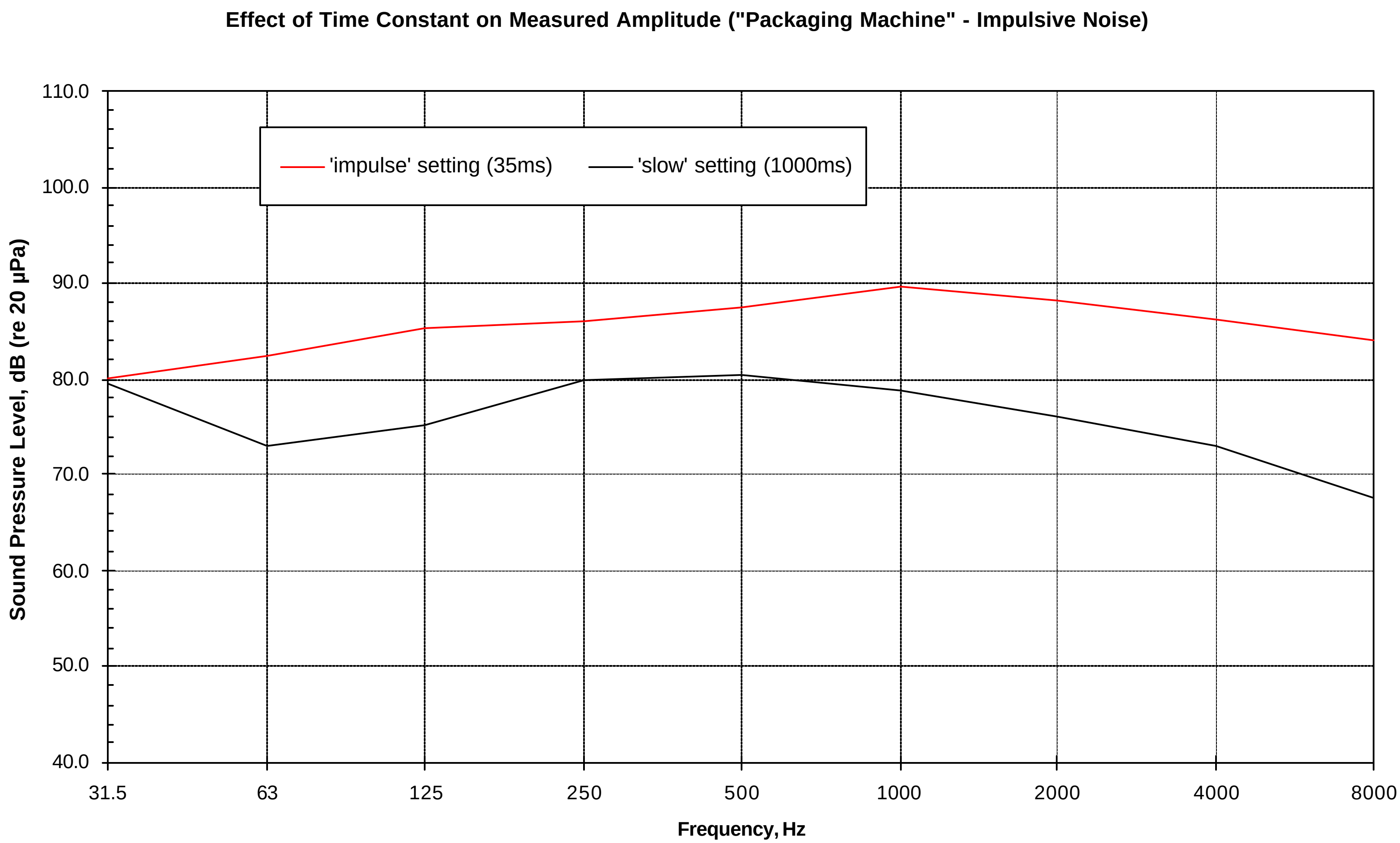
I. Acoustics Review (8)
Time Constant



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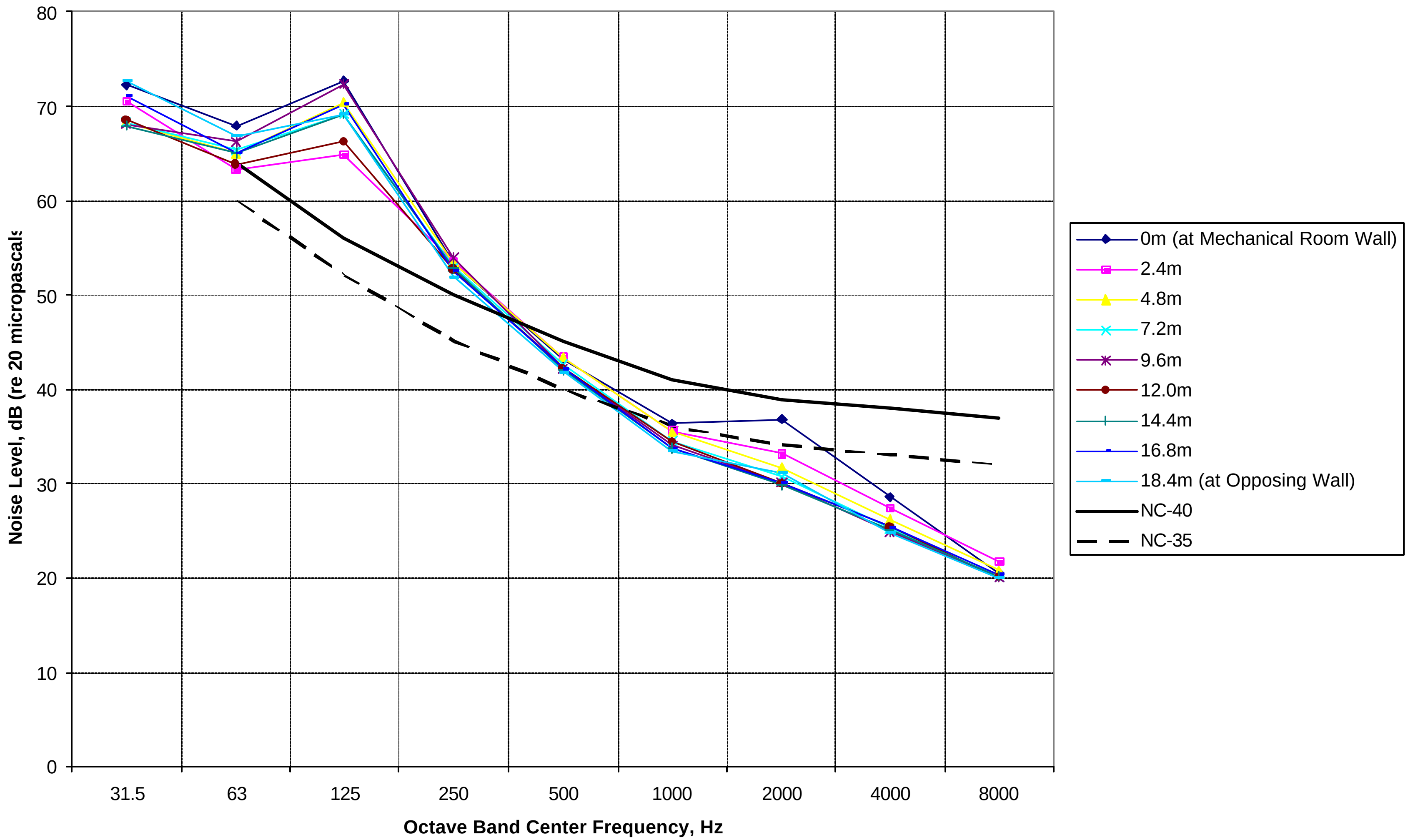
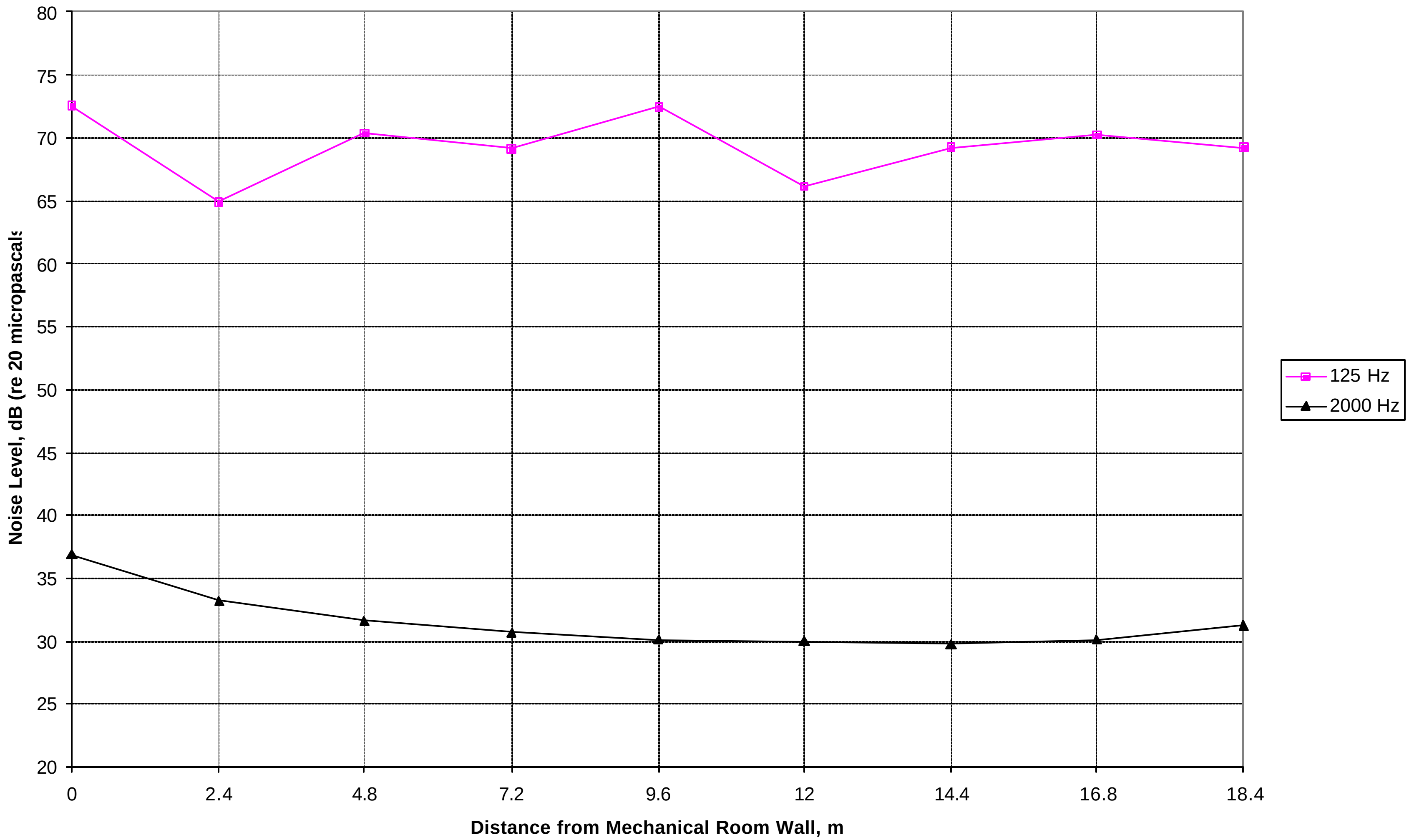
I. Acoustics Review (10)
Standing Waves (1)



I. Acoustics Review (11)
Standing Waves (2)



- Indices based on human perception
  - Frequency and amplitude range
    - 20 Hz to 20,000 Hz
    - 0 to 120 dB at 1000 Hz (varies with frequency)
  - Frequency-based criteria: NC, RC, NCB, NR, PNC, etc.
  - Overall indices: dBA, dBC, dB
- Indices based on research equipment sensitivity
  - None!
    - Should be tested and specific to the equipment
    - Optionally one can identify a standard frequency based curve (but not an overall index) that is entirely above a tested spectrum – but this may be overly conservative at certain frequencies

