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Fan Noise Control by Enclosure Modification

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Introduction - Fan Noise Control Solutions

- The most dominant source type for low-speed fans is the dipole-like source when the compact source assumption holds true
- The source strength of an aerodynamically-induced dipole is proportional to the sixth power of the flow speed

  → decrease in the rotational speed of a fan (while maintaining the volume flow rate by increasing its size to achieve the same cooling performance)
- Optimization of the fan blade shape
- Careful selection of the fan location so as not to entrain disturbed aerodynamic inflow
- Well-balanced so as not to cause significant vibration
- Well-isolated from the structure to which it is mounted

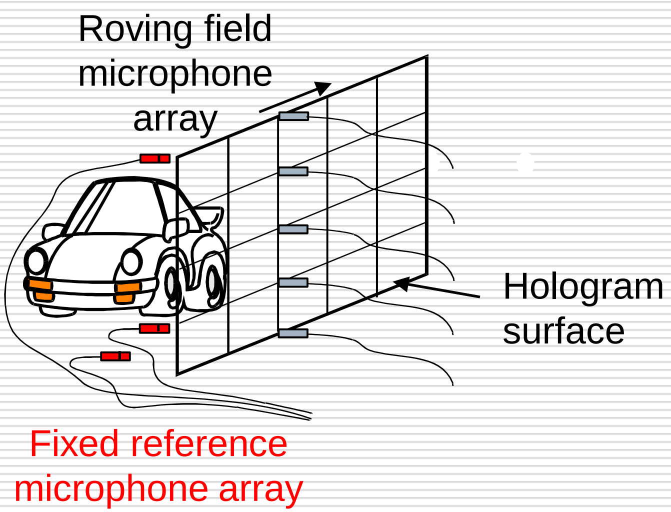
Introduction – Objective and Method

- When a fan is mounted to an enclosure, the sound radiation efficiency increases since
  - the sound radiation pattern becomes monopole-like rather than dipole-like
  - the sound level can be amplified by the effect of the enclosure's interior acoustical resonances
- The objective is to provide structural modification scheme in order to suppress the latter enhancement
- The introduction of an acoustical path between the sound fields on the two sides of a fan so that cancellation can occur
- Experimental verification will be presented by application to a consumer electronic enclosure
- The structural modification effects are visualized by using near-field acoustical holography (NAH)

Multireference, Cross-Spectral Measurement and Partial Field Decomposition

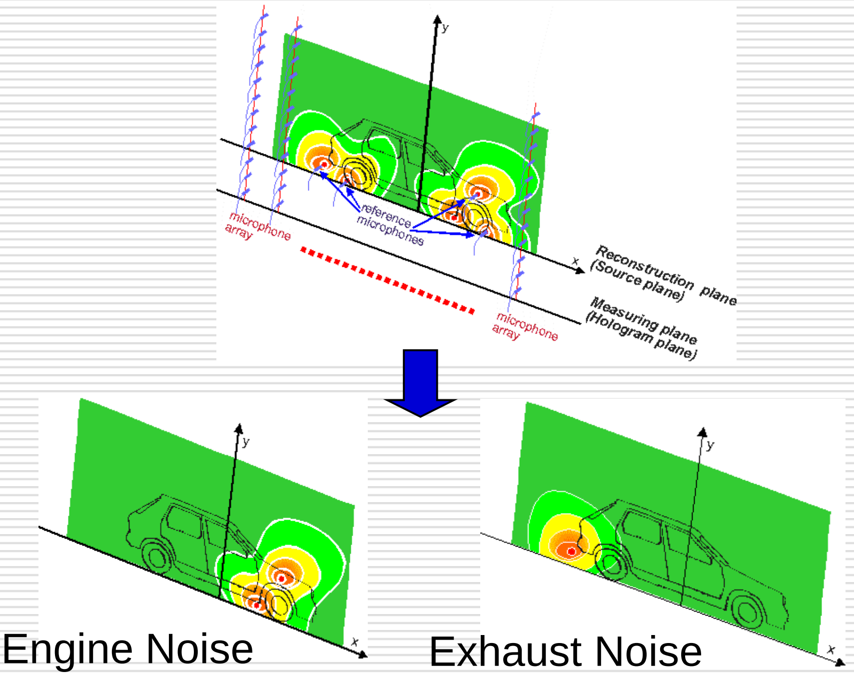
- Allows the separation of the total sound field resulting from a number of subsources into the mutually uncorrelated partial fields

