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STRUCTURAL DAMPING BY LAYERS OF FIBROUS MEDIA ON A PERIODICALLY-CONSTRAINED VIBRATING PANEL

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https://iopscience.iop.org/article/10.1088/1742-6596/1264/1/012043/

PURDUE MECHANICAL ENGINEERING

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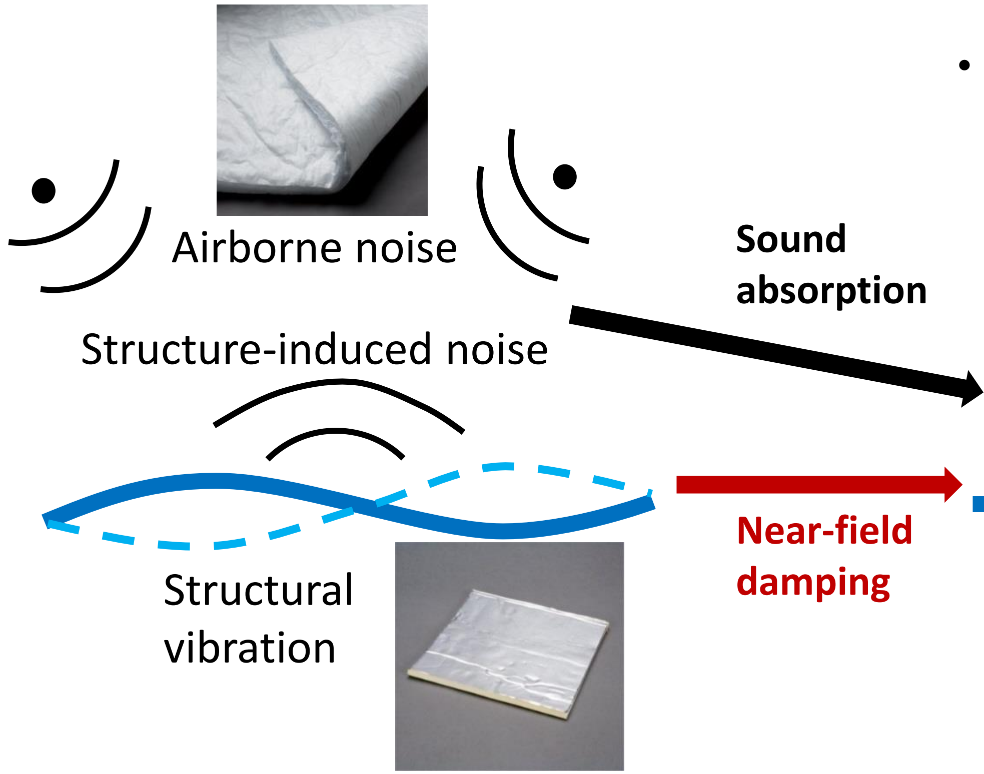
3M

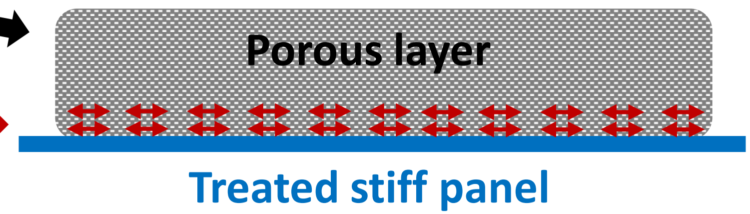
Challenge

- **Advanced Noise Control Materials**[1]
  - **What's important about a noise control material?**
    - **Cost**
    - **Safety**
    - **Weight**
    - **Volume**
    - **Recyclability**
    - **…**
    - **…**
    - **Acoustical Performance**

Objective: Multifunctionality

- **Near-field damping:** dissipating power through viscous interaction between the porous medium and the evanescent acoustical near-field of the panel associated with sub-critical panel motion[2–7]



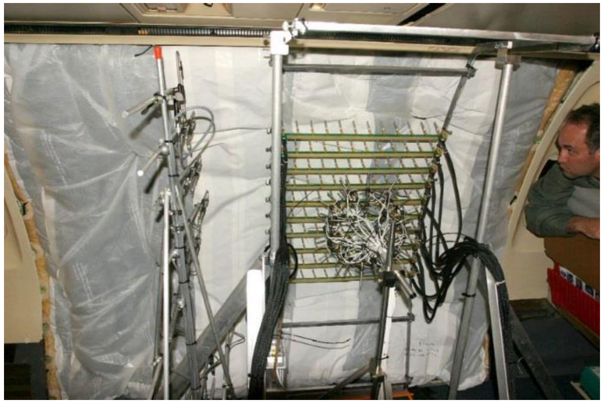


- **Objectives: modeling, predicting and optimizing** the near-field damping performance of conventional sound absorbing materials (fiber, foam, *etc.*), so that a properly-designed porous layer can achieve both structural damping and sound absorption at the same time → **save weight and cost**