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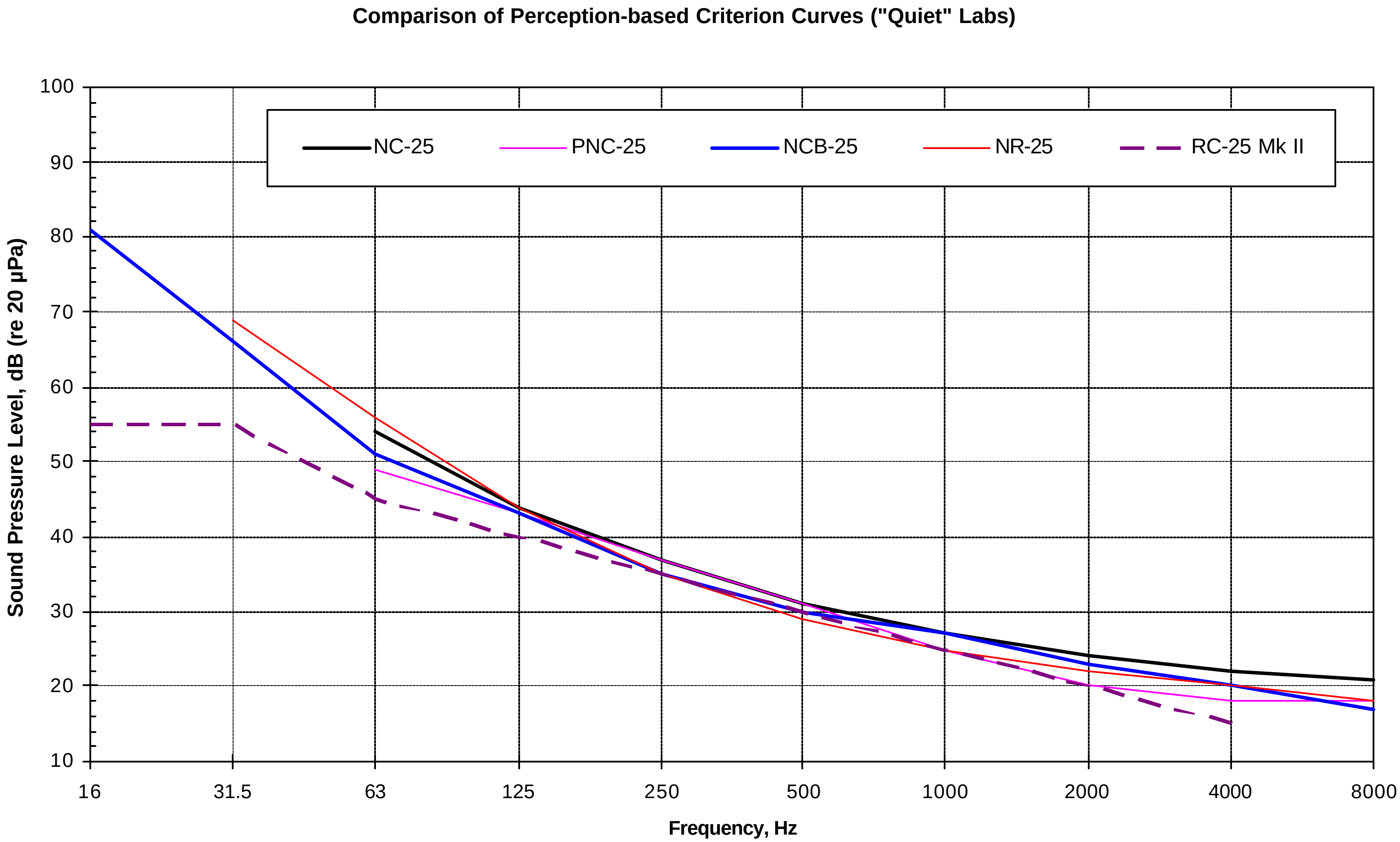
I. Acoustics Review (14)
Comparison of Criteria (1)



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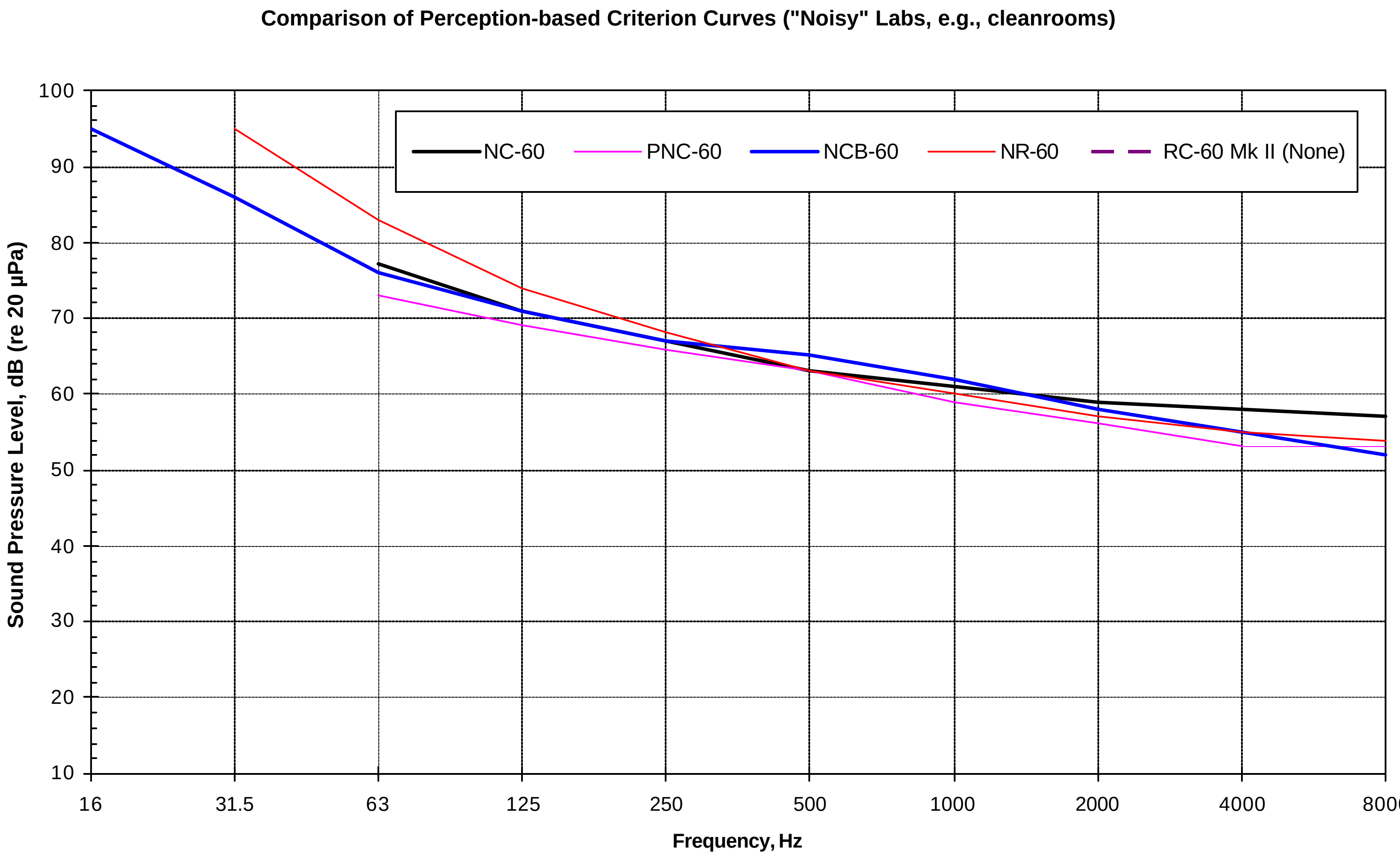
I. Acoustics Review (15)
Comparison of Criteria (2)



- Indices based on human perception

  Frequency and amplitude range

  - 20 Hz to 20,000 Hz
  - 0 to 120 dB at 1000 Hz (varies with frequency)

  Frequency-based criteria: NC, RC, NCB, NR, PNC, etc.

