

Acoustical Materials Workshop

Organized by:

Pranab Saha and Anita B. Carey

SAE Acoustical Materials Committee



2003 SAE NVC

Presentation Feature This Evening

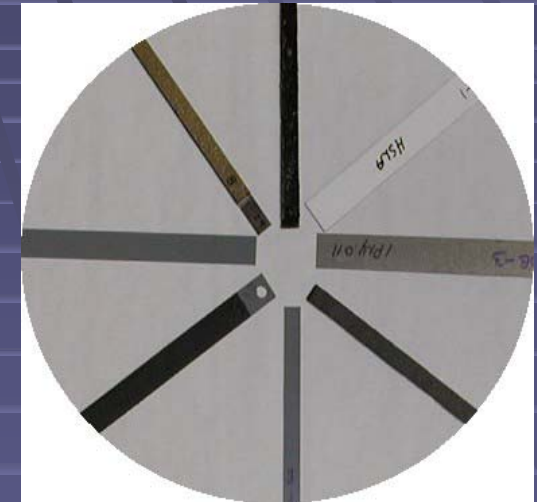
- Basics of Acoustical Materials - *Barry R. Wyerman*
- Test Methods for Determining Performance of Acoustical Materials - *Peggy Hoult*
- Predicting the Performance of Acoustical Materials - *Jerome E. Manning*

Materials



Absorber

Barrier



Damper

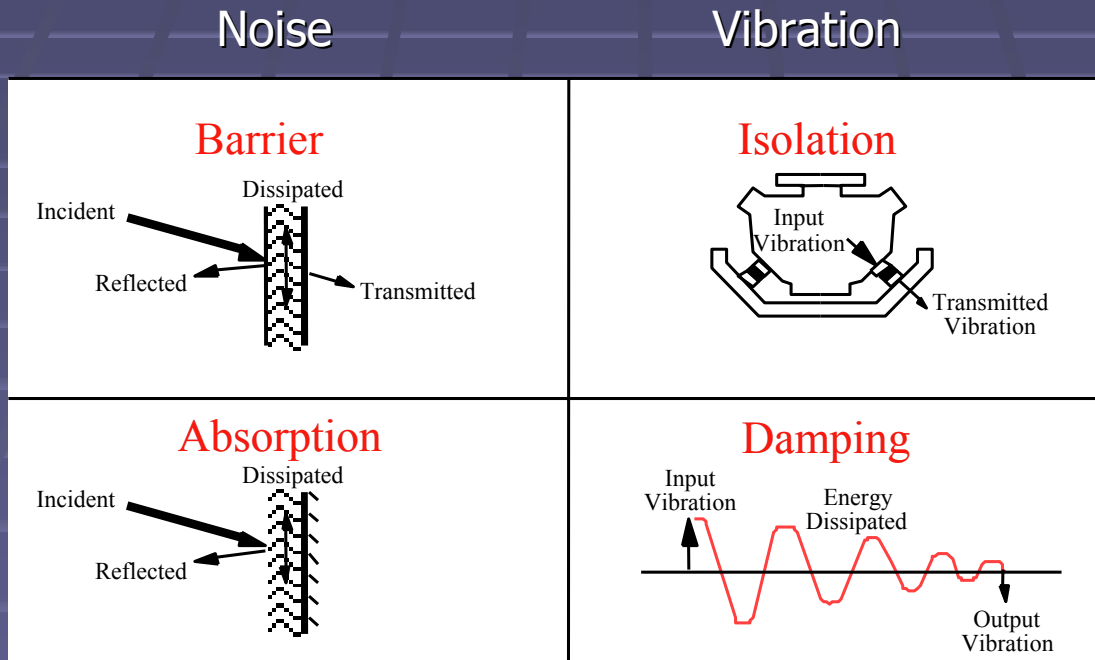
Basics of Acoustical Materials

Barry R. Wyerman
Lear Corporation



What is an Acoustical Material?

An acoustical material is any material that reduces noise and vibration
4 different materials are commonly used to control automotive noise and vibration

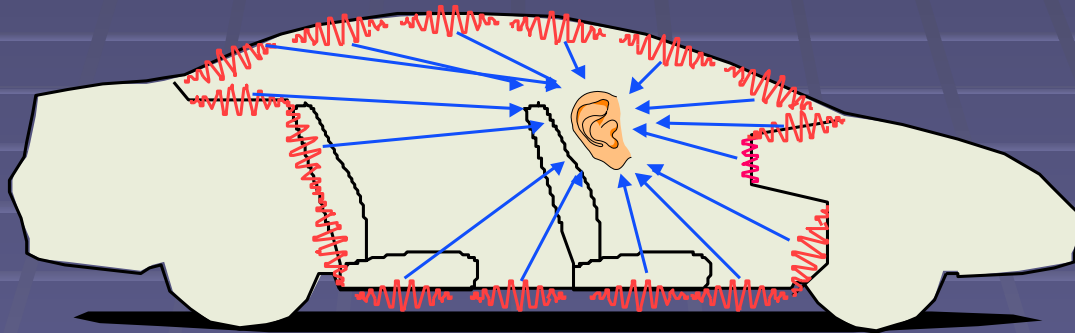


Each material performs a special function to reduce noise or vibration

Why do We Need Different Materials?

Some materials control airborne noise

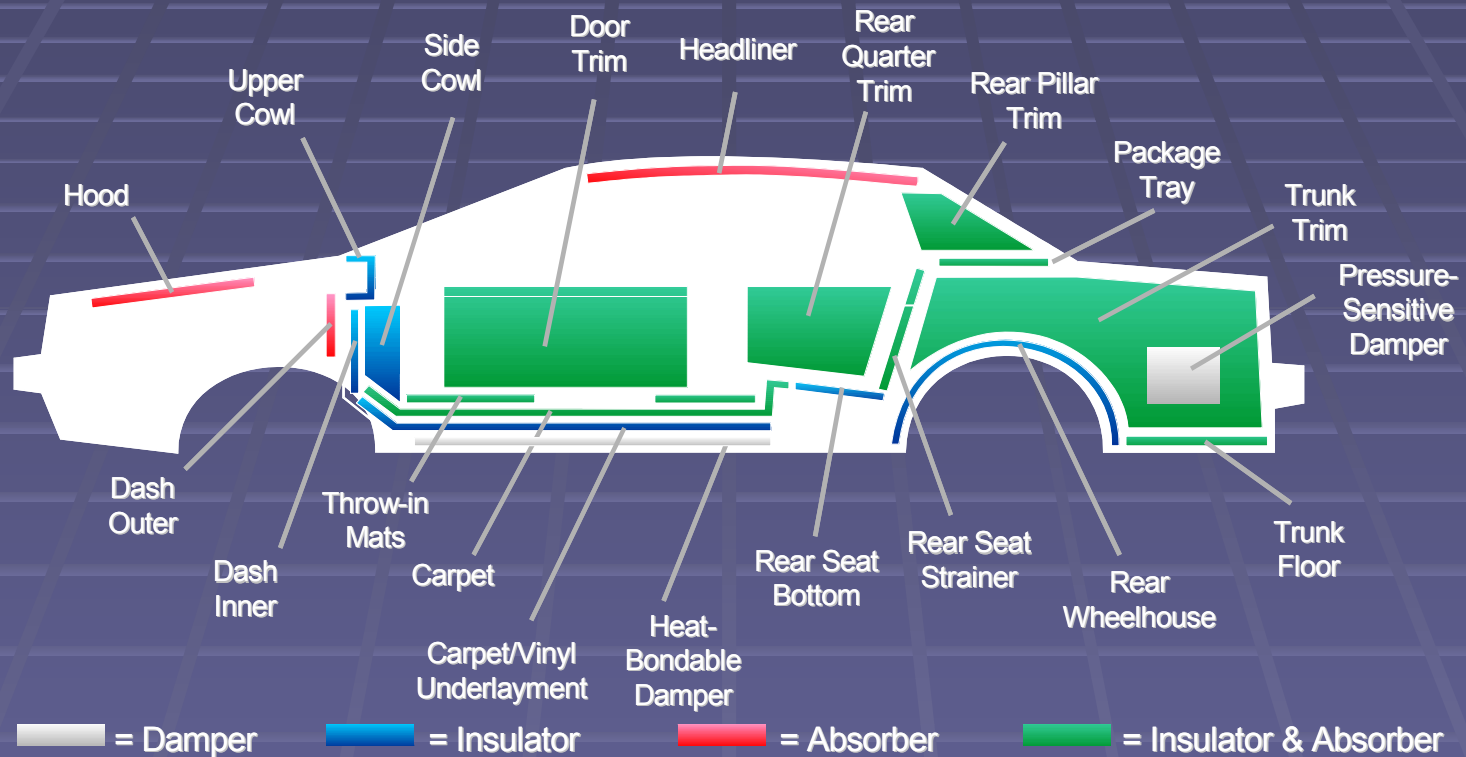
Some materials control structureborne noise



Interior noise is the summation of contributions from all interior surfaces

How are NVH Materials Used?

Materials are converted into products applied throughout the vehicle



What is a Sound Absorber?

A sound absorber controls (or minimizes) the amount of sound reflected from a surface

The effectiveness of a sound absorber is measured by the sound absorption coefficient which is the ratio of sound energy absorbed by a material surface to the sound energy incident upon the surface

$$\alpha = \frac{\text{acoustic energy absorbed by a surface}}{\text{acoustic energy incident on that surface}}$$

The sound absorption coefficient ranges from 0% to 100% and varies with frequency, based on the material properties



Typical Sound Absorption Plot

	Sample A	Sample B
Thickness (mm)		
Reported	20	21
Measured	21	20
Surface Weight (kg/m²)		
Reported	1.2	1.3
Measured	1.15	1.26

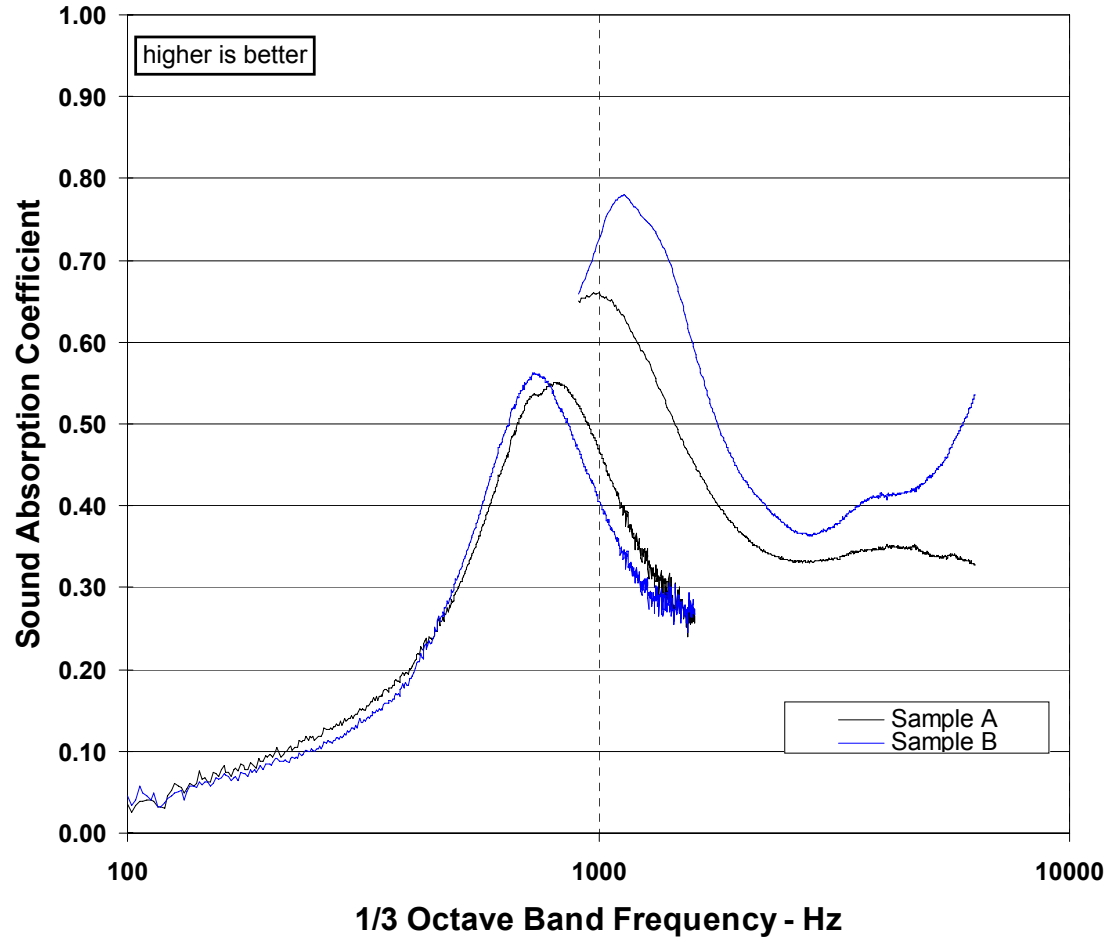
Sample A

Original Baseline / Company A Baseline
 Current production design
 Top Layer A at 1.4 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 12 mm thick

Sample B

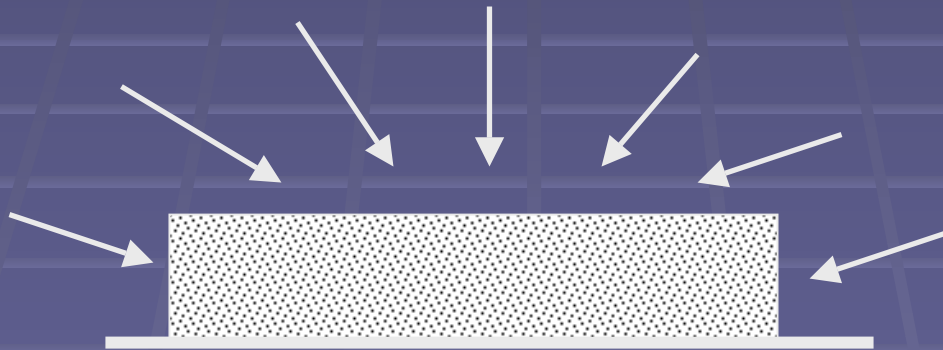
Proposal 1 / Company A-1
 Cost Reduction Proposal
 Top Layer A at 1.4 mm thick
 Middle Layer B at 8 mm thick
 Bottom Layer C at 12 mm thick

Normal Incidence Sound Absorption per ASTM E1050- 99
 SAE Standard Data Format



How does Sound Absorption Contribute to Vehicle Noise Control?

