April 16, 2020

Blocked Force Determination
Explanation and Examples

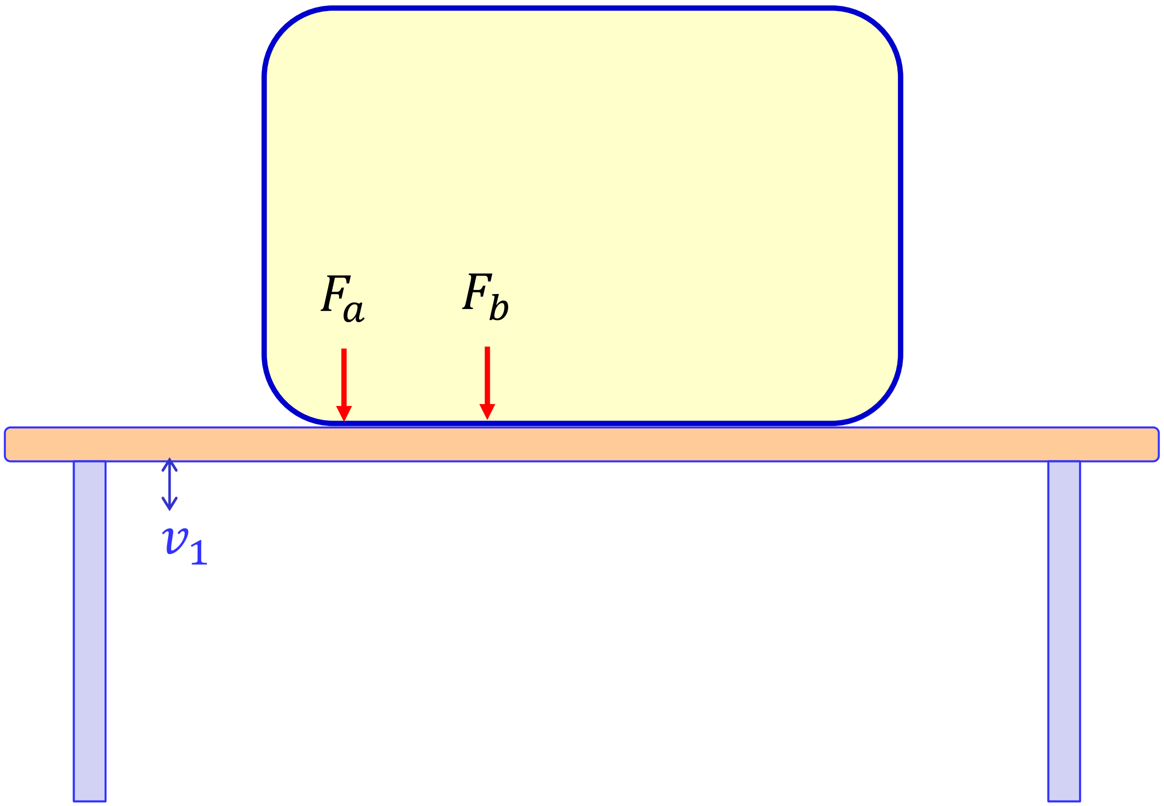
Vibro-Acoustics Consortium Web Meeting

University of Kentucky

Overview

- Transfer Functions and Superposition
- What are Blocked Forces?
- Similar Approaches
- Example: Small Compressor attached to Structure
- Example: Engine Cover attached to Plate
- Example: Acoustic Duct
- Future Work

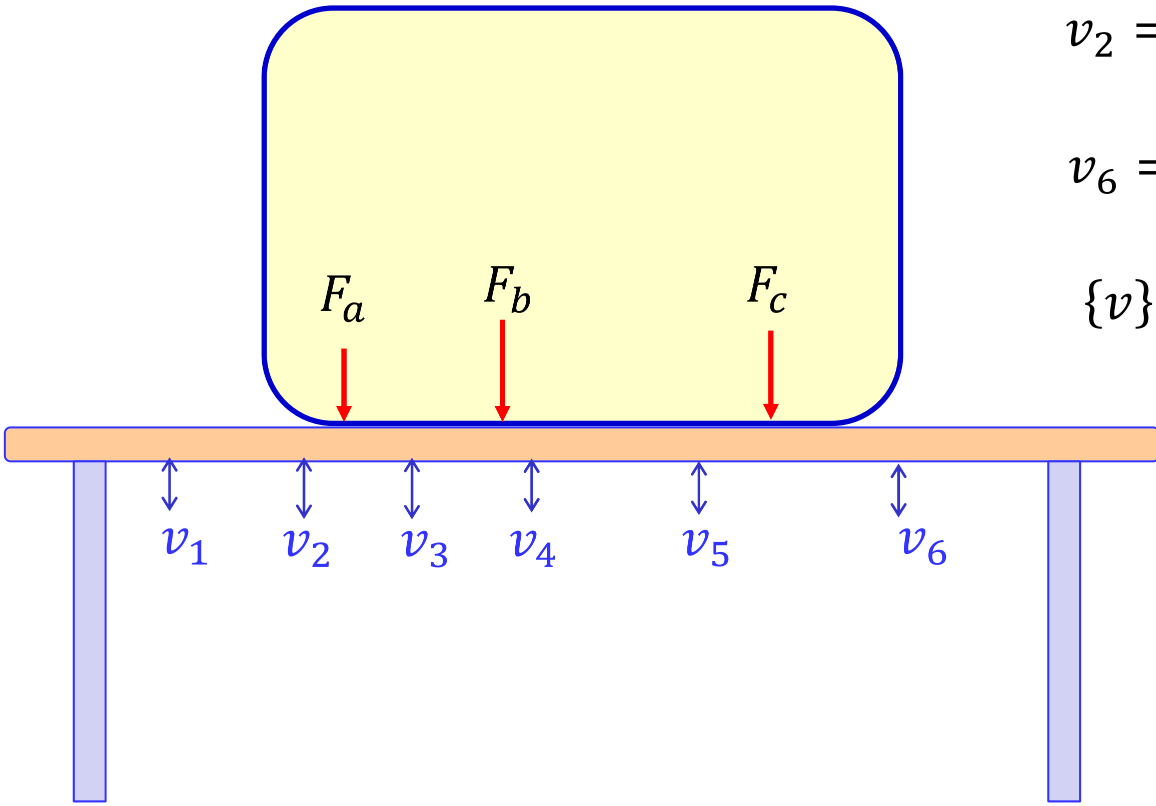
Transfer Functions



$$v_1 = H_{1a}F_a$$

$$v_1 = H_{1b}F_b$$

Linear Systems and Superposition



$$v_1 = H_{a1}F_a + H_{b1}F_b + H_{c1}F_c$$
$$v_2 = H_{a2}F_a + H_{b2}F_b + H_{c2}F_c$$
$$\vdots$$
$$v_6 = H_{a6}F_a + H_{b6}F_b + H_{c6}F_c$$

$$\{v\}_{6\times1} = [H]_{6\times3}\{F\}_{3\times1}$$

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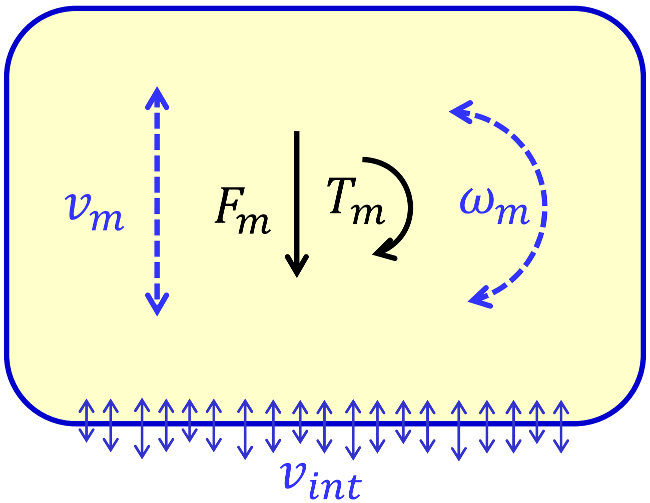
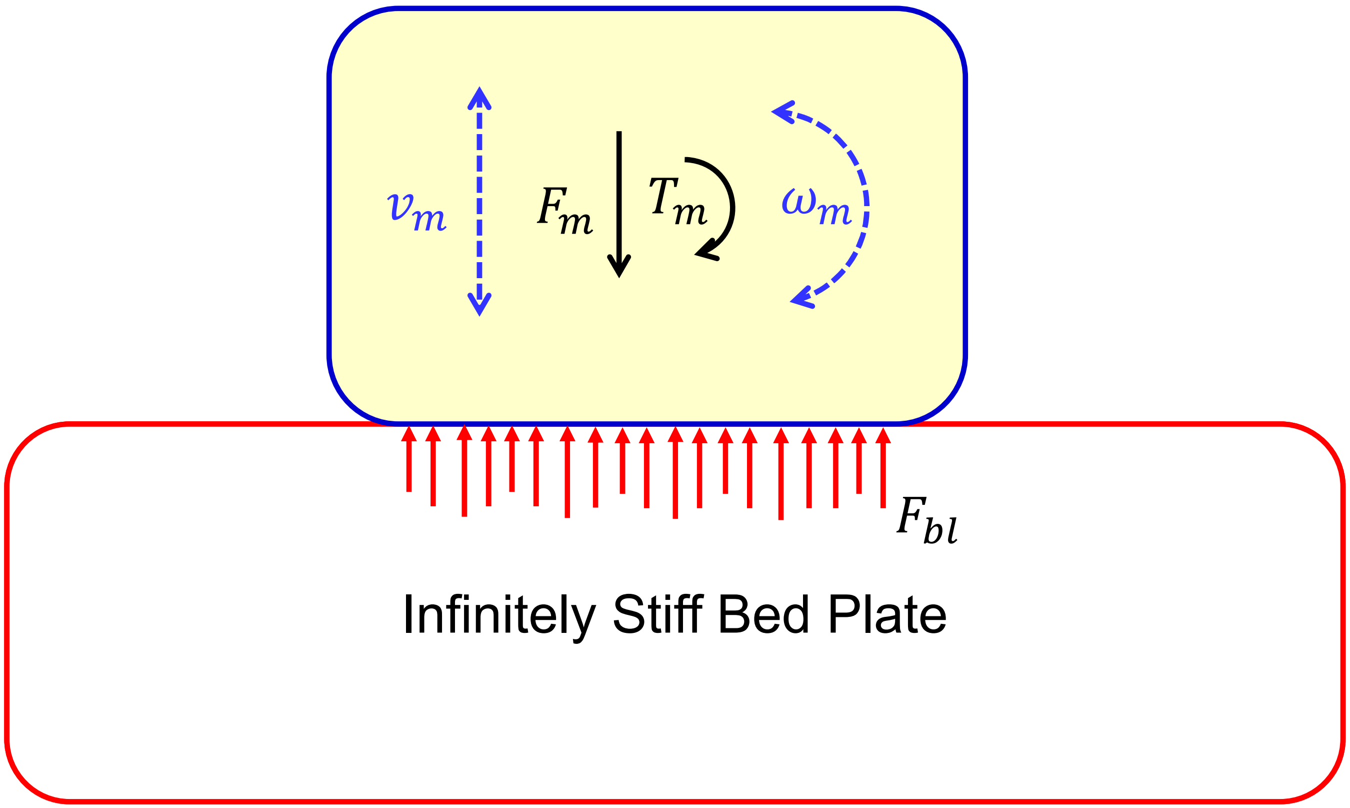
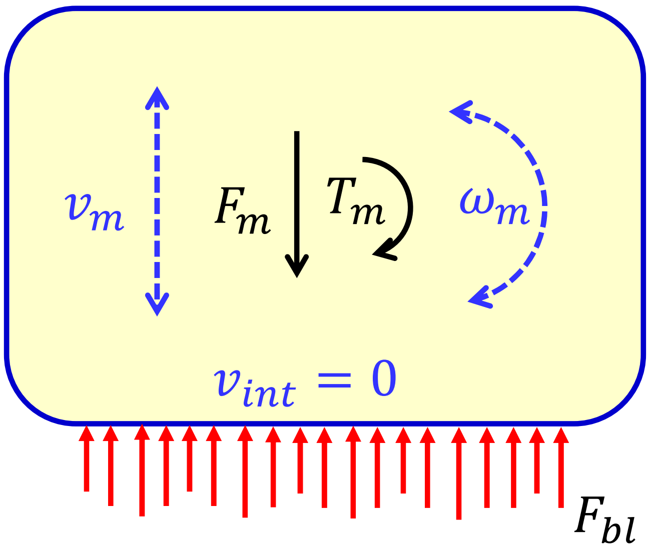
What Are Blocked Forces?



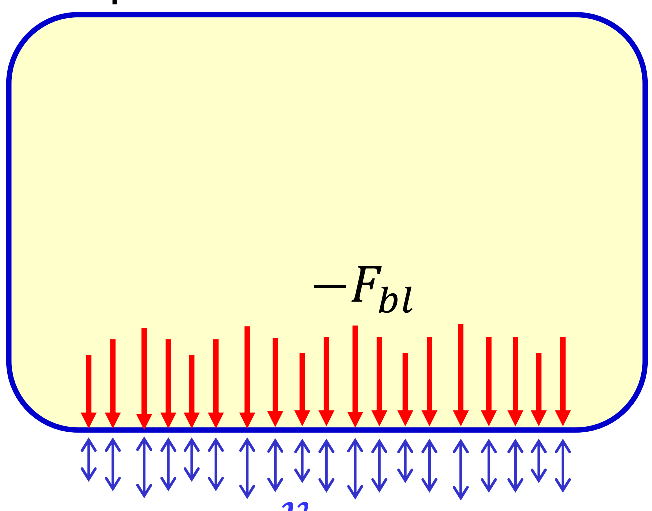
What Are Blocked Forces?



What Are Blocked Forces?