< Cross-Spectral Measurement >



$$\mathbf{C}_{pp} = \mathbf{C}_{rp}^{\mathrm{H}}\mathbf{C}_{rr}^{-1}\mathbf{C}_{rp} = \mathbf{H}_{rp}^{\mathrm{H}}\mathbf{C}_{rr}\mathbf{H}_{rp}$$

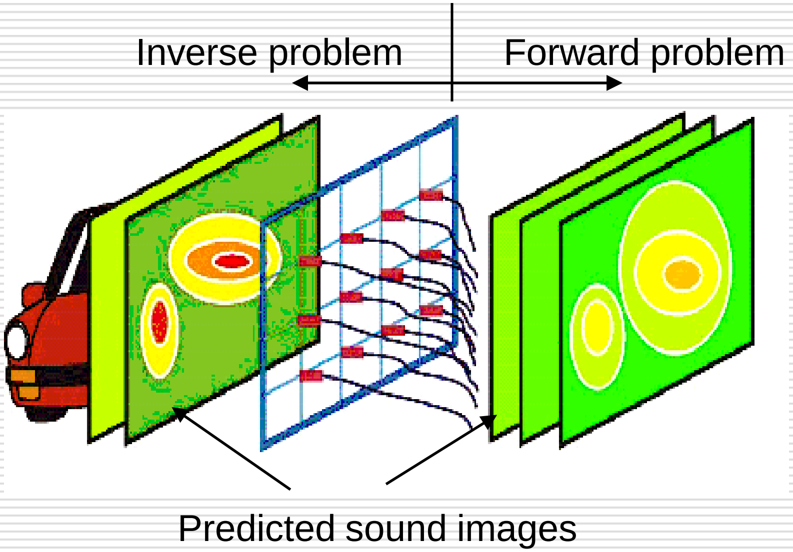
< Partial Field Decomposition >



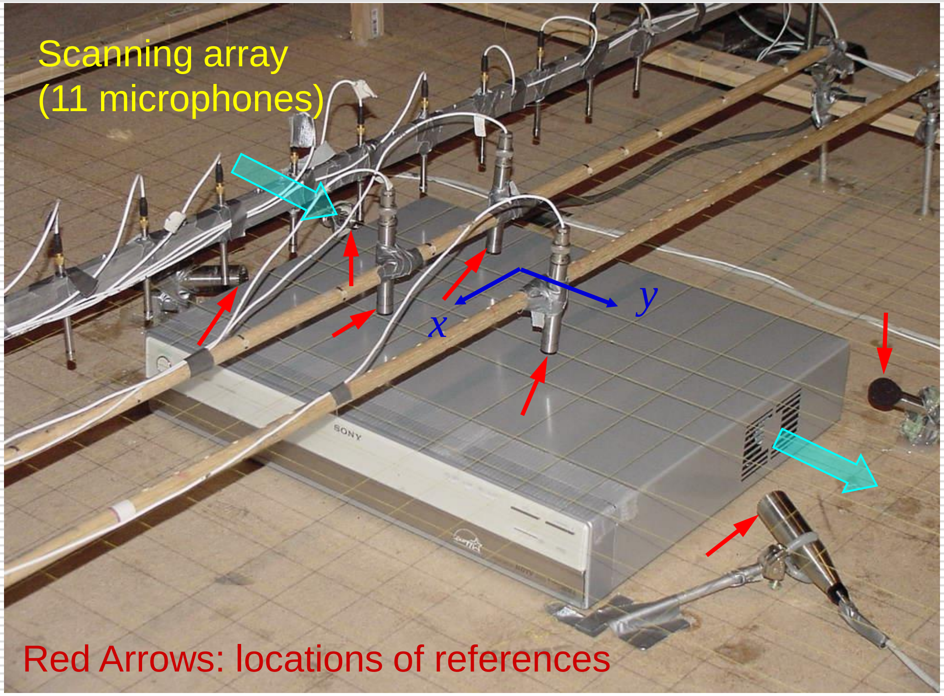
Near-field Acoustical Holography (NAH)