- Absorption dissipates noise once it has entered the vehicle
- The mechanism of sound absorption is thermal and viscous dissipation of sound energy passing through the material
- A sound absorber reduces reflected/reverberant sound but not the direct sound to the receiver

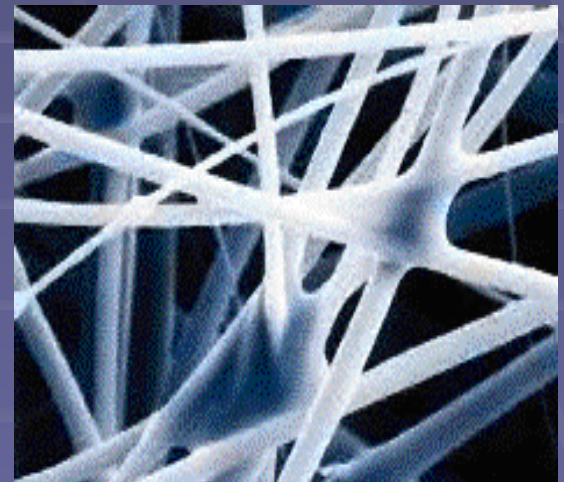


What Characteristics of Materials make them Absorptive?

Effective sound absorbers are usually porous, with performance increasing with thickness. Important material properties include the following:

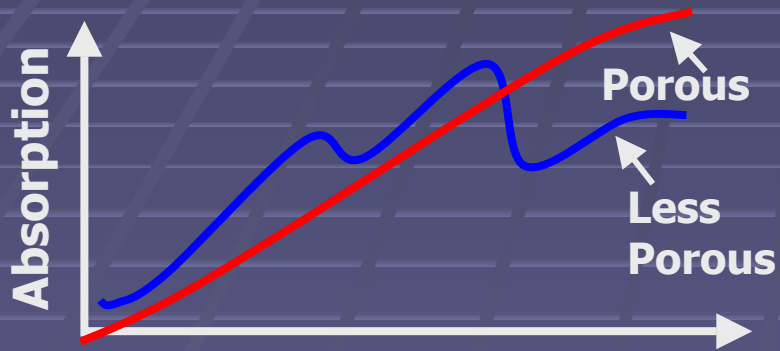
- **Porosity** is the percent open area within the material - it allows the sound waves to propagate into the material
- **Tortuosity** is the property that prevents direct flow through the material
- **Flow Resistance** is the result of porosity, tortuosity, and cell structure of a material and is often a good measure of how absorptive a material will be.

In general, smaller fiber diameters or smaller cell sizes create higher viscous drag and increase the flow resistance

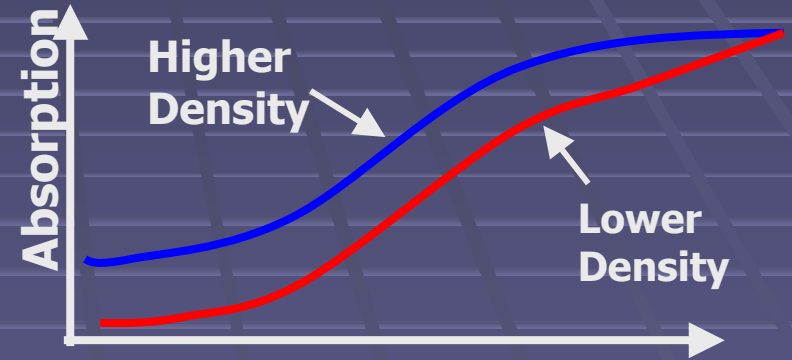


Sound Absorbers

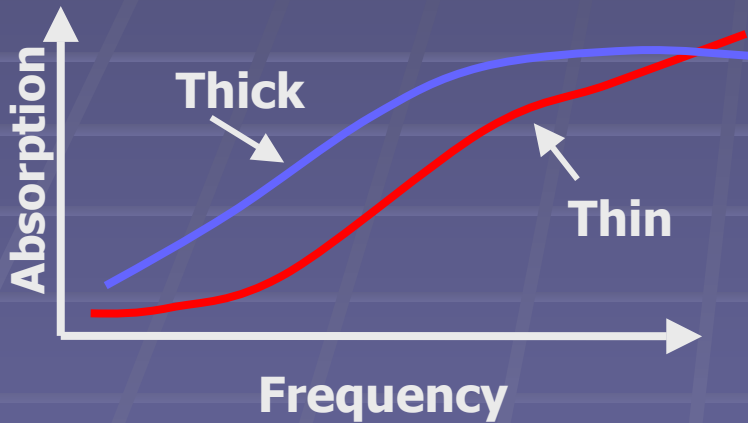
POROSITY



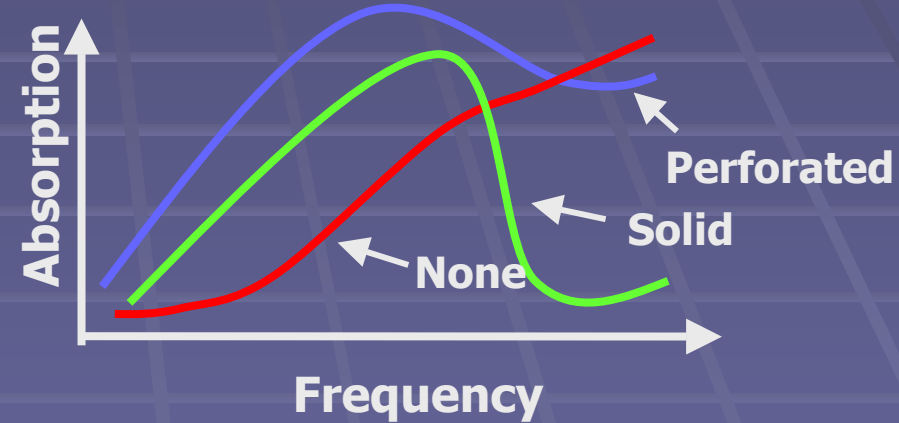
DENSITY



THICKNESS



FACING



Sound Absorbers

Typical sound absorbing materials

- Fibers - recycled cotton, glass fibers, thermoplastic fibers
- Foams - open cell polyurethanes
- Membrane absorbers - light weight membranes for tuned performance over a specific frequency range
- Hybrid constructions -
 - 1/4 wavelength cavities for high performance over a narrow frequency band
 - dual density constructions for a balance of absorption and transmission loss
- Micro denier fibers - porous materials with high internal surface area

Sound absorbing products

- Engine side treatments, headliners, floor systems, dash insulators



What is a Sound Barrier?

A sound barrier blocks the transmission of sound from one zone to an adjacent zone

The effectiveness of a sound barrier is measured by the Sound Transmission Loss (STL), which is the ratio of sound energy transmitted by a material surface to the sound energy incident upon the surface

$$\tau = \frac{\text{acoustic energy transmitted by a surface}}{\text{acoustic energy incident on that surface}}$$

$$\text{STL} = 10 \log_{10} \left(\frac{1}{\tau} \right)$$

The STL is measured in dB, varies with frequency, and can be as high as 80 to 90 dB at 10,000 Hz

Typical Sound Transmission Loss Plot

	Sample A	Sample B	Sample C	Sample D
Thickness (mm)				
Reported	20	21	22	23
Measured	21	20	22	23
Surface Weight (kg/m²)				
Reported	1.2	1.3	1.4	1.5
Measured	1.15	1.26	1.39	1.48

Sample A

Original Baseline / Company A Baseline
 Current production design
 Top Layer A at 1.4 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 12 mm thick

Sample B

Proposal 1 / Company A-1
 Cost Reduction Proposal
 Top Layer A at 1.4 mm thick
 Middle Layer B at 8 mm thick
 Bottom Layer C at 12 mm thick

Sample C

Proposal 2 / Company B-1
 Weight Reduction Proposal
 Top Layer A at 1.4 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 14 mm thick

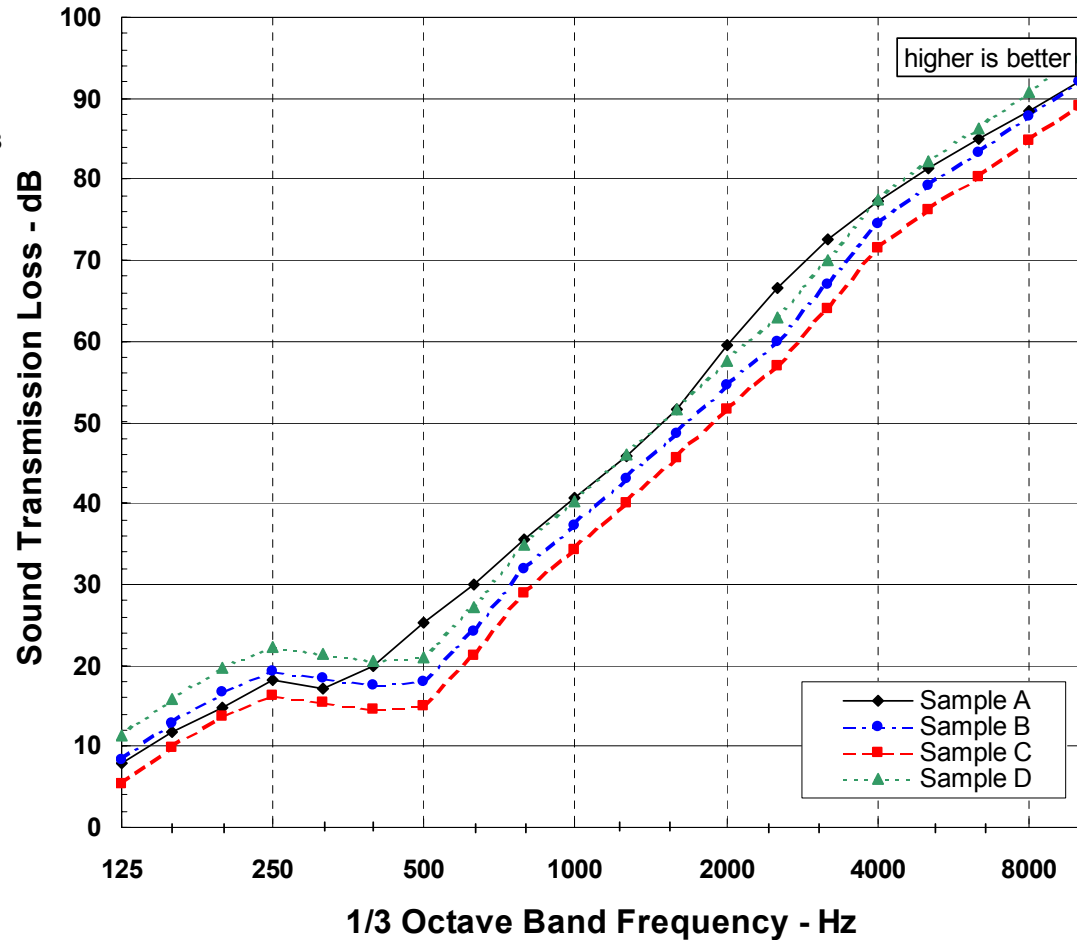
Sample D

Proposal 3 / Company C-1
 Best NVH Proposal
 Top Layer A at 3 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 12 mm thick

Technician: 11

Sound Transmission Loss per SAE J1400-7

SAE Standard Data Format



How does STL Contribute to Vehicle Noise Control?

- STL prevents noise from entering the vehicle, by acting as a barrier.
- The mass of the material prevents incident sound waves from being transmitted through the material, and minimizes the propagation of sound waves to the other side
- This equation is called the (single wall) mass law equation

$$STL = 20 \log_{10} (fw) - 47$$

Where: f is frequency, Hz
w is surface density, kg/m²

What Characteristics of Materials make them Effective Barriers to Noise?

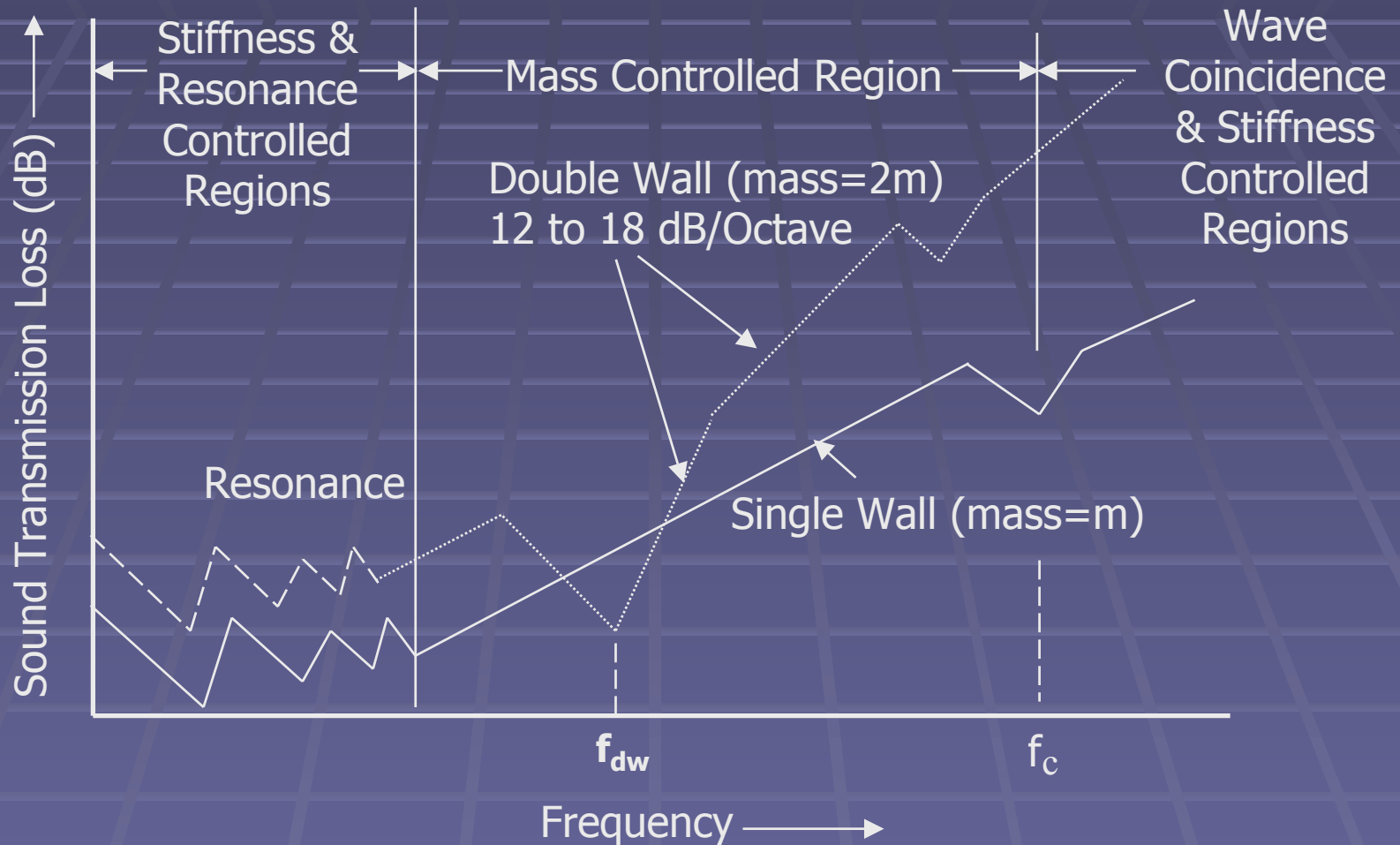
Non-porous materials provide an impervious barrier for sound transmission.

