2009 SAE Noise and Vibration Conference

SEA Workshop

Testing to Support SEA Model Development

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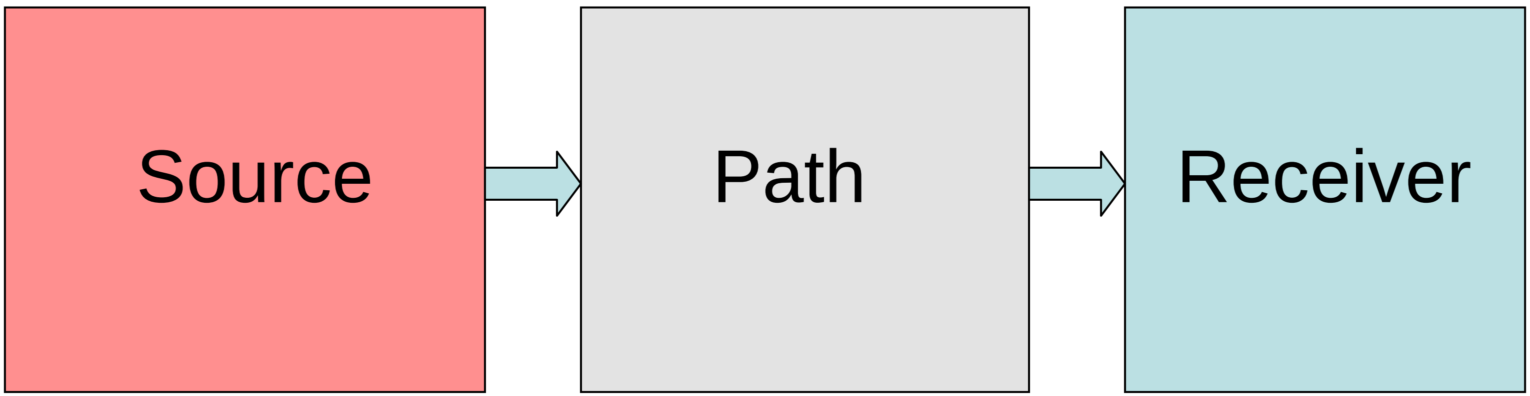
SEA Models



- SEA models track the diffusion of energy in a system.
- SEA models balance **damping** versus **diffusion**.
- **Power** and **Energy** are primary variables but are not observable.
- **Acceleration** and **Pressure** are observable but are derived quantities.
- The mechanical and acoustic **impedance** relate the Power and Energy to the Acceleration and Pressure.

Information on all elements of the model are required!

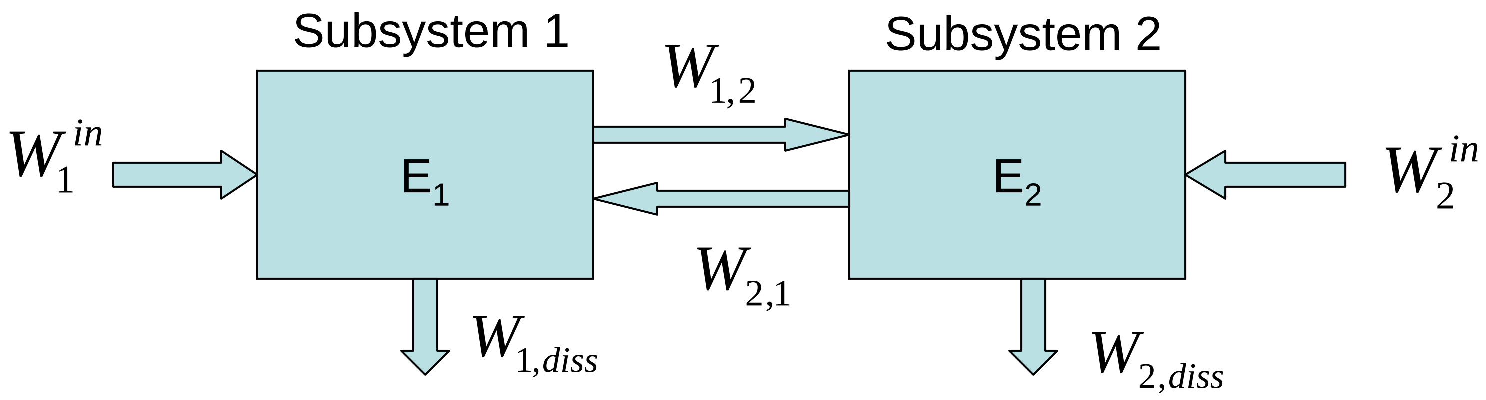
Models are used to do two things:

1. Assess Performance – Answer the question ‘Does the airplane meet its design requirements?’
2. Support Design – Answer the question ‘How do we improve the current design?’

Both tasks are important. Testing plays a crucial role in the development of the model. It is necessary to collect test data to assess both modeling tasks.

Process is important. Standard work and procedures are necessary to show the process is in control and to systematically improve the modeling capability.