- An array-based measurement techniques that allows a three-dimensional sound field to be visualized based on the use of the sound pressure measured on a two-dimensional surface (i.e., the hologram surface)

- Various acoustical properties can be obtained
  - Sound pressure
  - Particle velocity
  - Acoustic intensity
  - Sound power



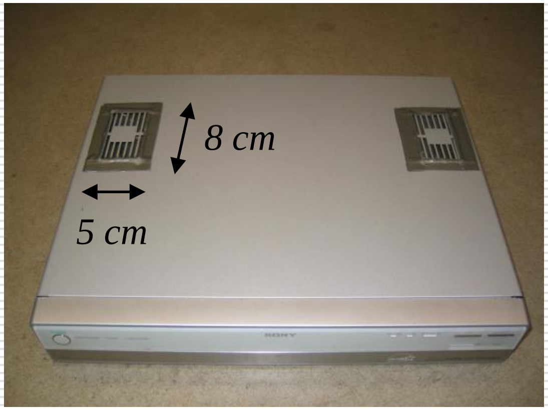
Experimental Setup



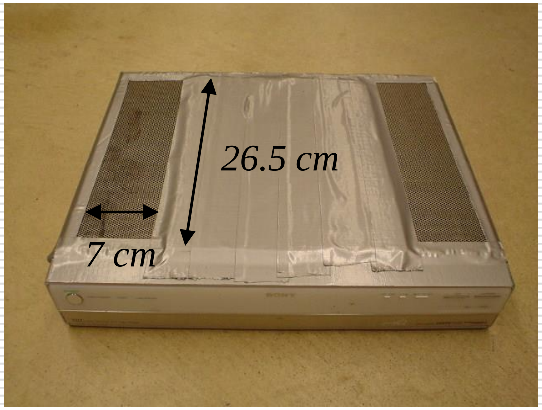
- Number of references: 7
- Axial position of the hologram surface: 2 cm above the top of enclosure
- Sample spacing: 8 cm
- Number of measurement points: 11-by-16 (*x*-by-*y*)
- Measurement bandwidth
  : 2.5 kHz
- Frequency resolution
  : 2 Hz

Enclosure Modifications

Mylar Top



Grilled port and mylar

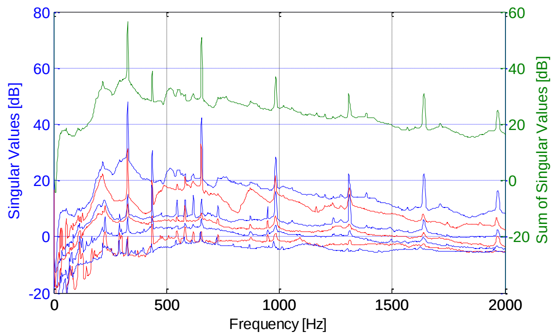


Perforated panel and mylar

- Mylar
  - Acoustically transparent, thus allowing free interaction between the sound fields on both sides
  - Maintain the air flow within the enclosure