Massive materials with greater surface density more effectively block transmission of sound waves striking the surface.

Limp materials prevent resonance effects. A limp material is relatively free of resonances (while a stiff material may ring like a bell!)

Double wall mass systems with a decoupler between mass layers are more effective than a single mass layer of the same weight

Sound Transmission Loss of Single Wall and Double Wall Constructions



Sound Barriers

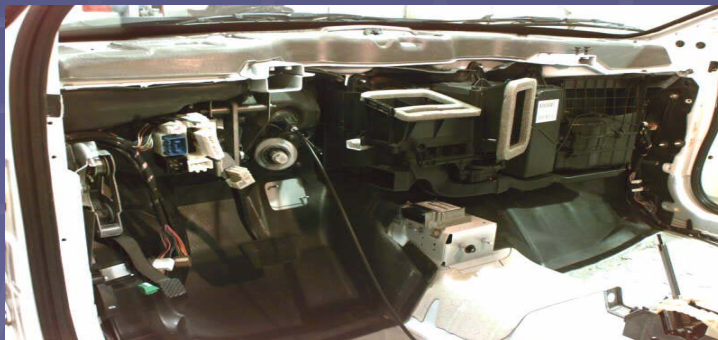
The best sound barriers have high mass per surface area and include a decoupler between the mass layers

Typical barrier materials

- Thermoplastic barriers with fillers (high mass per surface area)
- Barriers with fiber or foam decouplers
- Fiber/mastic/fiber constructions
- Lightweight impervious membranes

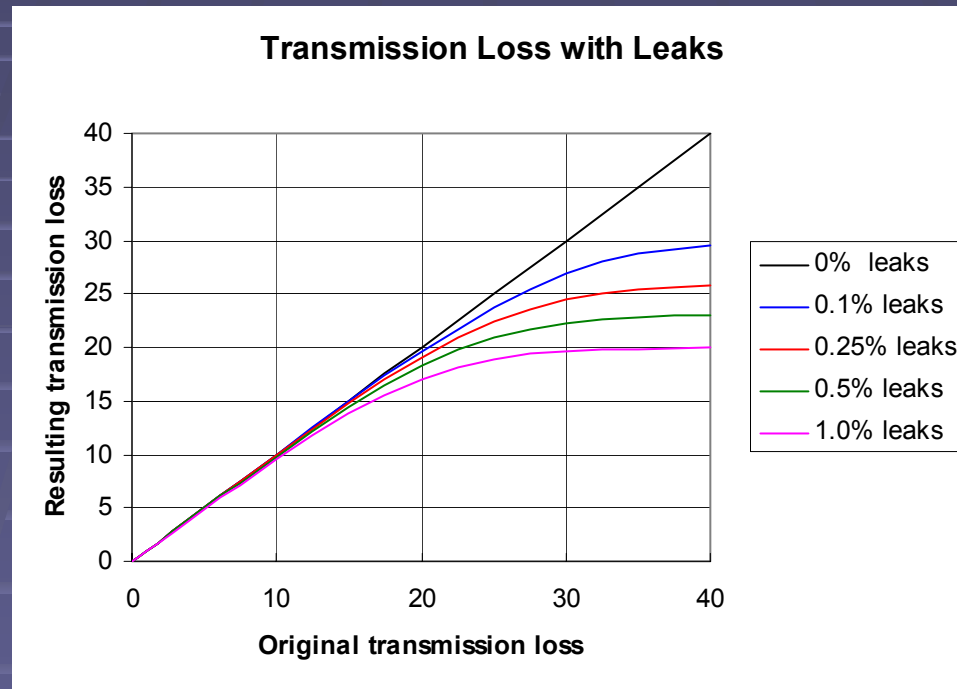
Barrier products

- Floor systems, dash insulators, cavity sealers



When is a Sound Barrier not a Barrier?

Holes in a barrier or gaps at edges can significantly reduce TL performance



When holes are present, other materials can provide an offset to the leak

- Design solutions - boots, sealing, improved fit
- Light weight barriers with high sound absorption

What is a Damping Material?

A damping material reduces the vibration of a surface and thereby minimizes transmitted vibration and radiated noise

The effectiveness of a damping material is measured by the loss factor, η

$$\eta = \frac{\text{Energy lost per unit of time}}{\text{Stored energy in the vibrating system}}$$

The loss factor varies with frequency and temperature

Typical Vibration Damping Plot

Composite Vibration Damping per SAE J1637- 93

SAE Standard Data Format

	Sample A	Sample B	Sample C	Sample D
Thickness (mm)				
Reported	20	21	22	23
Measured	21	20	22	23
Surface Weight (kg/m²)				
Reported	1.2	1.3	1.4	1.5
Measured	1.15	1.26	1.39	1.48

Sample A

Original Baseline / Company A Baseline
 Current production design
 Top Layer A at 1.4 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 12 mm thick

Sample B

Proposal 1 / Company A-1
 Cost Reduction Proposal
 Top Layer A at 1.4 mm thick
 Middle Layer B at 8 mm thick
 Bottom Layer C at 12 mm thick

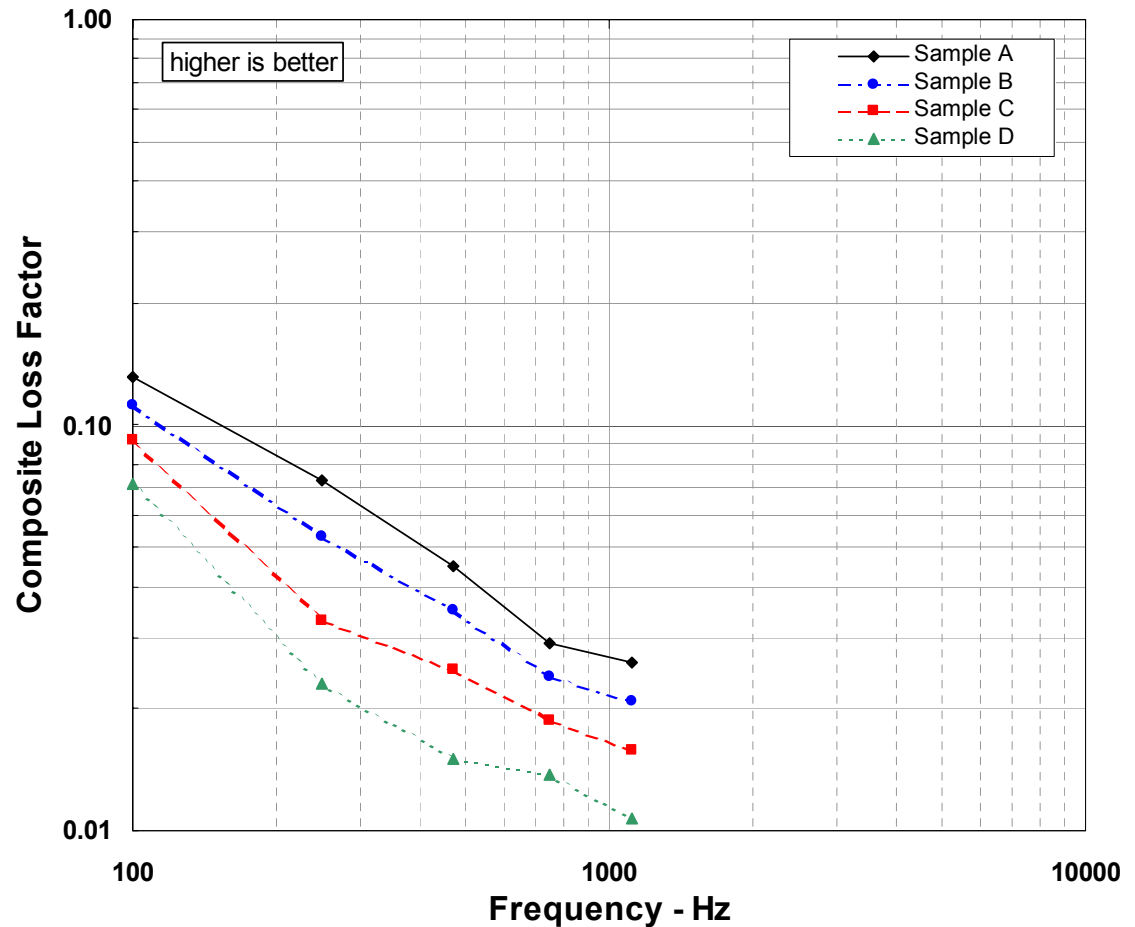
Sample C

Proposal 2 / Company B-1
 Weight Reduction Proposal
 Top Layer A at 1.4 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 14 mm thick

Sample D

Proposal 3 / Company C-1
 Best NVH Proposal
 Top Layer A at 3 mm thick
 Middle Layer B at 6 mm thick
 Bottom Layer C at 12 mm thick

Project number 21



How does Damping Contribute to Vehicle Noise Reduction?

Damping materials reduce the kinetic energy present in a system by transformation into thermal energy.

Damping materials reduce structure borne noise

Typical damping materials

- Bake-on asphalt
- Constrained layer dampers
- Curable constrained layers
- Spray applied damping material



Where are damping materials used?

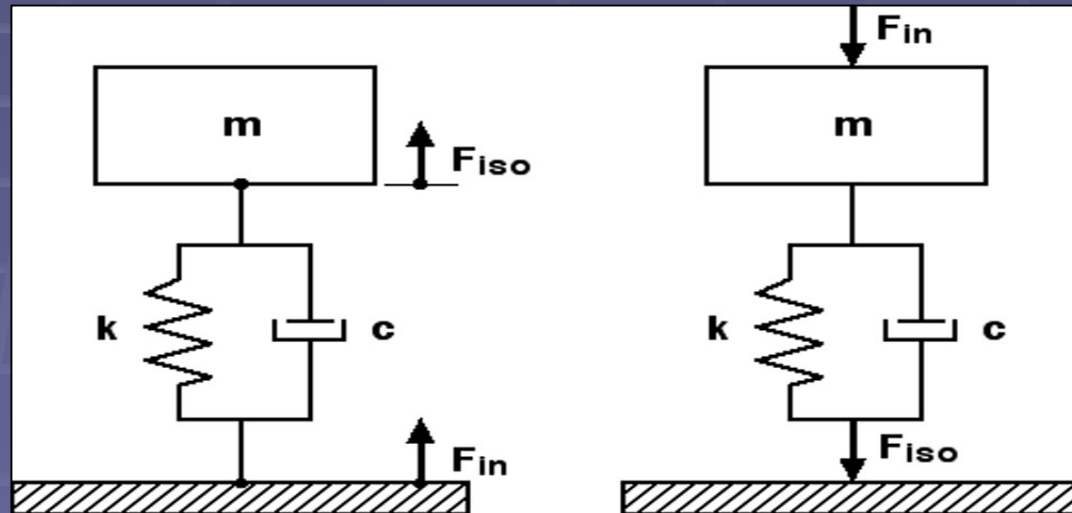
- Large surfaces of sheet metal - floor, front bulkhead, trunk, roof
- Surfaces prone to oil canning

What is a Vibration Isolator?

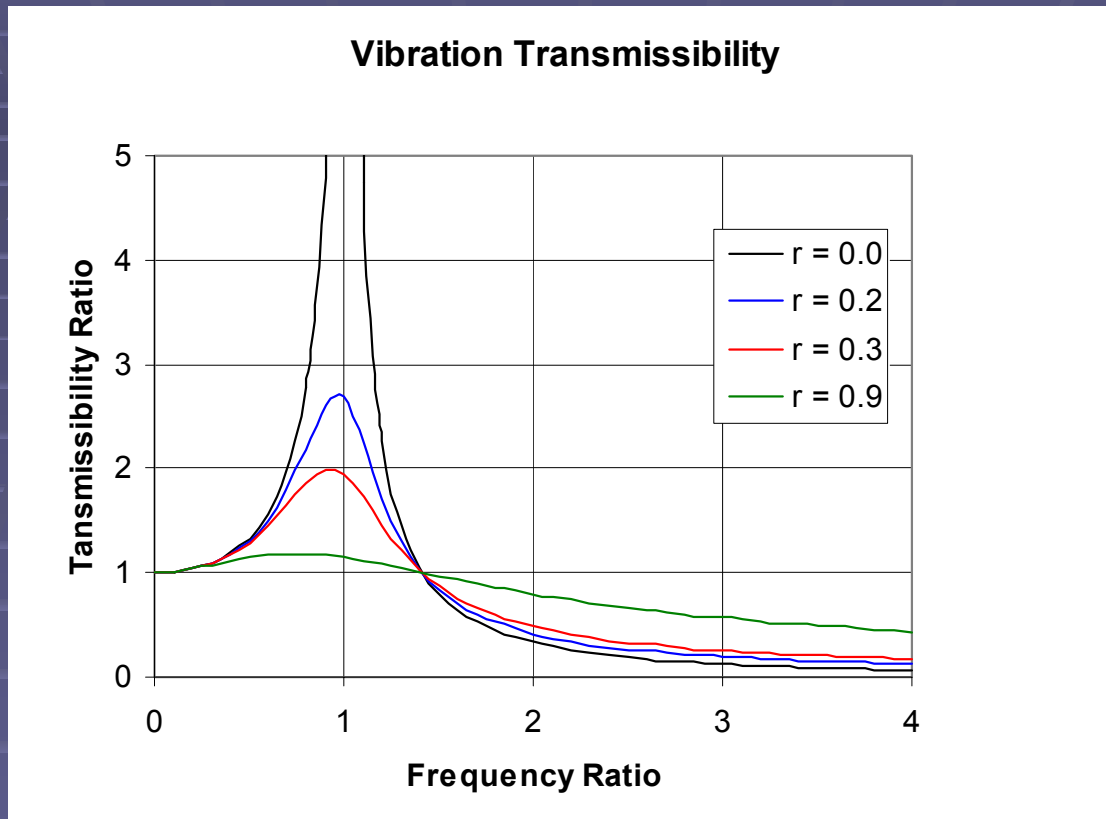
A vibration isolator reduces the vibration energy transmitted through a system

The effectiveness of a vibration isolator is measured by the transmissibility ratio, which ranges from 0 to 10 or more, depending on frequency

Isolation must be analyzed with respect to the natural vibration or resonance of the spring/mass system.



