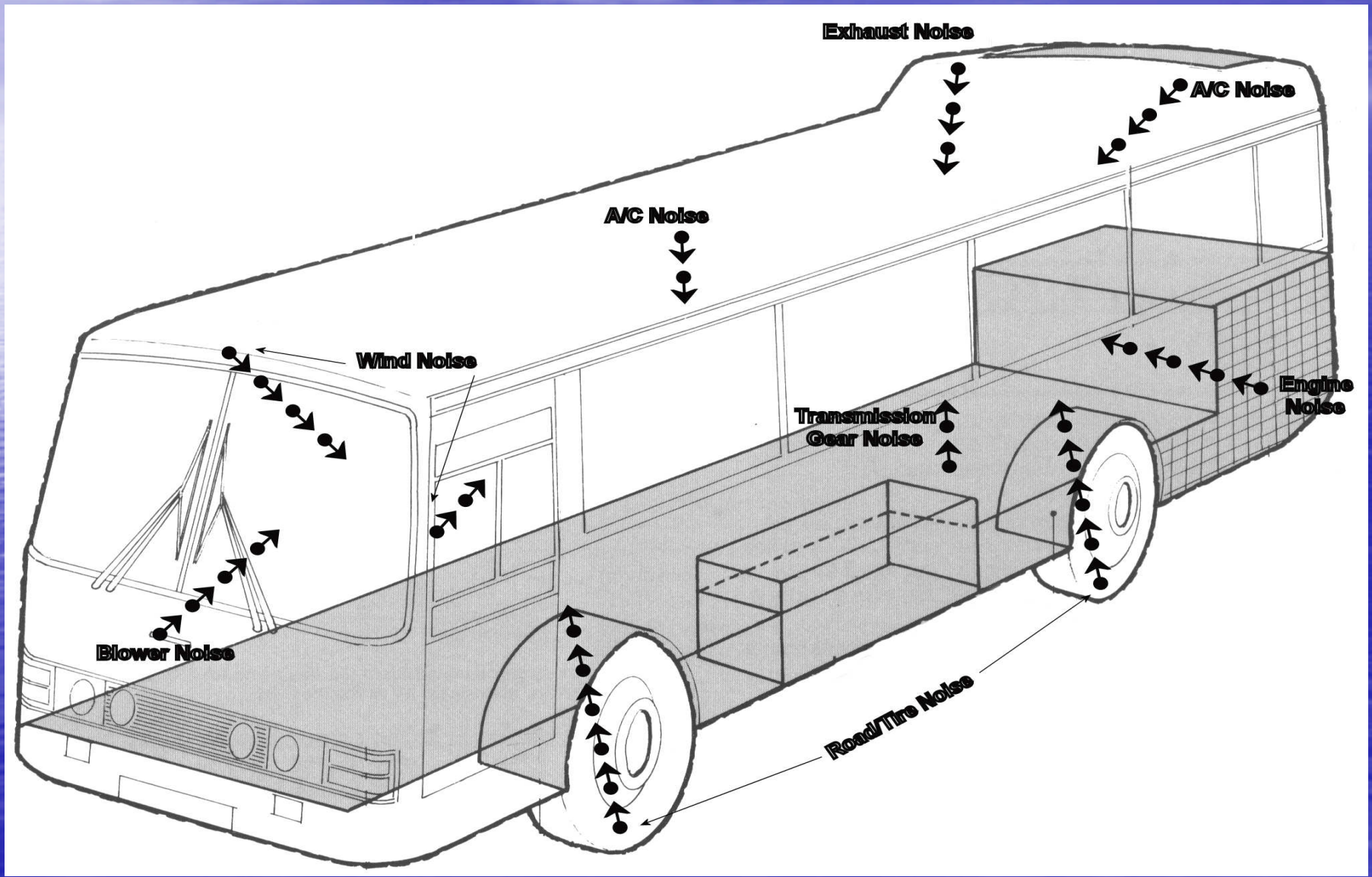
Lightweight, non-flammable noise-control methodology for transit vehicles

Peter Jackson
Technical Director
American Acoustical Products

Transit Vehicle Noise

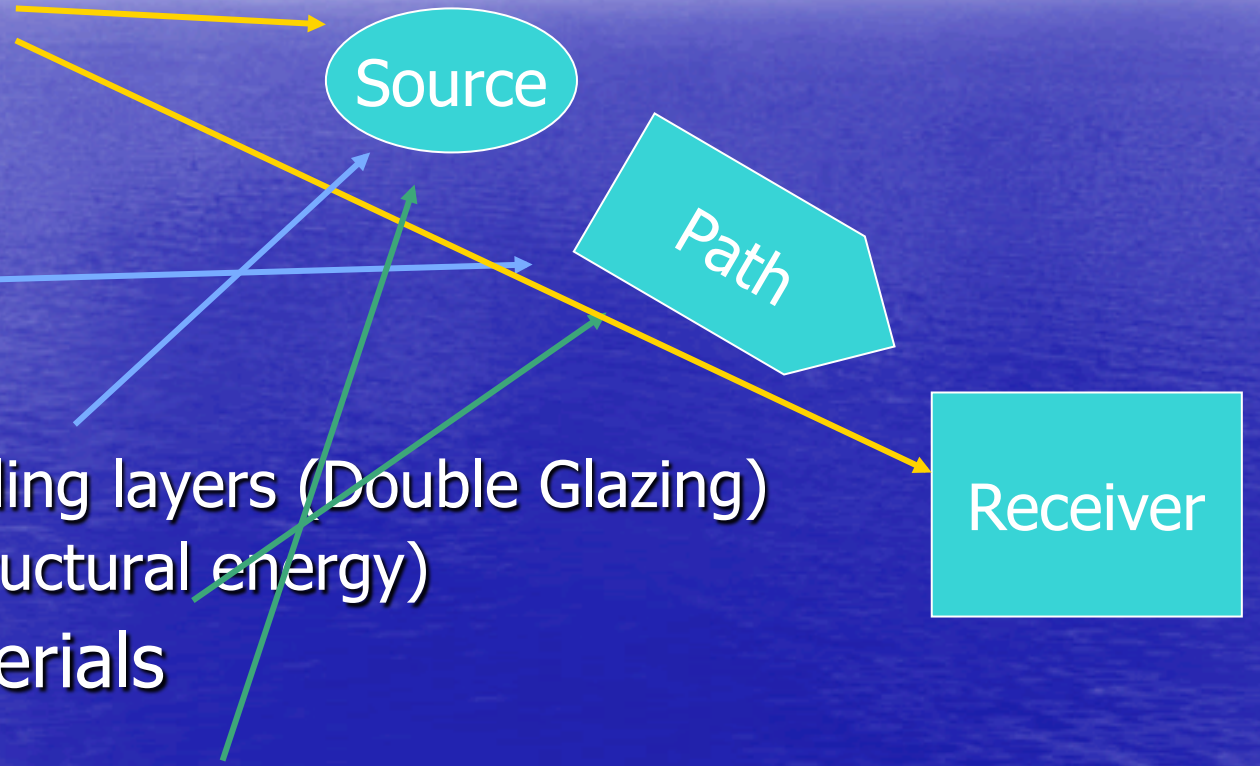


Acoustic Methodology
Design for silence

- Treat Source of Noise
- Treat Noise Paths
- Treat Receiver Environment

Acoustic Materials

- Absorbers
  - Basic
  - With cavities
- Barriers
  - Simple
  - With decoupling layers (Double Glazing)
  - Isolators (structural energy)
- Damping Materials
  - Extensional
  - Constrained Layer