  Overall indices: dBA, dBC, dB

- Indices based on research equipment sensitivity

  None!

  - Should be tested and specific to the equipment (See Section II)

II. Noise Impact to Research and Process Equipment

In this section, discussed are some of the mechanisms that make advanced technology equipment sensitive to noise. This is important, as it will help identify what type of tool specifications we should expect to find, and thus help us define our lab noise criteria.

- The mechanism by which acoustic noise interferes with equipment

  Among other things, the achievable resolution of an optical tool is a function of differential vibration between critical elements in the tool, say, between a lens and the observed target. Vibration of elements within a tool can be stimulated by:

  - vibration sources within the tool;
  - external vibration sources, transmitting to the tool via its support structure; and
  - **acoustic noise in the laboratory environment that causes vibration of exposed elements of the tool, which is then passed on to sensitive internal elements via the tool structure**.

- Acoustic excitation of equipment components (example: casing panels)

Example 1: vibration induced in an 560 x 710 x 0.4 mm thick steel panel due to the presence of five different levels of broadband acoustic noise (white noise)

  - Demonstration of linear relationship between the sound pressure level impinging on the panel and the vibration level measured on the panel
  - Primary impact in 75 to 150 Hz range

Example 2: vibration induced in an 210 x 350 x 6 mm thick aluminum panel due to the presence of acoustic noise (white noise)

  - Structures will tend to respond more readily to impinging noise at their modal or natural frequencies
  - This can be especially dramatic in low-damped structures excited at their fundamental, or “low order,” resonance frequencies, when these frequencies are high enough that the size of the structure equals or exceeds the acoustic wavelengths.
  - There is a significant amount of vibration at several of the plate modal frequencies (275, 750, 785, 960, and 1370 Hz), but at other frequencies relatively little vibration is induced.
  - The amount of vibration induced in a structure is not only a function of the noise level, but also the frequency.

II. Noise Impact to Equipment (4)
Noise Induced Vibration (1)

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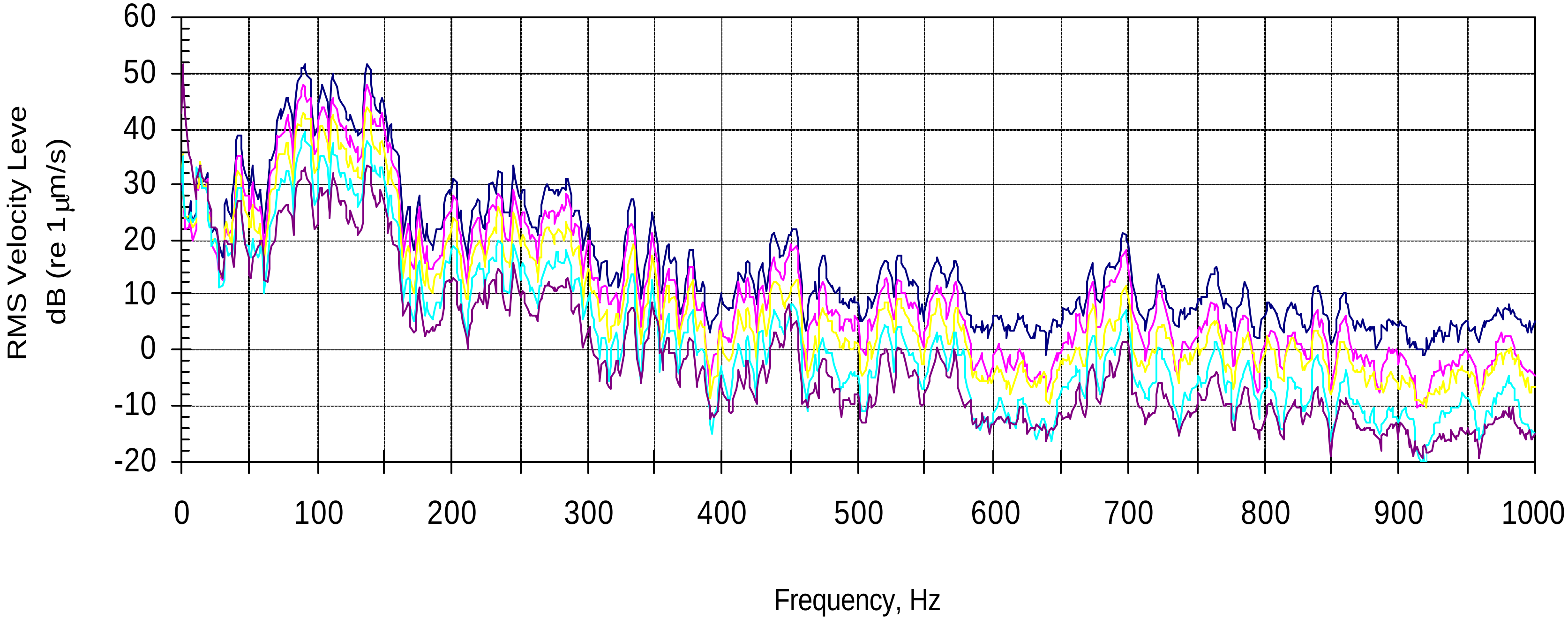
Noise induced vibration in a 560 x 710 x 0.4 mm thick steel panel (Source: white noise at 5 different amplitudes)



- Acoustic excitation of equipment components (example: casing panels)
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    - The amount of vibration induced in a structure is not only a function of the noise level, but also the frequency.