Main Idea

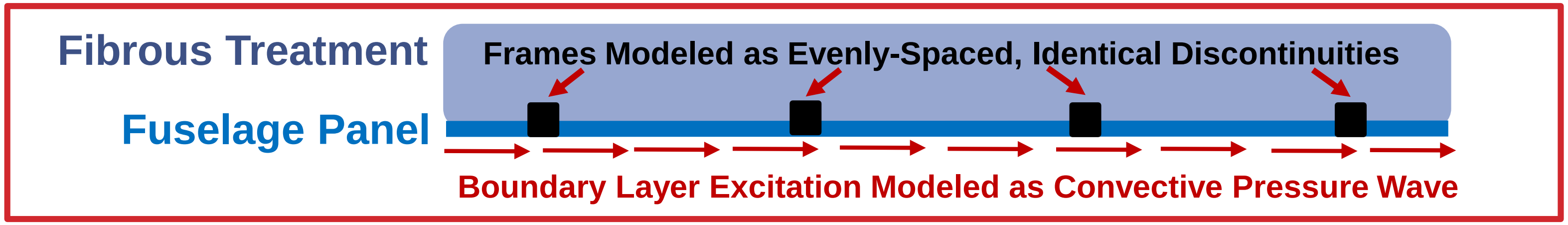
- **Periodic Structure in Practical Scenarios**

Nadeau *et al.*, *J. of Aircraft* (1999)



Klos *et al.*, *Noise-Con* (2005)

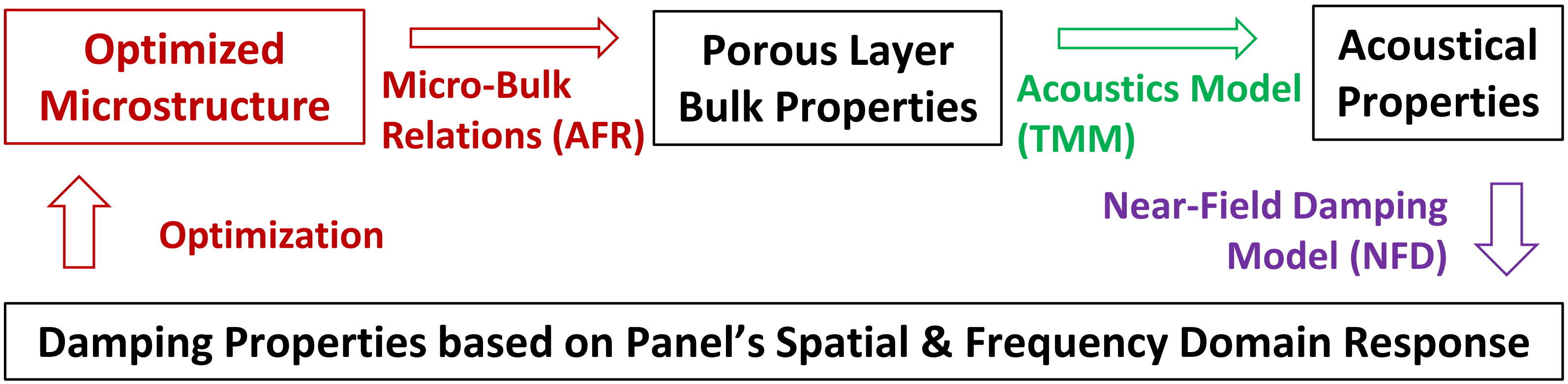
Room 3057, Herrick Labs



- Model the periodic structure, evaluate and optimize the damping of the treatment

General Approach

- Connecting damping material's properties and performance

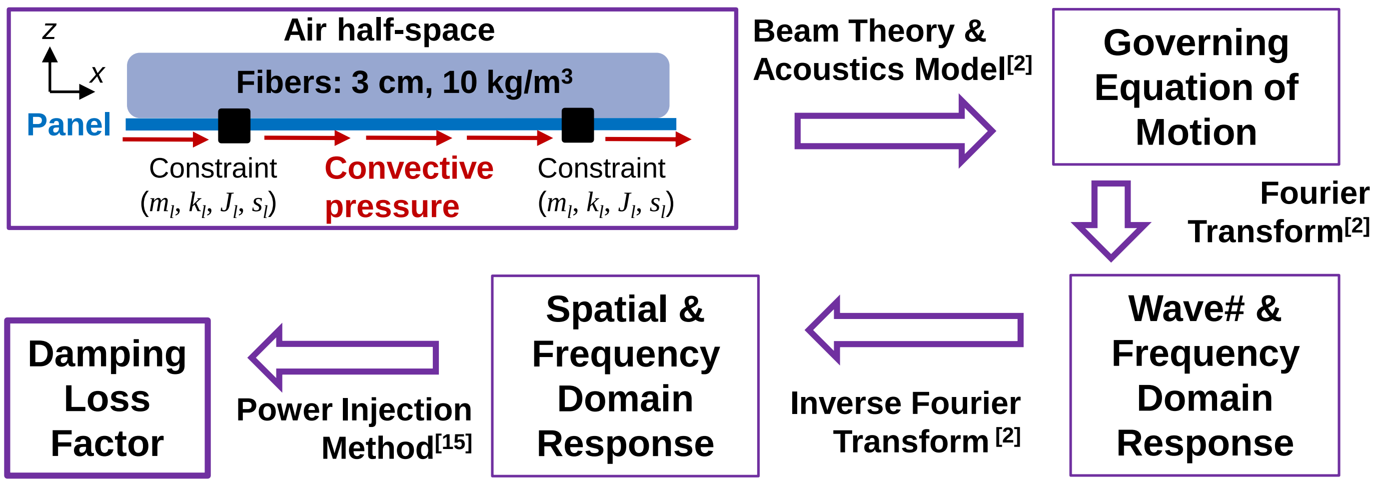


- **AFR:** micro-bulk relations for porous media made of fibers[8]
- **TMM:** bulk-acoustical relations[9,10] including Johnson-Champoux-Allard (JCA) model[11], Biot theory[11–15] and B.C.s interpretation[13,16]
- **NFD:** acoustical-damping relations including Euler-Bernoulli beam theory, wavenumber-space Fourier transform[17] and power analysis[18]