Treat Source of Noise

- Usually Most Cost Effective in Long Run
  - One Source Many Paths
- Vibration Isolation
- Acoustical Shielding
- Sound Absorption

Noise Sources

- Engine Intake and Exhaust
- Engine Cooling Fan
- Tire or Rail Noise
- Compressors and Blower Noise
- HVAC Noise
- Wind Noise

Engine Intake and Exhaust

- Engine Firing Frequency
- Reactive Muffler
- Tuned Side Ports for Specific Frequencies
- Intake Air from Outside Engine Compartment
- Exhaust Gas Away from Sensitive Direction

Engine Cooling Fan

- Decouple from Engine
- Swept Blades (Avoid Pure Tones)
- Avoid Struts close to blades (Avoid Turbulence)
- Control Fan Speed (N)
  - SPL ∞ $N^{5 \text{ or } 6}$
  - Q (volume) ∞ N and Size
  - P (Pressure) ∞ N^2

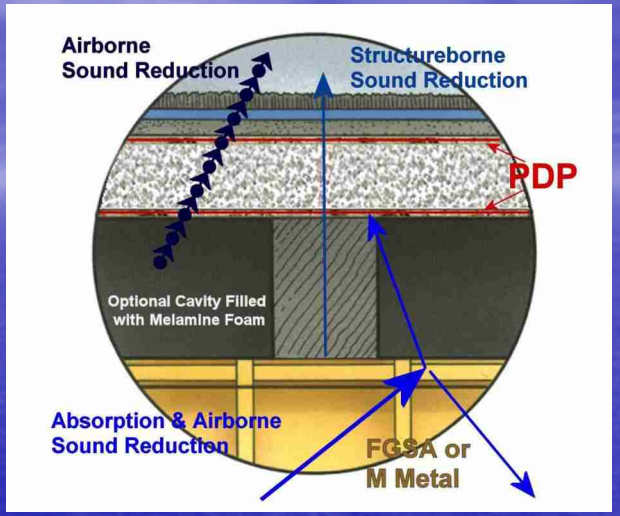
Flammability Issues with Foam Products

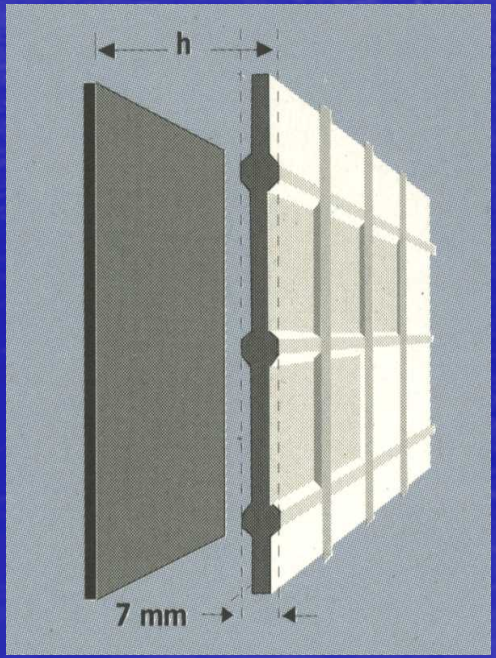
Engine Compartment Absorption

- Cover about 60% of free surfaces
- Spaced Absorber on common wall/floor areas for enhanced Transmission Loss