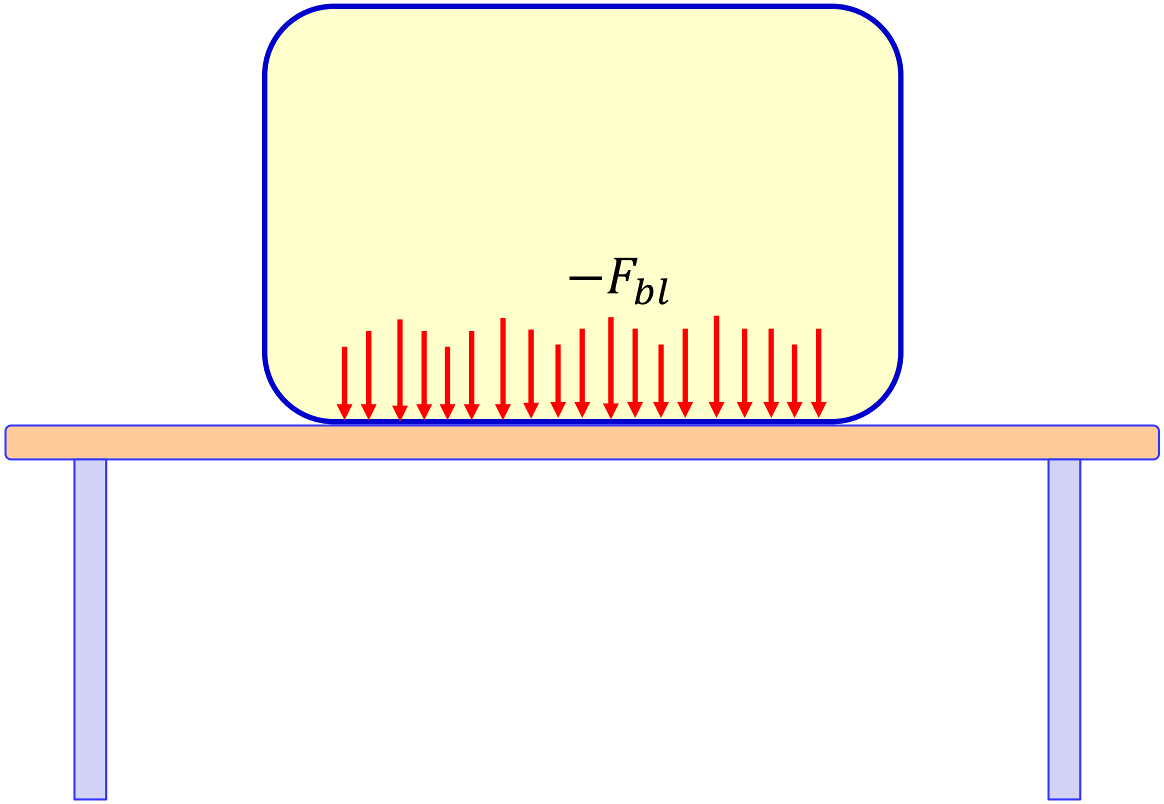


What Are Blocked Forces?

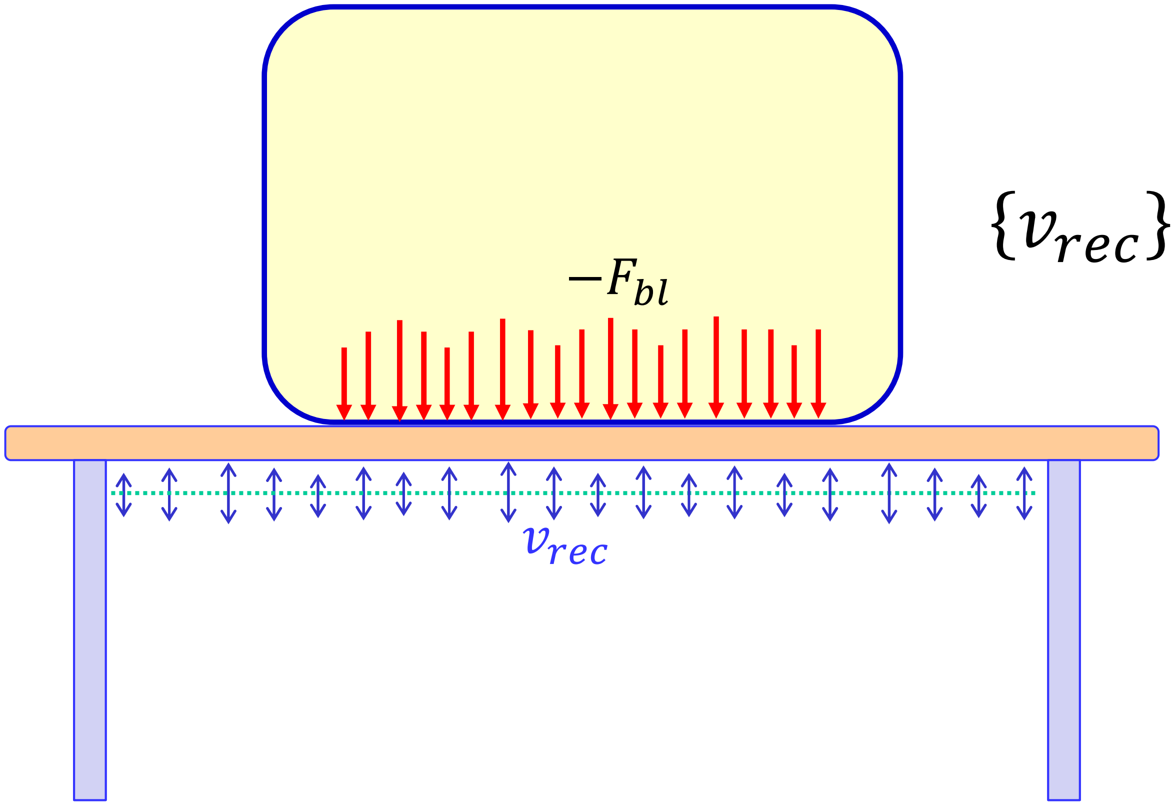


What Are Blocked Forces?

Blocked forces are independent of the receiver.



Blocked Force Analysis



$$\{v_{rec}\}_M = [H_{bl}]_{M\times N}\{F_{bl}\}_N$$

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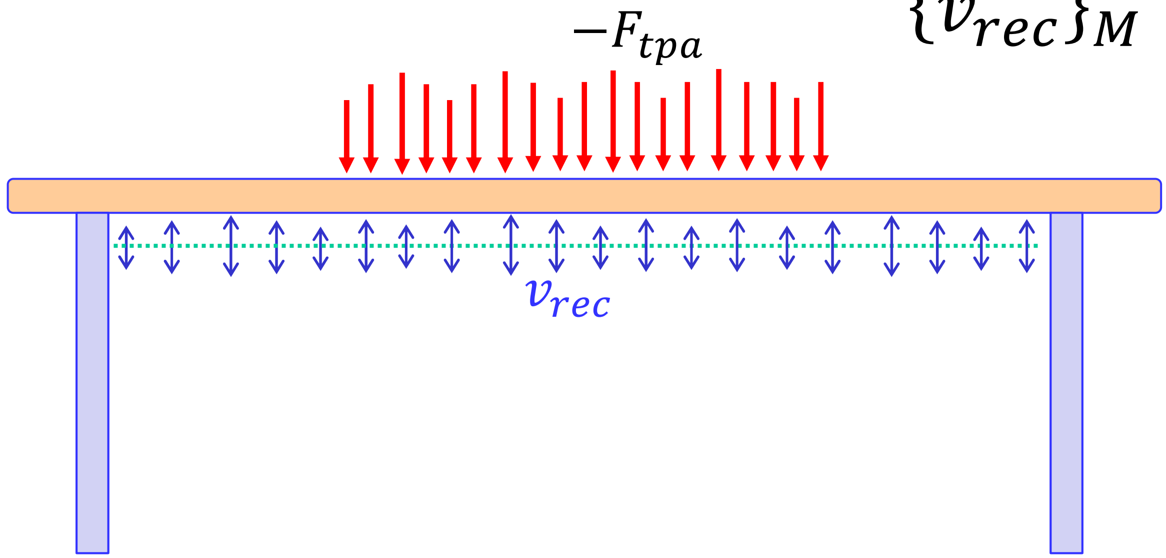
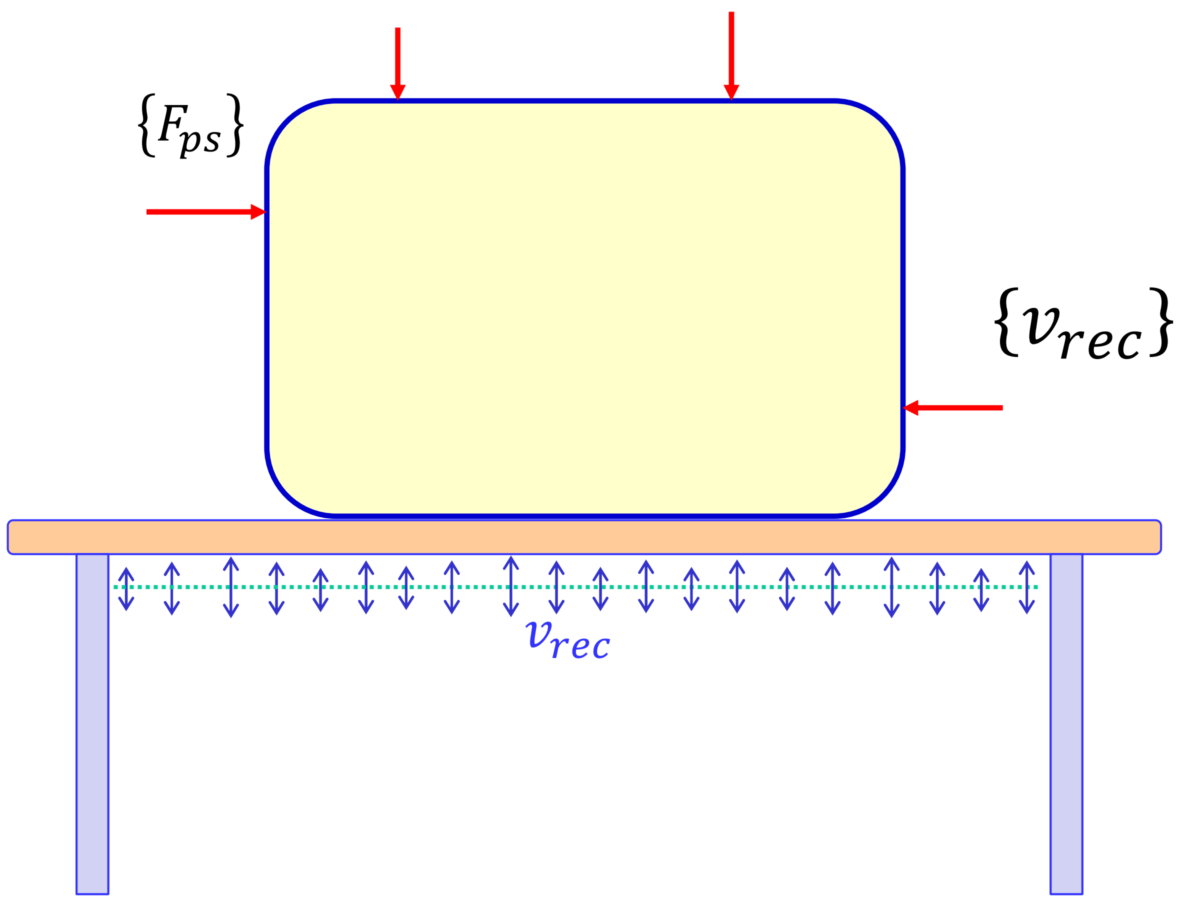
Classical Transfer Path Analysis



$$\{v_{rec}\}_M = [H_{tpa}]_{M\times N}\{F_{tpa}\}_N$$

Pseudo Force Analysis



$$\{v_{rec}\}_M = [H_{ps}]_{M \times N} \{F_{ps}\}_N$$

Force Identification Approaches

Measured Transfer Functions
Source is “off”

$$\{v_{rec}\}_M = [H]_{M\times N}\{F_{bl}\}_N$$

Indicator Responses
Source is “on”

Unknown Blocked Forces
Inverse least squares

Summary

Method	Transfer Function Measurement	Inverse Force Locations	Can Inverse Forces be Used with Modified Receiver?
Classical TPA	Remove Source	Interface between Source and Receiver	If Source is well Isolated
Blocked Forces	Include Source	Interface between Source and Receiver	Yes
Pseudo Forces	Include Source	User Decided	Maybe