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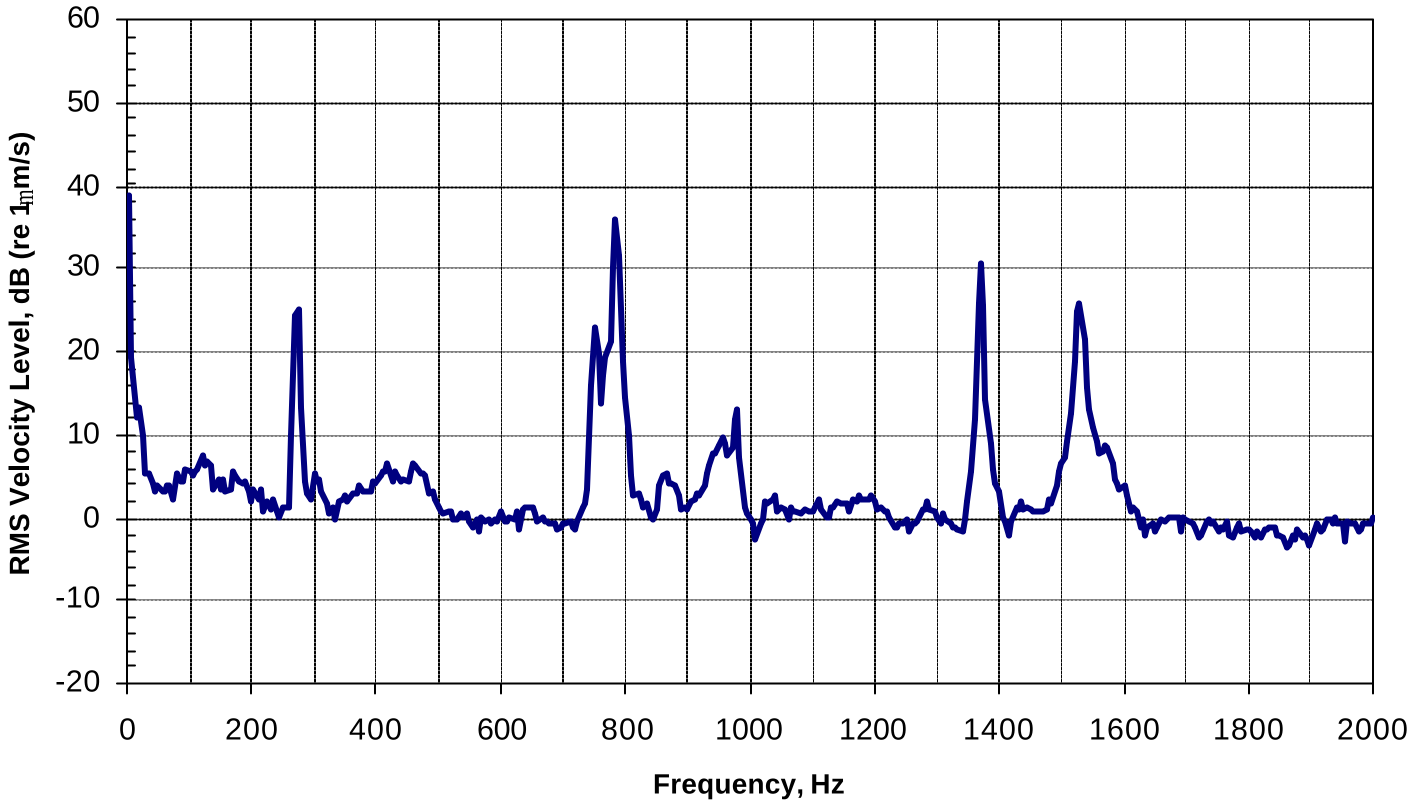
II. Noise Impact to Equipment (6)
Noise Induced Vibration (2)

Noise induced vibration in a 210 x 350 x 6 mm thick aluminum plate (Source: white noise)



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- Assess likelihood of impact by dividing noise into three general frequency regions

  low frequency range (low impact probability)

  - acoustic wavelength is significantly longer than the dimensions of the tool structures, coupling between the two is relatively inefficient.
  - Exceptionally, very low frequency pressure fluctuations may interfere with tools with open beams (some interferometers, atomic force microscopes, etc.).

  mid frequency range (higher impact probability)

  - In the mid to high frequency range, especially at the "coincidence" frequency (where the acoustic and structural bending wave speeds are equal) and above, the structure is more likely to be excited by acoustic energy.
  - As with the aluminum plate example, the "middle" frequency range might also contain easily excitable low order resonance frequencies.

  high frequency range (low impact probability)

  - acoustic excitation of structures is often less of a concern due to fact that there is usually less acoustical energy available with increasing frequency (see Section III), among other reasons.

- Indices based on research equipment sensitivity

  None!

  - Should be tested and specific to the equipment
  - Optionally one can identify a standard frequency based curve (but not an overall index) that is entirely above a tested spectrum – but this may be overly conservative at certain frequencies