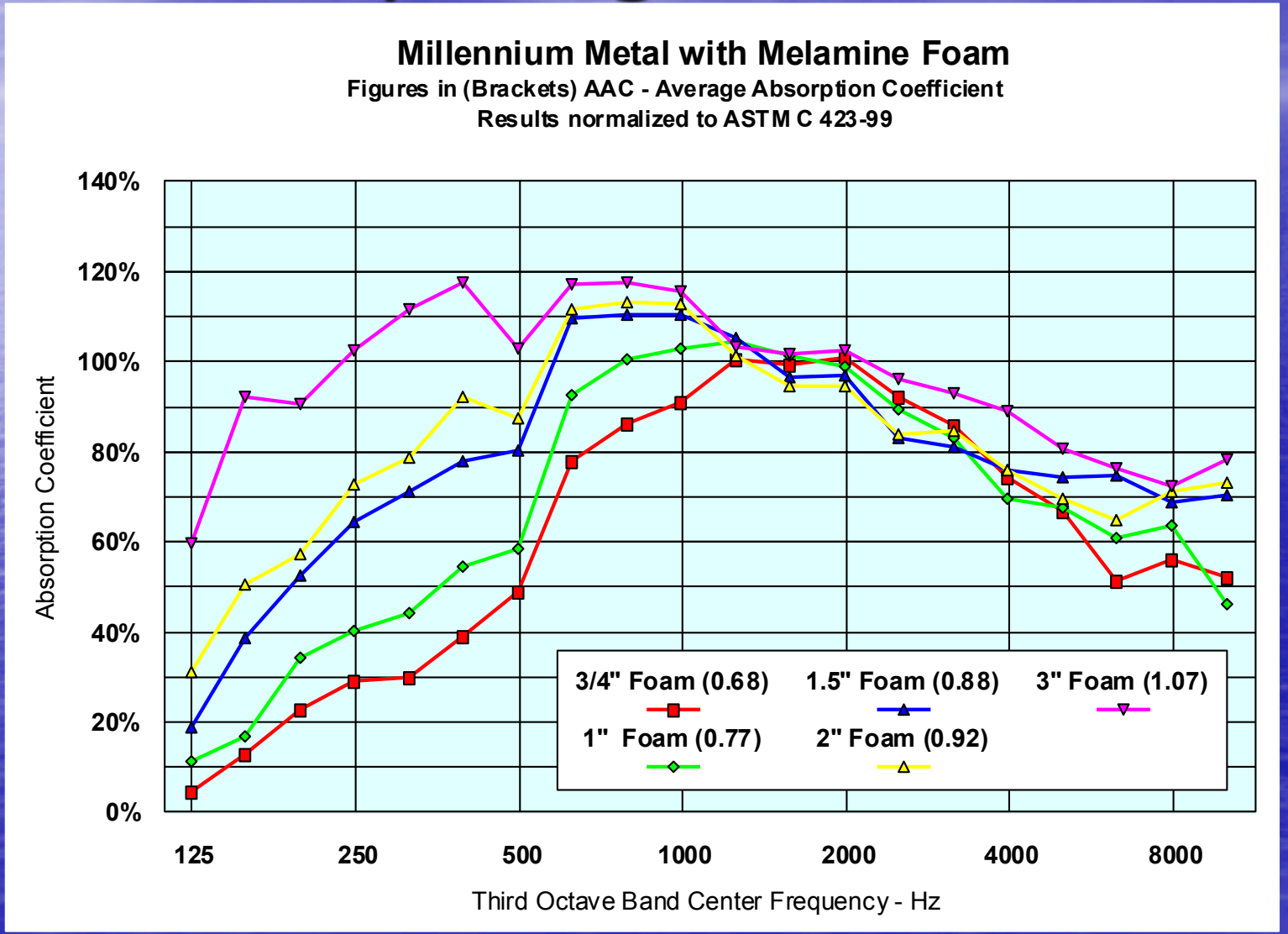
Spaced Absorbers

- Enhanced Low Frequency
- Decoupled Impedance
- FGSA – Film facing
- Millennium Metal
- Foam in Cavity –Further Enhances Low Frequency





Effect of Spacing



Wheel and Tire Noise

- Noise Mechanics
  - Air Displacement
  - Tire Tread Block Impact
- Regular Pattern Creates Tones
- Tread Designed to Lay Down not Impact
- Rubber Compound to be High Resilience

Blower Noise

- Driver Noise Requirement [75dB(A)]
- Fan Speed Reduction
  - SPL ∞ (Fan Speed)$^{5 \text{ or } 6}$
- Smoother Airflow
- Larger Fans(= Slower for same duty)
- Heated Glass Instead of demisting Blowers

HVAC Noise

- Decouple Compressor from Engine
- Control Fan Speed
  - SPL $\propto N^{5 \text{ or } 6}$
  - $Q \propto N$
  - $P \propto N^2$
- In Duct or Plenum Absorption Materials
- Move Air Return to Floor Level (85dB(A) Limit in Cabin)

Wind Noise

- Design
  - Aerodynamic Mirrors
  - Avoid Sharp curves
  - Add spoilers to deflect flow from weak areas
- Window Seals
- Door Seals - double or triple
- Double Glazing and or laminated Safety Glass

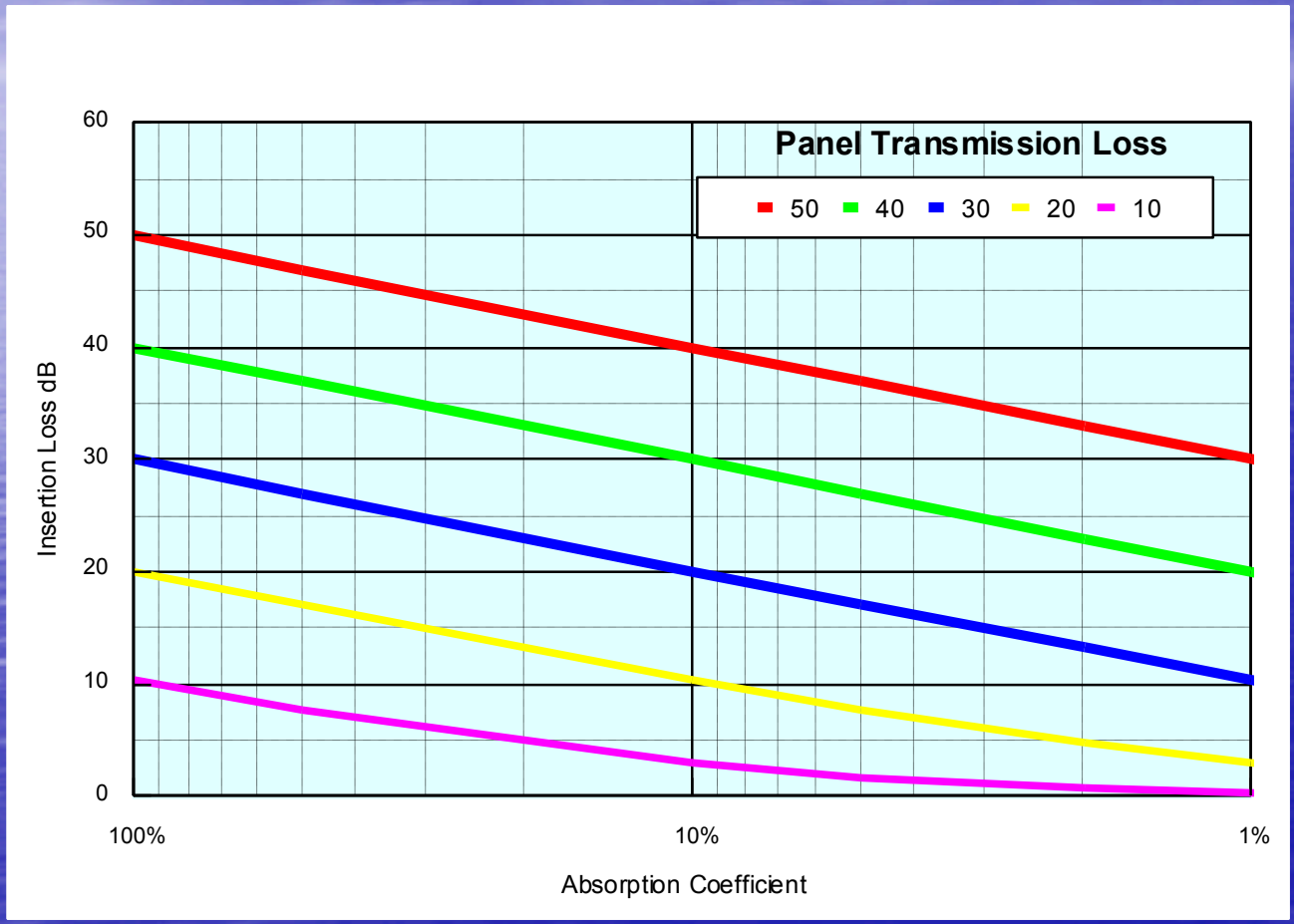
Acoustic Methodology
Design for silence

- Treat Source of Noise
- **Treat Noise Paths**
- Treat Receiver Environment

Noise Path

- Sound Absorption
- Close off all holes and pass-through areas
- Mass Controlled Attenuation
- Bending Wave reduction
- Vibration Isolation
- Vibration Attenuation