➢ **TMM** + **NFD** + **AFR** provides an micro-damping model to maximize fibrous media's damping performance by optimizing their microstructures

NFD Modeling

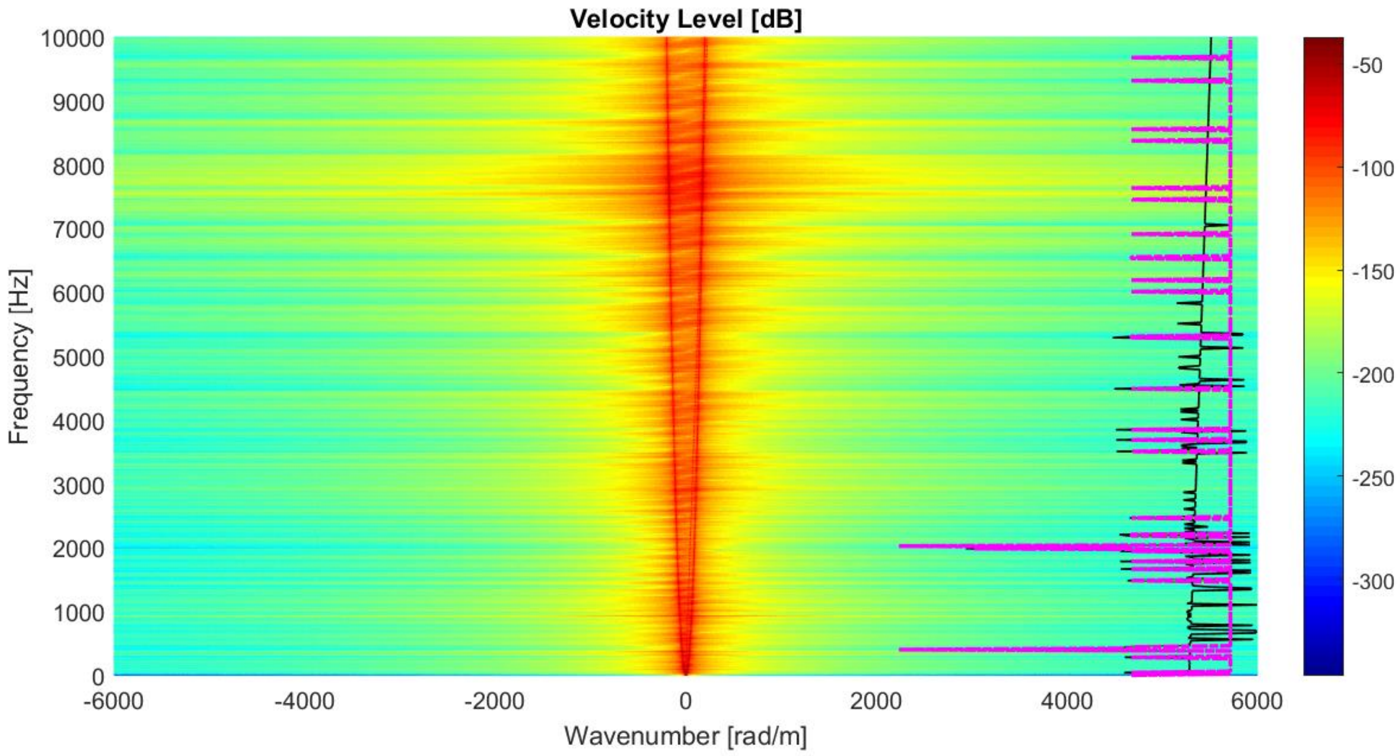
- **Fibrous layer is assumed to be limp, 3 cm thick with bulk density 10 kg/m³**
- **Fiber solid material densities:** $\rho_{glass} = 2730\ \mathrm{kg/m^3}$, $\rho_{polymer} = 910\ kg/m^3$



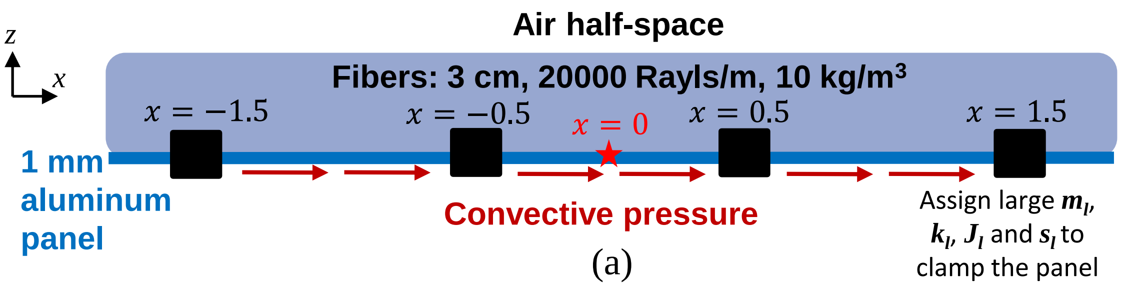
Governing Equation

$$D\frac{\partial^4 w(x,t)}{\partial x^4} + m_s \frac{\partial^2 w(x,t)}{\partial t^2} = -p_1(x,t) + \underbrace{F e^{+i\omega t} e^{-ik_v x}}_{\text{Convective pressure}} + \underbrace{\sum_{i=1}^{N_l} F_{l,i}\delta(x - x_{l,i}) + \sum_{i=1}^{N_l} M_{l,i}\delta(x - x_{l,i})}_{\text{Reaction forces due to constraints}}$$