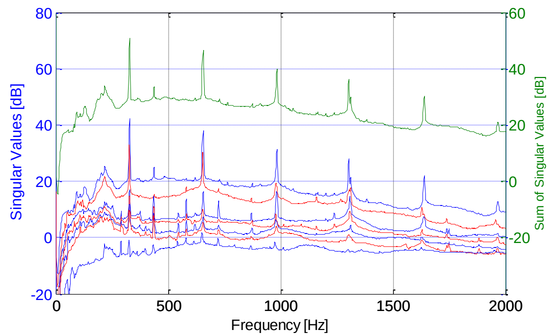
Singular Values of the Reference Cross-Spectral Matrix

71.3 dB



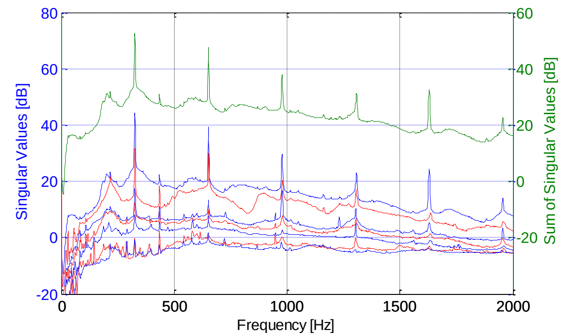
< original enclosure >

70.9 dB



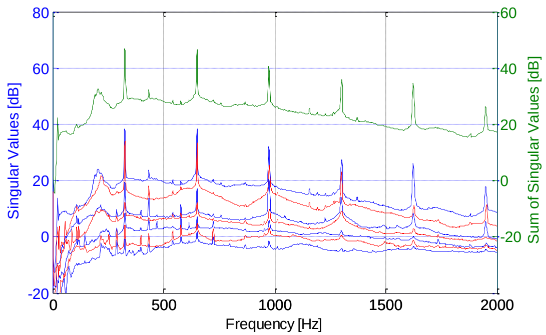
< mylar top >

71.1 dB



< grilled port and mylar >

70.8 dB



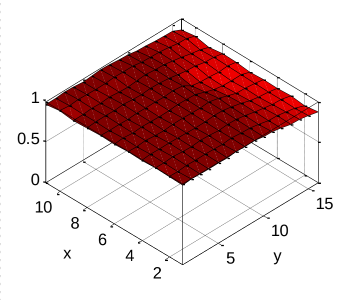
< perforated panel and mylar >

- The first two blade passing tones are dominant
- Two source mechanisms exist but the first partial field is the main contributor to the total sound field
- The overall levels of the summed reference autospectra are compared

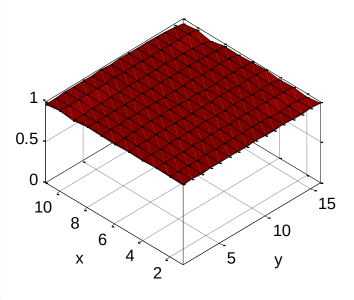
Virtual Coherence Function

- Represents the contribution of each partial field to the total sound field
- The number of partial fields (i.e., the number of incoherent subsources) required to construct the total sound field can be identified by examining the sum of the virtual coherence functions

The sum of the virtual coherence functions in the original enclosure case at the first blade passing frequency (328 Hz)