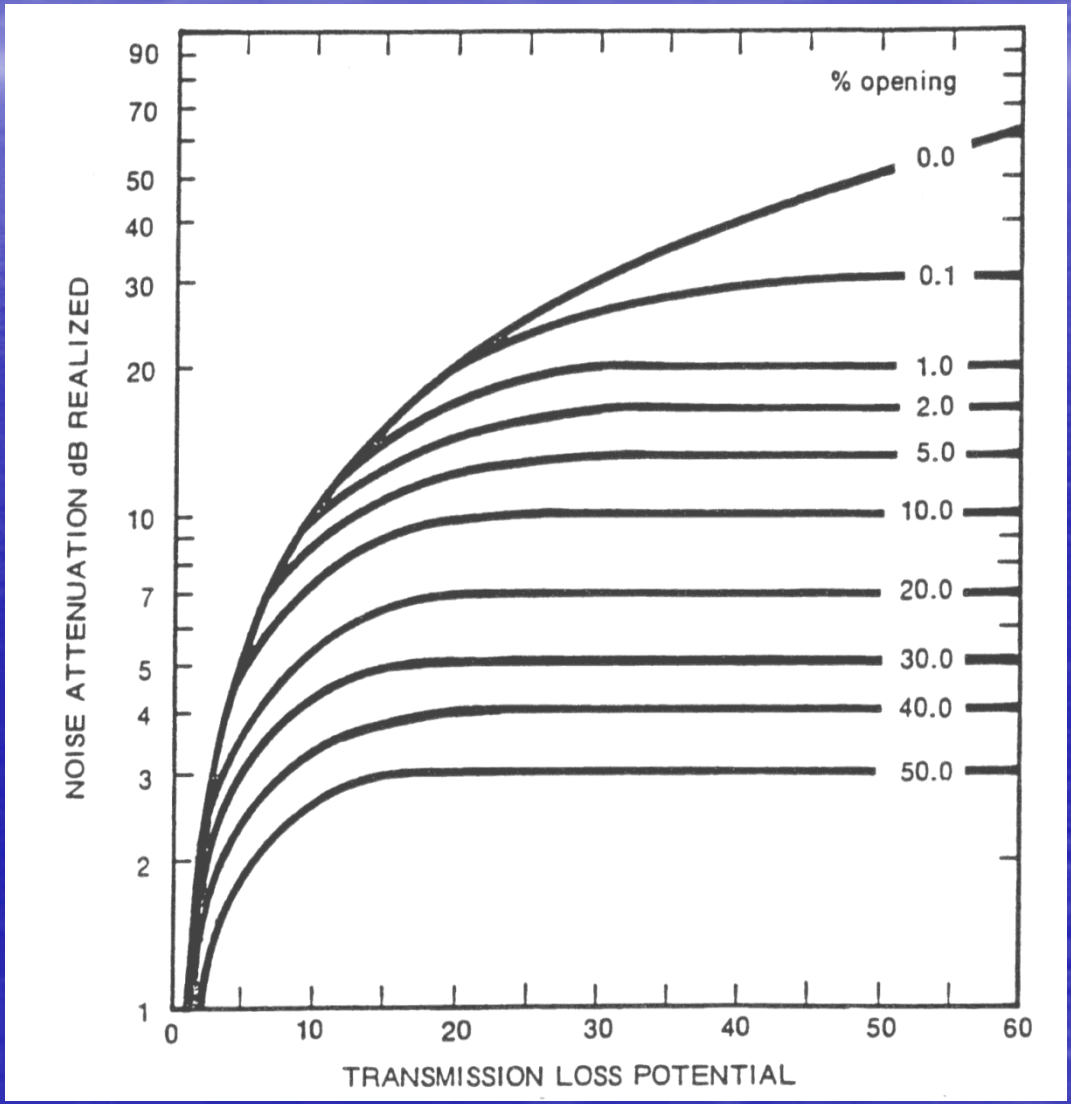
Effect of Absorption on Insertion Loss



IL = TL + 10*log (alpha + Tau) where Tau = $1/(10^{TL/10})$

Effect of Holes on Sound Transmission

- STL is limited by holes
  - 0.1% 30dB
  - 1% 20dB
  - 10% 10dB

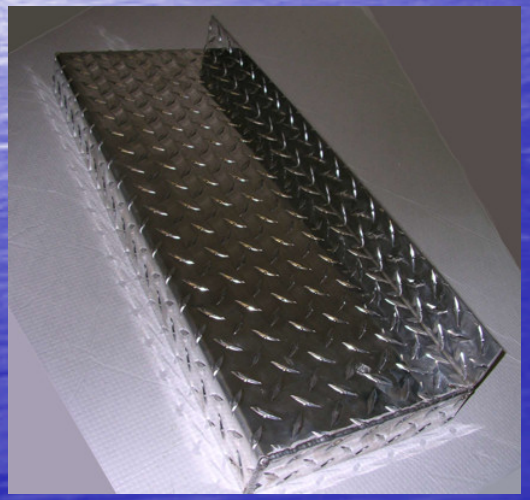


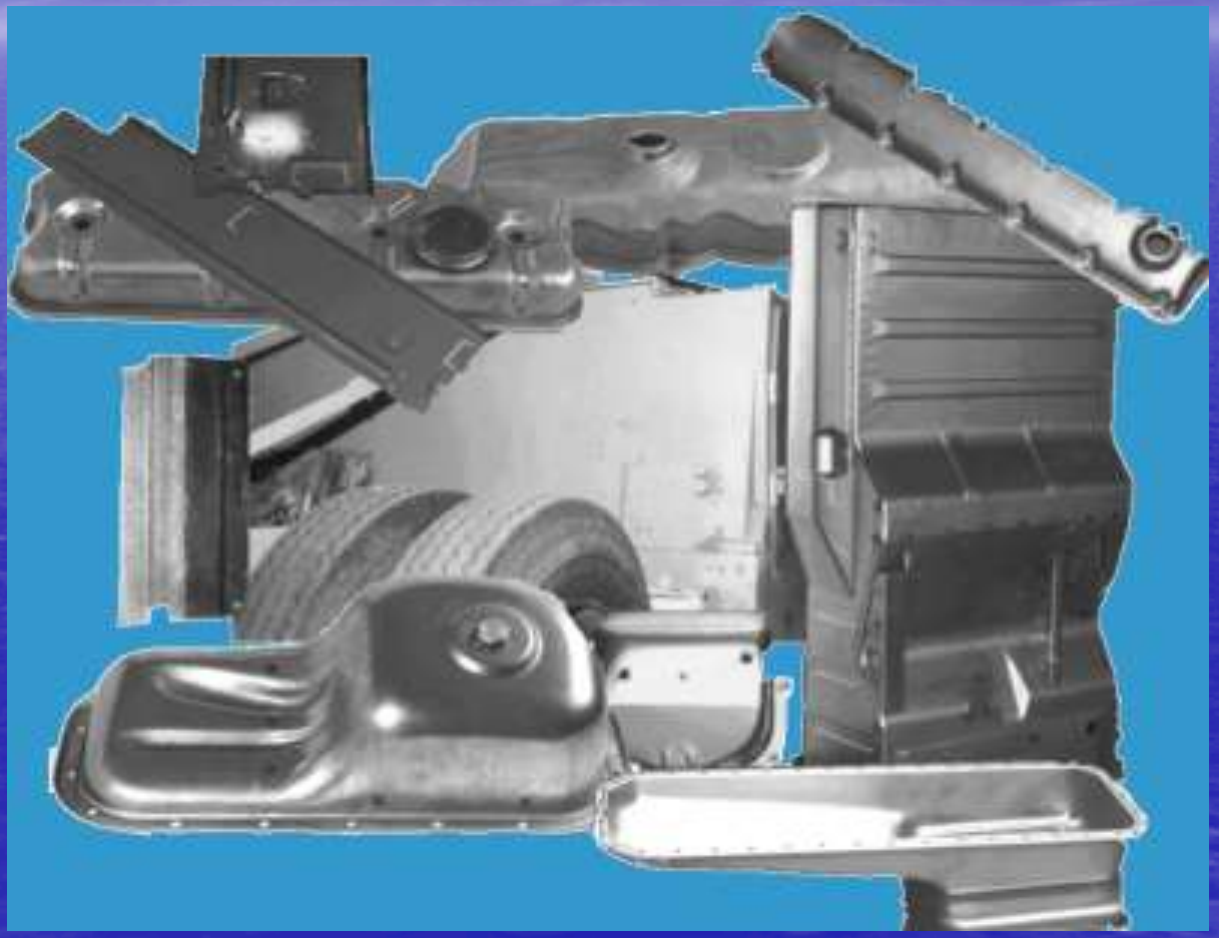
Damping

- Extensional Damping
  - Modulii Mismatched
  - Excessive Amounts Required
  - Material Exposed – Flammability Durability etc
- Constrained Layer Damping
  - Viscoelastic Material at or Near Neutral Axis
  - Constraining Layer Matches Bending Stiffness of Structure