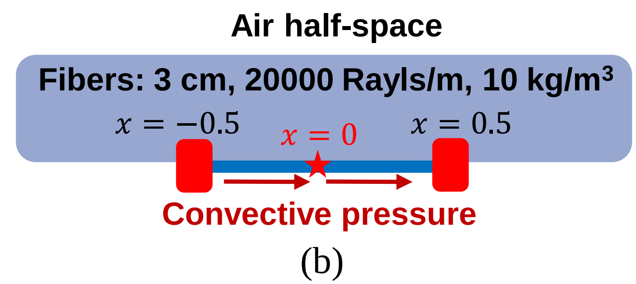
IDFT Sampling Parameters



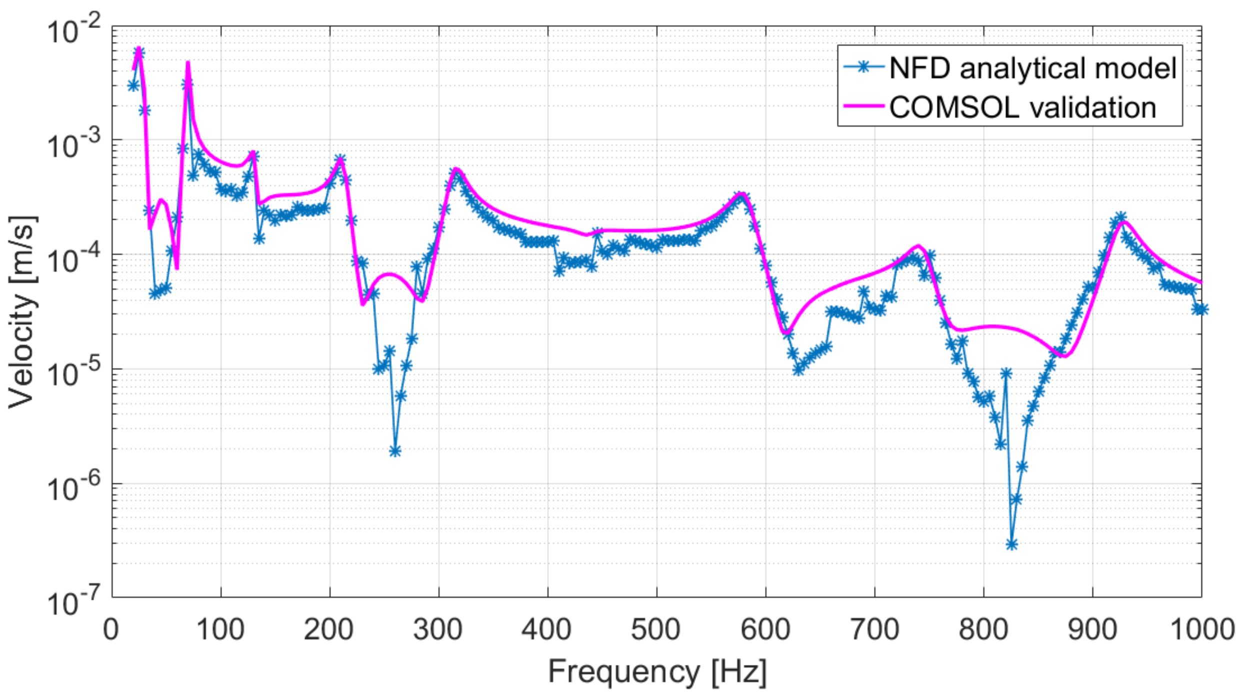
Model Validation



NFD model



COMSOL finite element model



Fuselage Structure Wavenumber Response

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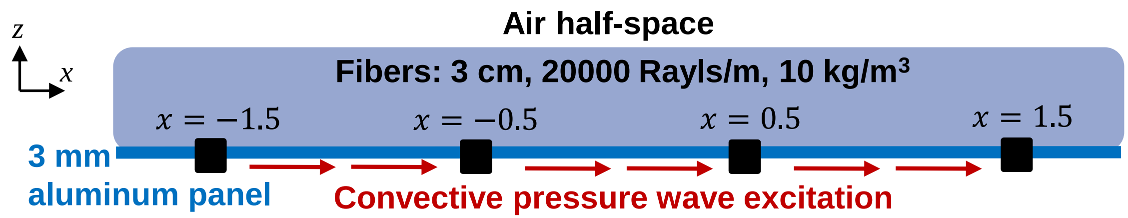
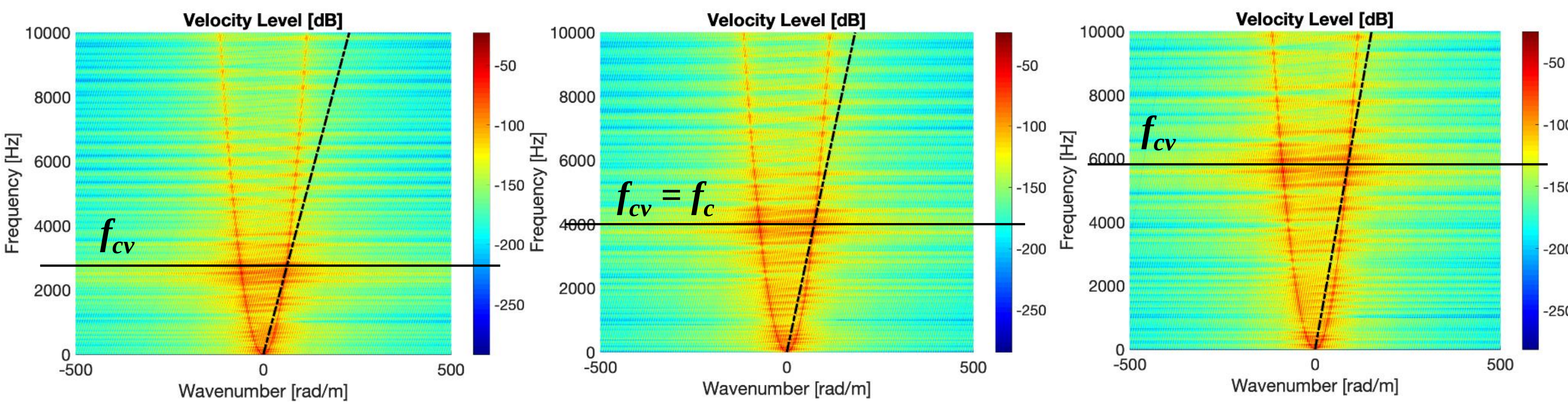