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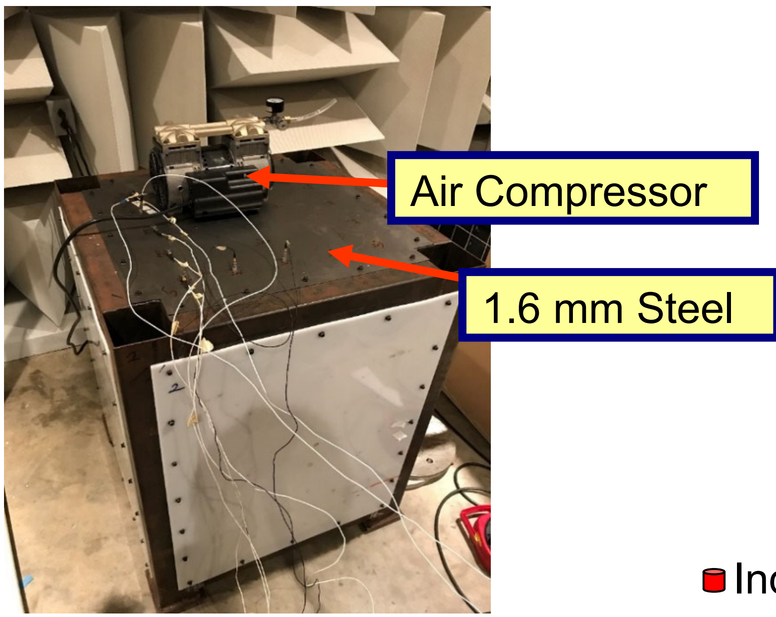
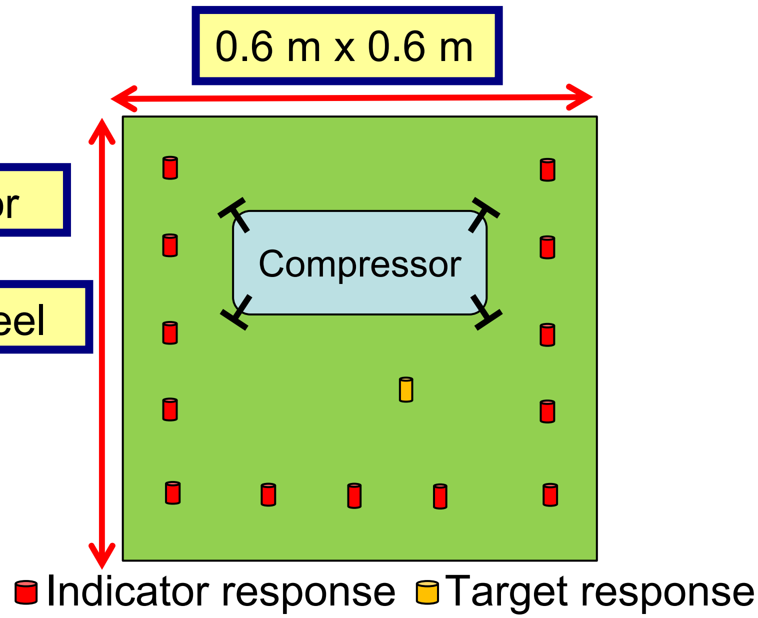
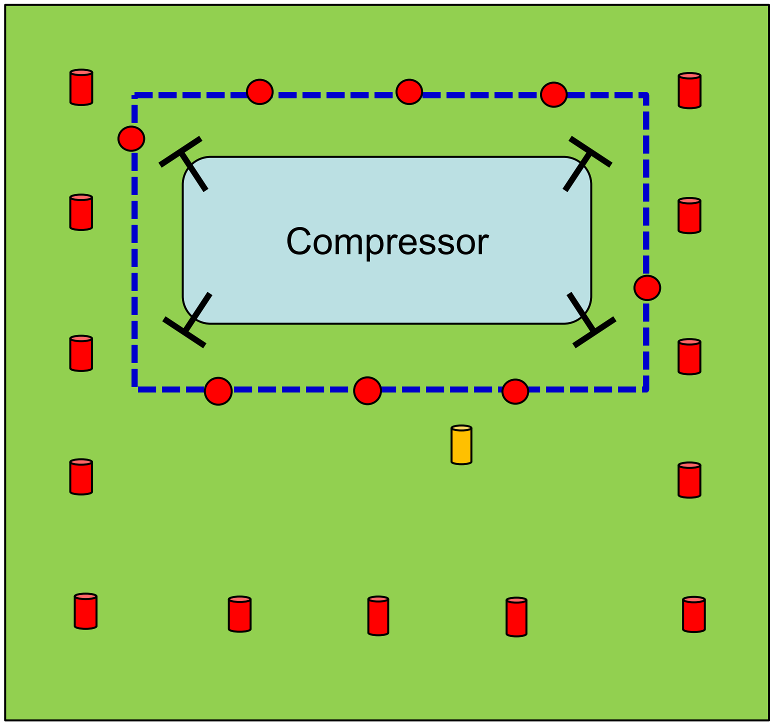
Source and Test Structure

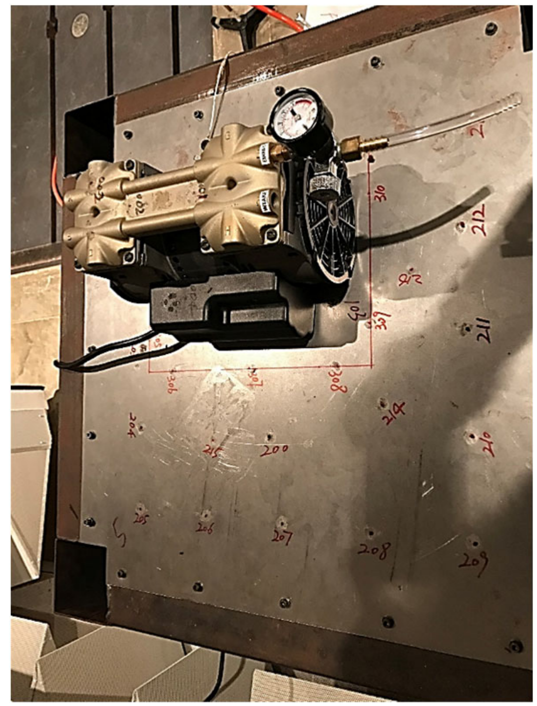
- Classical TPA, pseudo force and blocked force methods are used to predict target response.





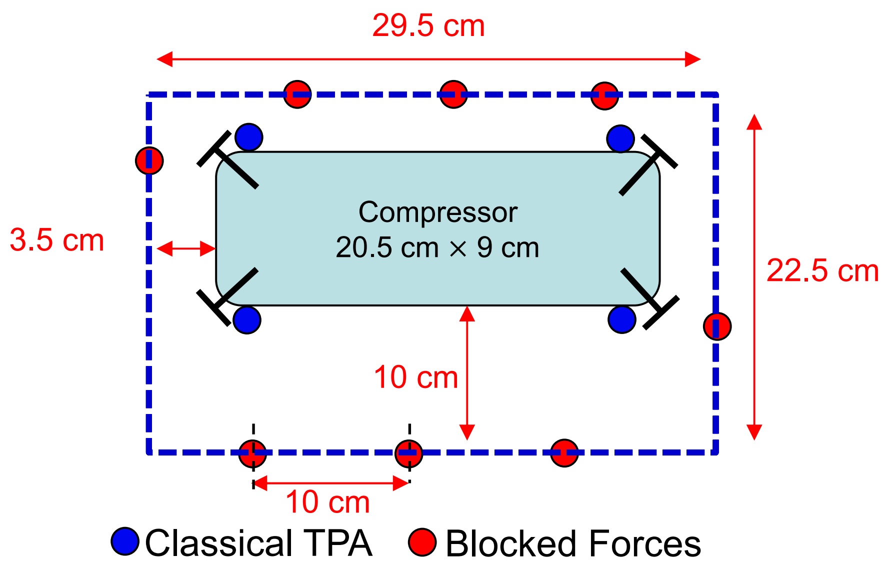
Blocked Force Locations





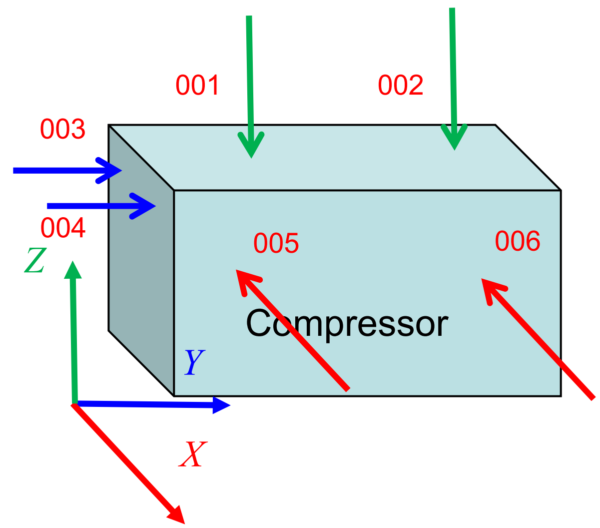
Input Force Locations

- For Classical TPA, transfer functions are measured with compressor removed from steel plate.

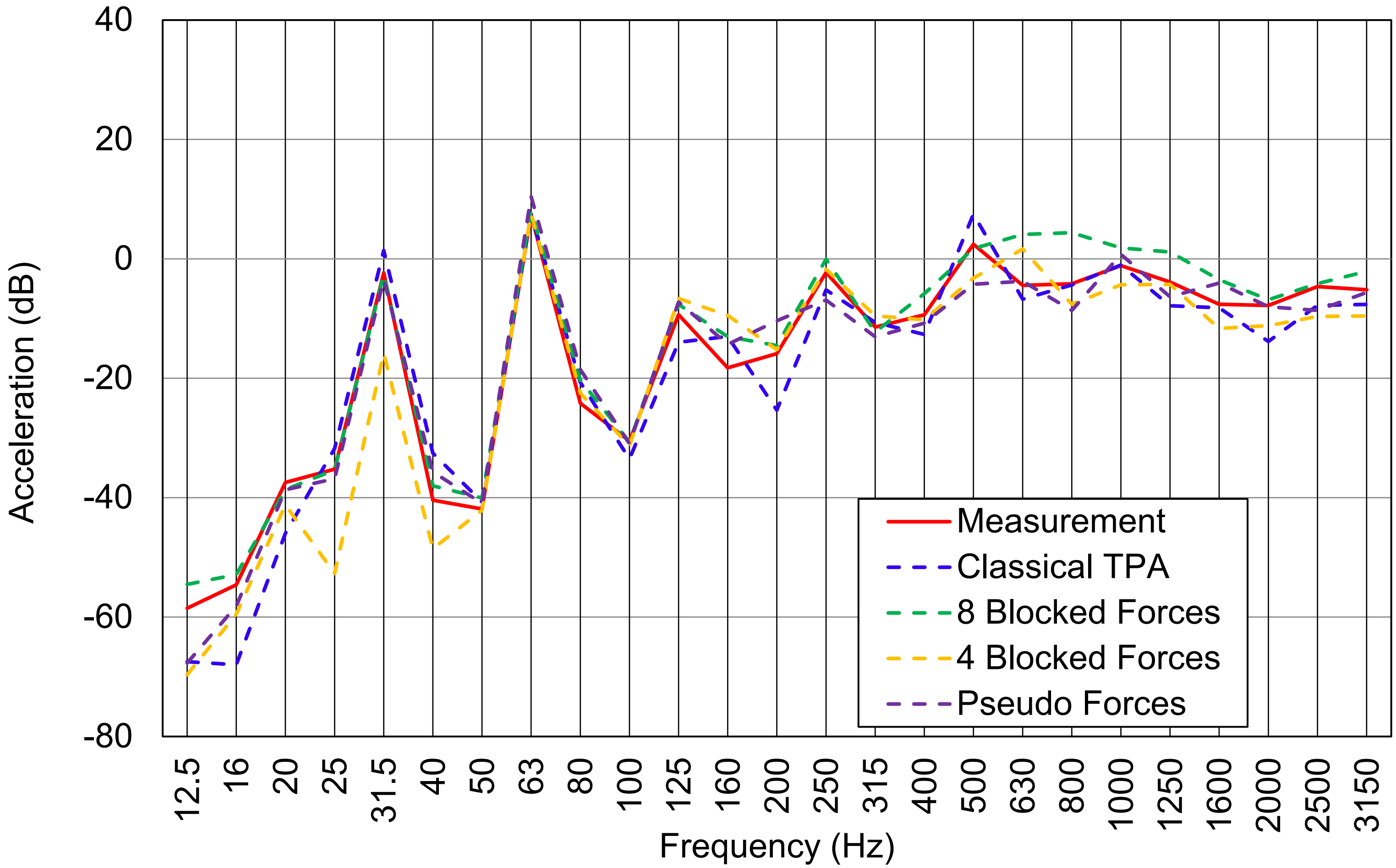


Input Force Locations

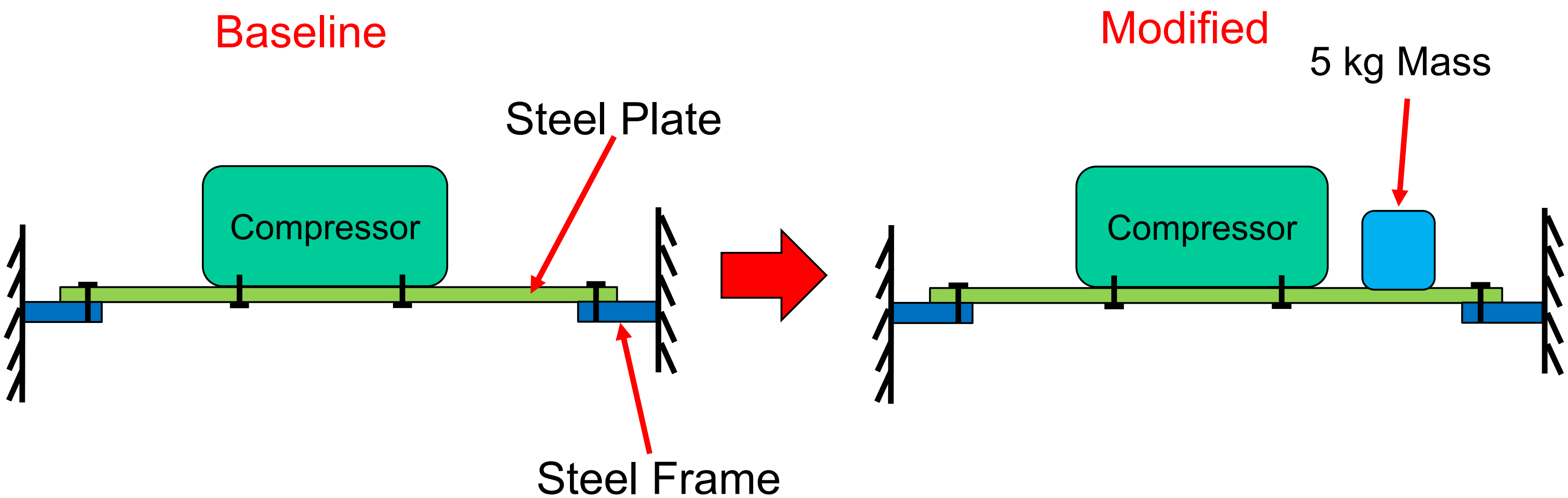
- For pseudo force method, 6 input force points should capture all 3 translational and 3 rotational motions of compressor.