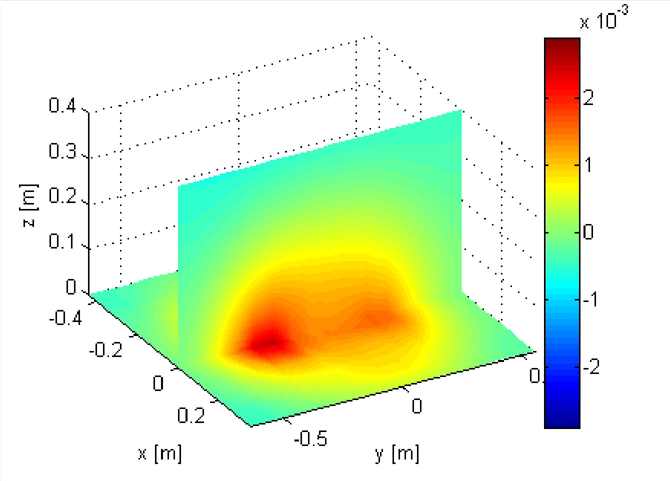
when the first partial field was used



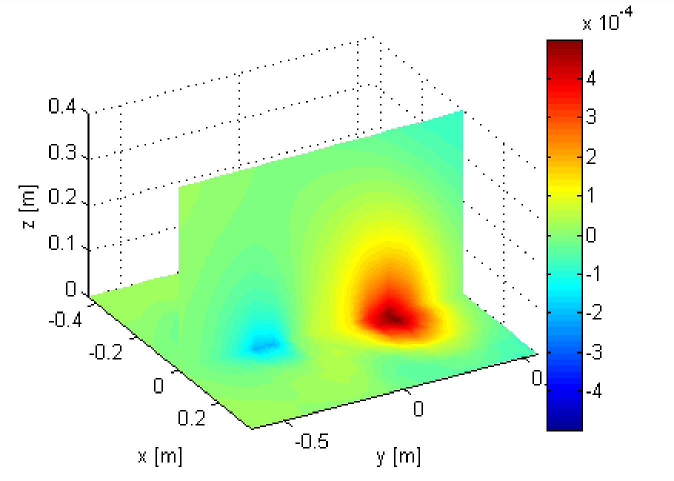
when the first two partial fields were used

Reconstructed Sound Field (1)

- Original enclosure case at the first blade passing frequency (at 328 Hz)



< the first partial field >

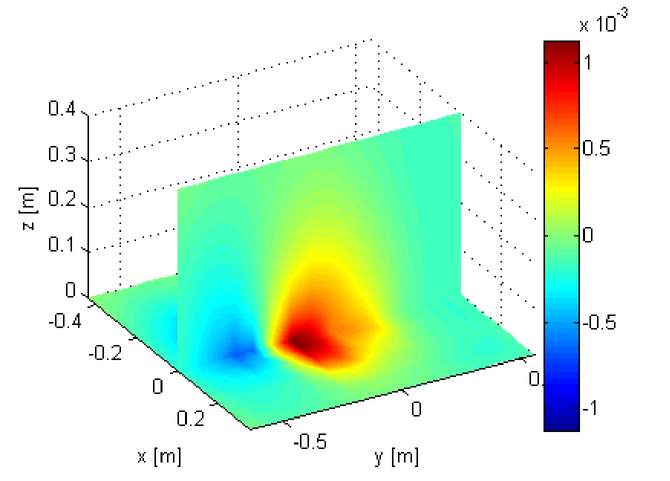


< the second partial field >

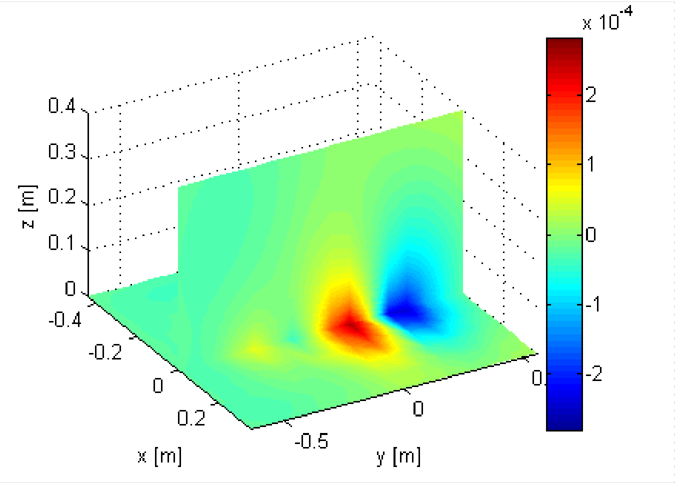
  - Both fields monopole-like

Reconstructed Sound Field (2)

