High Frequency Interior Noise Prediction Model Based on Energy Finite Element Analysis

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virtual PRODUCT DEVELOPMENT CONFERENCE

MSC SOFTWARE®

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Vibro-Acoustic Modeling

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Computations modeling is necessary for the effective application of noise control procedures at the early stages of product's design

Design improvements and tuning of critical components require the ability to model overall response over a wide frequency range in a reliable and affordable way

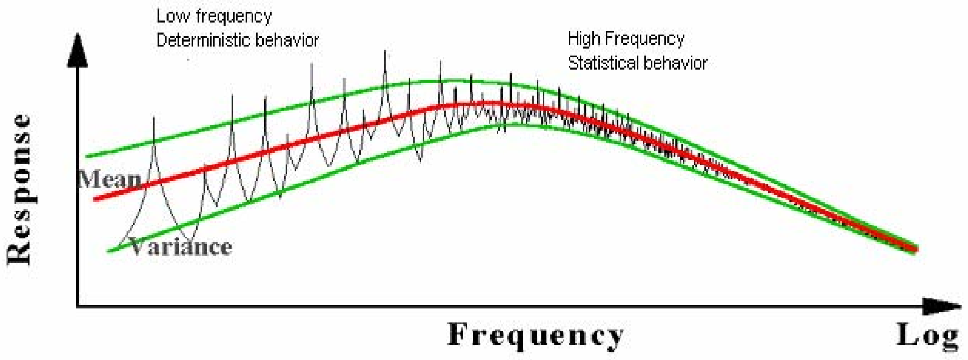
Selected modeling techniques should take into consideration the characteristics of behavior

Low Frequency

- Long wave length
- Deterministic approaches used

High Frequency

- Short wave length
- Statistical approaches used



Low Frequency Modeling

Finite and/or boundary element methods are typically used

- Governing equations are derived from differential volume
- Structures and acoustic cavities are divided into elements – size depends on analysis frequency
- Structural (velocity) and acoustic (pressure, particle velocity) is allowed to vary within each sub-system

Advantages

- Based on firmly established principle of mechanics
- Allows detailed response evaluations
- Tools are well developed – Many commercial software packages (MSC.Nastran, etc.) are available

Disadvantages

- Huge database as the frequency increases – High modeling and computational time

High Frequency Modeling

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Statistical Energy Analysis (SEA)

Energy Finite Element Method (EFEM or EFEA)

Asymptotic Modal Analysis (AMA)

Energy (Phase) Envelop Method

Mobility methods

Ray Tracing

- SEA is widely used
- EFEA exhibits high potential

Statistical Energy Analysis

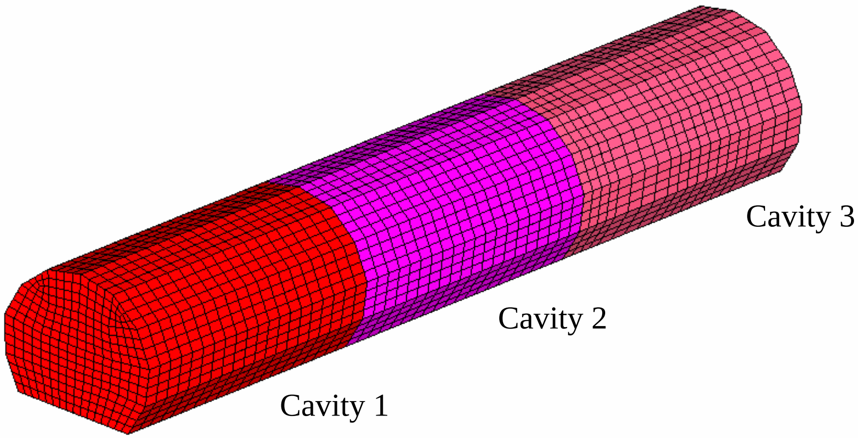
- Structural members and acoustic cavities are divided into smaller structures and cavities called sub-systems which are comprised of similar modes
- State of vibration is expressed in terms of stored, dissipated and transmitted energies of sub-systems
- Energy balance is performed for all sub-systems to solve for sub-system energy levels