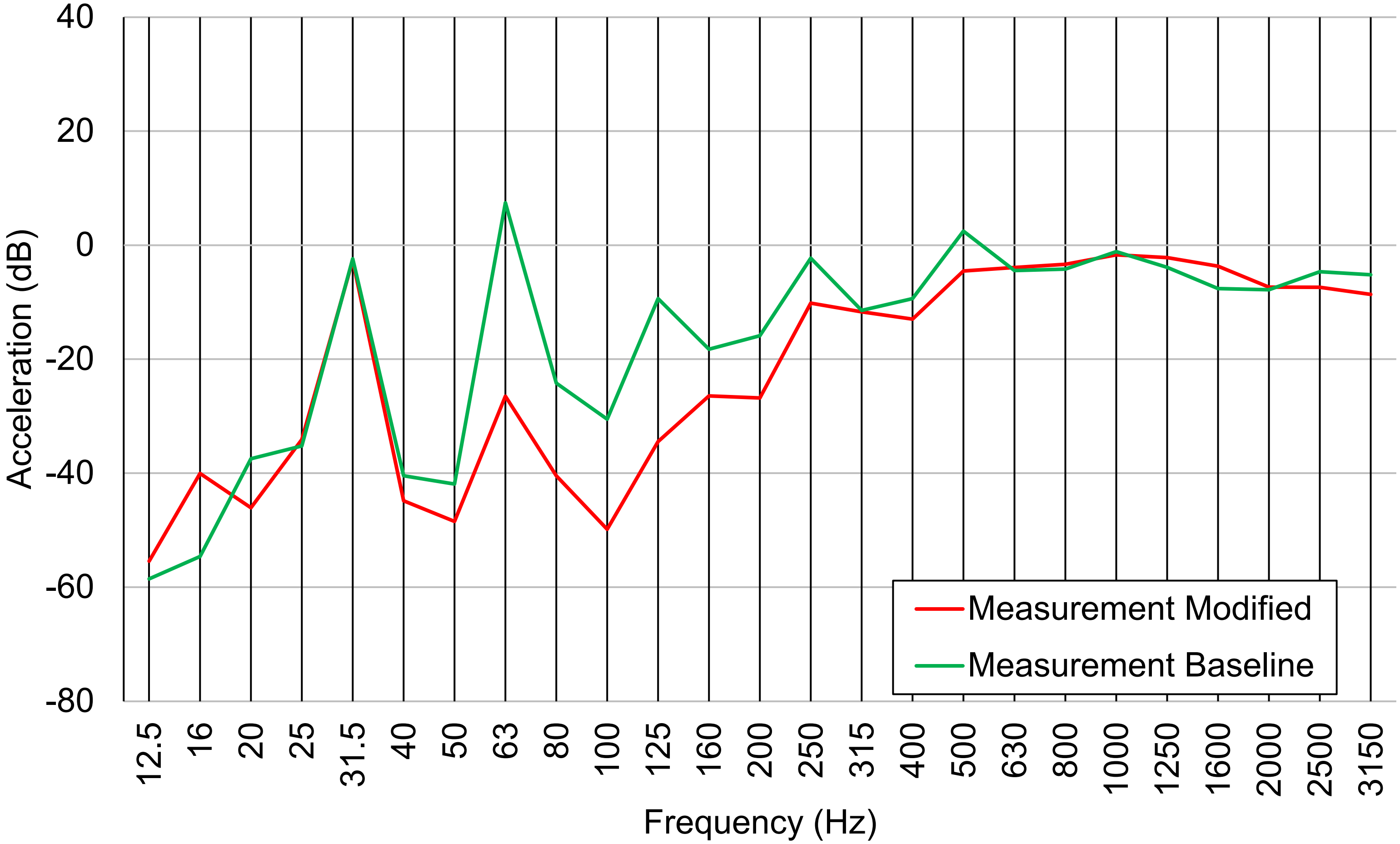
Acceleration Target Comparison



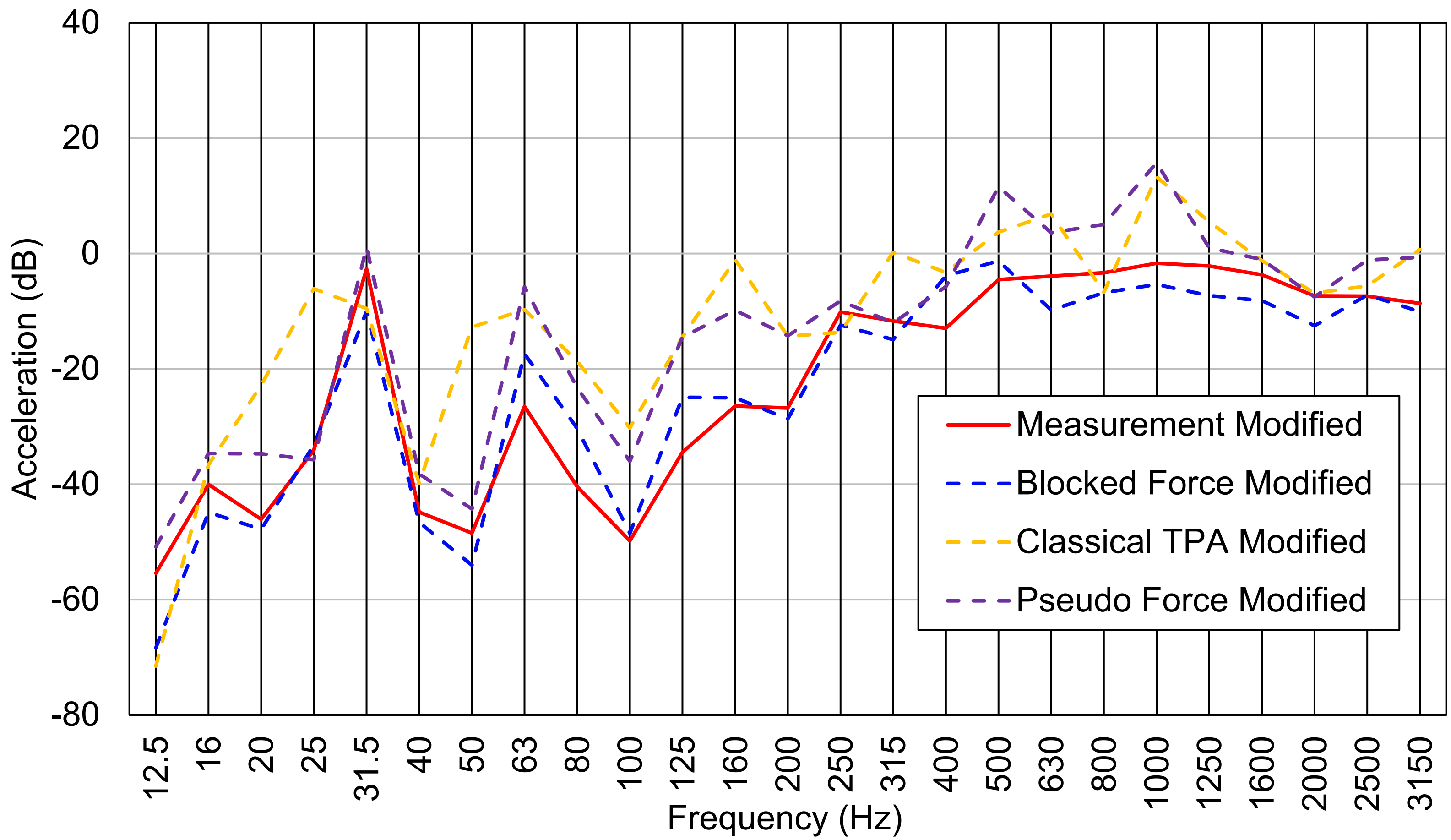
Modification Added Mass



Measurement Case Target Comparison



Measurement Case Results Comparison



Recommendations

- A spacing (s) of $s \leq 0.5\lambda_B$ is recommended along an interface for plate and shell structures where λ_b is the bending wavelength. This spacing has been validated using FEM analyses.

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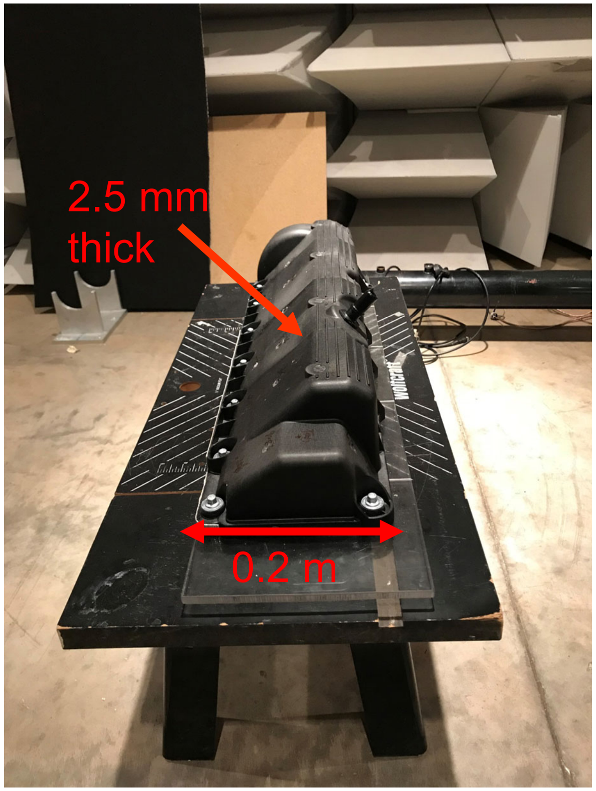
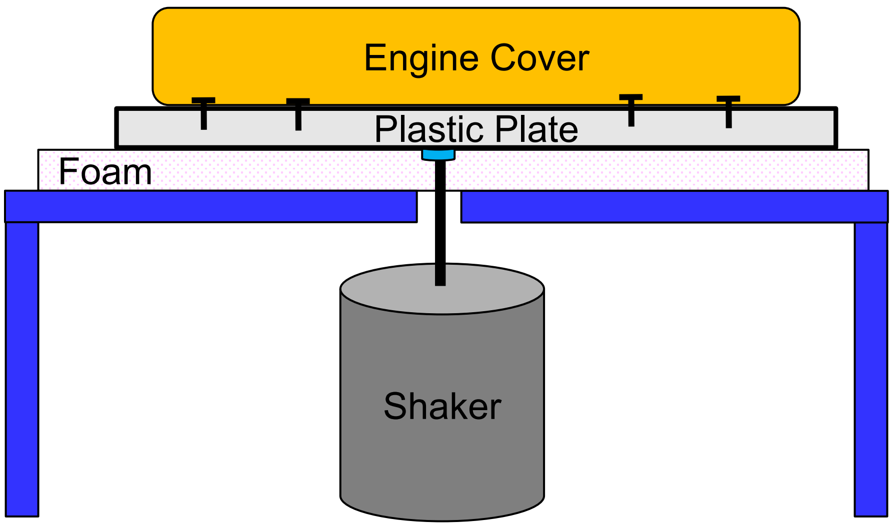
Engine Cover

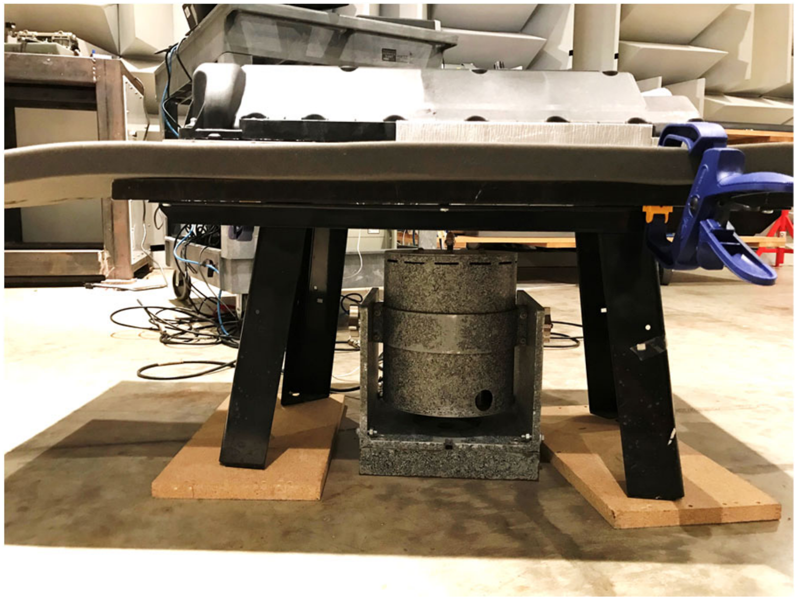
- Engine cover (receiver) is bolted on a plastic plate (source)



Measurement Setup

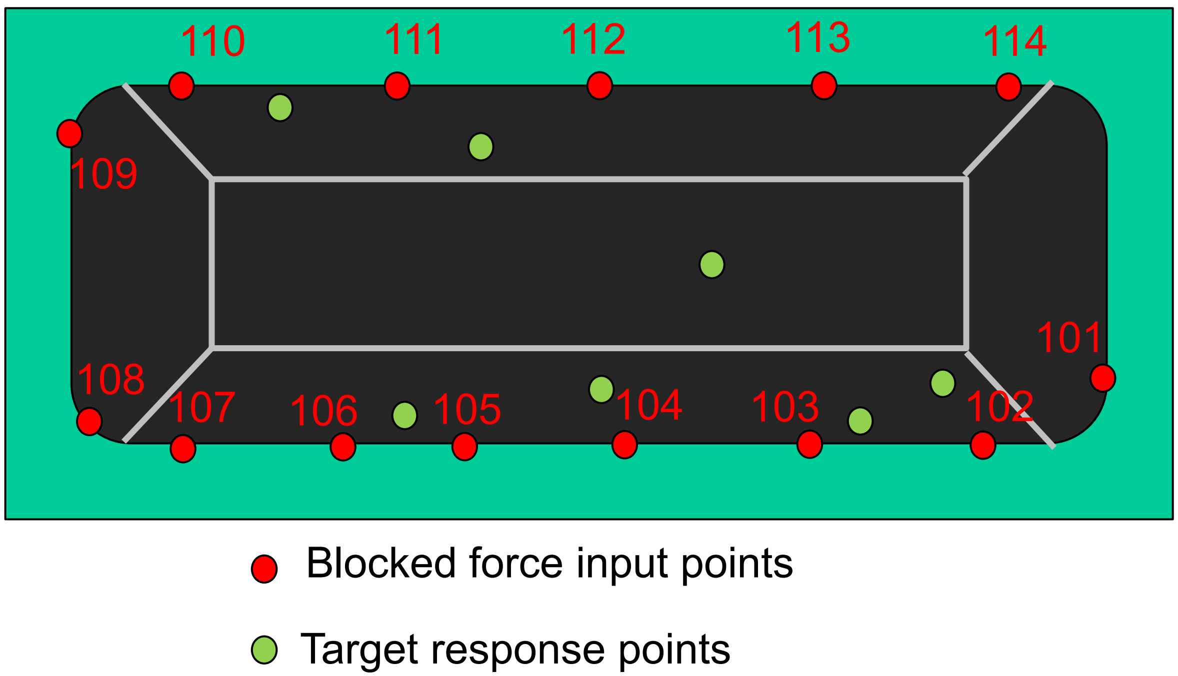
- Electromagnetic shaker is used to excite plastic plate.
- Assembled system is placed on foam to simulate free-free boundary condition.