Vibration Isolation



Resonance occurs where the frequency ratio is 1.0
Isolation in the resonance region requires damping

How does Vibration Isolation Contribute to Vehicle Noise Control?

Vibration isolators reduce structureborne vibration which can propagate throughout the vehicle and be converted into noise when a vibrating surface becomes an efficient radiating panel

Isolation requires soft springs to lower the resonant frequency and allow operation above the area of resonance

Most isolators have a compliant element (spring) and a damper (internal losses or separate damper)

Vibration Isolators

Typical vibration isolators

- Springs
- Springs with dampers
- Elastomeric mounts
- Fluid filled mounts
- Switchable dampers
- Semi active systems



Vibration isolator products

- Engine mounts
- Suspension mounts
- Body mounts



NVH Material Facts

No one material will solve all noise and vibration problems in a vehicle

The 'Best' NVH packages use materials from each of the 4 types of solutions so that the different materials work together to reduce noise

The factors for selecting NVH materials include:

- NVH performance
- Cost
- Weight
- Recyclability

Thermoplastic properties of materials allow molded parts to be produced to fit the intended application

The best material selection can be compromised by poor design of a product or poor installation



Acoustical Material Development

New technology under development includes:

- Sound absorbers with tunable frequency response
- Barriers with tunable transmission loss
- Hybrid, lightweight materials with a balance of sound absorption and transmission loss
- Damping materials with extended temperature range
- Adaptable or Semi-active vibration systems
- Active noise and vibration reduction systems

NVH Material Questions

How do we evaluate the performance of acoustical materials?

This is the subject of Part II

Test Methods for Determining Performance of Acoustical Materials

Peggy Hoult

Test Methods for Determining Performance of Acoustical Materials

Peggy Hoult

Rieter Automotive North America, Inc.



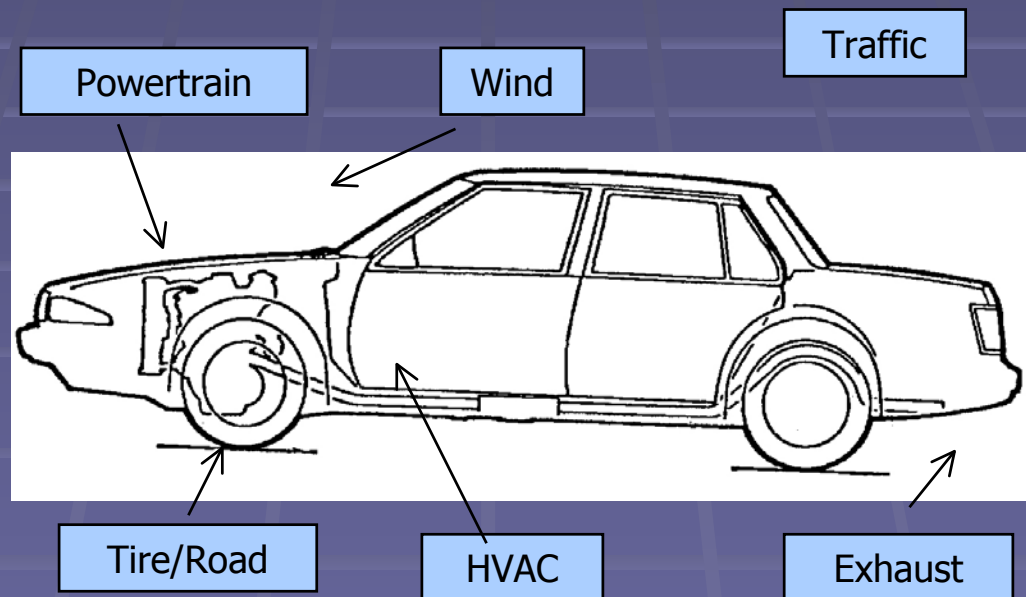
What NVH Issues does the Vehicle Exhibit?

How do we determine what those issues are?

- **By means of a vehicle test.**

How do we know what materials will work in the vehicle to resolve the NVH issues?

- **We test the vehicle and we test the materials.**



Test Methods

Absorption

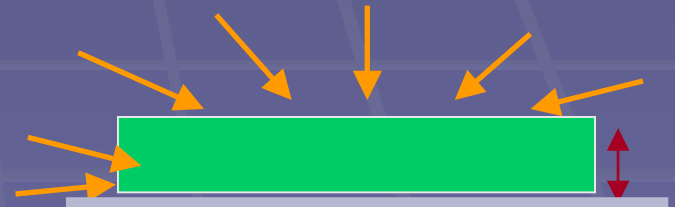
What are the different types of measured absorption?

Normal incidence absorption - impedance tube

- Test specifications: ASTM C384
ASTM E1050

Random incidence absorption - reverberation room (large or small)

- Test specifications: ASTM C423



Absorption

Normal Incidence Absorption

as measured by an impedance tube

This method of absorption testing is considered desirable due to the associated speed with which testing occurs, and the equipment is more readily attainable than a large reverberation room for random incidence absorption.

The fraction of the perpendicularly incident sound power absorbed or otherwise not reflected.



$$\alpha_n = \frac{I_a}{I_i} = 1 - \frac{I_r}{I_i}$$

Normal Incidence Absorption

ASTM C384 Test Method

A plane wave traveling in one direction down a tube is reflected back by the test sample and produces a standing wave along which pressure is measured.

Procedure:

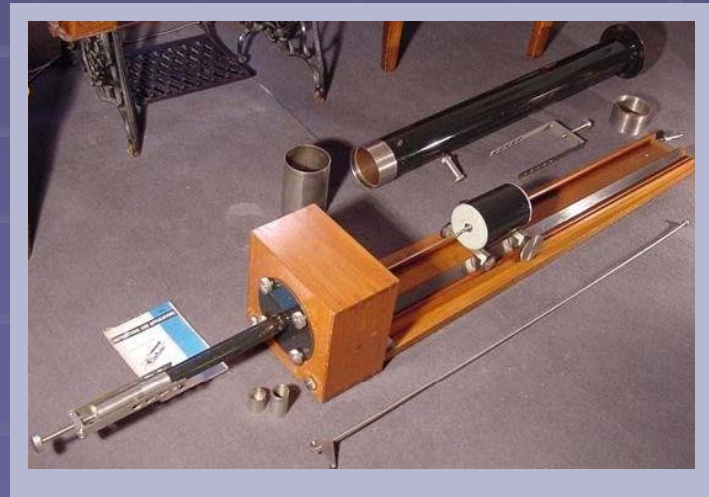
Test sample is placed at one end of tube against massive metal reflector.

Generate electronically a pure tone at opposite end.

Move the microphone to measure maximum and minimum pressures in tube.

Compute normal incidence.

$$\alpha_n = \frac{4P_{\max} P_{\min}}{(P_{\max} + P_{\min})^2}$$



Normal Incidence Absorption

ASTM E1050 Test Method

This method is similar to that of ASTM C384.



A plane wave, generated using a random noise source, traveling in one direction down a tube is reflected back by the test sample and produces a standing wave. Two wall-mounted microphones and a two channel analyzer measure acoustic pressures at two fixed locations. A computer performs all complex acoustic transfer function calculations.

Absorption

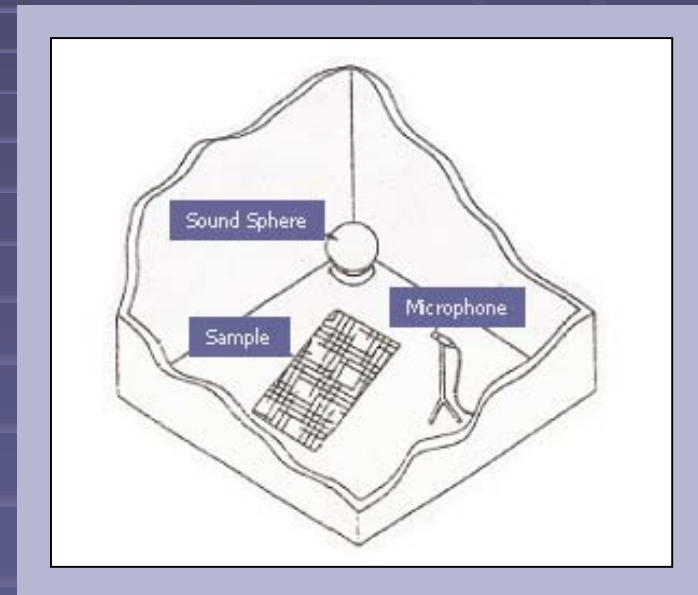
Random Incidence Absorption as measured in either a large reverberant room or a small reverberant room (a diffuse environment).

Without Sample in the room (Bare room measurement)

- Random noise is generated
- Noise is turned off
- Rate of decay of the noise is measured (dB/sec)

With Sample in the room

- Random noise is generated
- Noise is turned off
- Rate of decay of the noise is measured (dB/sec)



The decay rate with the sample present should be smaller than the bare room, as the sound waves would more readily be absorbed when a sample is present.

Random Incidence Absorption

Absorption of the room (with or without sample) is calculated by:

$$A = 0.921VD/c$$

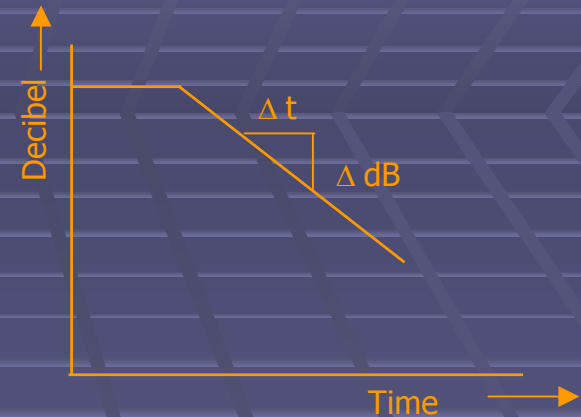
where

A = Sound absorption metric Sabins

V = Volume of reverberation room, m³

c = Speed of sound, m/sec

D = Rate of decay, dB/sec



$$\text{Decay Rate} = \frac{\Delta \text{ dB}}{\Delta t}$$

If the sound absorption of the empty room is A_1 and the room with the sample is A_2 (metric Sabins), the sound absorption coefficient of the test sample is given by:

$$\alpha = (A_2 - A_1) / S$$

S = surface area of the sample, m²

Absorption

Cautions/Advisories:

- Environmental conditions impact measurement results (humidity, temperature, barometric pressure)
- Room architecture (non-diffuse)
- Sample size and fit (appropriate for room size)
- Sample orientation (too close to reflective surface)
- Air gaps (additional absorption due to air)
- Edge effects (increasing absorptive area)
- Different results are generated from different facilities
- Flow resistance as one guide to understanding material absorption characteristic of materials and components

Absorption

SAE Round Robin Study of Small Sample Reverberation Room

SAE Acoustical Materials Committee is conducting a study of absorption performance of different sized reverberation rooms with the objective of standardization of small sample room testing.

ASTM C423 was developed initially for non-automotive applications where the specimen size was significantly larger.

The associated frequency ranges and sample sizes of smaller reverberation rooms are components of this study.

What are the Different Types of Measured Sound Transmission Loss (STL)?

- SAE J1400 Method
- ASTM E90 Method
- Sound Intensity Method

In all cases:

$$STL = 10 \log (1 / \tau)$$

where $\tau =$ Sound Transmission Coefficient : the fraction of the airborne sound power incident on a partition that is transmitted by the partition and radiated to the other side.

Sound Transmission Loss

Sound Transmission Loss as measured by the SAE J1400 method:

SAE J1400 – Laboratory Measurement of the Airborne Sound Barrier Performance of Automotive Materials and Assemblies

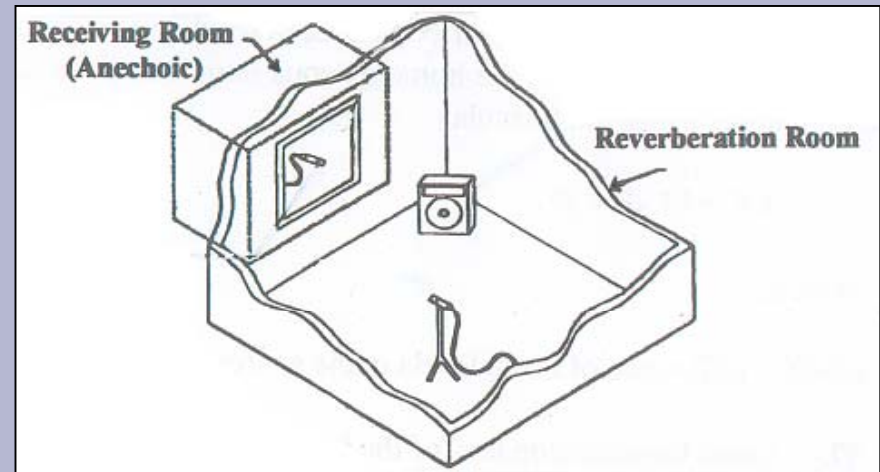
STL measurements incorporate a diffuse reverberant source room, an anechoic receiving room, and a test specimen between.