Identical aluminum constraints with size 5 cm x 5 cm (m_l = 6.75 kg/m, k_l = 2.66×10 kg/(s^2·m), J_l = 0.0028 kg·m, s_l = 1.11×10 kg·m/(s^2)) are evenly distributed along the panel with separation of 1 m

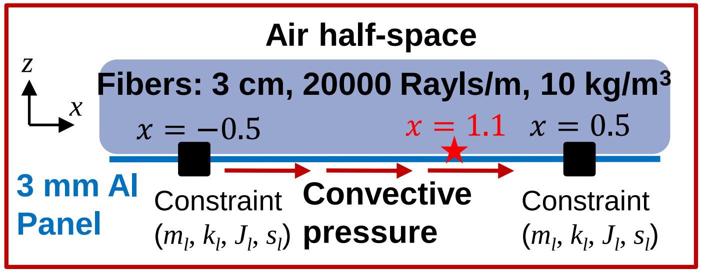


(a) Ma=0.8 (Subsonic)

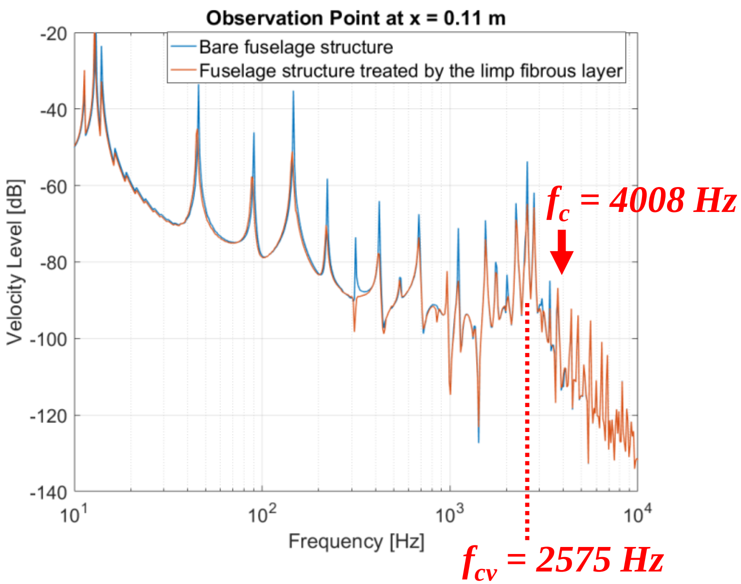
(b) Ma=1.0 (Sonic)

(c) Ma=1.2 (Supersonic)

Fuselage Structure Velocity Response Spectrum

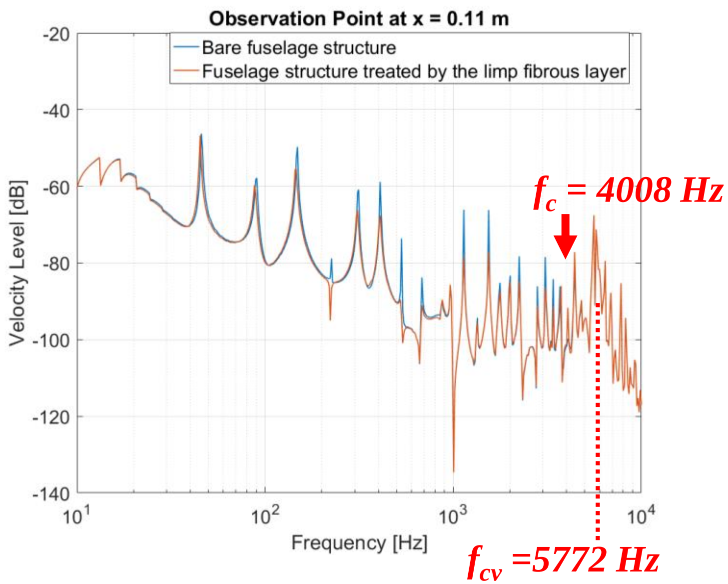


- **Observation at x = 0.11 m**
- **Vibration peaks below f_c were reduced by 5–15 dB by the fibrous layer**



(a)