Energy Finite Element Method

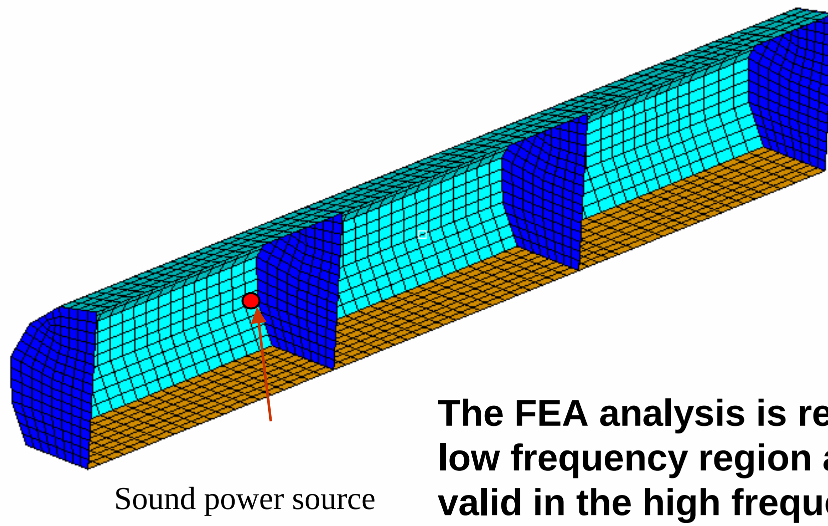
- State of vibration can be represented by stored, dissipated and transferred energies
- Differential volume is used to derive governing equations
  - Structural members and acoustic cavities are divided into finite elements as in deterministic methods
  - Allows spatial variation of energy within sub-system
  - Allows modeling of localized damping
  - Local (eg. Point force) excitation is feasible
- Predicts spatial and frequency averaged variables

Problem Description

The coupled acoustic analysis in MSC.Nastran is used to determine the cavity response.



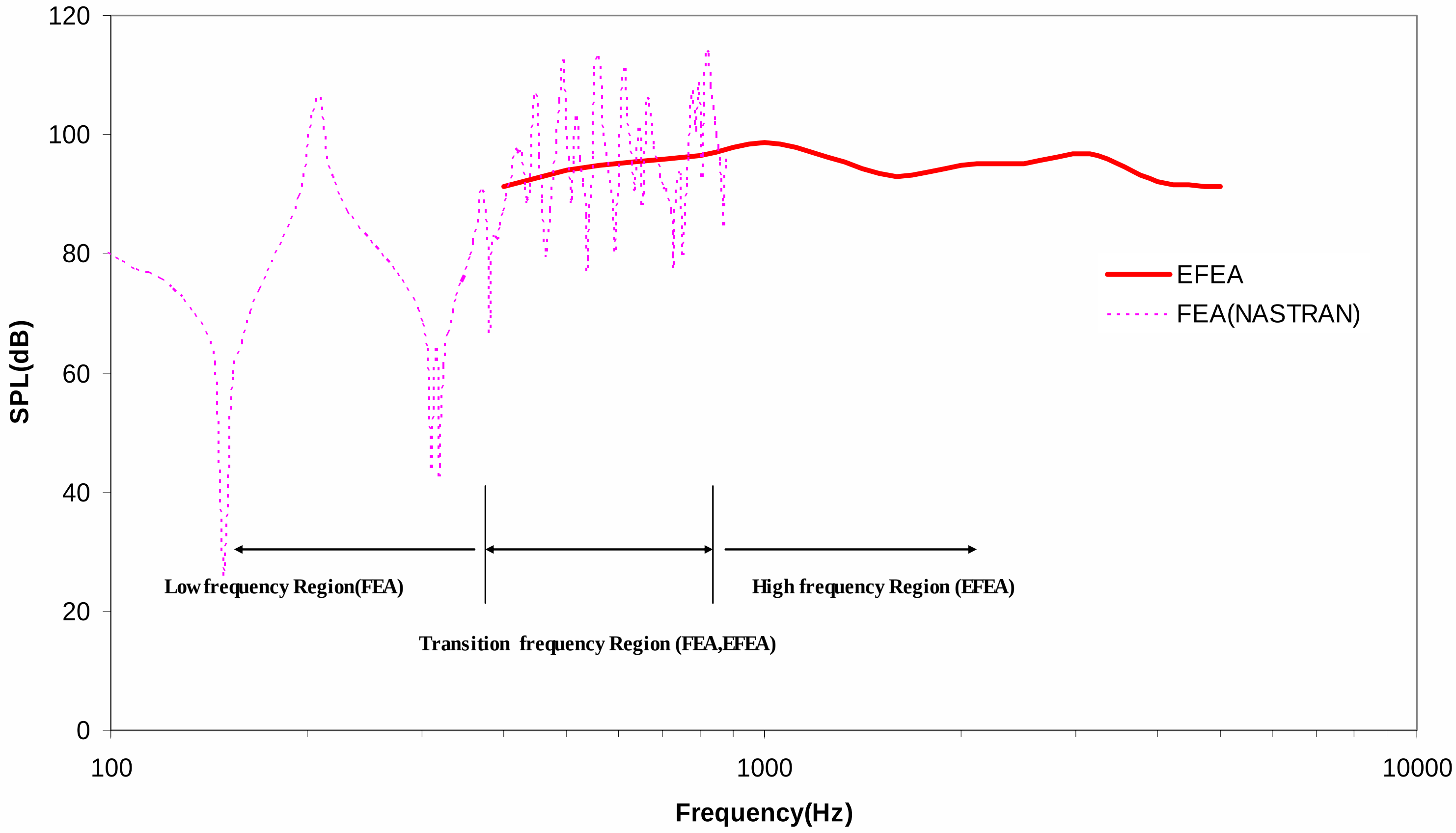
FEA model
-14880 acoustic elements
-4352 structural elements.