Reference Sample (homogeneous limp panel)

- Random noise is generated
- SPL is measured in source room and anechoic receiving room

Test Specimen

- Random noise is generated
- SPL is measured in source room and anechoic receiving room



Sound Transmission Loss

SAE J1400

$$STL_{(\text{reference})} = 20 \log W + 20 \log f - 47 \text{ (dB)}$$

W = Surface Weight (kg/m²)

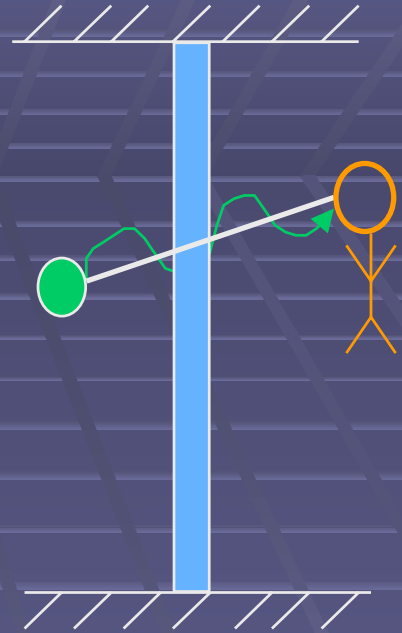
f = Center Frequency (Hz)

$$CF = MNR_{(\text{reference})} - STL_{(\text{reference})}$$

CF = Correlation Factor (relevant to test opening and room conditions)

MNR = Measured Noise Reduction

$$STL_{(\text{specimen})} = MNR_{(\text{specimen})} - CF$$

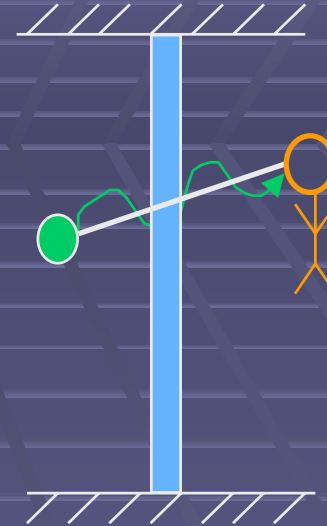


Sound Transmission Loss

ASTM E90

Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

This method incorporates diffuse reverberant rooms for both source and receiving rooms, with a test panel between (of a typically larger dimension than SAE J1400).



ASTM E90

$$STL = SPL_{(source\ room)} - SPL_{(receiving\ room)} + 10 \log S - 10 \log A_{(receiving\ room\ surface)} \text{ (dB)}$$

S = area of test specimen (common to both rooms)

A = sound absorption of receiving room with test specimen in place (metric Sabins)

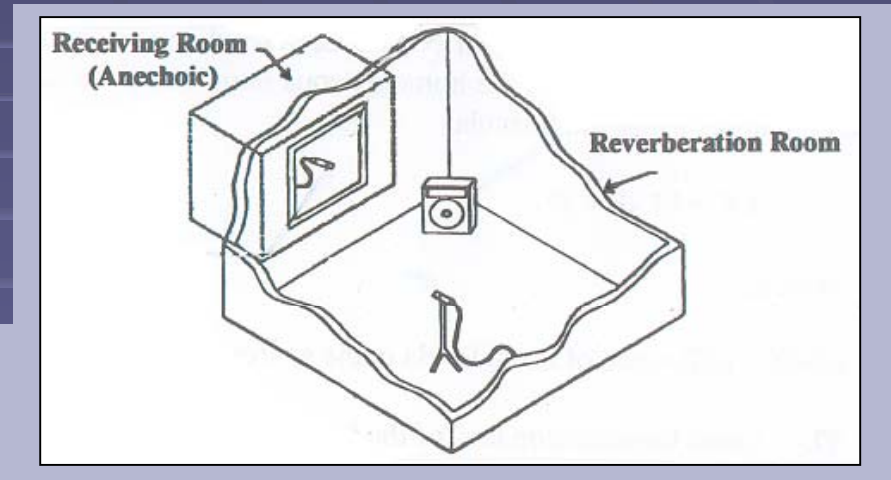
Measured pressure and energy in a diffuse reverberant room are comparable

Sound Transmission Loss

STL as measured by the Sound Intensity method:

Sound Intensity method incorporates a diffuse reverberant source room, and an anechoic receiving room, with the test panel between. The intensity method utilizes measured intensity in the anechoic chamber.

(Not Standardized)



$$STL = 10 \log \left[\frac{I_i}{I_t} \right]$$

$$I_i = \frac{P_{RMS}^2}{4\rho c}, \text{ incident normal intensity}$$

I_t = transmitted normal intensity averaged over the panel

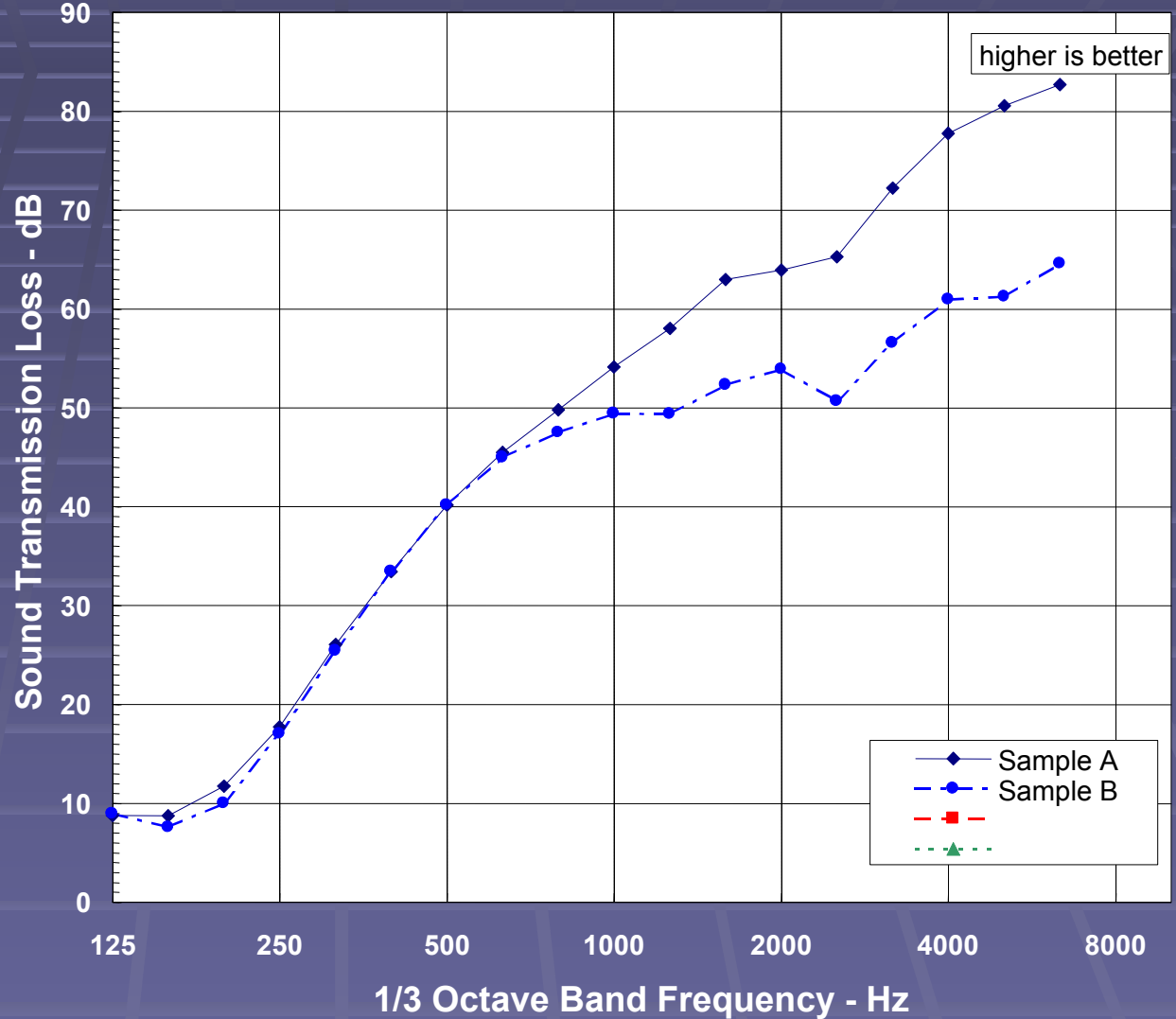
Sound Transmission Loss

Cautions/Advisories:

- Sealing
- Holes
- Air gaps
- Edge
- Importance of appropriate sample sizes and fit
- Environmental conditions:
 - Temperature, humidity, barometric pressure
- Room considerations
- Sample orientation

Sound Transmission Loss

Sound Transmission Loss per SAE J1400-90
Effect of Leakage on STL



Sample A

Sample B

0

0

Thickness (mm)

Reported

Measured

Mass (kg)

Reported

Measured

Test A

Description

Double wall sample - everything Normal
1a

Test B

Description

Same Double wall sample - no frame no
4a

Test C

Description

Test D

Description

Sound Transmission Loss

Insertion Loss and Noise Reduction \neq Sound Transmission Loss

Insertion Loss

The difference in sound pressure levels measured at a receiver location with and without the sound package treatment in place.

Noise Reduction

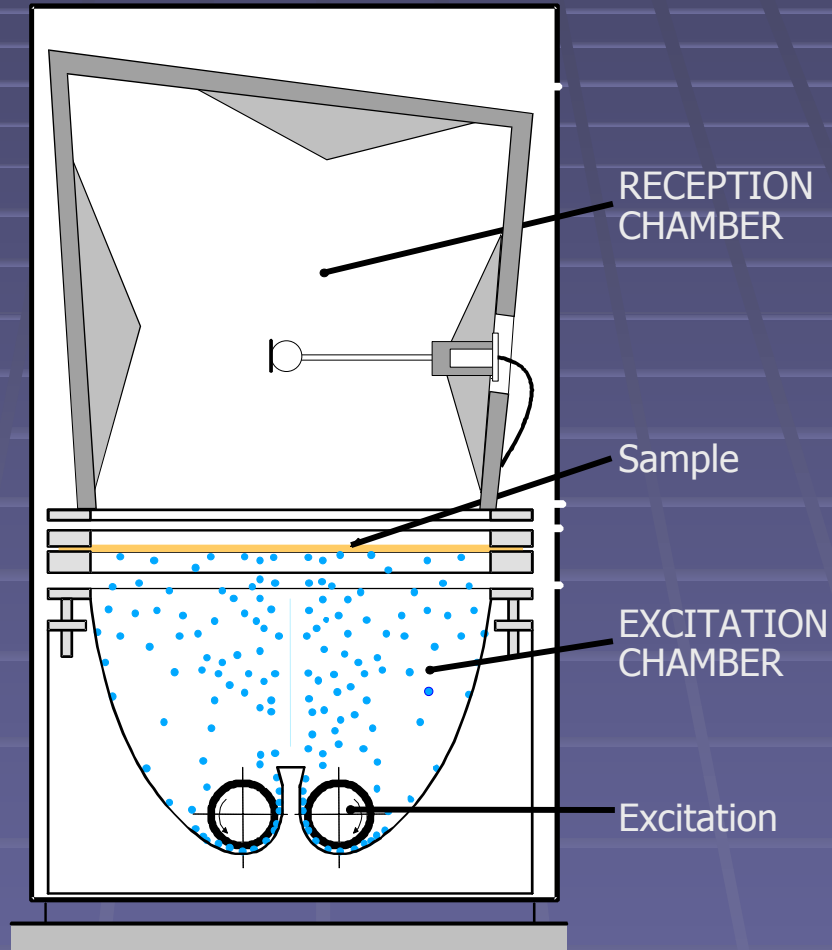
The difference in sound pressure levels measured on the source side and the receiver side of a sound package treatment (i.e. P-over-P).