- Mylar top case at the first blade passing frequency (at 328 Hz)



< the first partial field >

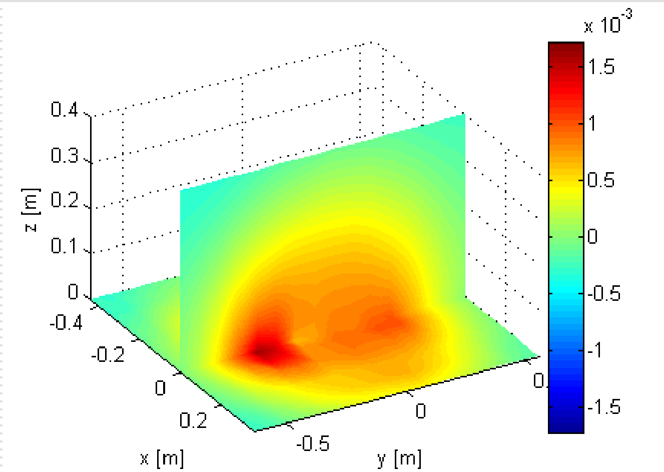


< the second partial field >

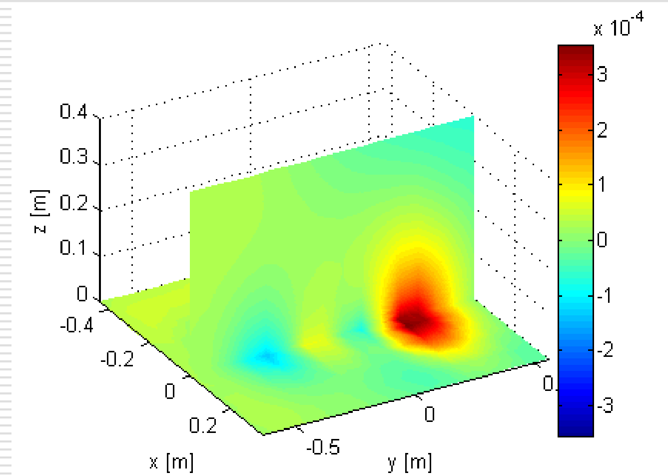
- Both fields dipole-like

Reconstructed Sound Field (3)

- Grilled port and mylar case at the first blade passing frequency (at 326 Hz)