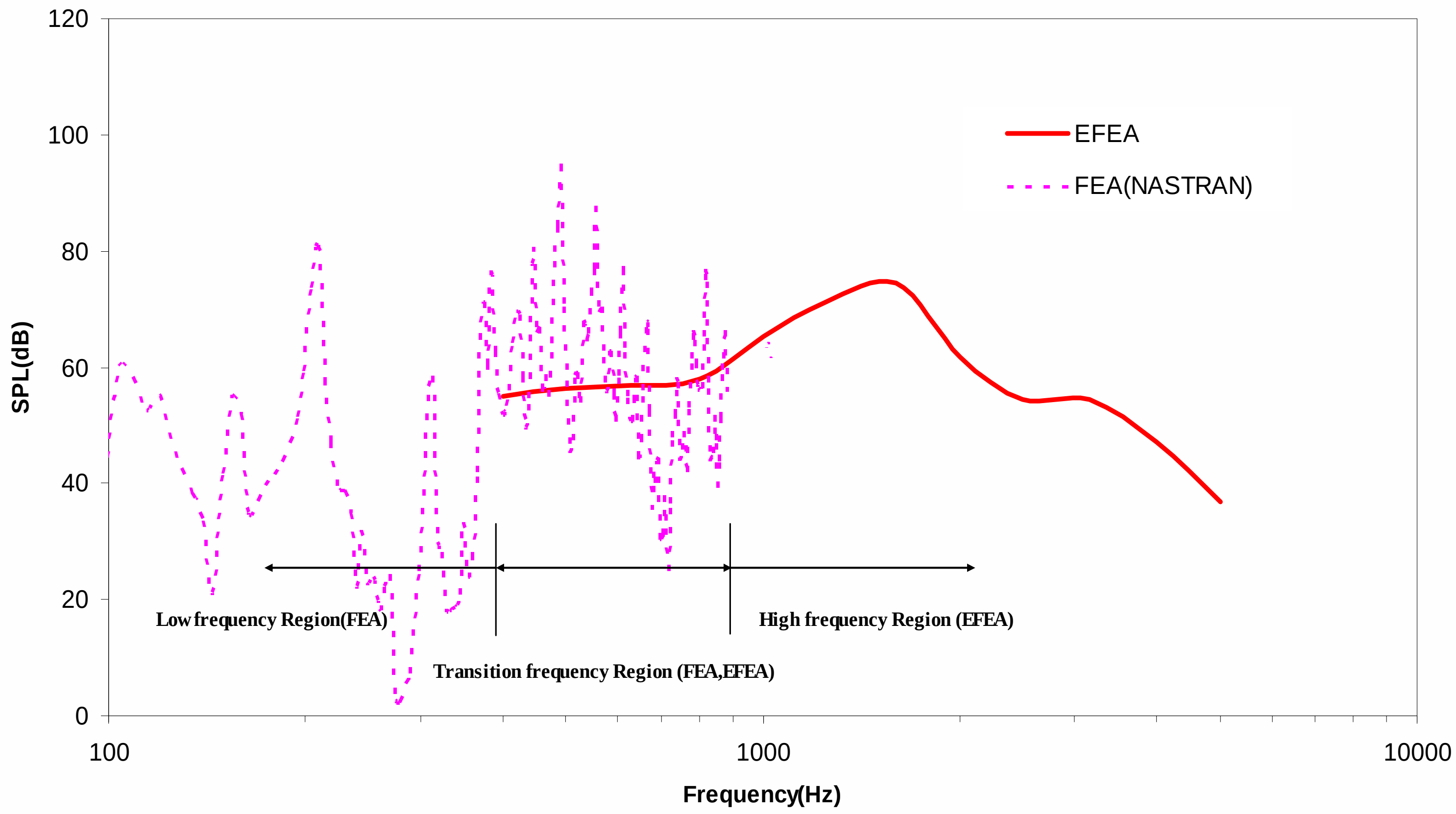
The FEA analysis is reliable in the low frequency region and EFEA is valid in the high frequency region.