II. Noise Impact to Equipment (9)

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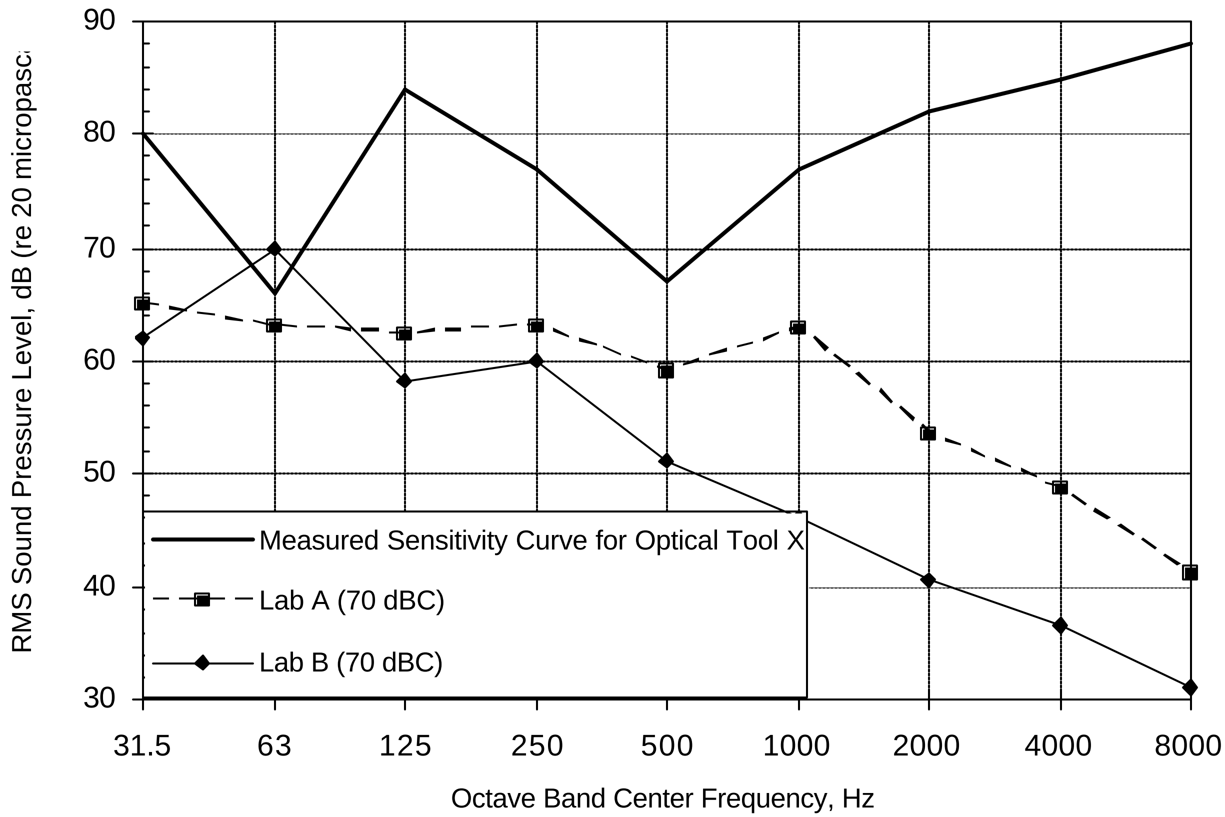
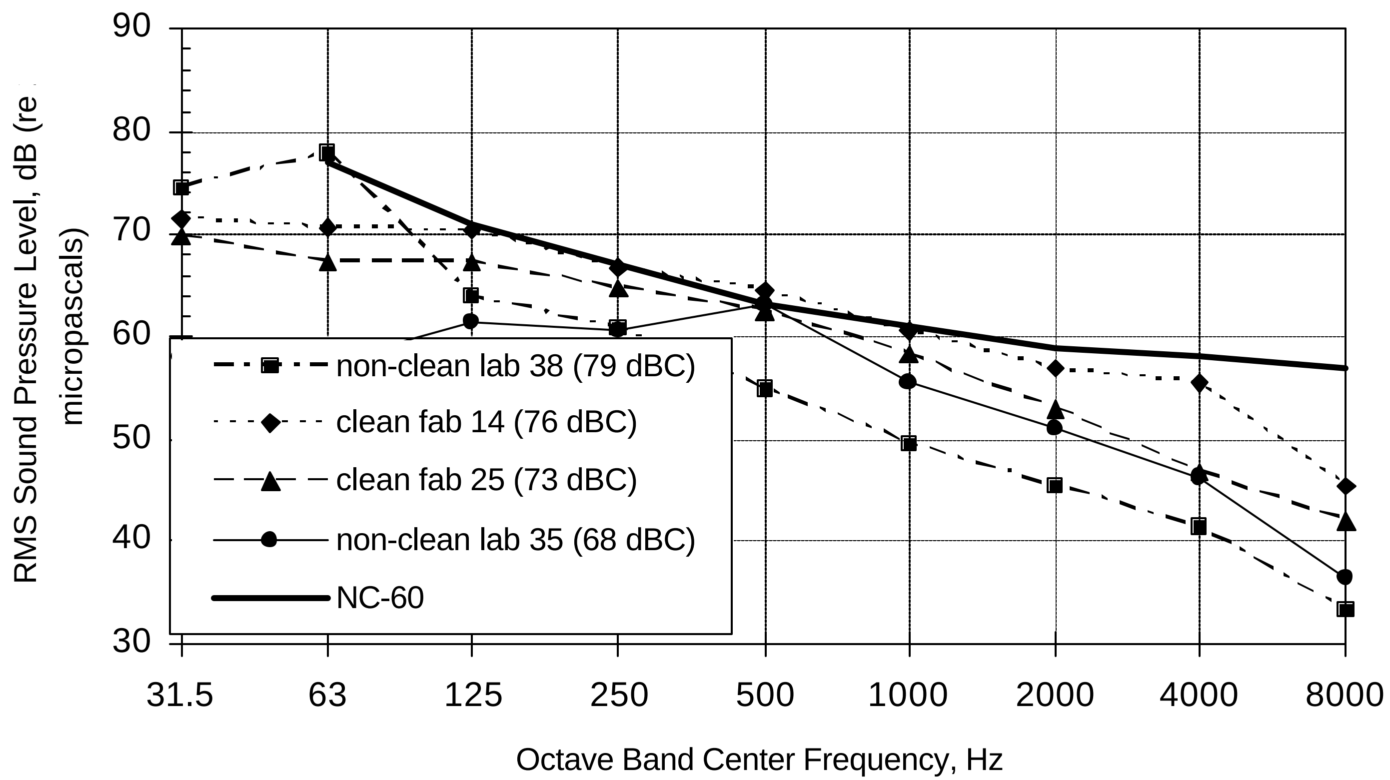
Research equipment sensitivity is not well represented by overall noise indices such as dBC. 1. An optical tool that probably functions better in one 70 dBC laboratory (Lab A) than in another 70 dBC laboratory (Lab B).



Research equipment sensitivity is not well represented by overall noise indices such as dBC. 1. Four laboratories that meet the NC-60 HVAC design criterion, with an 11 dB range in equivalent dBC performance.



III. Laboratory Noise Sources and Control

The final section of this presentation regards the types of noise sources that will be encountered in the facility, typical noise spectra, and an outline of noise control methods.

- Noise sources and typical spectra

HVAC noise sources

Typical operating cleanroom and lab noise levels and source frequency ranges

- HVAC (fans) – broadband and sometimes tonal noise, usually predominant in the 63 to 250 Hz octave bands (occasional motor or other tones to 1000 or 2000 Hz)
- Equipment and support equipment – broadband and tonal, 250 to 2000 Hz range (occasional higher frequencies, especially from air flow or air activated components in tools)
- HVAC (diffusers / flow noise) – broadband and occasionally tonal 1000 to 8000 Hz range
- Fluid flow, valve, and air leakage noise – broadband 1000 Hz and above