< the first partial field >

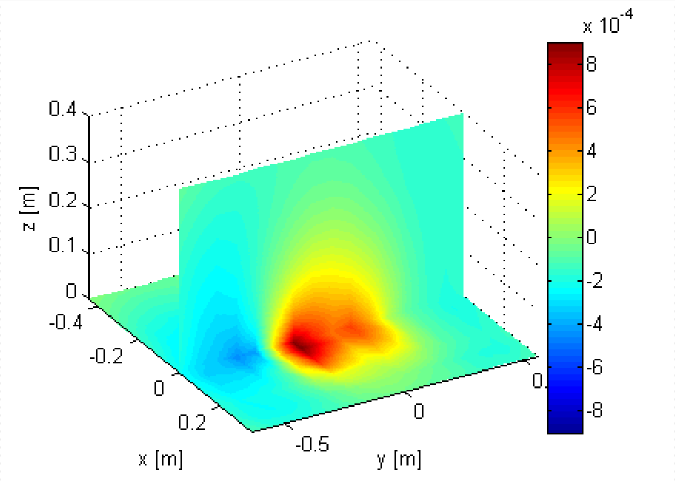


< the second partial field >

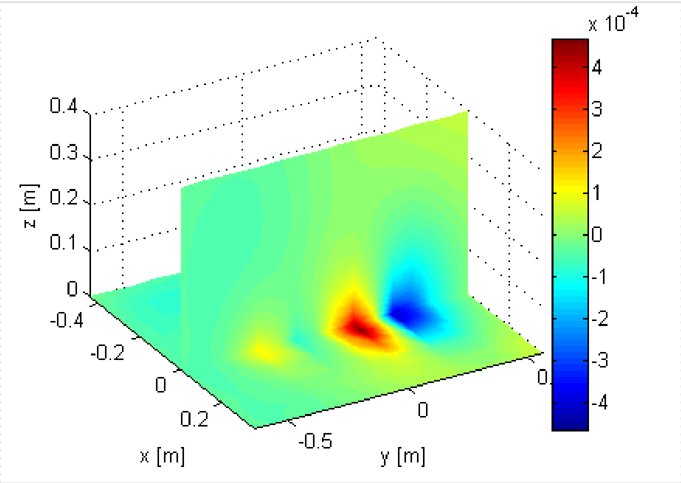
- Level drops, but radiation pattern changed slightly

Reconstructed Sound Field (4)

- Perforated panel and mylar case at the first blade passing frequency (at 324 Hz)



< the first partial field >

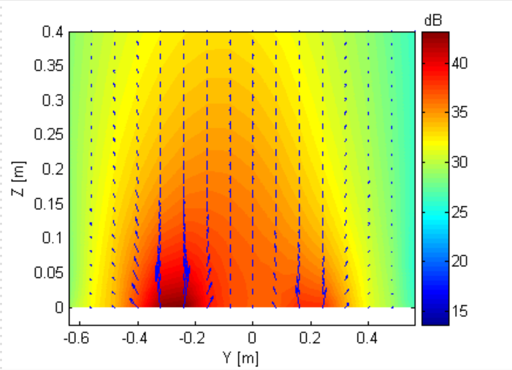


< the second partial field >

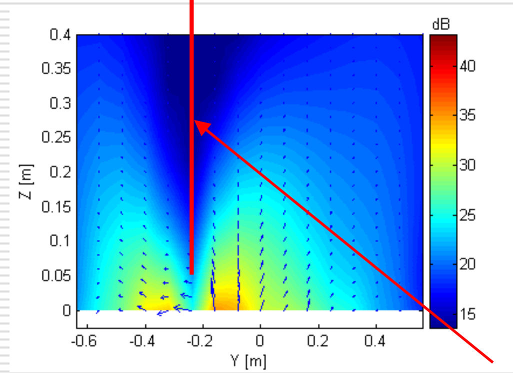
- Both fields dipole-like

Acoustic Intensity (at the first blade passing frequency)

On the plane defined by *x* = 0 (i.e., where two fans lay)