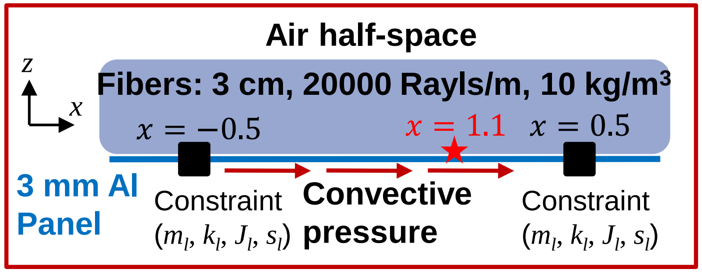
Ma=0.8



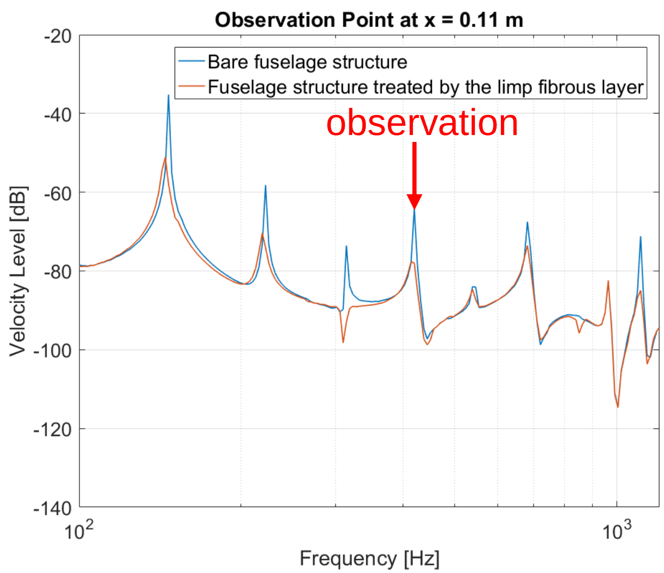
(b)

Ma=1.2

Fuselage Structure Velocity Response Spectrum

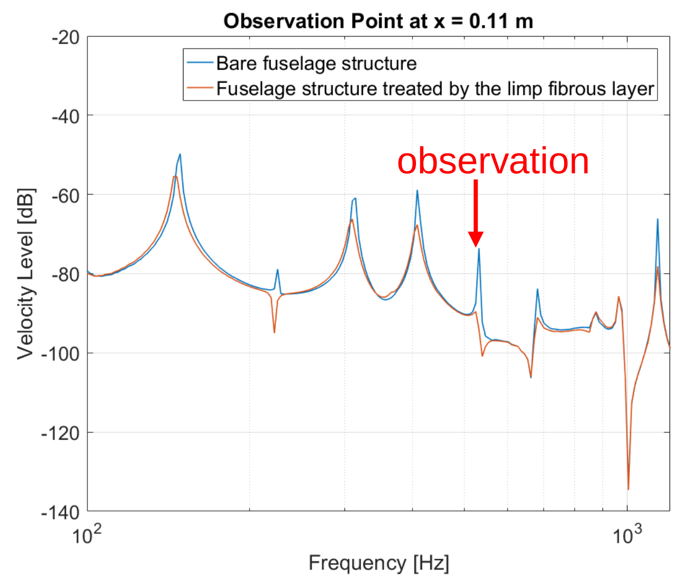


- **Zoom into 100–1000 Hz to see the peak reduction**
- **Choose the peak at certain frequency as an observation point**



(a)

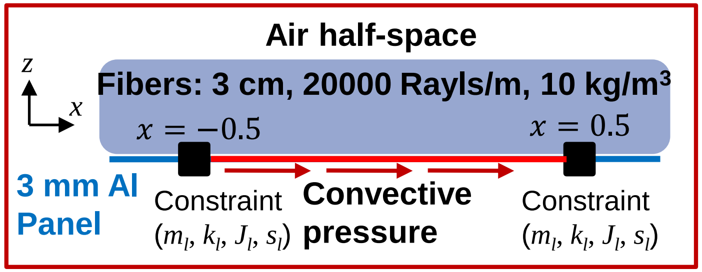
Ma=0.8



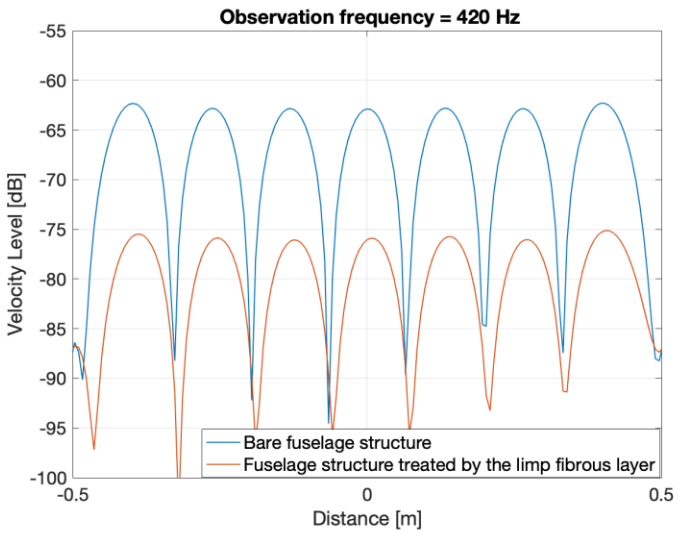
(b)