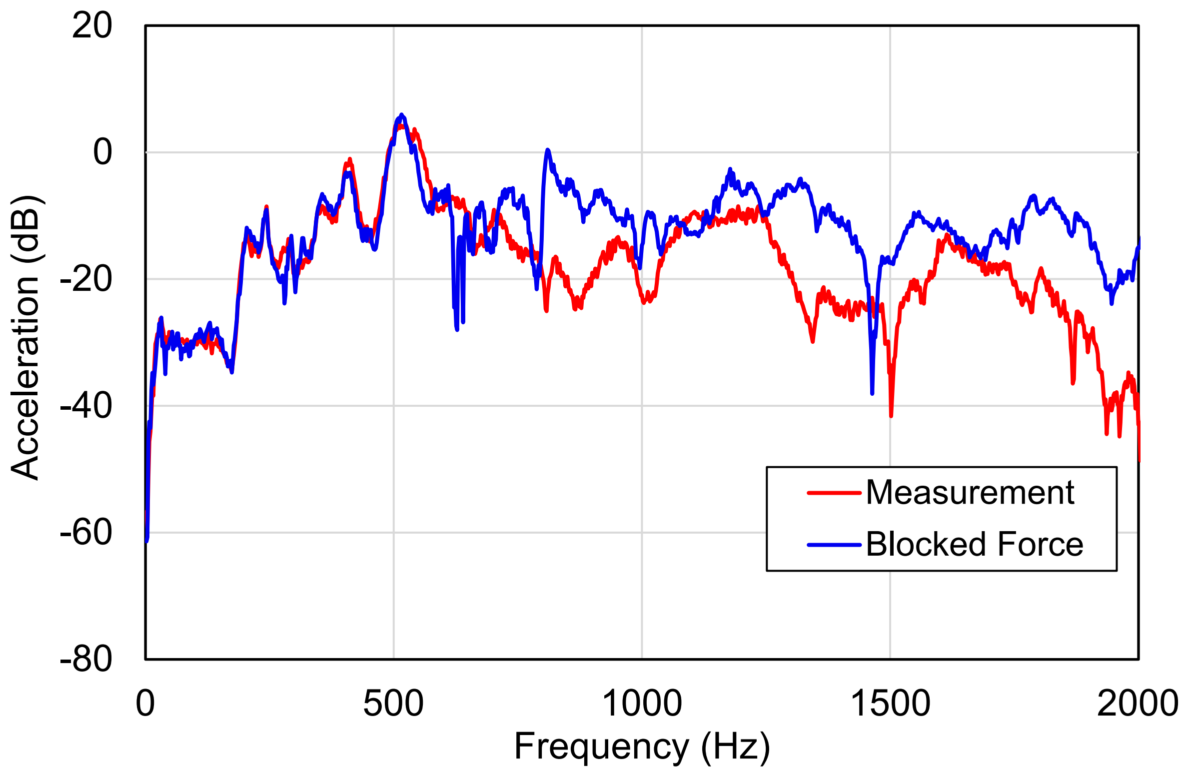


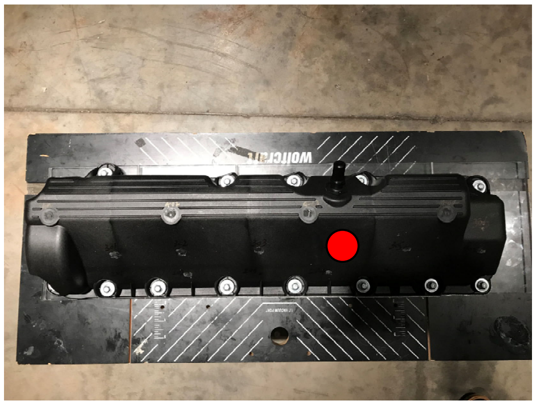
Blocked Force Determination

- 14 blocked force input points are chosen on the bolts in normal direction.
- 21 indicator points are evenly spaced on engine cover.
- 7 target points are chosen on engine cover



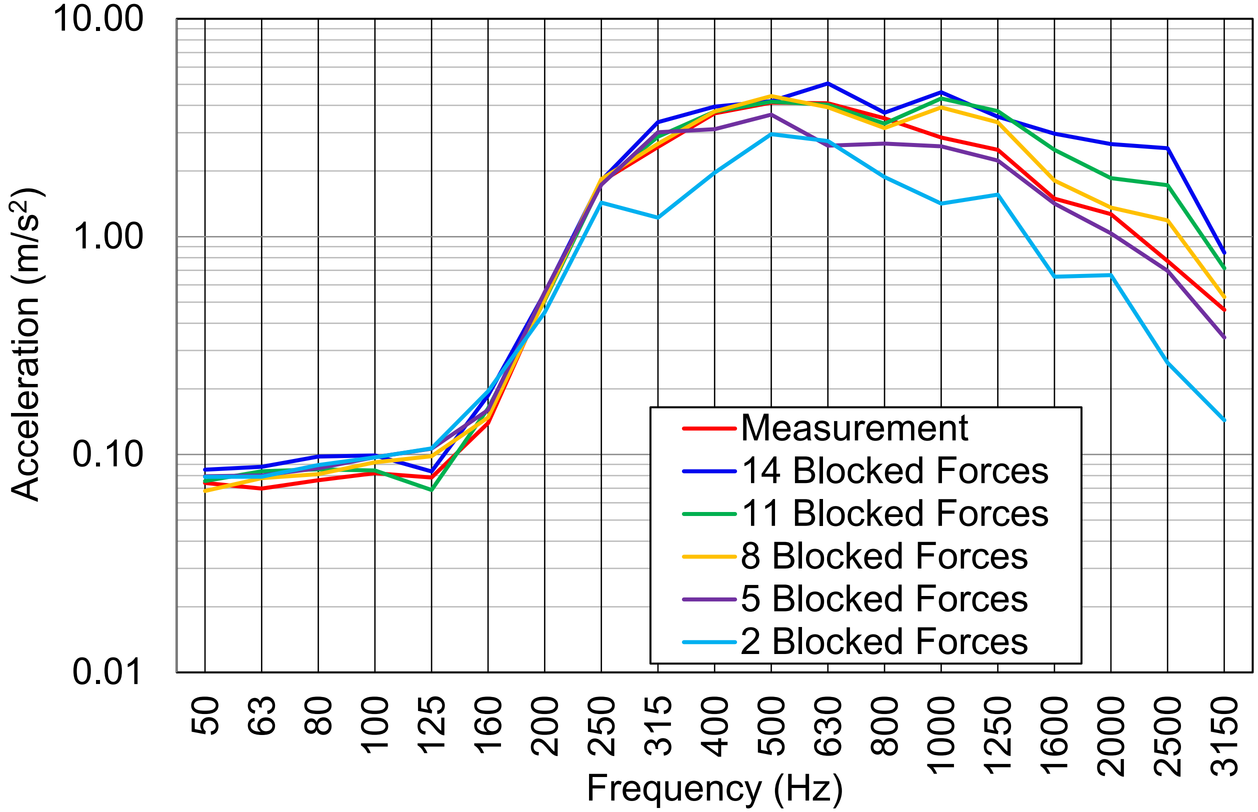
Correlated Single Target Comparison





Correlated Target Average Comparison

Average acceleration level of 7 target points is compared between measurement and blocked force prediction.

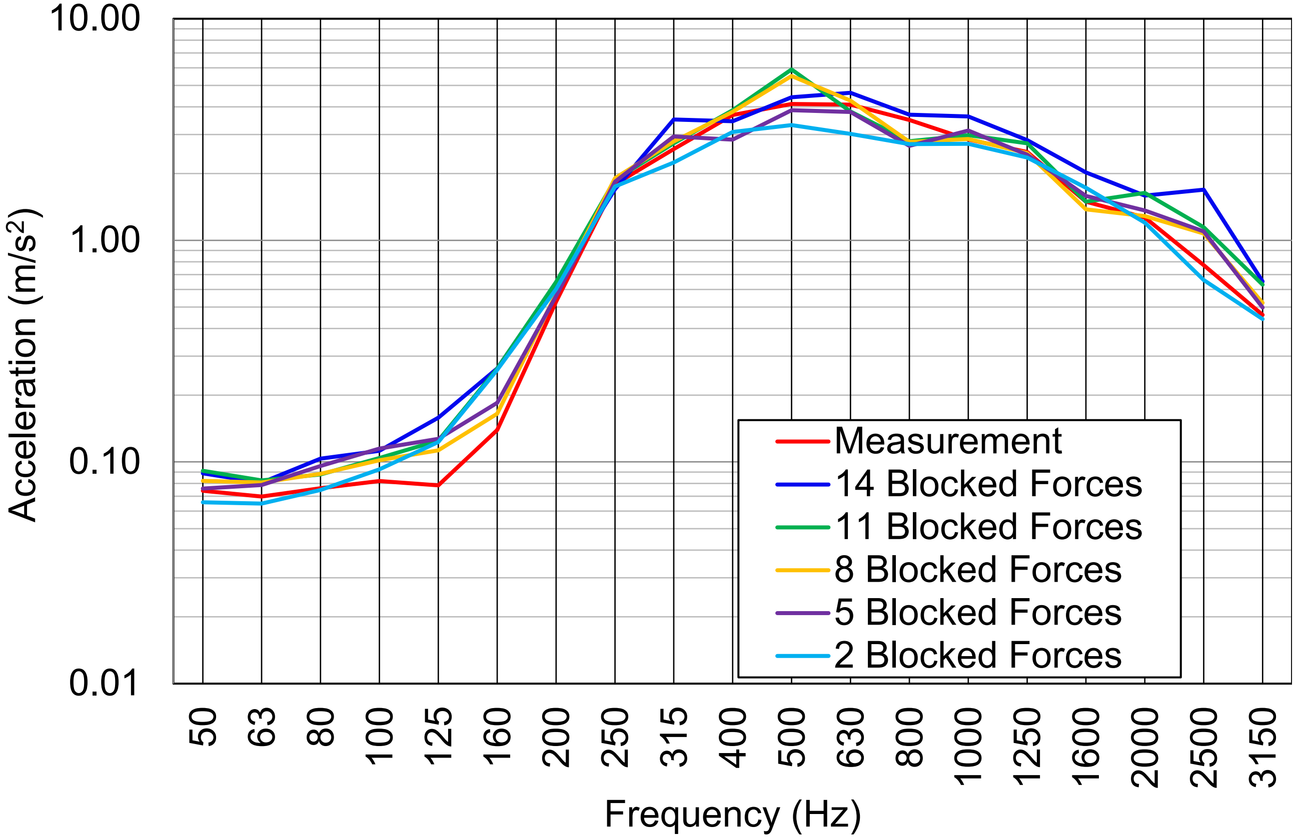


Uncorrelated Blocked Force

- Phase is not included in the calculation.