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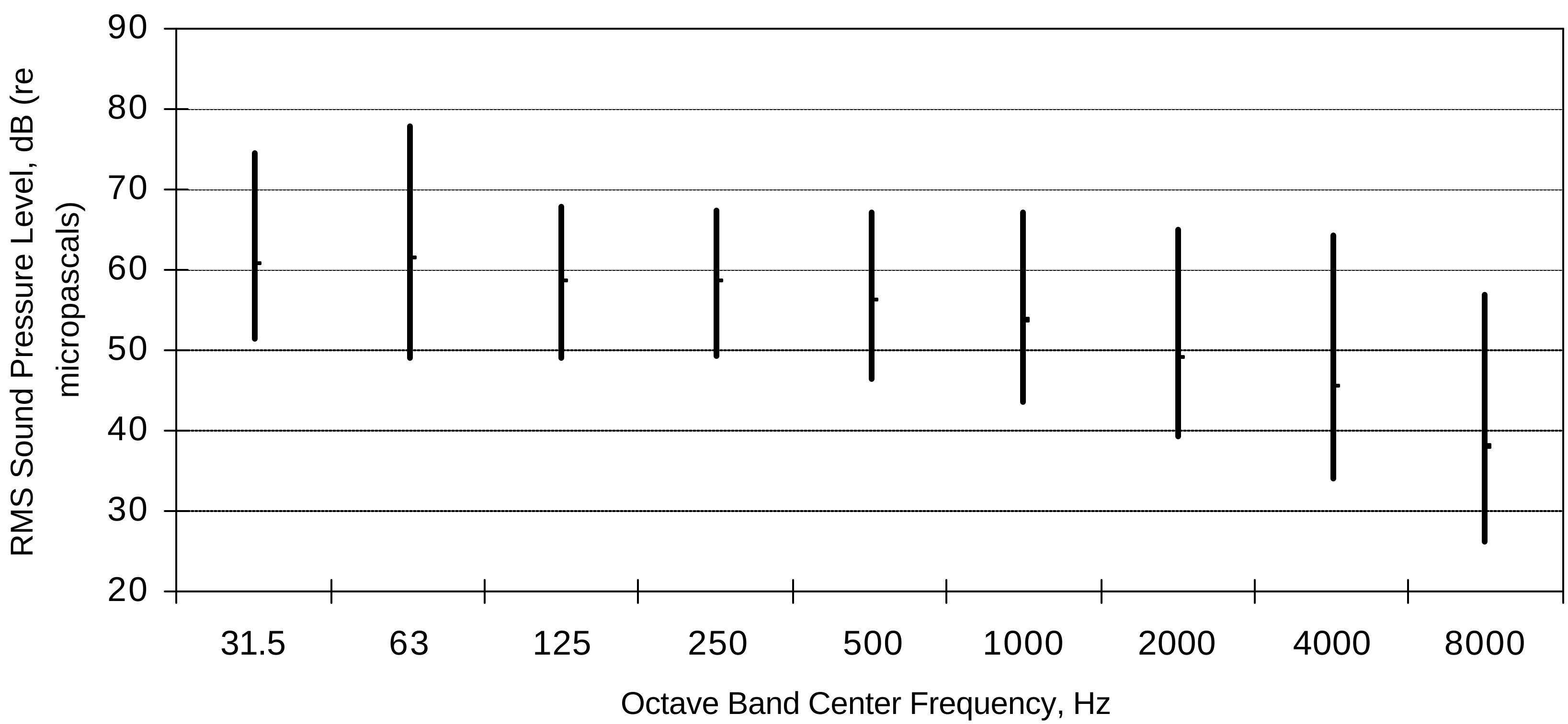
Lab Noise Levels

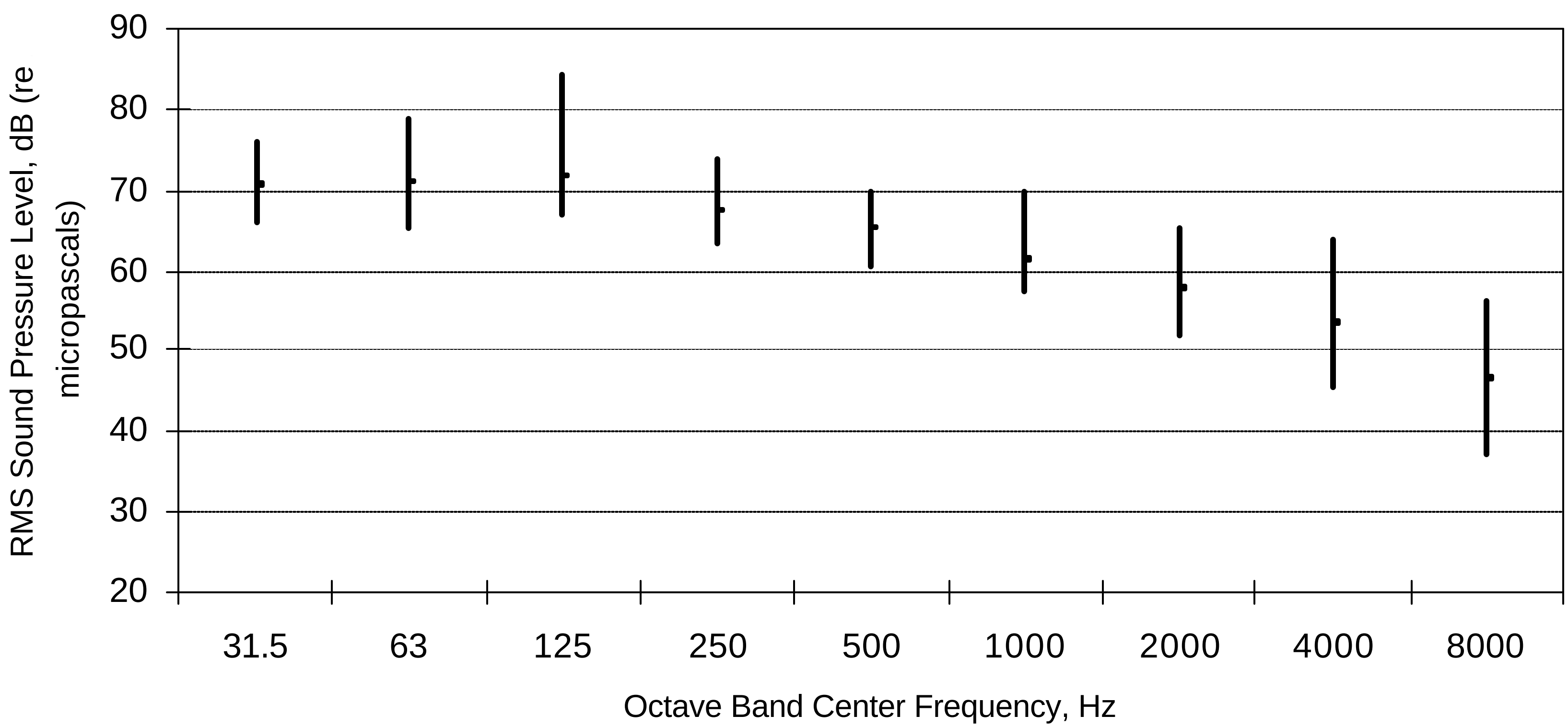
Statistical distribution of measured operational non-clean laboratory noise levels - 20 data records (each data record is a space-averaged 20s Leq, "slow" time constant, no frequency weighting)



III. Lab Noise Sources and Control (4)

Cleanroom Noise Levels

Statistical distribution of measured operational class 1 cleanroom noise levels - 28 data records (each data record is a space-averaged 20s Leq, "slow" time constant, no frequency weighting)



- Noise sources and typical spectra

Research equipment (tools) and tool support equipment (dry pumps, compressors, mini-environment fans, air and fluid flow noise, mechanical actuators and solenoids, etc.)