FEA model of an airplane cabin

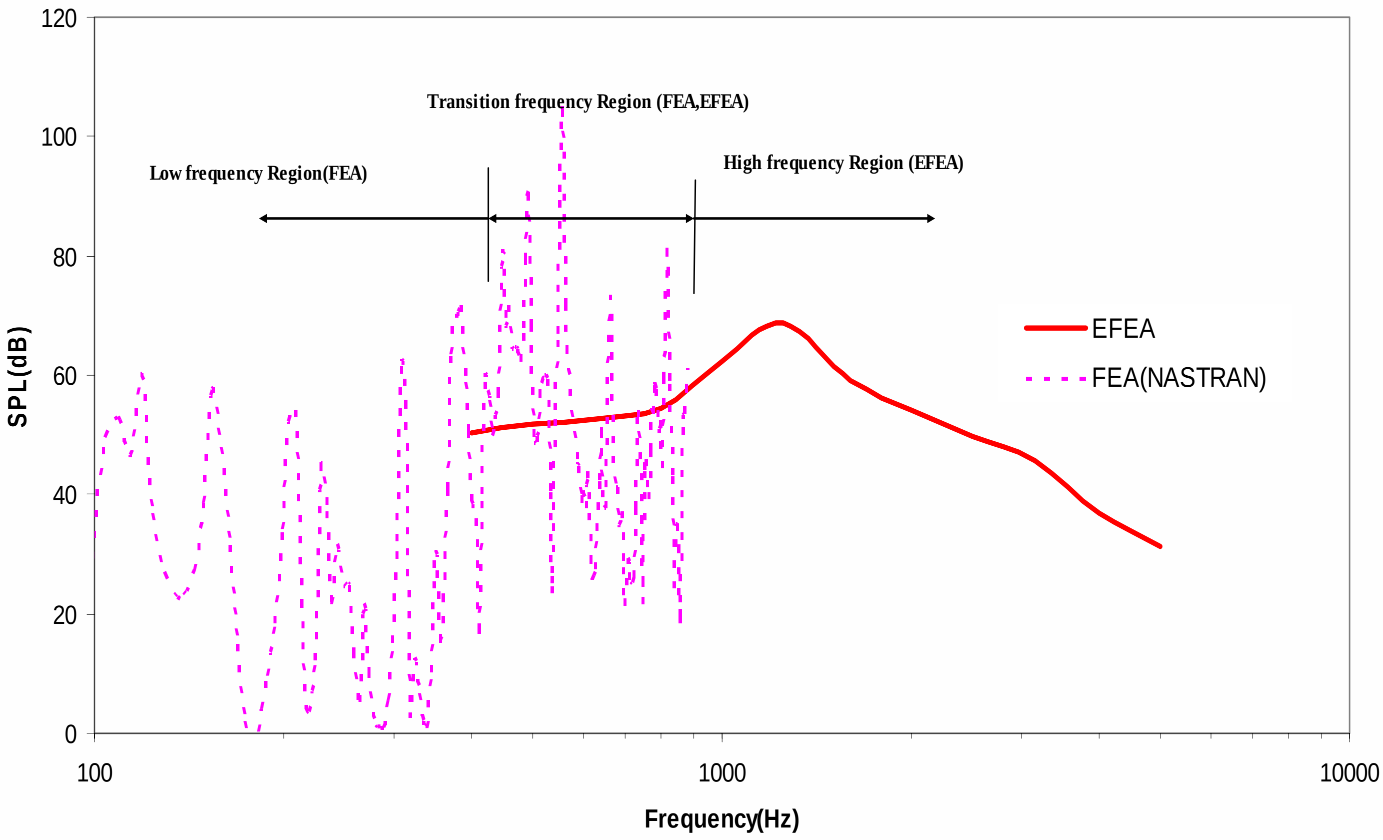
Sound Pressure Level in Cavity 1



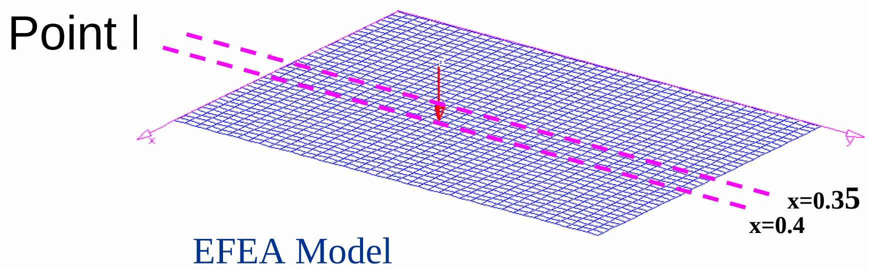
Sound Pressure Level in Cavity 2

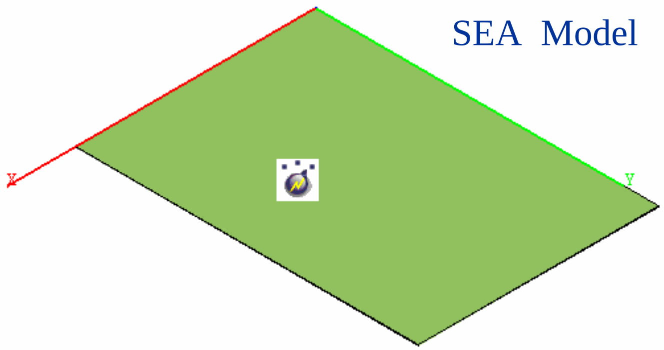


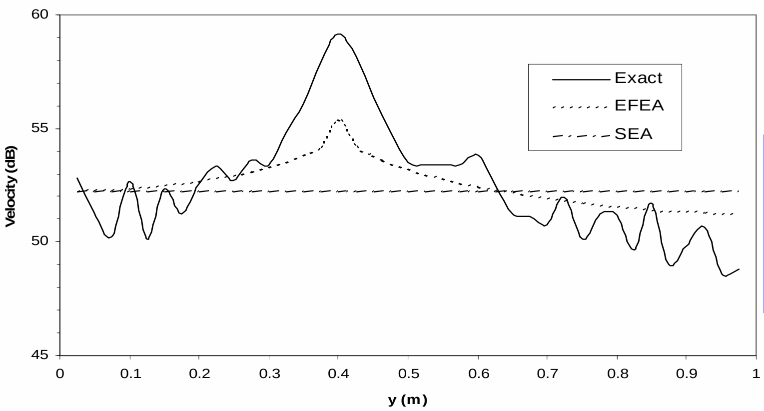
Sound Pressure Level in Cavity 3



Modeling of Spatial Variation





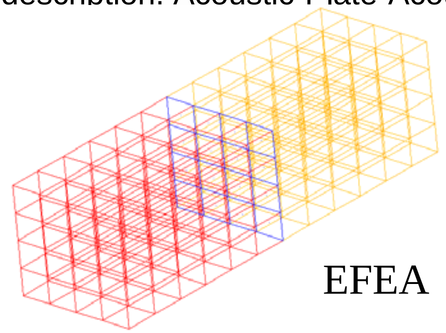


- EFEA captures spatial variation better than SEA
- Inclusion of direct field will further improve EFEA prediction

Velocity along an axis pass through the excitation point (x=0.4, Damping=0.1)