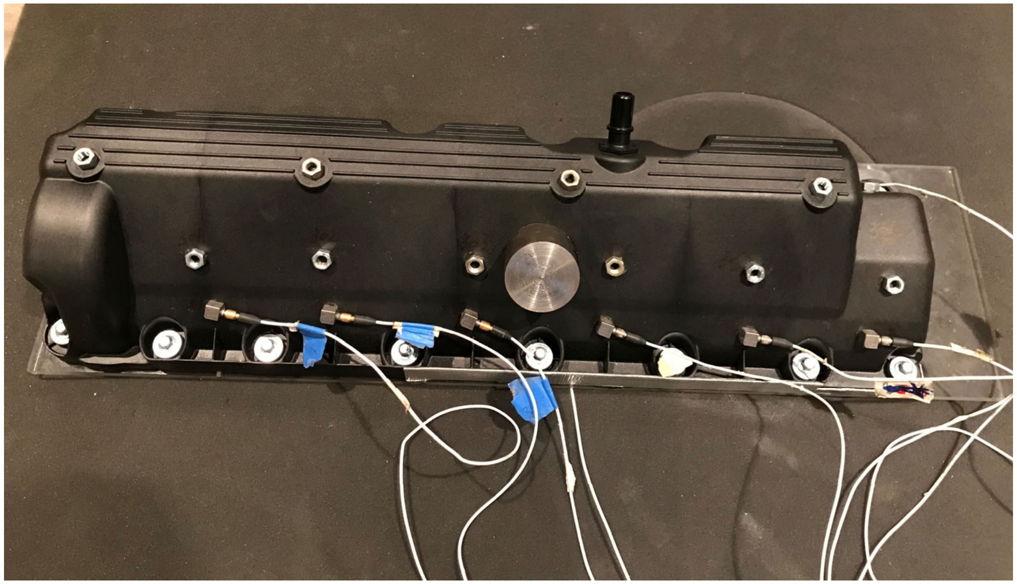
$$\{\hat{a}_{rec}\}_M = \left[\hat{H}\right]_{M\times N}\left\{\hat{F}_{bl}\right\}_N$$

Uncorrelated Target Average Comparison

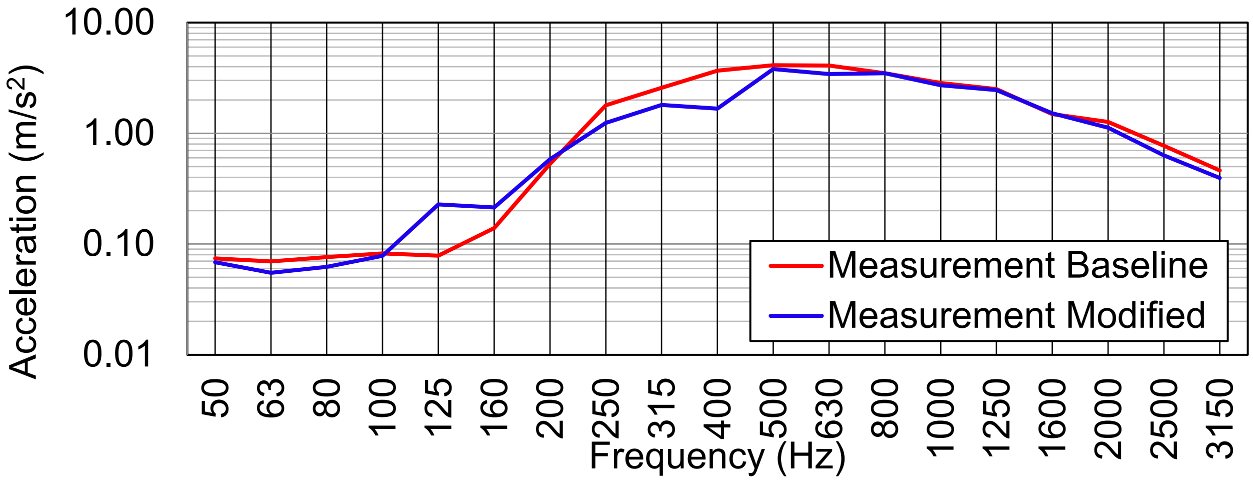


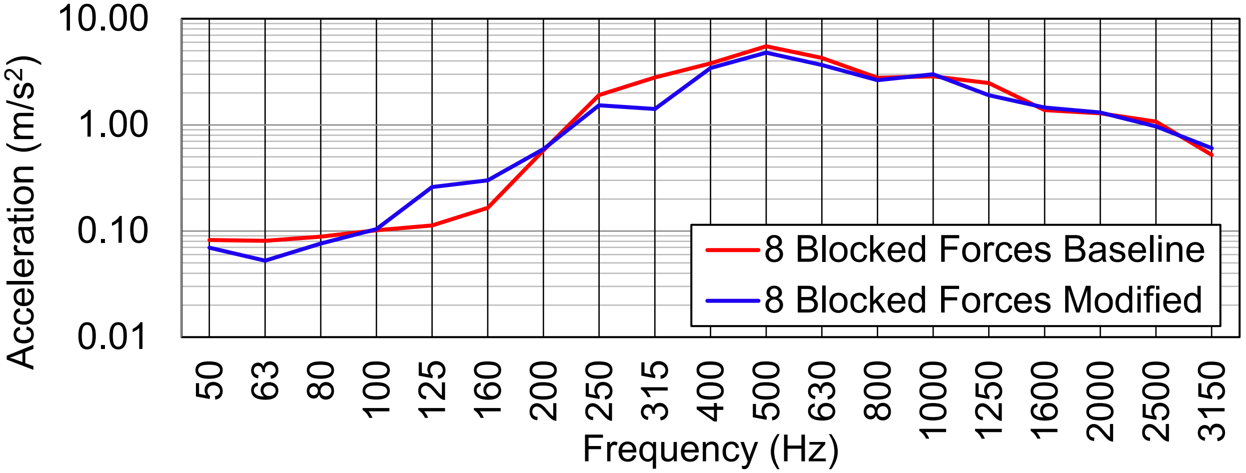
Measurement Case Modification

- Cylinder shaped mass is glued on engine cover to reduce acceleration level.
- The added mass is about 1/4 of the engine cover.
- Can uncorrelated blocked forces be used to predict the effect of a modification?



Uncorrelated Averaged at Targets





Recommendations

- A spacing (s) of $s \leq 0.5\lambda_B$ is recommended along an interface for plate and shell structures where λ_b is the bending wavelength. This spacing has been validated using FEM analyses.
- Once $s \geq 0.5\lambda_b$, it is recommended to use uncorrelated forces.

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Acoustic Blocked Source Analysis

Transfer Functions

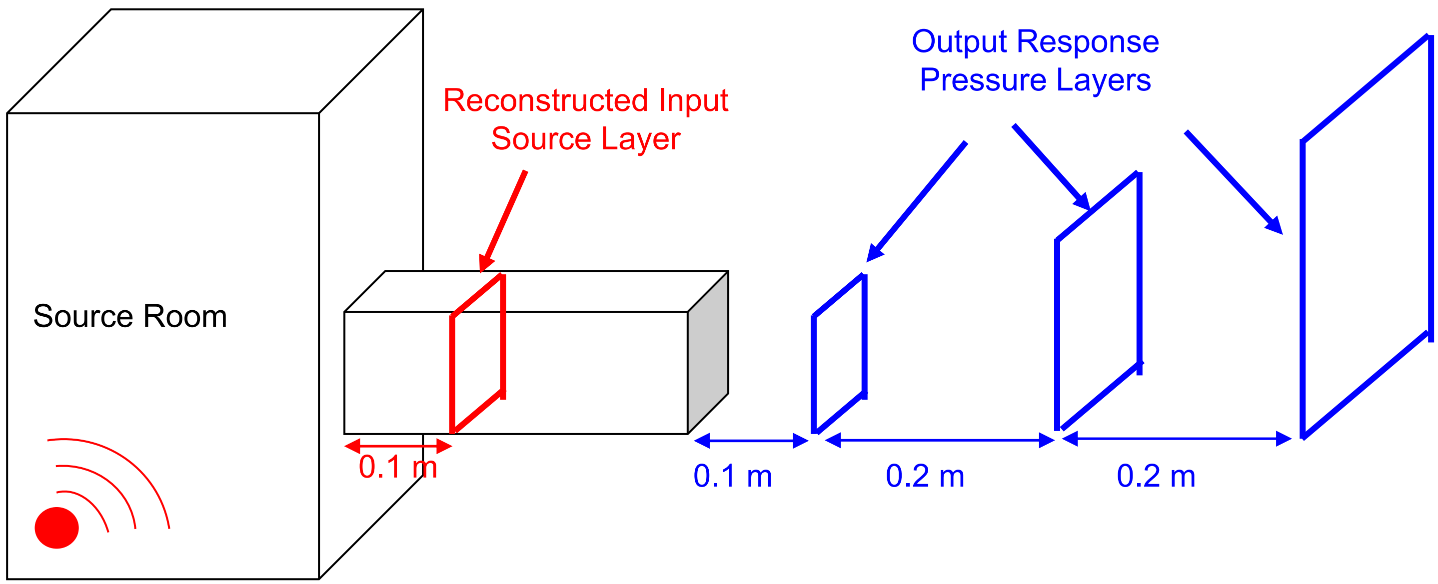
$$\{p\}_M = [H]_{M\times N}\{Q\}_N$$

Output Response Pressure

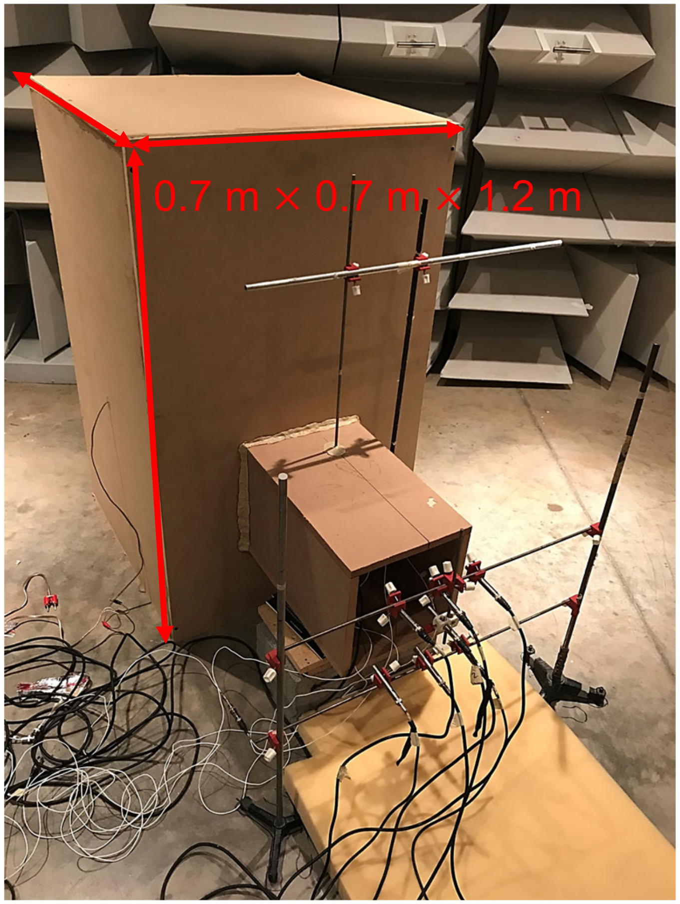
Volume Velocities
- Acoustic Blocked Forces

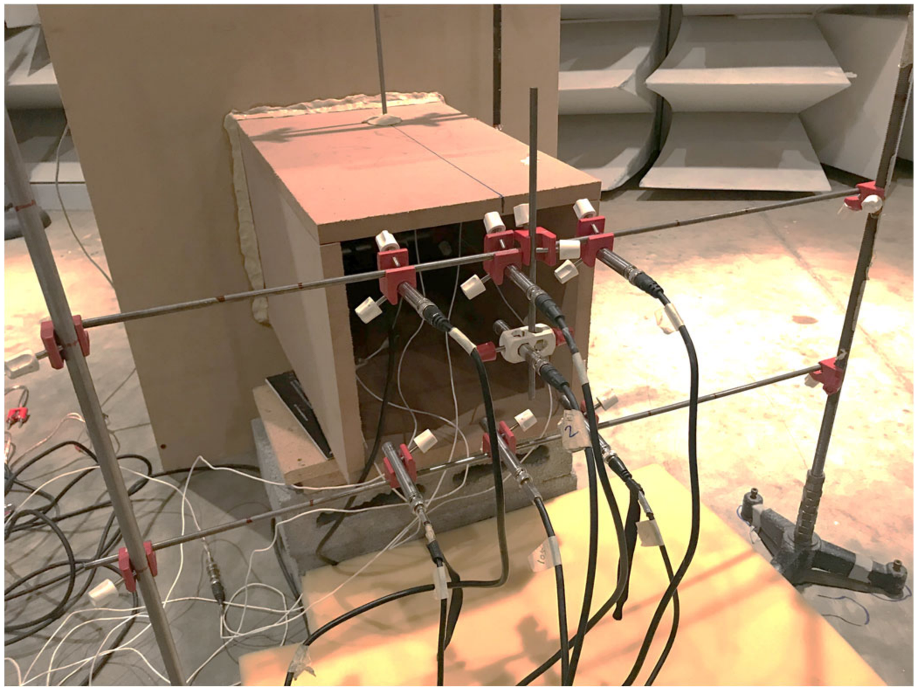
Acoustic Duct

- Input source layer has 6 reconstructed sources
- Each output response layer has 6 indicators and 1 target.