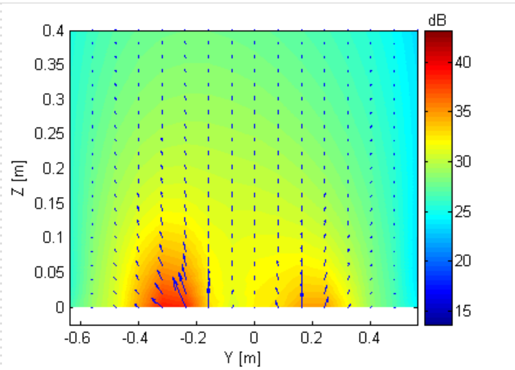


< original enclosure >

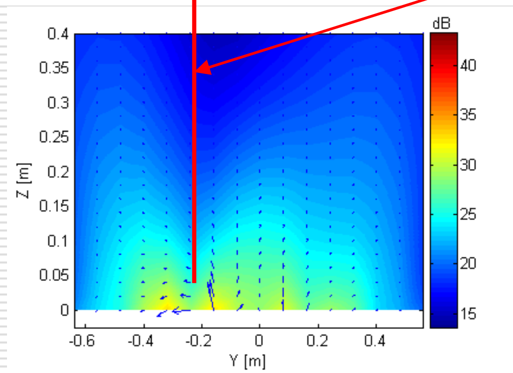


< mylar top >

A clearer cancellation can be observed when the size of opening is large

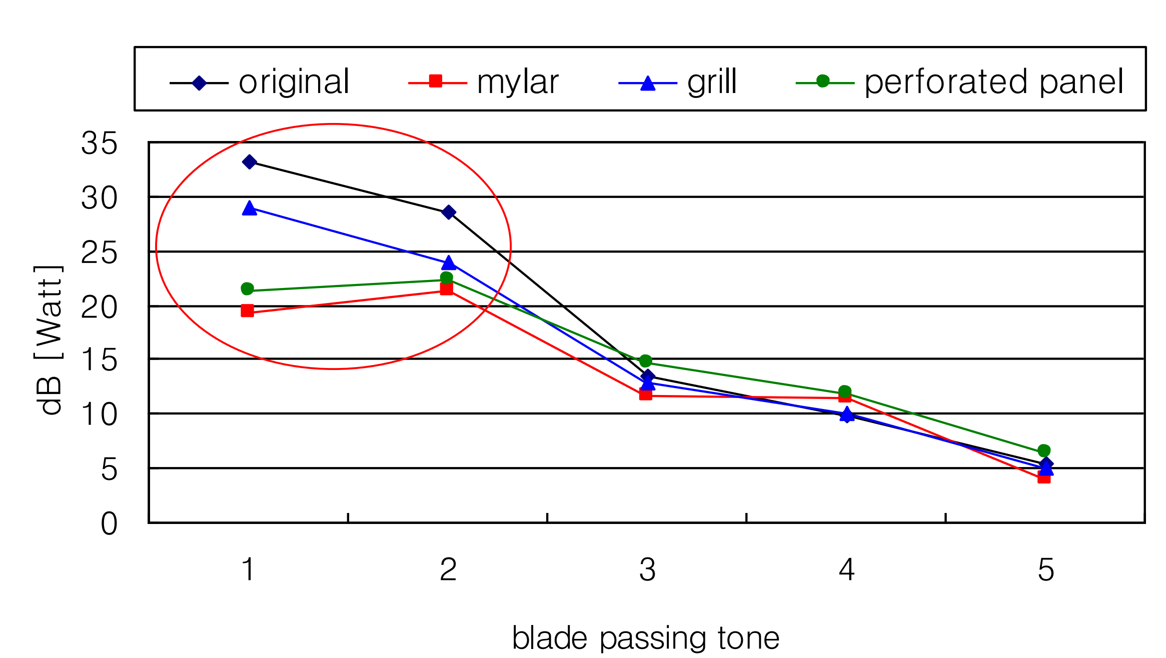


< grilled port and mylar >



< perforated panel and mylar >

Sound Power at the Blade Passing Frequencies



- A larger opening resulted in a greater reduction of the sound power at the first two blade frequencies but caused a slight increase at the higher harmonics
- The total sound power of the first five blade passing tones was reduced from 34.5 dB to 24 dB, 30.3 dB, and 25.7 dB

Summary

- The effect of an enclosure is expected to appear in various ways:

  At low frequencies (when the sound field radiated by a fan in a free space can be modeled by a point dipole),

  - The radiation pattern is monopole-like since the interaction between the sound field on both sides of a fan is prevented

    → enhanced radiation efficiency
  - The sound level at the source is likely to be amplified by being coupled with the interior acoustical resonances

  At high frequencies,

  - The sound muffling effect of an enclosure is larger those that can be observed at low frequencies
- The size and location of the enclosure openings needs to be optimized to fit a specific case

Conclusions

- It was shown that a fan mounted to an enclosure radiates sound more efficiently than a fan operating in free space particularly at low frequencies
- The enhancement of radiation efficiency can be reduced by introducing an acoustical path that allows:
  - the sound fields on two sides of the fan to interact
  - the effect of interior acoustical resonances to be reduced
- The effects of enclosure modifications were quantified and the corresponding sound fields were visualized by using near-field acoustical holography in conjunction with a multireference, cross-spectral measurement