System Model Generation

Problem description: Acoustic-Plate-Acoustic System



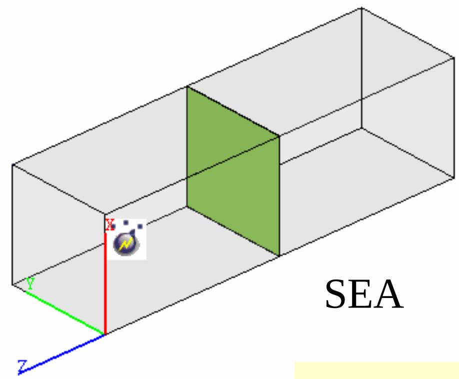
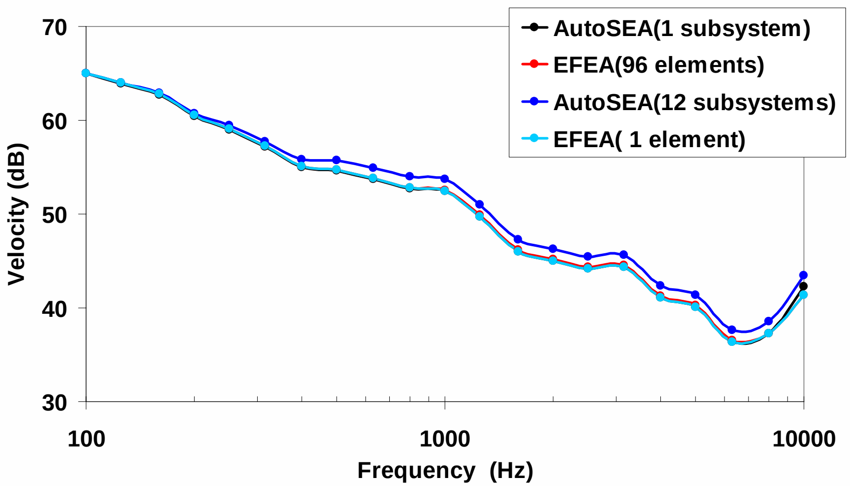
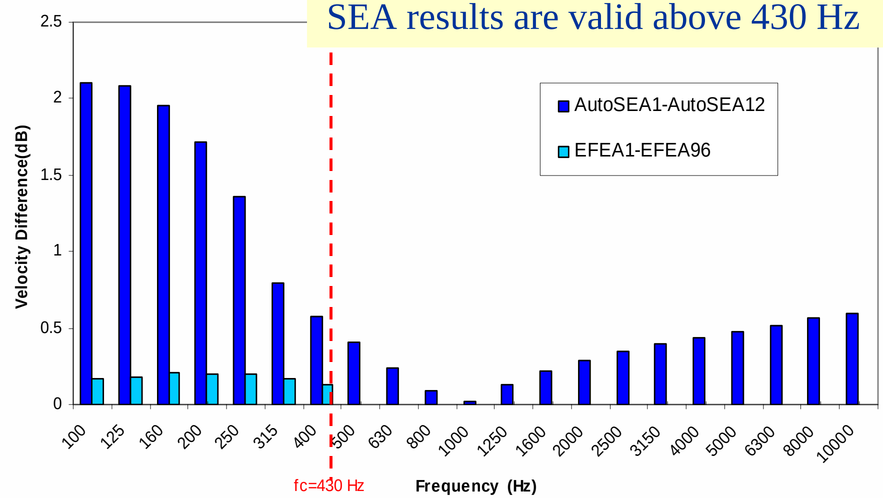