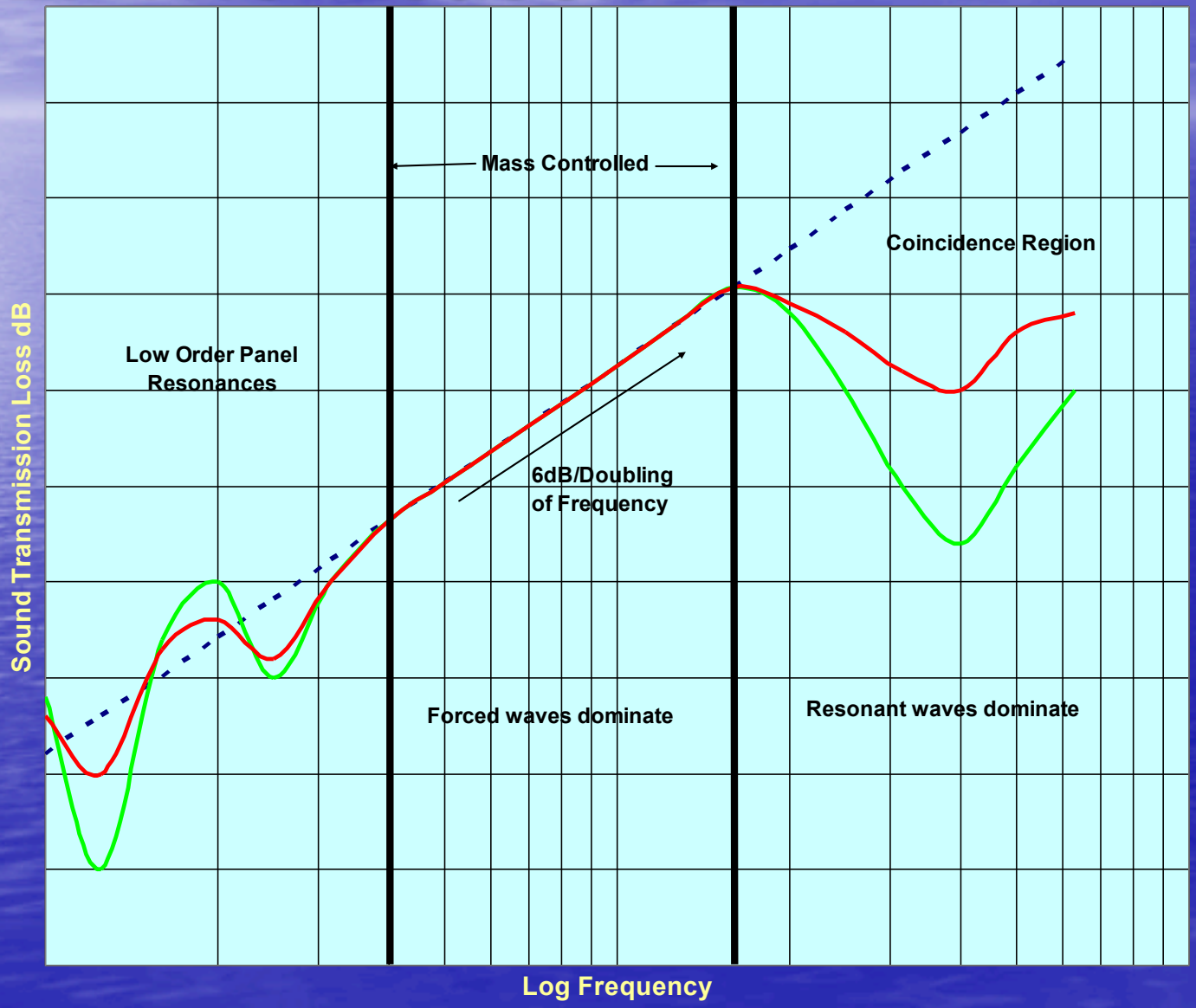
Noiseless Metal

- Formable
- Paintable
- Weldable

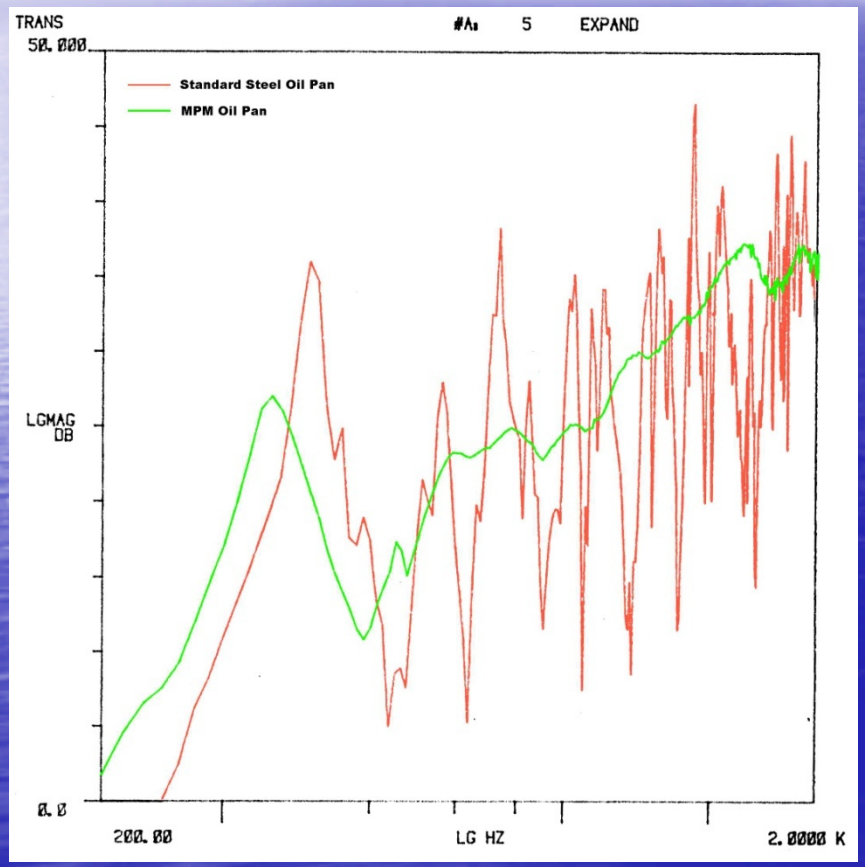


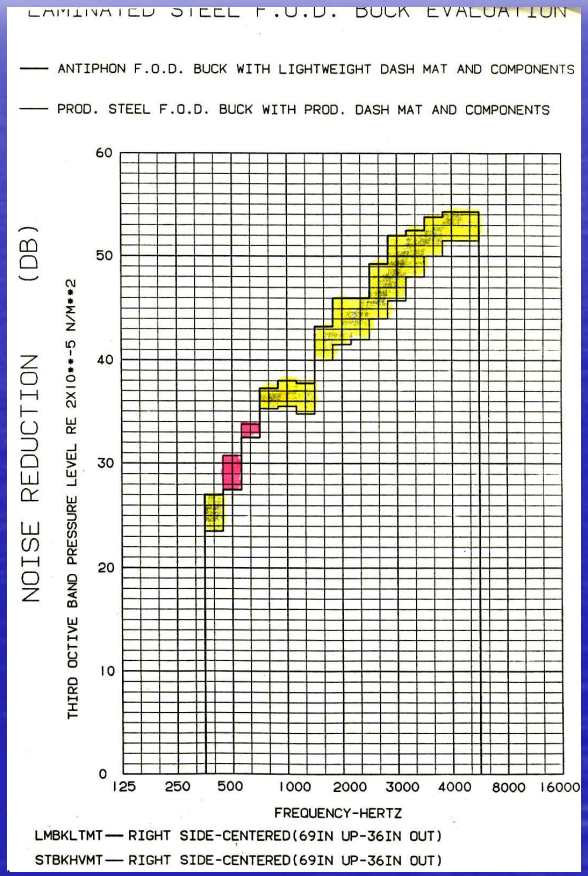


STL: The Reason



Noiseless Metal Acoustics