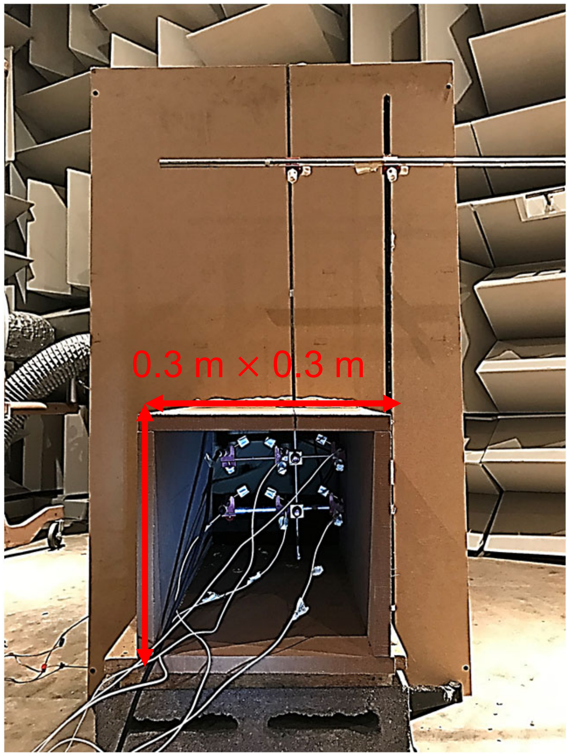
Measurement Case Baseline Setup

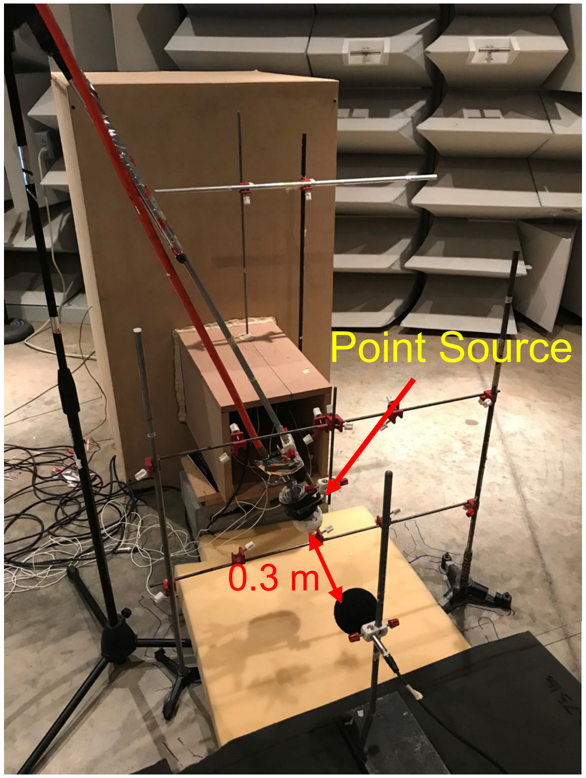




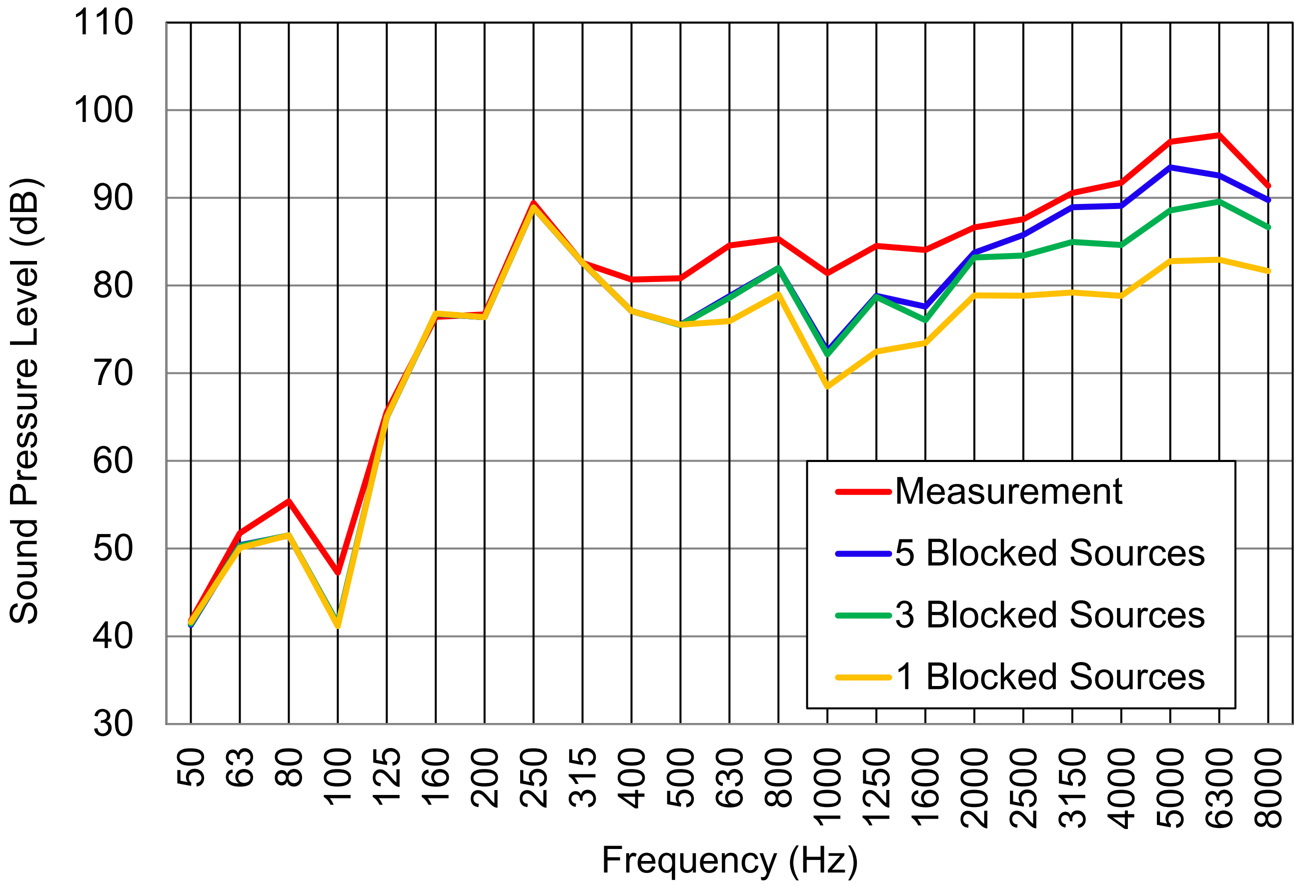
Transfer Function Measurement

- Reciprocity method is used to calculate transfer function.
- A reference microphone is placed 0.3 m away from the volume source to calculate the volume velocity.





Correlated Targets Comparison



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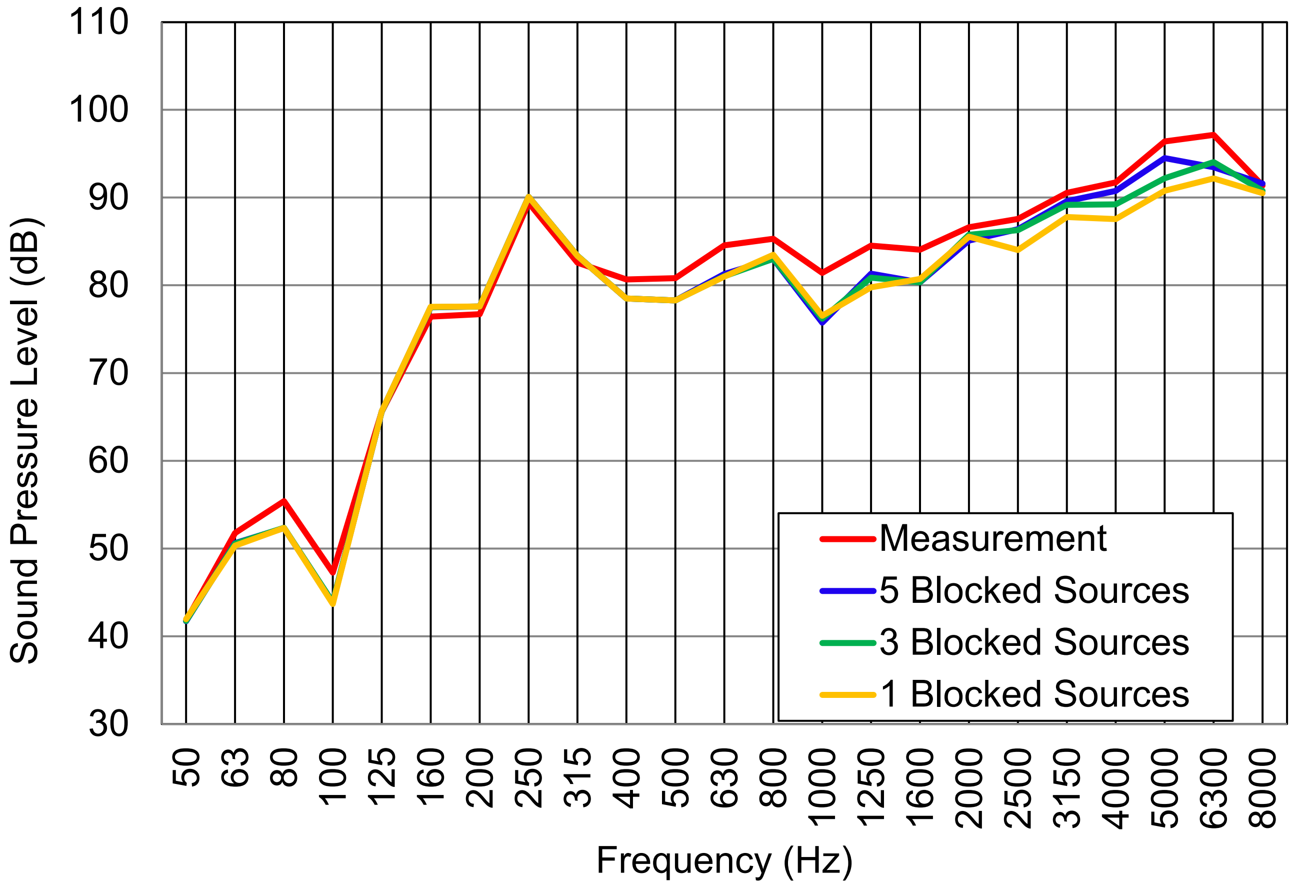
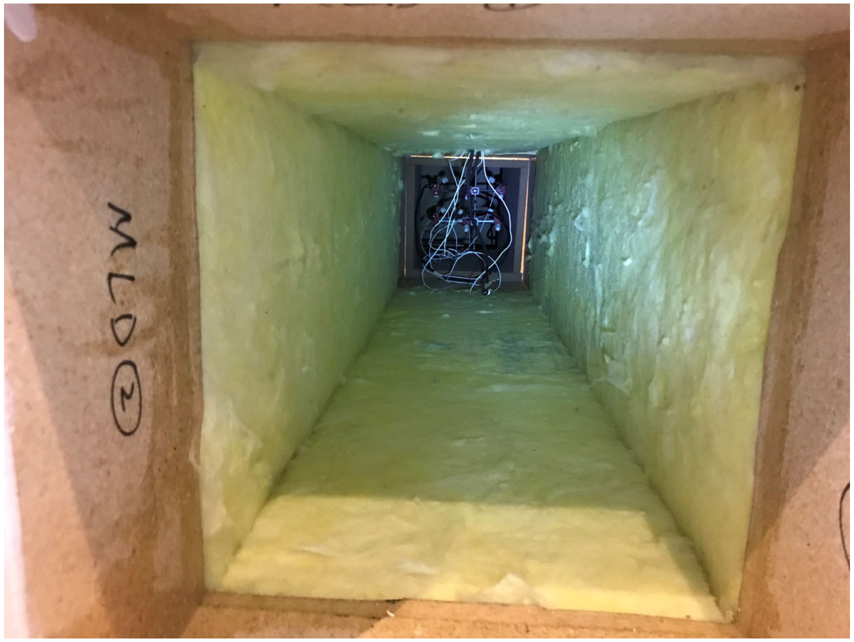
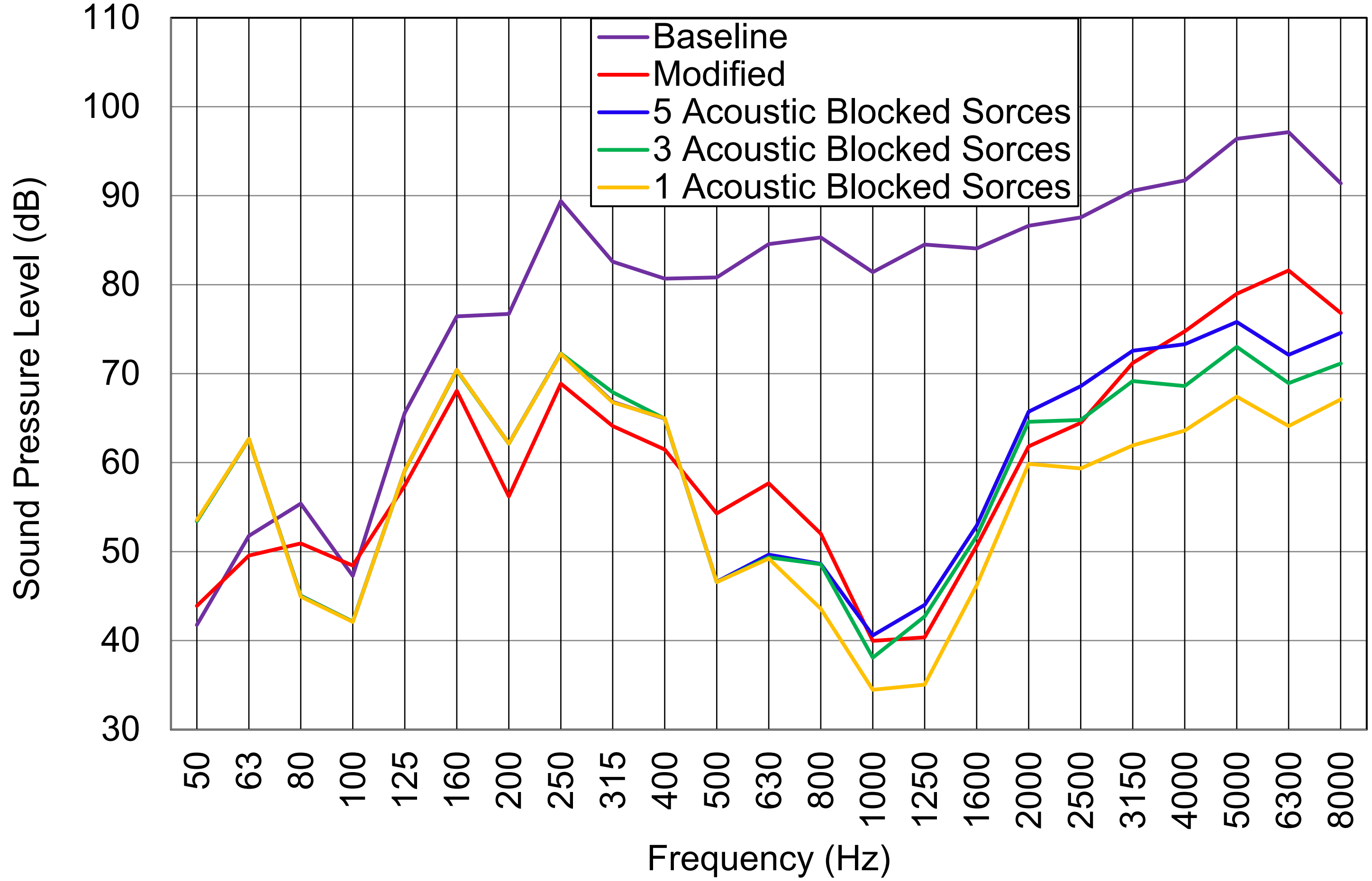


Modification Lined Duct

- A lined duct (5 cm fiberglass) is connected to the baseline case
- Reconstructed acoustic blocked forces for baseline will be used to predict sound pressure level for modification case