Plate – 1.05mx1.05m
Cavity – 1.05mx1.05mx1.8m

SEA results are valid above 430 Hz



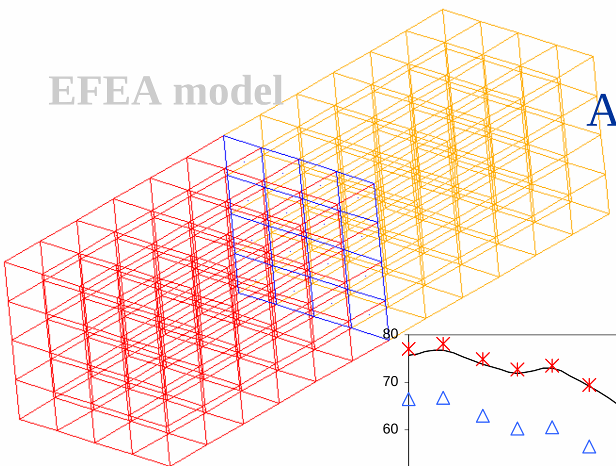


- SEA results are highly sensitive to model

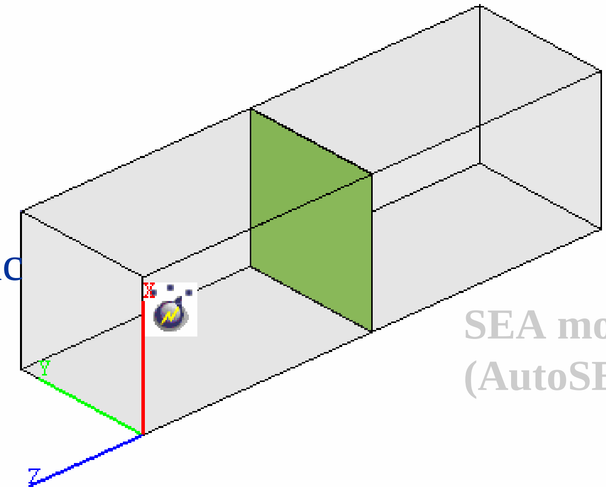
Air-Borne Noise Prediction Model

Problem description – Two acoustic cavities divided by a plate

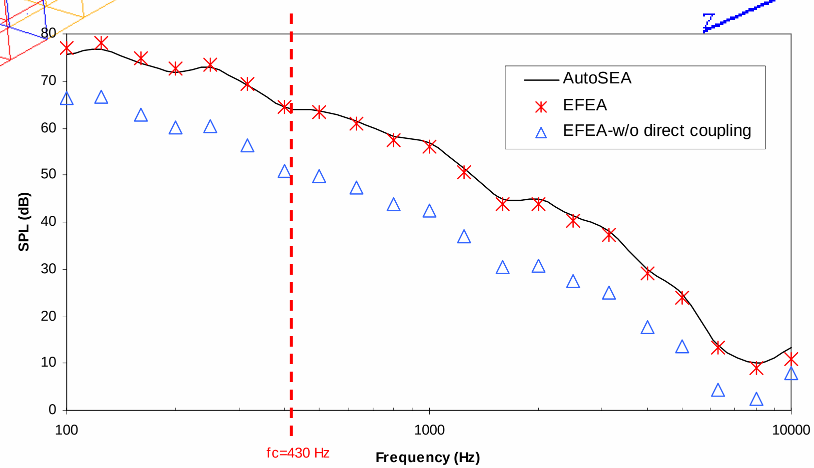
EFEA model



Acoustic-plate-acoustic system



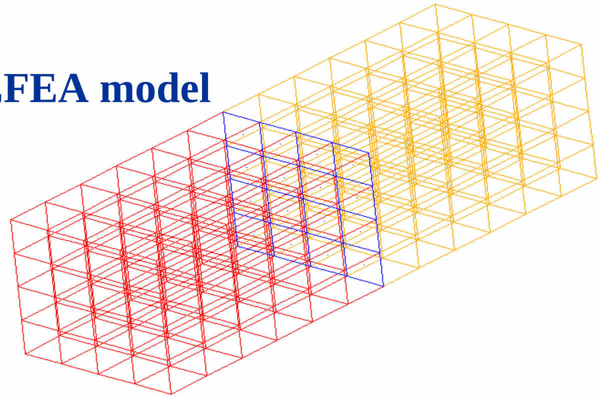
SEA model (AutoSEA)



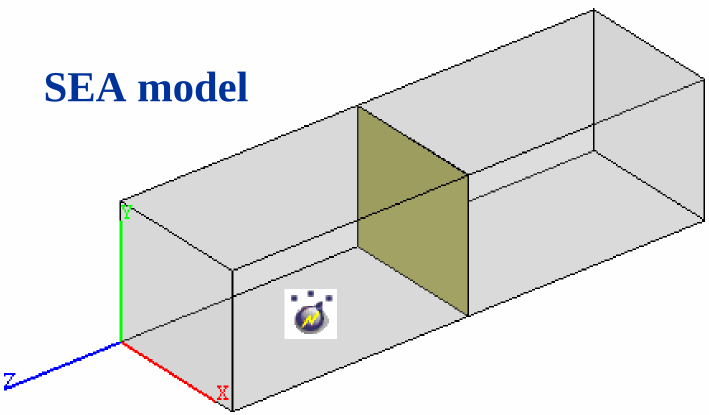
- Coincident frequency is high (11,000 Hz)
- Non-resonant path is important
- New EFEA development includes resonant & non-resonant paths