Neither are Standardized

Insertion Loss

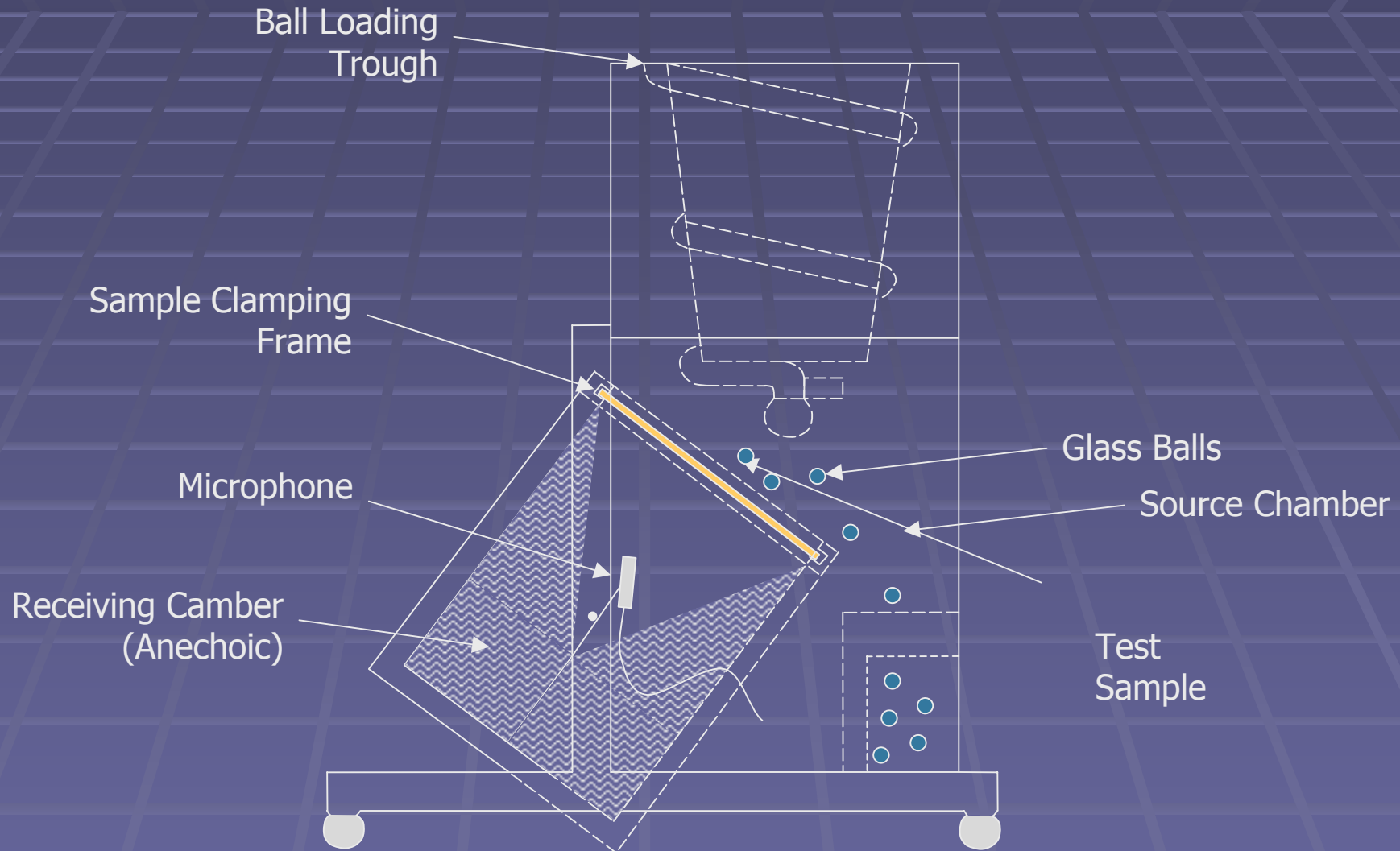
Schematic of an APAMAT II Device

Overall Acoustic Performance of Treatments



Insertion Loss

Schematic of an Acoustic Gravelometer



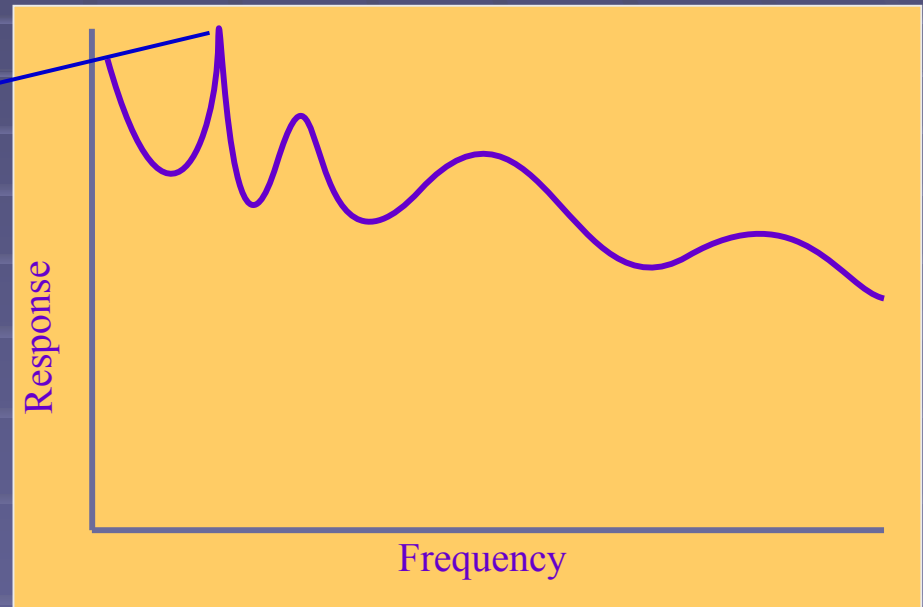
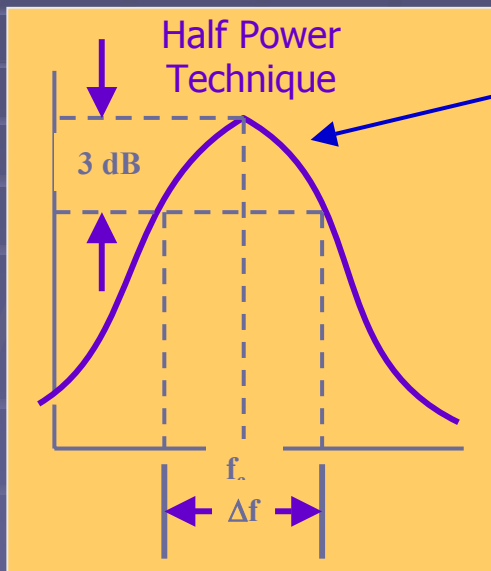
Damping

How are damping metrics communicated?

Damping loss factor (η) is the measure by which the amount of damping is determined. The loss factor is the ratio of the dissipated energy of the system to the entire energy of the system.

$$\eta = \Delta f / f_c$$

Damping Broadens Response Spikes



A higher loss factor ($\eta > 0.1$) means better damping

Damping

How is the damping loss factor measured?

SAE J1637 Method

Laboratory Measurement of the Composite Vibration Damping Properties of Materials on a Supporting Steel Bar

ASTM E756 Method

Standard Test Method for Measuring Vibration-Damping Properties of Materials

NOTE: SAE J1637 method prescribes the measuring of the composite loss factor, whereas ASTM E756 is for the measurement of the independent material.

SAE J1637 was developed after ASTM E756, but specifies the bar material, size, and mounting conditions which impact the results of the test.

∟ **Different Oberst bars provide different loss factor results** ∟

Damping

Measuring Material Damping Properties

- Excite the damped bar at ...
 - Particular modes of vibration
 - Temperatures of interest
- Determine the resonant frequency
- Measure the lower and upper frequencies (3 dB down from resonant frequency)
- Calculate Damping Loss Factor
$$\eta = \Delta f / f_c$$
- Repeat for other modes and temperatures of interest

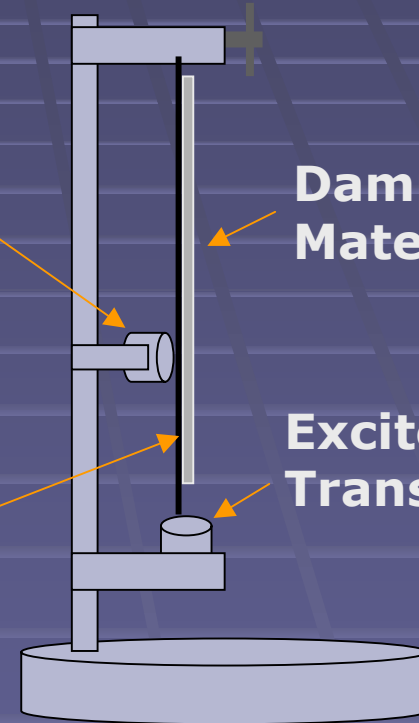
Motion Transducer

Steel Bar

Oberst Bar

Damping Material

Exciter Transducer



SAE J1637
ASTM E756

Damping

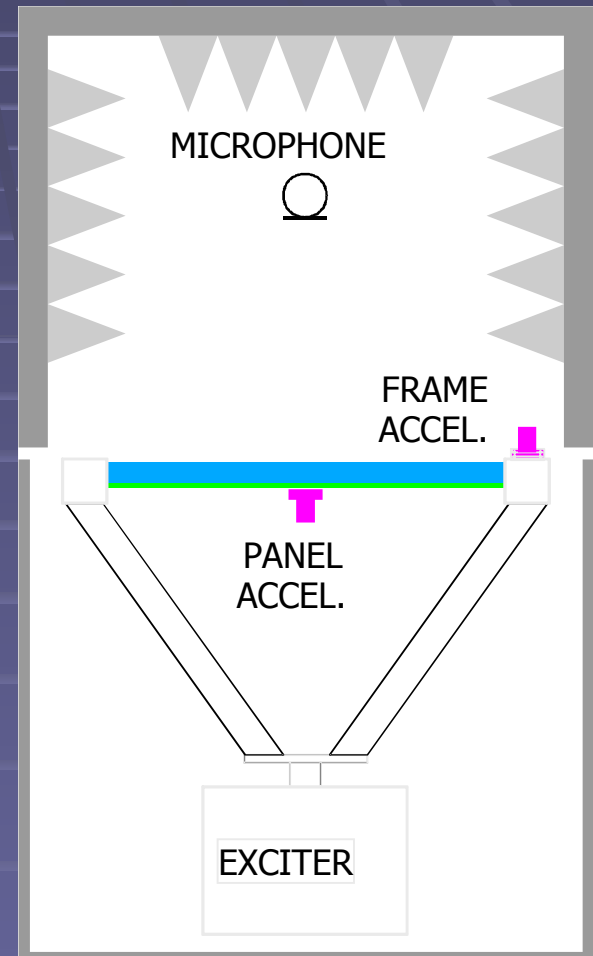
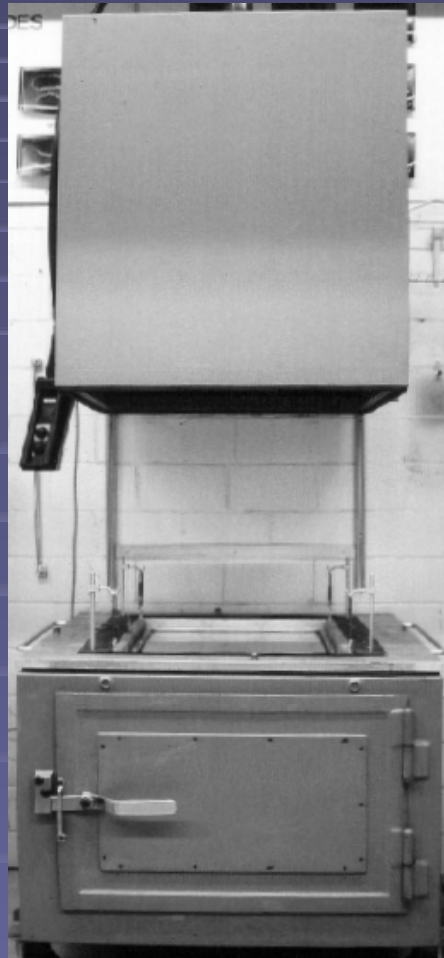
Schematic of an RTC III Test Fixture (Rayonnement des Toles de Carrosserie)

Radiation of Body Sheetmetal

Non-Standardized

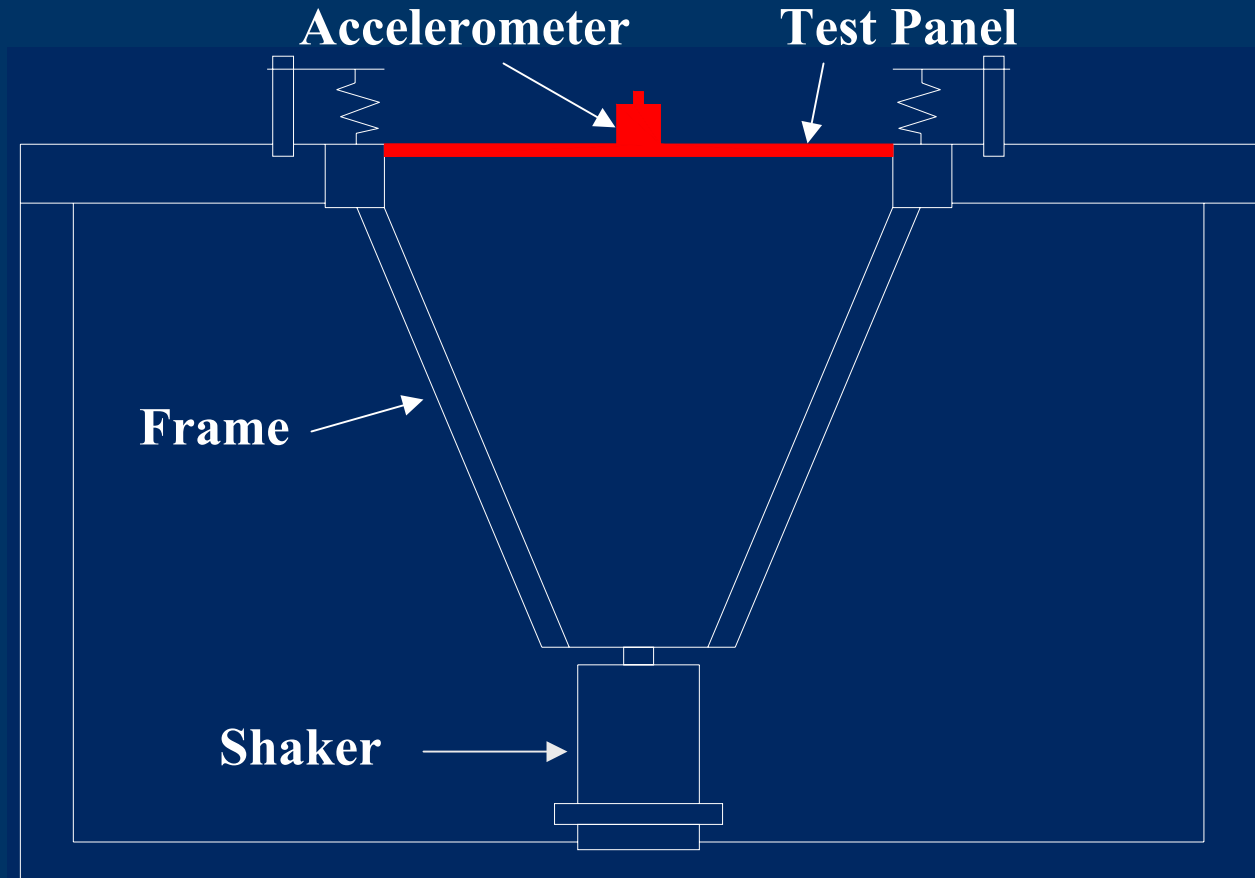
Performance of treatments regarding structure-borne excitation

Flat, Beaded and Curved plates



Damping

Schematic of another Panel Vibration Test Rig



Vibration Isolation

Test Fixture Used for Vibration Isolation Measurements

Non-Standardized

Loading Plate

Test Sample

Accelerometers

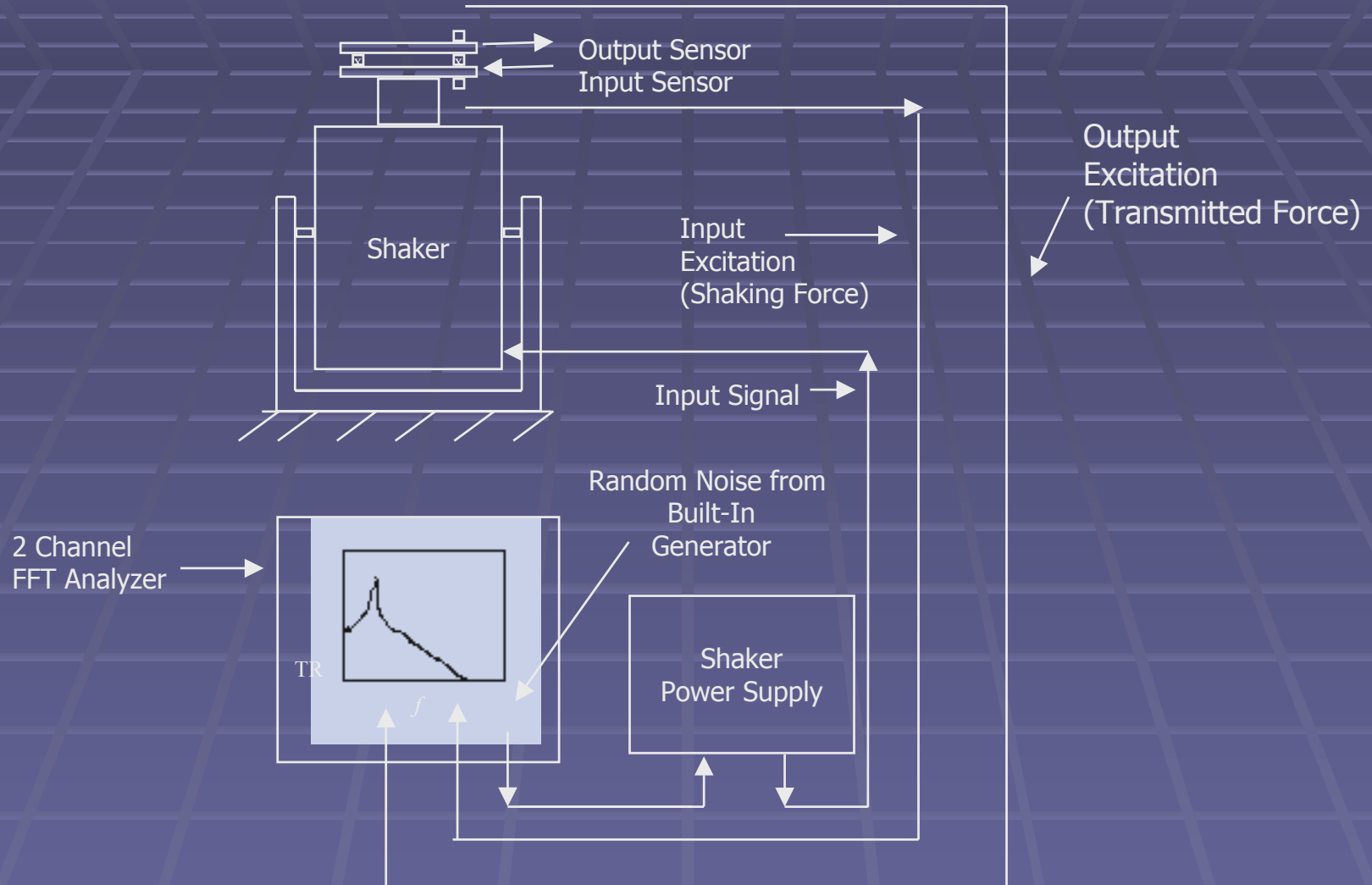
Holding Plate



Shaker

Vibration Isolation

Vibration Isolation Typical Test Set-up



NVH Material Questions

How can materials and data show benefits in the vehicle application?