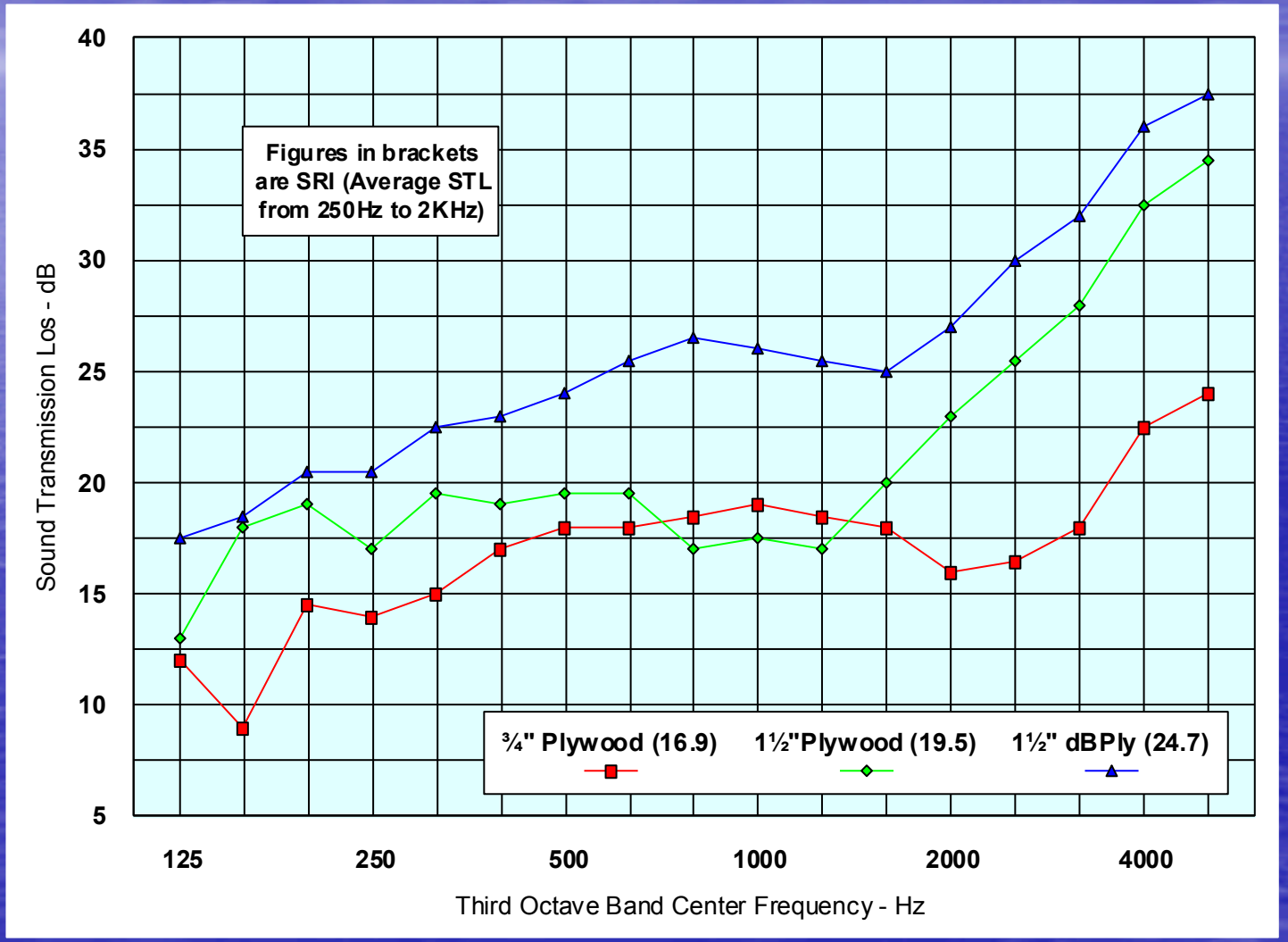


Plywood Floor Transmission Loss

¾" Plywood

1½" Plywood

1½" dBPly



PDP

- Noiseless Fiberglass
- Encapsulated to Protect Inner Layer
- Apply to relatively Flat areas Only
- Improves STL
- Absorbs Structural Noise Energy