Ma=1.2

Fuselage Structure Spatial Response

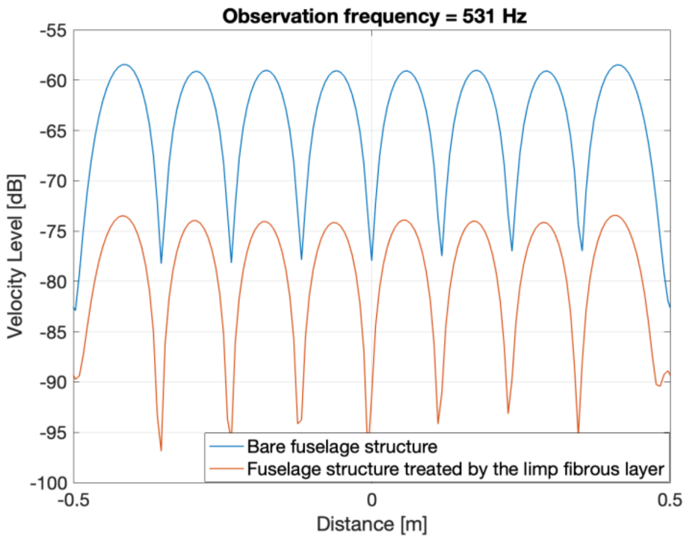


- About **15 dB reduction of** vibration can be achieved at modal peak frequency ***f*** **= 420 Hz** (Ma=0.8) or ***f*** **= 531 Hz** (Ma=1.2)



(a)

Ma=0.8



(b)

Ma=1.2

Fuselage Treatment Damping Loss Factor

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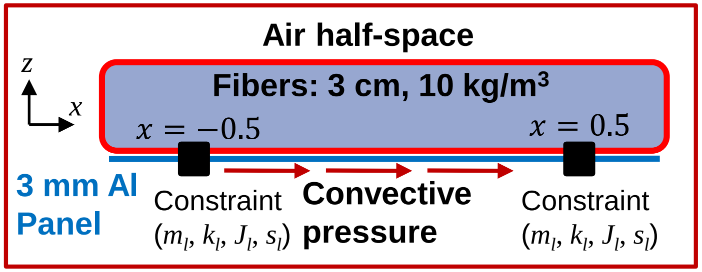
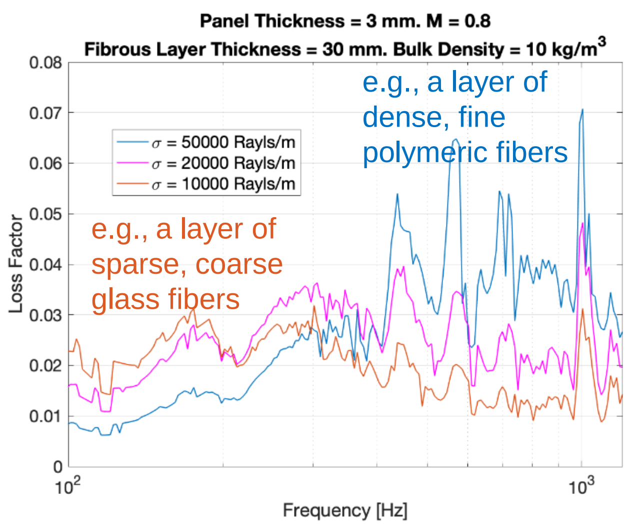


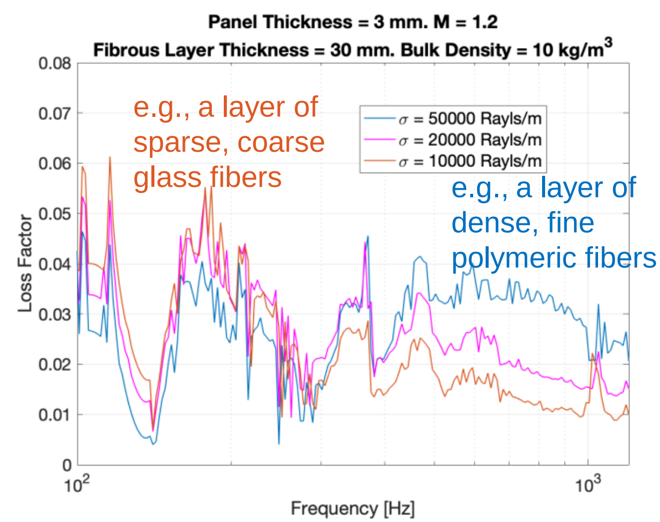
Power injection method[16]

- **Fibrous layer with lower airflow resistivity is better at reducing lower frequency vibration**
- **Idea: optimal bulk/micro structure can be find to achieve optimal damping at certain frequency for a given structure**



(a)

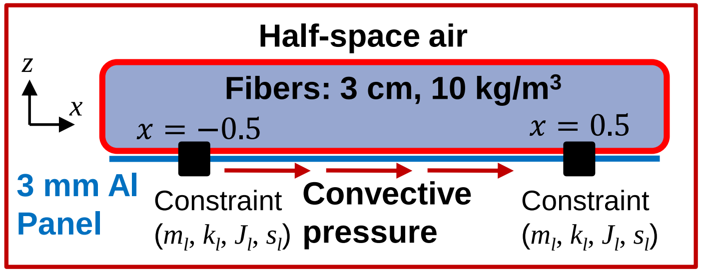
Ma=0.8



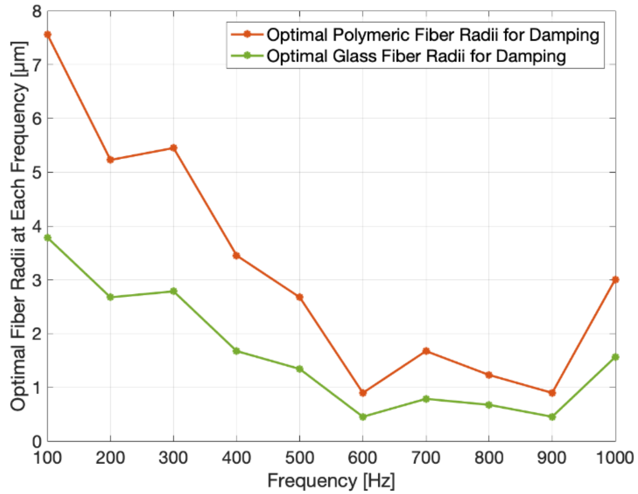
(b)