This is the subject of Part III

Predicting the Performance of Acoustical Materials
Jerome E. Manning

Predicting the Performance of Acoustical Materials

Jerome E. Manning

Cambridge Collaborative, Inc.



Cambridge Collaborative, Inc.



Why Bother to Predict

Mathematical models allow performance and cost goals to be reached without expensive vehicle tests.

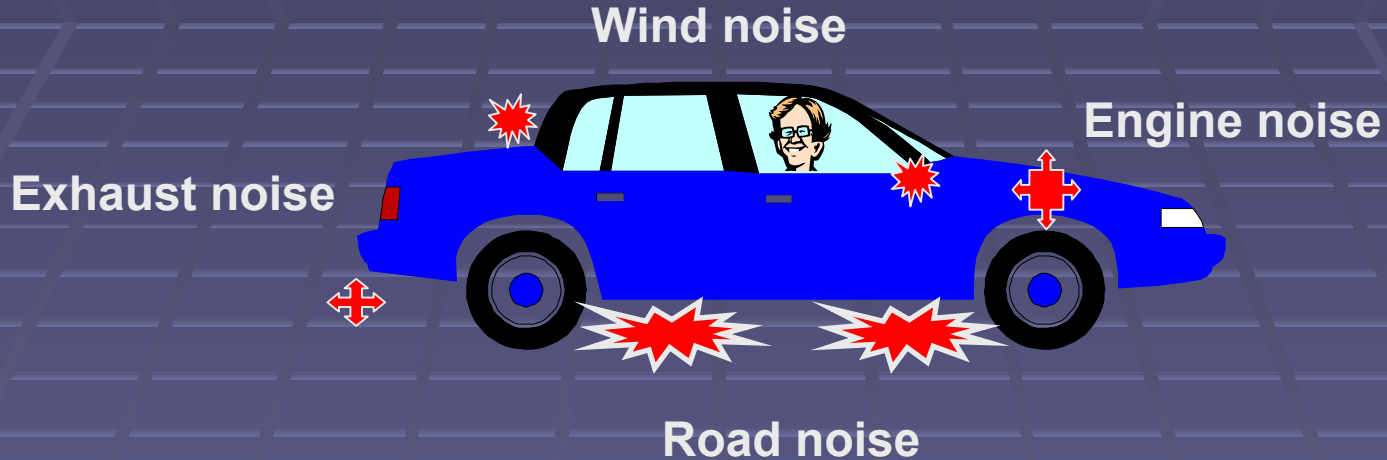
“What If” studies can be conducted easily and quickly.

Optimum designs can be achieved.

Challenge

- Can we predict vehicle noise using mathematical models?
- What acoustical material properties do we need to measure?
- What accuracy is expected?
- How should these models be used?

Vehicle Noise Sources



The sound package reduces noise inside the vehicle by using acoustical materials to increase sound absorption and decrease sound transmission.

Prediction Model Overview

Acoustic

Absorbers

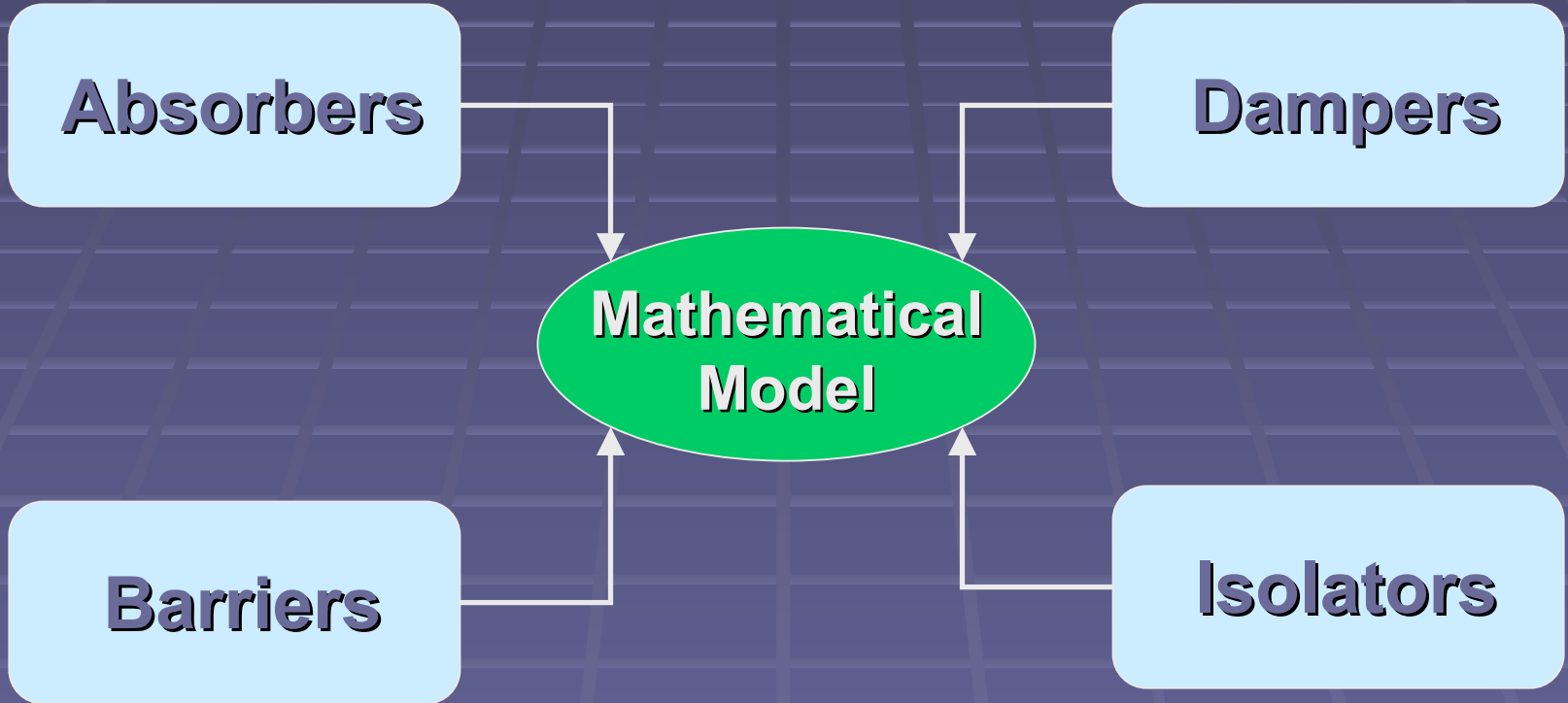
Vibration

Dampers

**Mathematical
Model**

Barriers

Isolators



Prediction Technique Overview

Finite Element / Boundary Element Analysis

Low frequencies - below ~ 200 Hz for vehicle NVH
Difficult to model damping and absorption

Statistical Energy Analysis

High frequencies - above ~ 200 Hz for vehicle NVH
Provides only a statistical estimate of response

What is FEA?

Finite

Divide the vehicle structure and acoustic spaces into a large number of small finite elements.

Element

Use mathematical models to represent displacements within each element.

Analysis

Study the effect of geometry and material properties on vehicle noise at selected locations and frequencies.

What is SEA?

Statistical

Take a statistical approach to the description of systems and their dynamic properties.

Energy

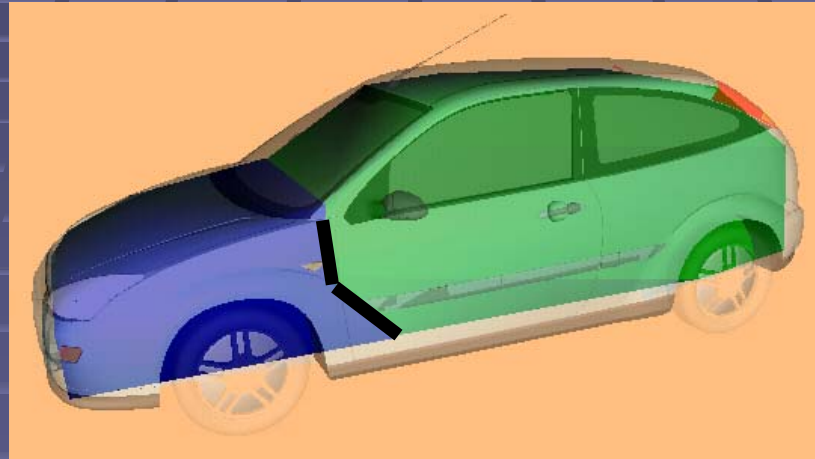
Follow the flow of structural and acoustic energy through the system.

Analysis

Provide a framework for the study of dynamical systems.

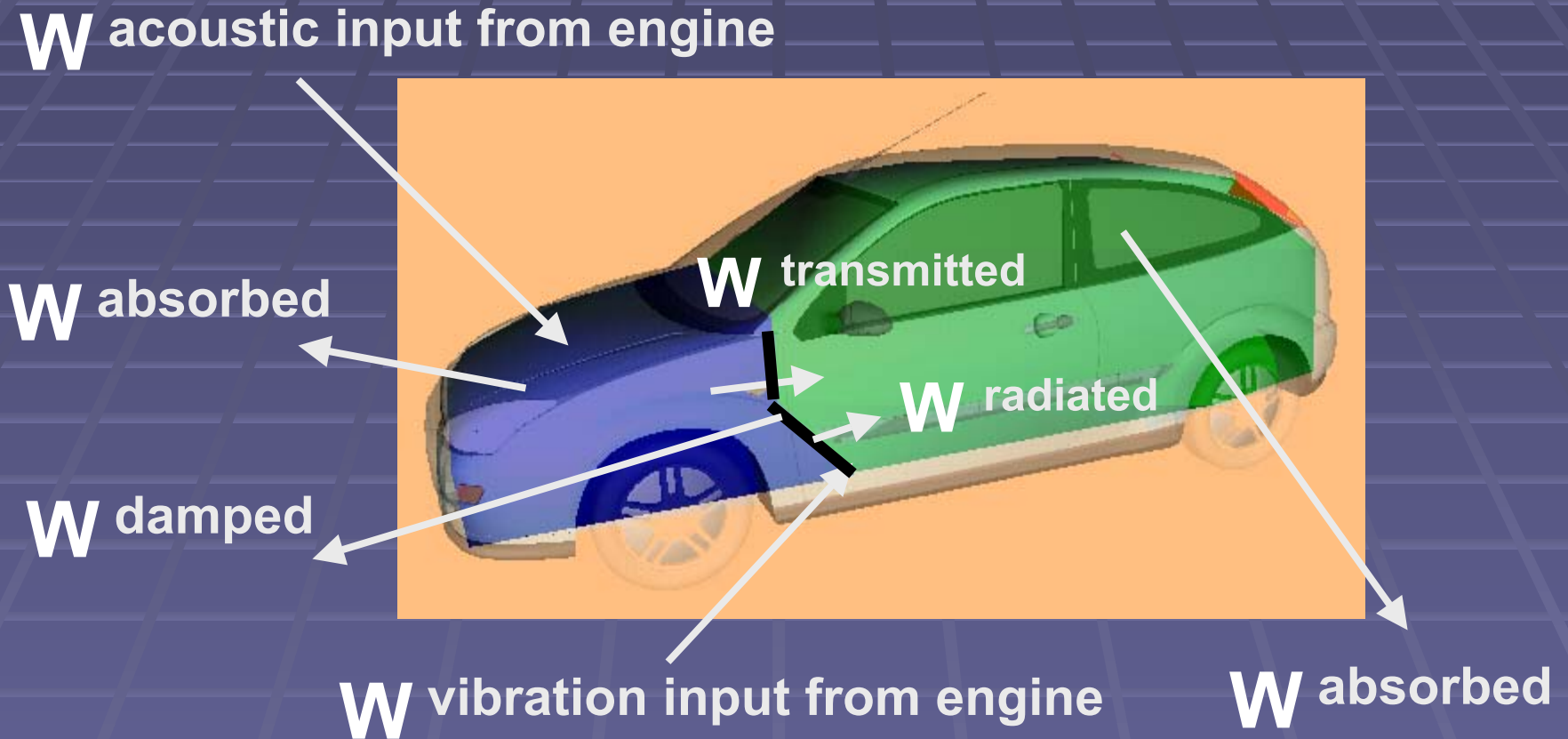
Example: Vehicle Engine Noise

The engine is a source of acoustic energy.



Three energy storage subsystems are used:
Engine space, dash structure, passenger space.