Foam Cored Panels

Before

10mm(3/8″) Fiberglass

60mm (2 3/8″) Divinicell

10mm(3/8″) Fiberglass

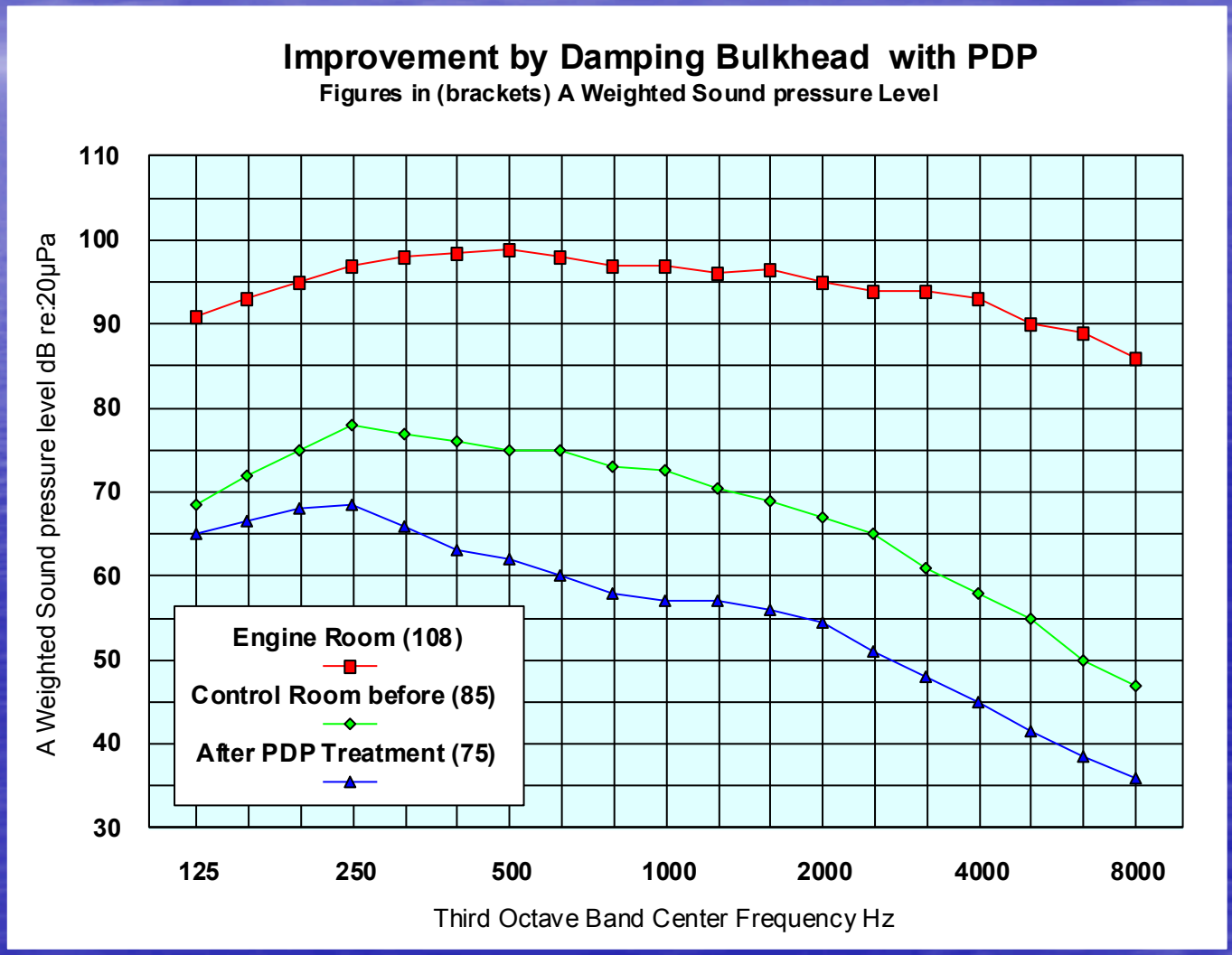
After

2 x 10mm(3/8″) Fiberglass

PDP

60mm (2 3/8″) Divinicell

10mm(3/8″) Fiberglass



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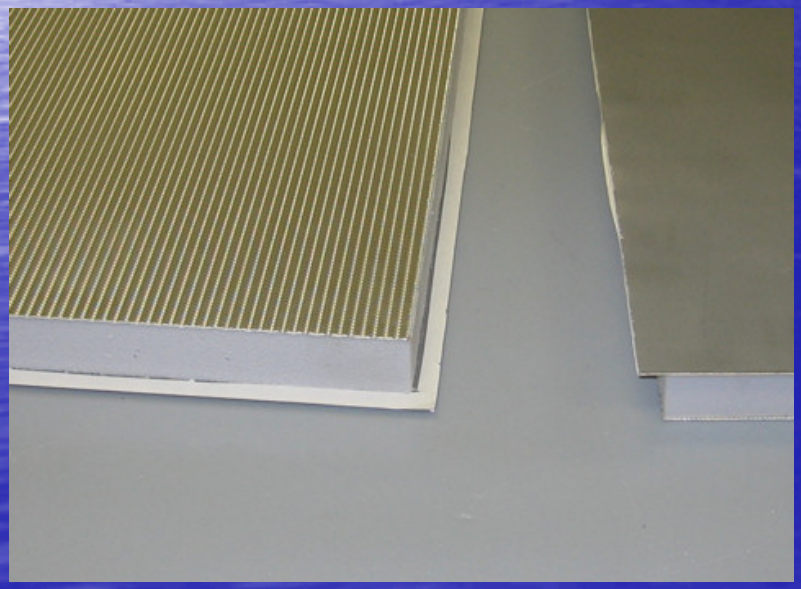
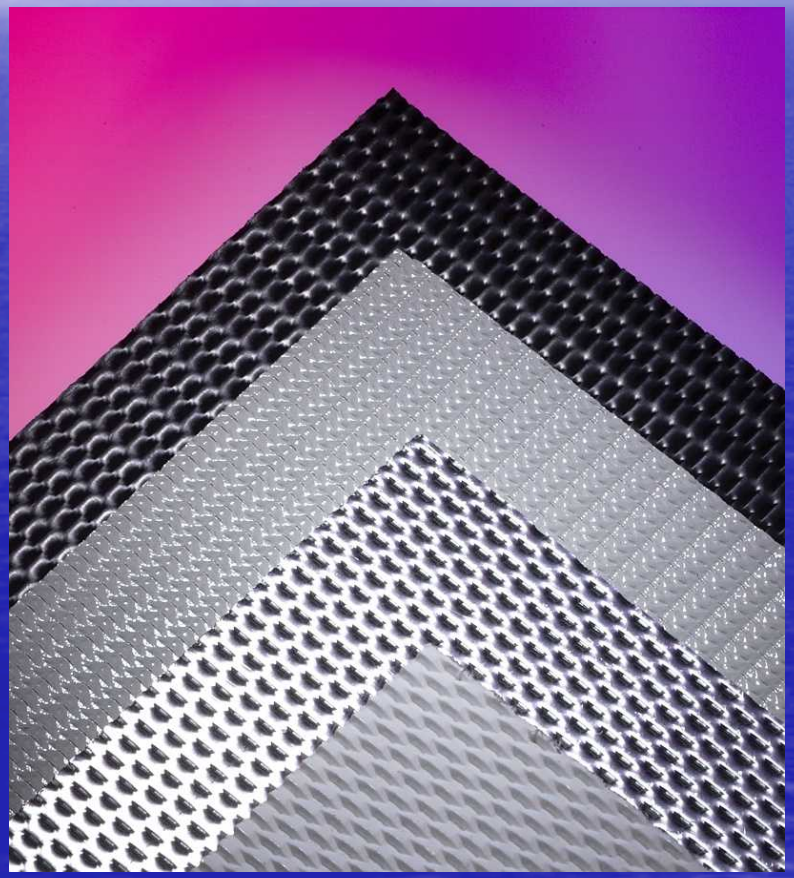
Absorption