Correlated Targets Comparison



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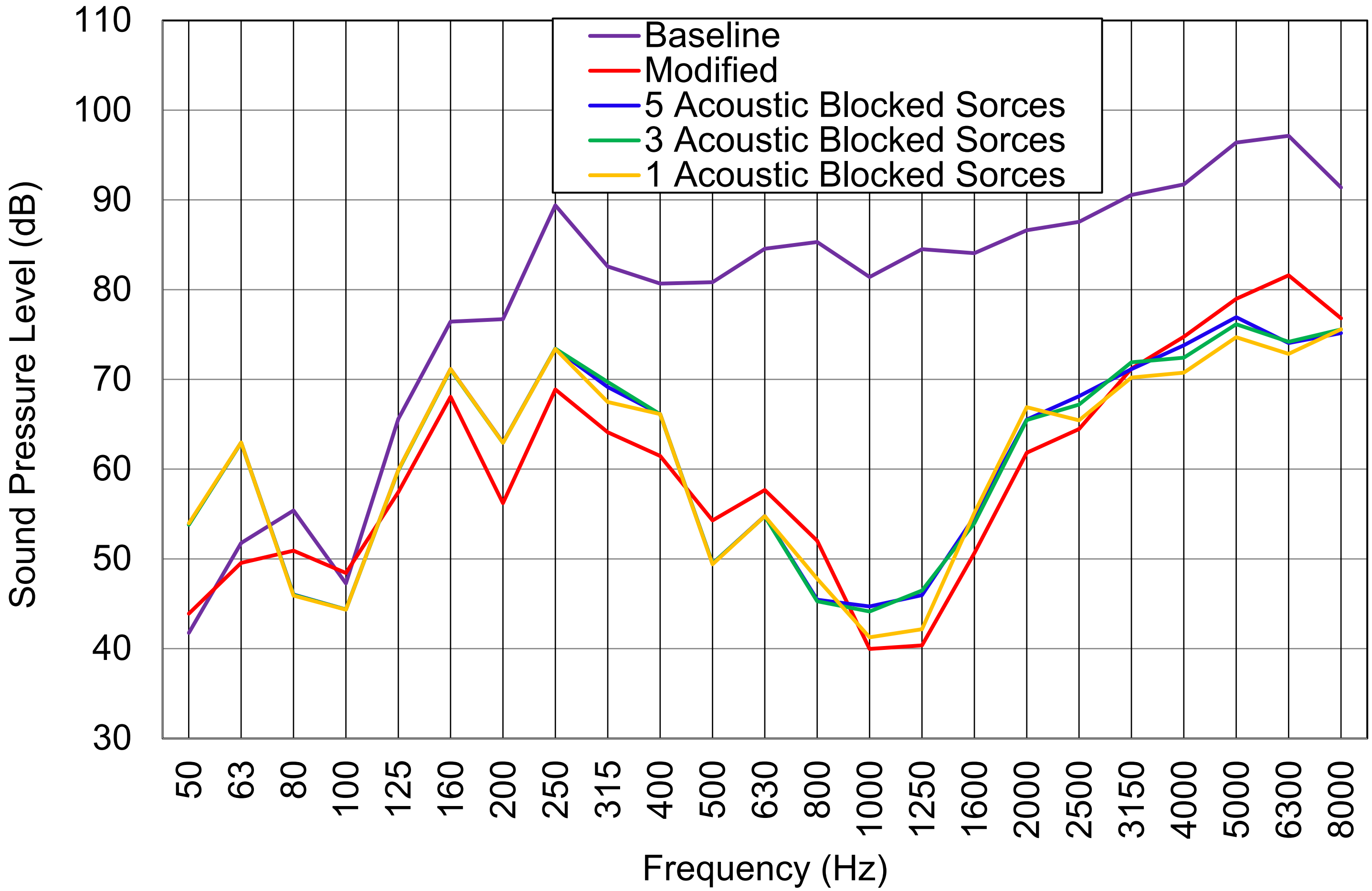

Summary

- A spacing (s) of $s \leq 0.5\lambda_a$ is recommended along the cross-section where λ_a is the acoustic wavelength.
- Once $s \geq 0.5\lambda_a$, it is recommended to use uncorrelated acoustic sources.

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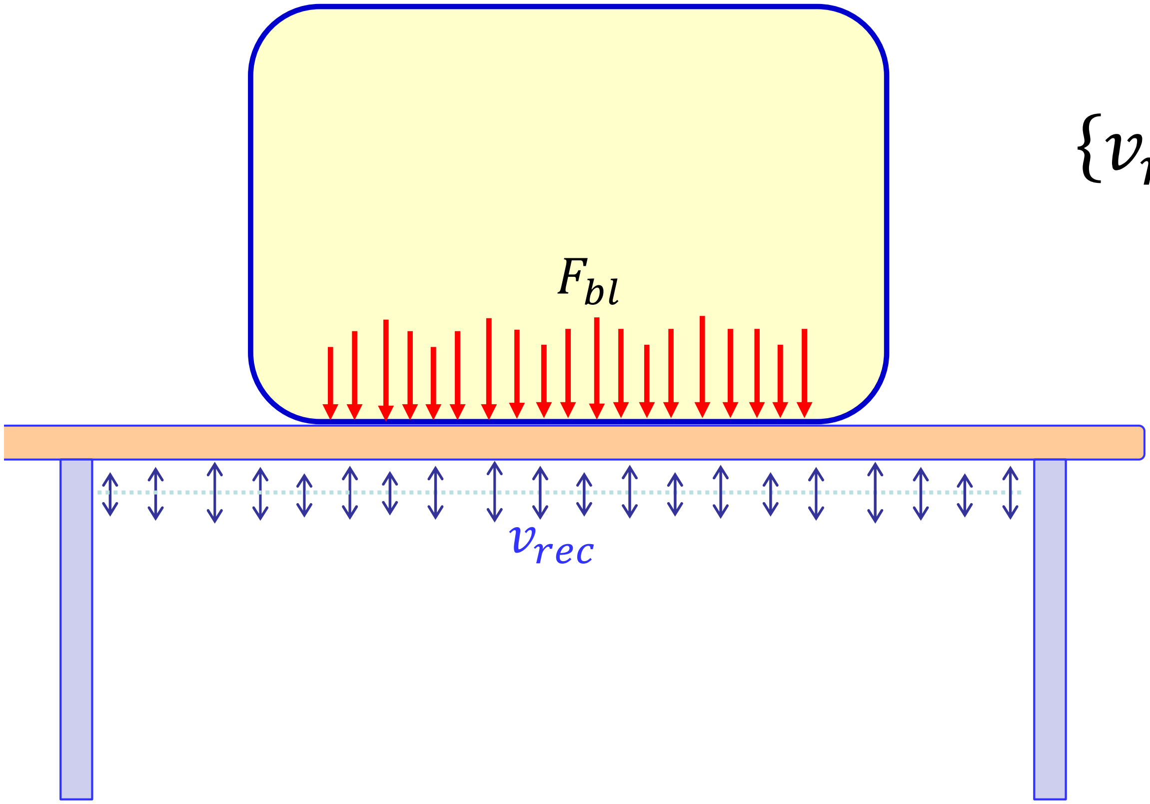
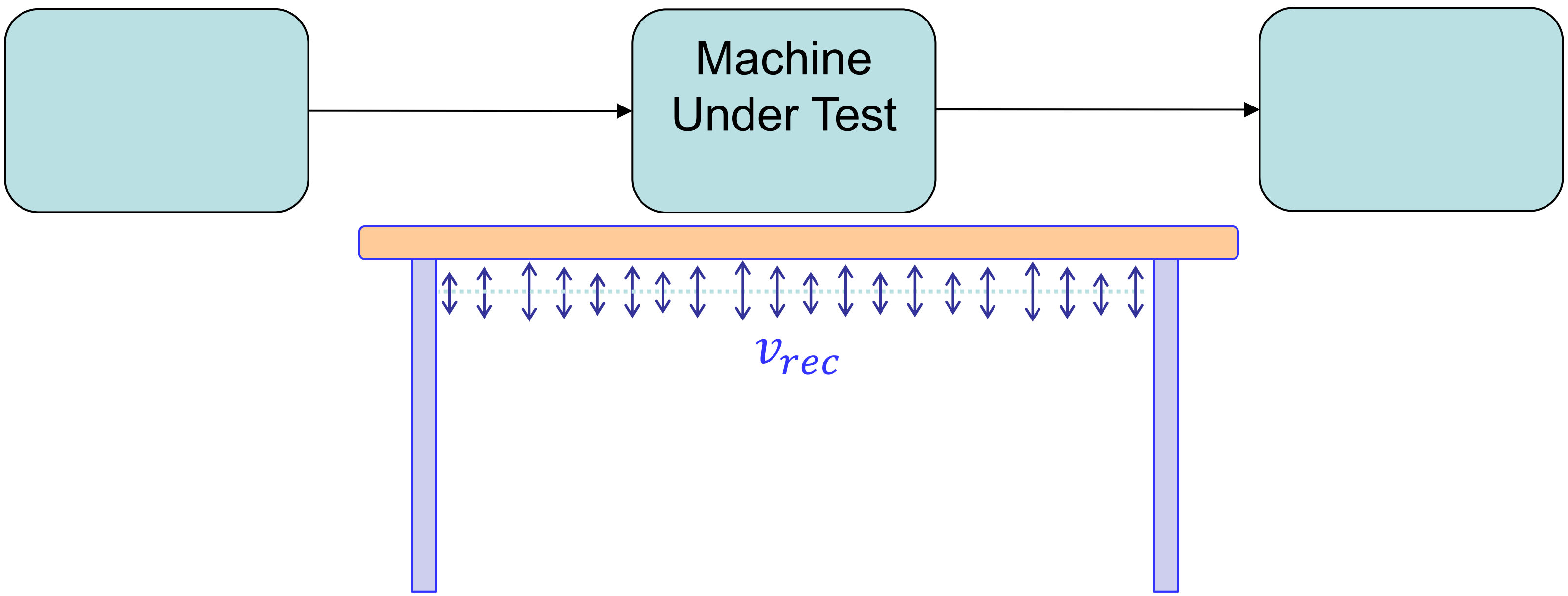
Future Work

- Use response measurements for source diagnostics.



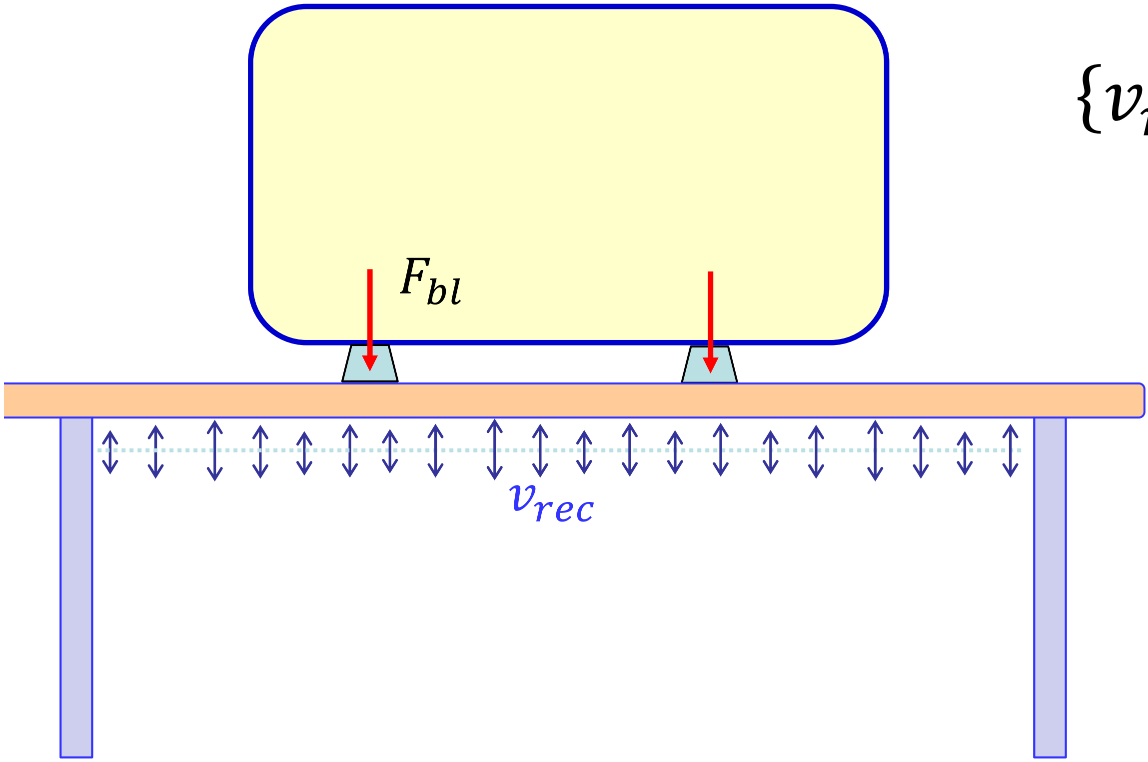
$$\{v_{rec}\}_M = [H]_{M\times N}\{F_{bl}\}_N$$

Future Work



Future Work

- Blocked forces characterize a source with its isolators irrespective of the receiver substructure.



$$\{v_{rec}\}_M = [H]_{M\times N}\underline{\{F_{bl}\}_N}$$

References

- Moorhouse, A. T., Elliot, A. S., and Evans, T. A., "In-situ Measurements of the Blocked Force of Structure-Borne Sound Sources," Journal of Sound and Vibration, Vol. 325, No. 4-5, pp. 679-685 (2009).
- Lennström, D., Olsson, M., Wullends, F., and Nykänen, A., "Validation of the Blocked Force Method for Various Boundary Conditions for Automotive Source Characterization," Applied Acoustics, Vol. 102, pp. 108-119 (2016).
- Chen, K. and Herrin, D. W., "Technical Note – Blocked Force Determination on Plate Structures using an Offset Interface," Applied Acoustics, Vol. 158, Paper No. 107044 (2020).
- Chen, K., Herrin, D. W., and Baker, J. R., "Determination of Correlated and Uncorrelated Blocked Forces on an Engine Valve Cover," Noise-Con 2019, San Diego, CA, August 26-28 (2019).