People noise (voices, telephones, transportation activity, etc.)

- More likely to be controllable by user

External noise (Air and ground traffic, mechanical equipment, etc.)

- Primarily a low frequency problem, as a function of the typical insertion loss of building facades.

III. Lab Noise Sources and Control (6)

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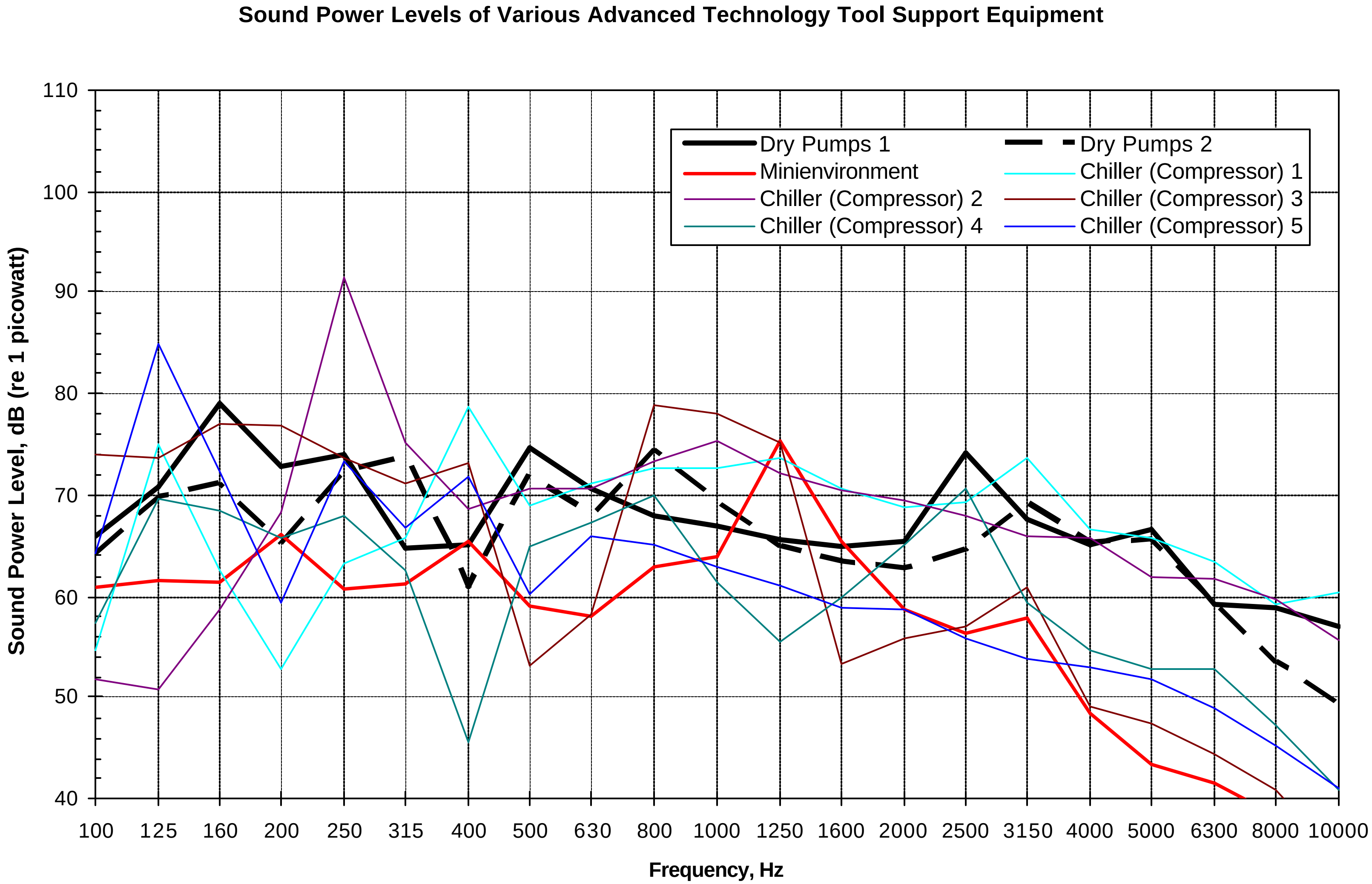
Lab Equipment Noise Sources



- Noise sources and typical spectra
  - Research equipment (tools) and tool support equipment (dry pumps, compressors, mini-environment fans, air and fluid flow noise, mechanical actuators and solenoids, etc.)
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External noise (Air and ground traffic, mechanical equipment, etc.)

- Primarily a low frequency problem, as a function of the typical insertion loss of building facades.

- Noise control

HVAC

- at the source
  - Fans and air handling units
    - Fan selection / specification
    - Dump walls
    - Spliiters (internal silencers)
    - Devices producing laminar inlet flow
  - Terminal elements (diffusers, duct elements, air terminals, etc.)
    - selection / specification
- in the path
  - distance (long duct paths)
  - duct lining (where possible)
  - silencers (lined and unlined)

Tool support equipment noise

- at the source
  - equipment selection (depends on having good noise data from manufacturer)
  - improved casework
- in the path
  - pump chases, sub-fabs, etc.
  - enclosures

- Noise control (continued)

  Tool noise

  - (probably designed to work with itself originally – primary concern is "add-ons", such as mini-environments)
  - "Local" enclosures for sensitive components

  Reverberation control

  - Surface treatment, clean class, and outgassing

  External noise control

  - partition design, basic considerations

    single vs double partitions

    leaks (penetrations, doors, HVAC services, etc.)

- Noise control (continued)

  Tool noise

  - (probably designed to work with itself originally – only concern is "add-ons", such as mini-environments)

  Reverberation control

  - Surface treatment, clean class, and outgassing

  External noise control

  - Building façade and partition design, basic considerations

    single versus double partitions

    leaks (penetrations, door and door seals, HVAC services, etc.)

Questions?