Ma=1.2

Glass Fibers *vs.* Polymeric Fibers
– finding optimal fiber radius

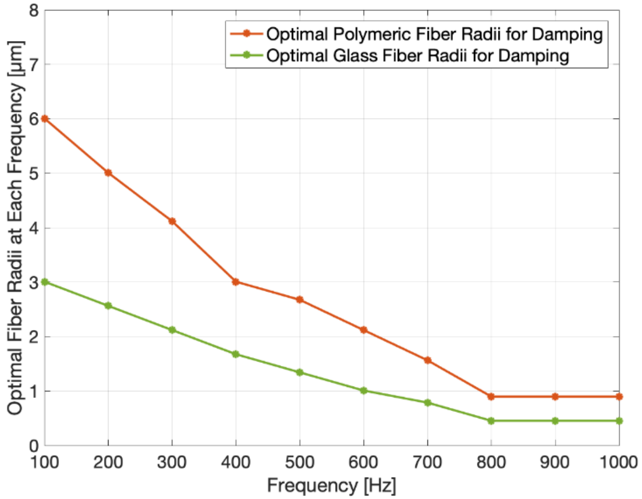


- **Larger fiber is better at reducing lower frequency vibration**
- **Heavy (e.g., glass) fiber would need a smaller fiber size than light (e.g., polymeric) fiber to achieve optimal damping performance**



(a)

Ma=0.8

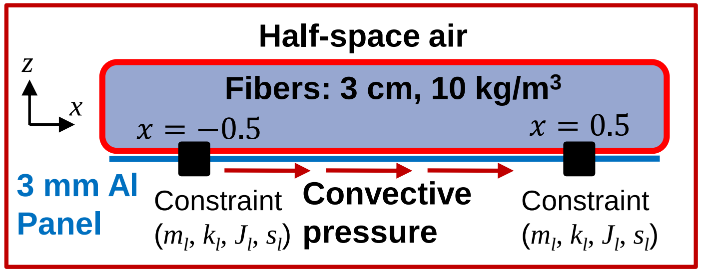


(b)

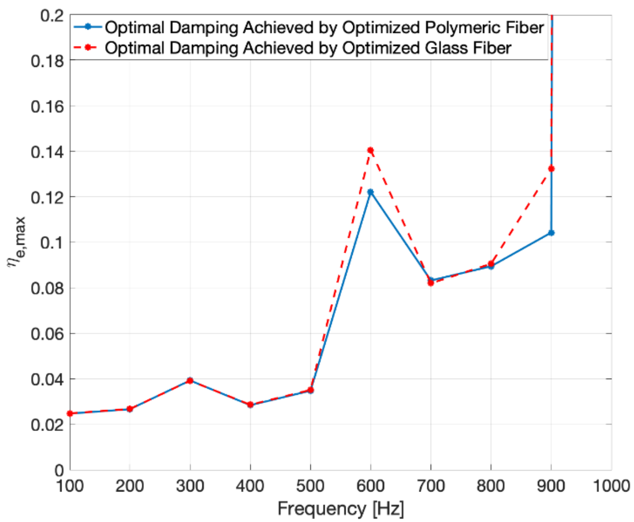
Ma=1.2

*** Fiber size was optimized to achieve the largest damping for certain frequency & panel of interests**

Glass Fibers *vs.* Polymeric Fibers
– optimal damping loss factor

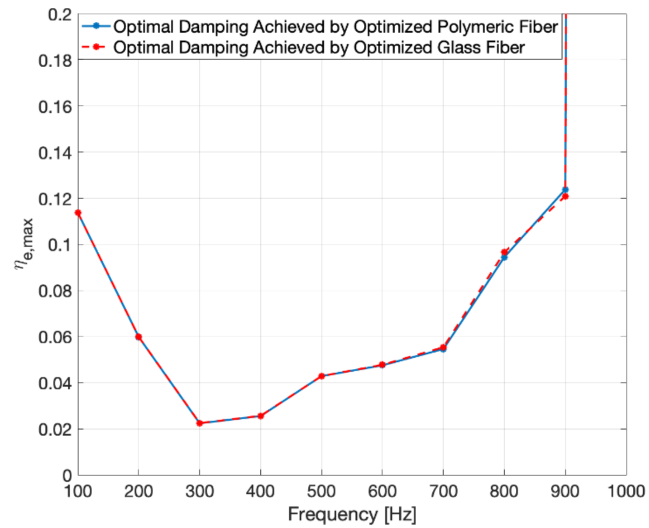


- **Optimized fibrous layer made of either polymeric or glass can achieve equivalent optimal damping**



(a)

Ma=0.8



(b)

Ma=1.2

*** Fiber size was optimized to achieve the largest damping for certain frequency & panel of interests**

CONCLUSIONS

❖ Lightweight fibrous damper parametric study on microscopic properties

- Relatively large fibers are effective at damping low frequency vibration
- Heavy (e.g., glass) fiber would need a smaller fiber size than light (e.g., polymeric) fiber to achieve equivalent optimal damping performance
- Significant levels of damping can be achieved by properly designed fibrous treatment → multifunctional (absorbing & damping) fibrous layer saves weight, space and cost

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