- Close to Driver – Additional Absorption and Screening
- Absorption panels in walls and ceiling of main cabin
- Absorptive Seating – Melamine foam for smoke and fire suppression

Millennium Metal

- Tough Durable Facing
- Optimized Acoustics
- Structural Panel





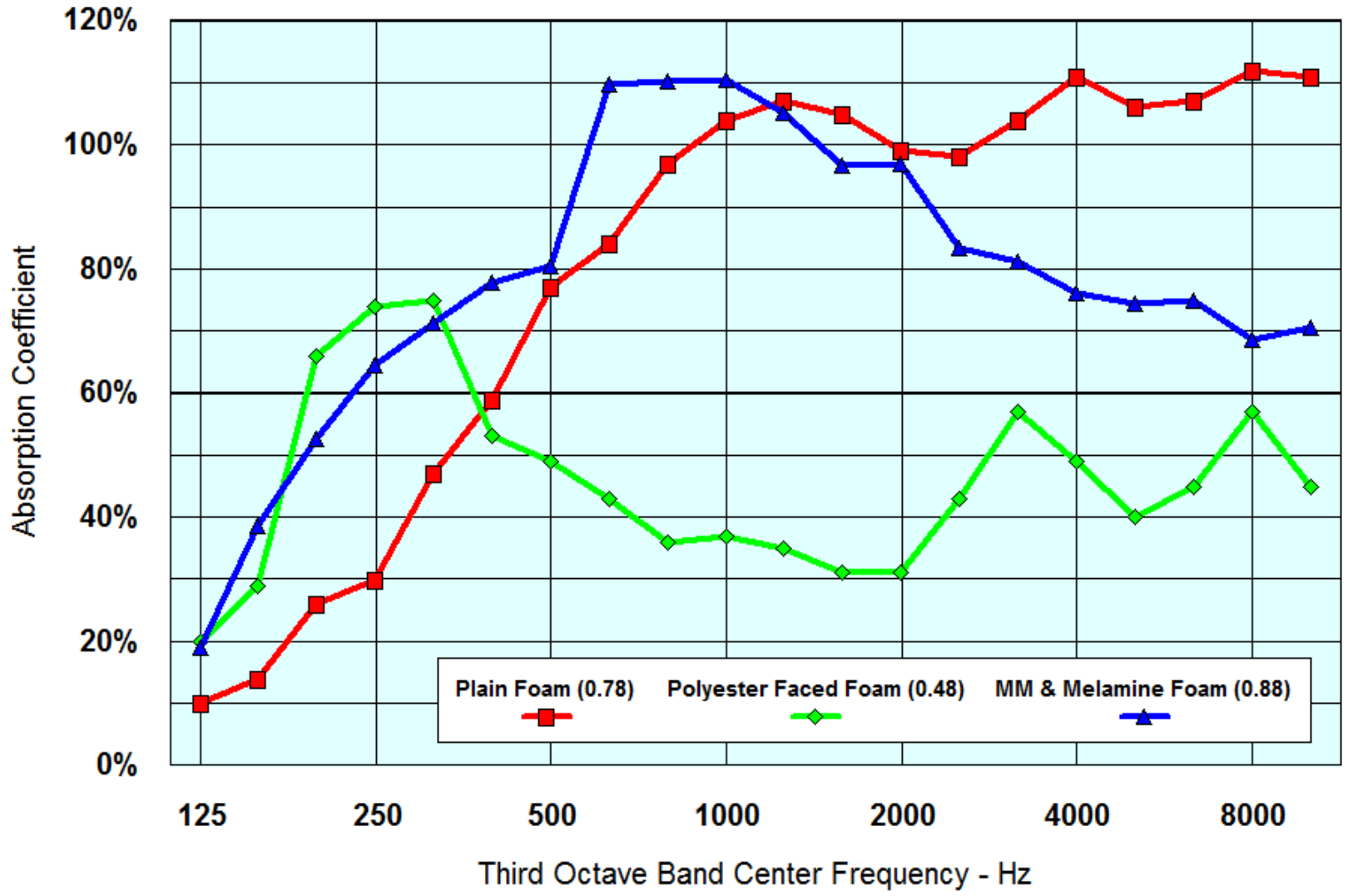
Interior Absorption

- Powder Coated Millennium Metal with Melamine foam Thermal Insulation
- Safe Durable Fire resistant decorative

Comparison of Absorption of 1.5" (38mm) Absorption

Figures in (Brackets) AAC - Average Absorption Coefficient

Results normalized to ASTM C 423-99



Summary

- Closing Holes and leaks is Job #1
- Reduce Fan speeds
- Millennium Metal & Melamine in Engine compartment = BIC for Noise and Flammability
- Constrained Layer Damping = BIC STL for Optimum Weight Noiseless Metal, dBPLy & PDP in Bulkhead and Wheel Wells
- Constrained layer damping (dBPly) for floor
- Millennium Metal & Melamine in Roof of Cabin