Modeling Noise Control Treatments

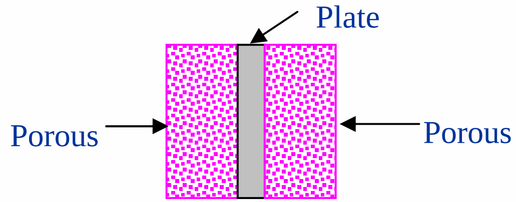
EFEA model



SEA model

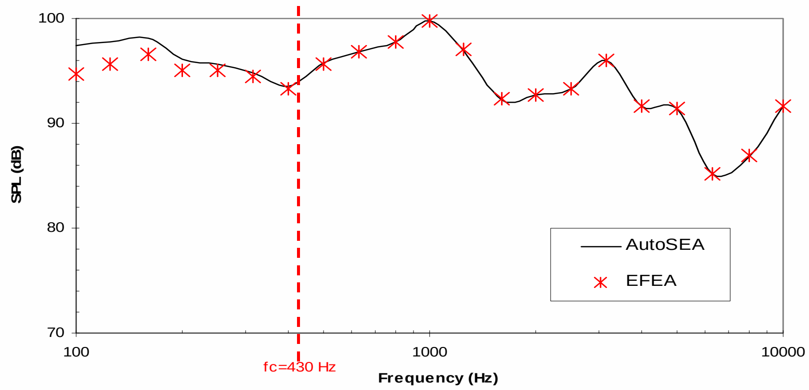


Problem description

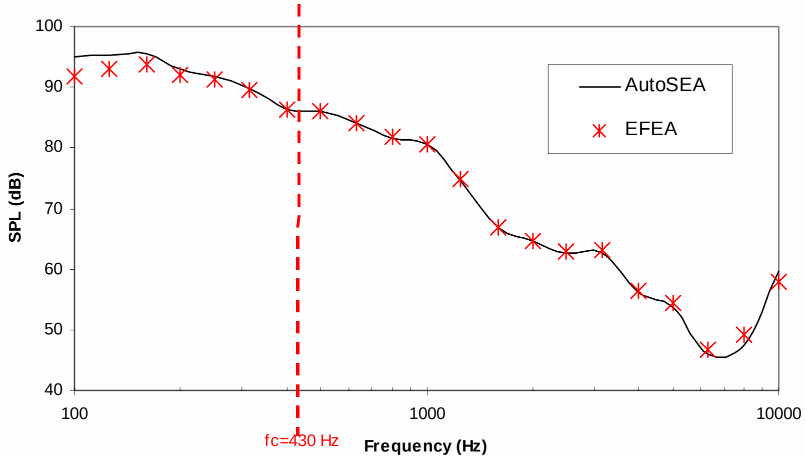


Parameters	**Porous layer 1**	**Plate**	**Porous layer 1**
Thickness (m)	0.005	0.001	0.005
Porosity	0.99	-	0.99
Flow Resistivity ($Nm^{-4}s$)	10000	-	10000
Tortuosity	1.0	-	1.0
Young's Modulus (Pa)	2.0E8	6.43 E10	2.0E8
Density of the Frame (kgm^{-3})	100	2800	100
Poisson Coefficient	0.4	0.34	0.4
Structural Damping	0.1	0.016	0.1
Thermal Characteristic Length (m)	0.00012	-	0.00012
Viscous Characteristic Length (m)	0.00012	-	0.00012

EFEA Results Validation



Sound pressure level at source cavity



Sound pressure level at receiving cavity

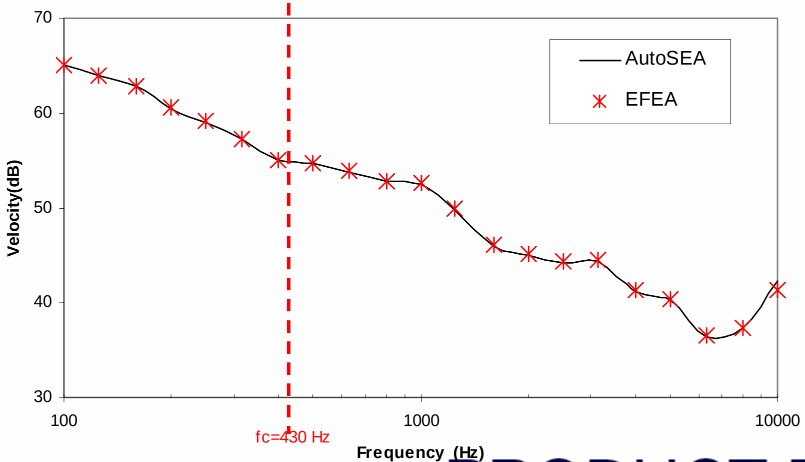


Plate velocity amplitude

Concluding Remarks

- Deterministic FEA results are not suitable for high frequency analysis
- High frequency solutions based on Statistical Energy Analysis (SEA)
  - High level of expertise
  - No mesh concept, etc.
- Energy Finite Element Method (EFEM) provides a unified framework for the solution of high frequency vibro-acoustic problems
  - Conceptually same mesh can be used for both low and high frequency vibro-acoustic analyses

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