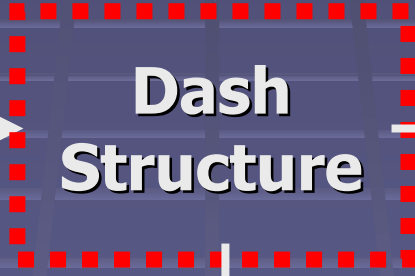
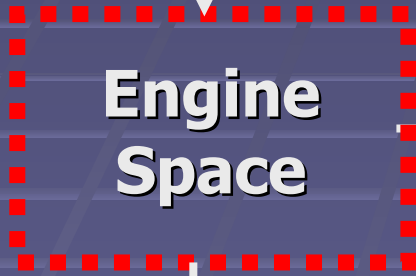
Engine Noise SEA Model



SEA Power Balance

acoustic power
radiated by engine

vibration power
through engine
mounts



power dissipated
by hood liner

power dissipated
by vibration
treatment

power dissipated
by interior sound
package



SEA Acoustic Energy Dissipation

The absorption coefficient, α , controls the dissipation of acoustic energy in an acoustic space.

$$W_{\text{diss}} = \left[\frac{c_o A}{4V} \right] \alpha_{\text{absorption}} E_{\text{acoustic}}$$

SEA Vibration Energy Dissipation

The damping loss factor, η , controls the dissipation of vibration energy of a structure.

$$W_{\text{diss}} = \omega \eta_{\text{damping}} E_{\text{vibration}}$$

SEA Coupling Loss Factors

The coupling factor, η , controls the power flow between connected subsystems.

$$W_{\text{trans}} = \omega \eta_{s;r} E_s - \omega \eta_{r;s} E_r$$

The coupling factor is related to the transmission coefficient, t , and the transmission loss, TL.

$$\eta_{s;r} = \left[\frac{c_s S_{s;r}}{4\omega V_s} \right] \tau$$

$$TL = 10 \log_{10} \frac{1}{\tau}$$

Set of Linear SEA Equations

Power Balance for engine compartment, e

$$(\eta_e + \eta_{e;d} + \eta_{e;p})E_e - \eta_{d;e}E_d - \eta_{p;e}E_p = \frac{1}{\omega} W_e^{\text{input}}$$

Power Balance for dash structure, d

$$(\eta_d + \eta_{d;e} + \eta_{d;p})E_d - \eta_{e;d}E_e - \eta_{p;d}E_p = \frac{1}{\omega} W_d^{\text{input}}$$

Power Balance for passenger space, p

$$(\eta_p + \eta_{p;d} + \eta_{p;e})E_p - \eta_{d;p}E_d - \eta_{e;p}E_e = 0$$

SEA Model Accuracy

Prediction Accuracy is controlled by

- *The accuracy of power inputs from sources*
- *The accuracy of sound package absorption and transmission loss properties*
- *The accuracy of material properties*
- *The modal overlap factor*

Modal Overlap Factor

$$\text{MOF} = \frac{\pi}{2} N_{\text{modes}} \eta_{\text{damping}}$$

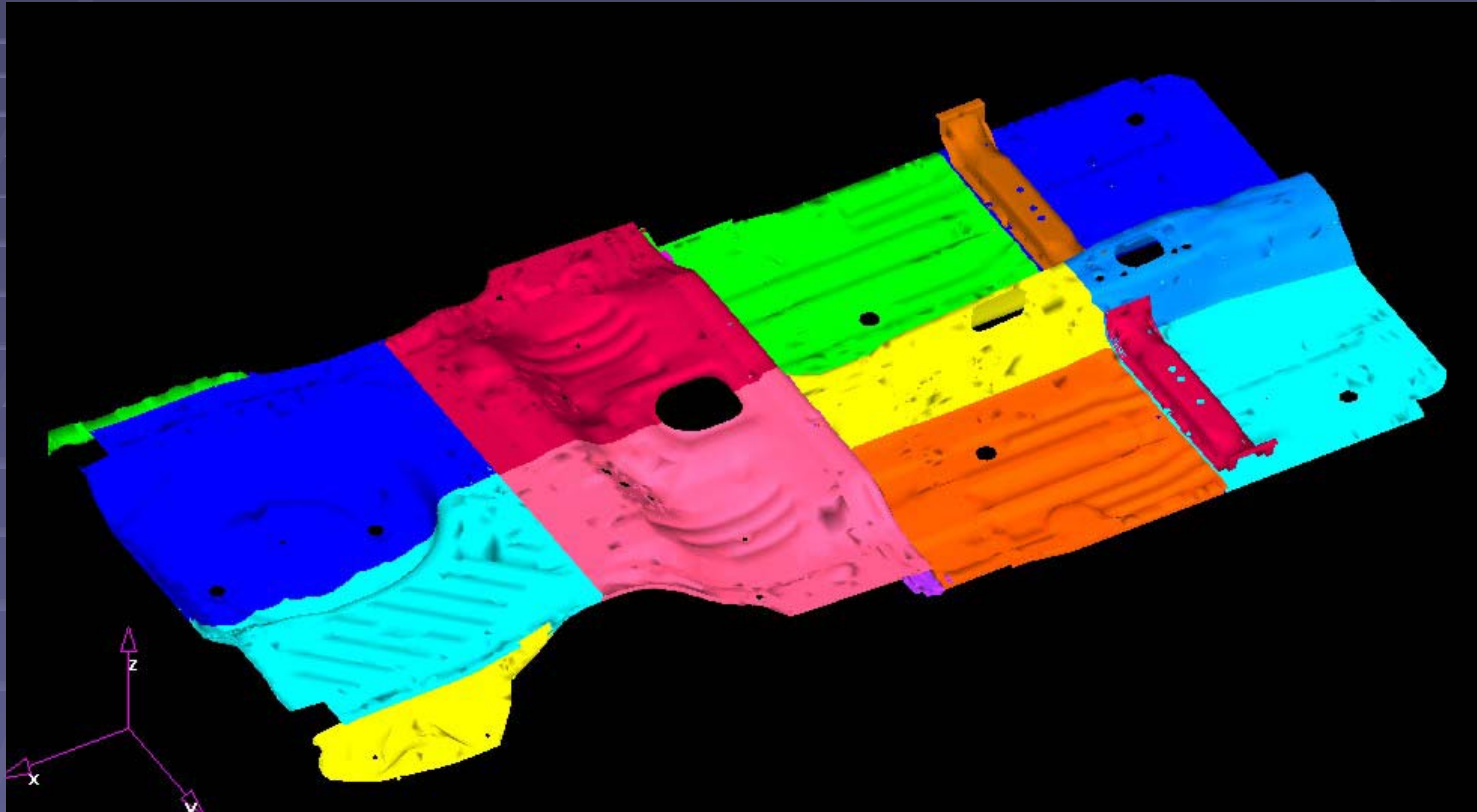
N_{modes}

The number of modes

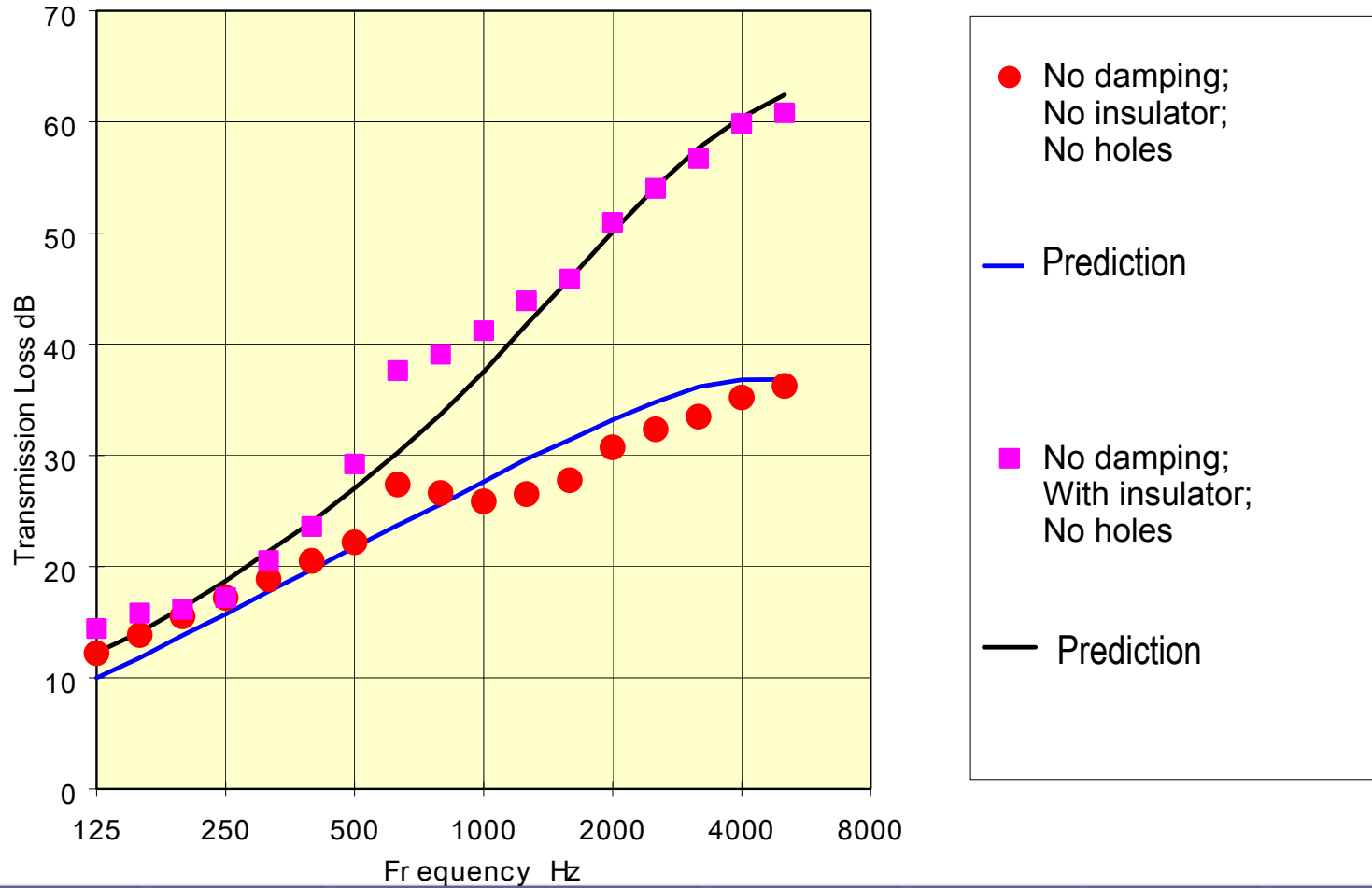
η_{damping}

The effective damping

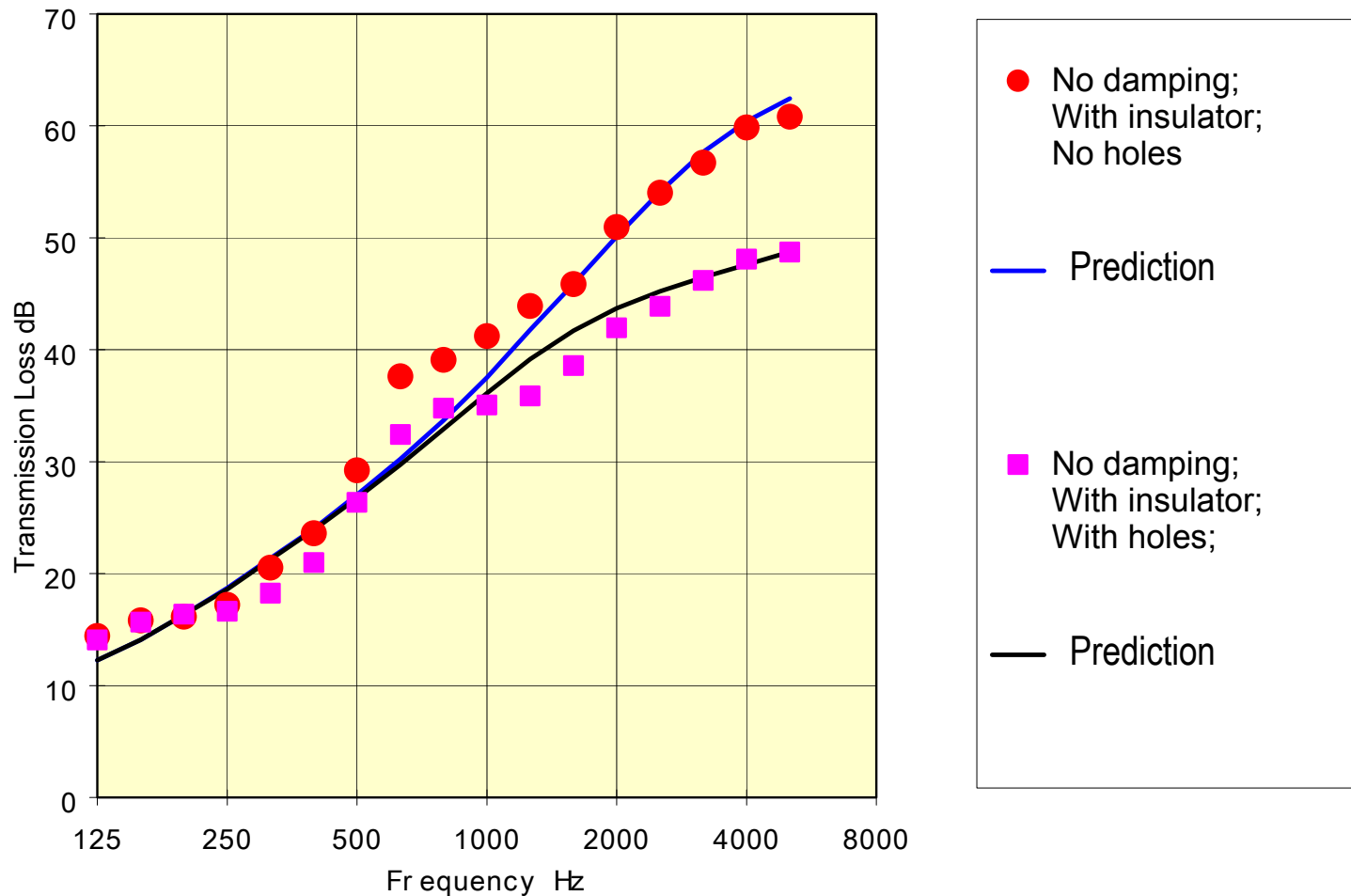
Vehicle Floor SEA Subsystems



Vehicle Transmission Loss



Effect of Penetrations (Holes)



Model Development Time

- Simple SEA models to predict component sound transmission loss.

 1 to 3 days

- Models to predict airborne noise.

 3 to 4 weeks

- Complete vehicle models with both airborne and structure-borne noise paths.

 2 to 3 months

Conclusions

- We can predict vehicle noise using mathematical SEA models.
- Accurate prediction requires accurate measurement of acoustical material properties.
- Accuracy of 3 dB in 1/3 octave bands is expected.
- Models are best used for parameter studies.

Challenge

- Do results from material measurements correlate with results from component and vehicle measurements?
- If not, can we explain why?