SEA Models



Classical SEA Equations derived from power balance requirements:

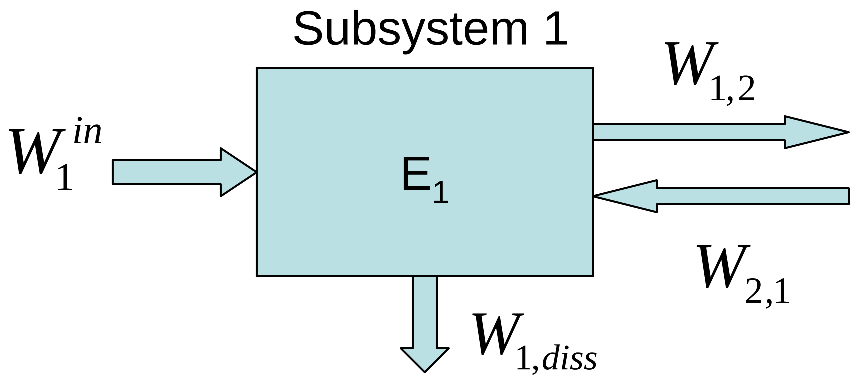
$$\omega\left[g_{i,j}\right]\left\{E_i\right\} = \left\{W_i^{in}\right\}$$

where

$$g_{i,i} = \eta_{i,diss} + \sum_{j=1}^{N} \eta_{i,j}$$

$$g_{i,j} = -\eta_{j,i}$$

Receiver – Subsystem Characterization

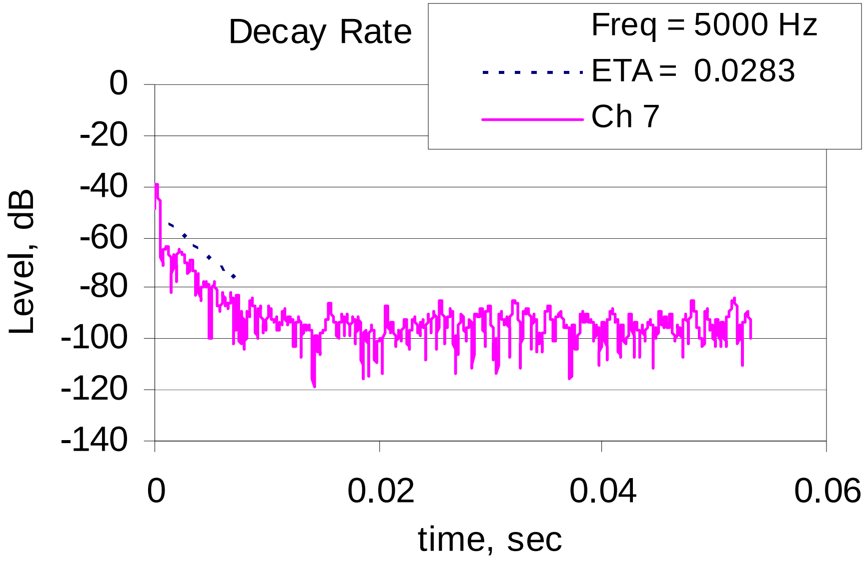


1. Damping
2. Number of modes – impedance
3. Wave speed

Receiver – Subsystem Characterization
Damping

Typically measured:

1. Reverberation Decay
2. IRDM – Impulse Response Decay Method
3. Power Injection
4. Half Power Bandwidth



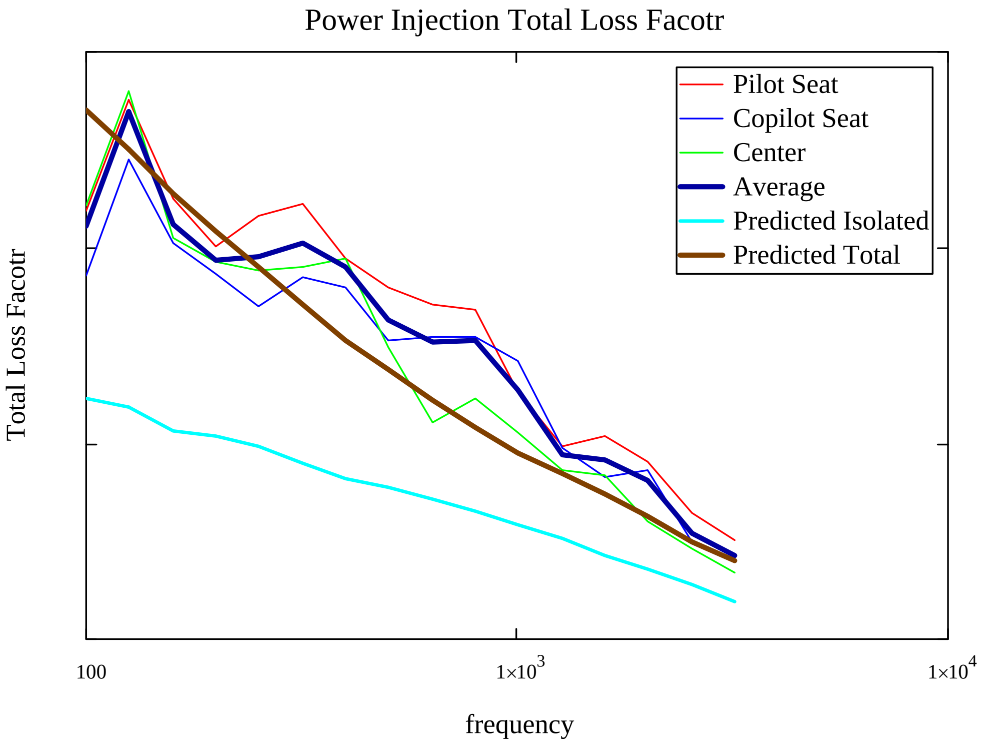
Receiver – Subsystem Characterization Damping

$$\Pi_{in} = \omega \eta_{tot} E_{tot}$$

$$\Pi_{in} = \rho_{air} \omega^2 Q^2 / 8\pi c$$

$$E_{tot} = p^2 Volume / \rho_{air} c^2$$

$$\eta_{tot} = \frac{\omega \rho_{air}{}^2 c}{8\pi Volume} \left\{ \frac{Q^2}{p^2} \right\}$$



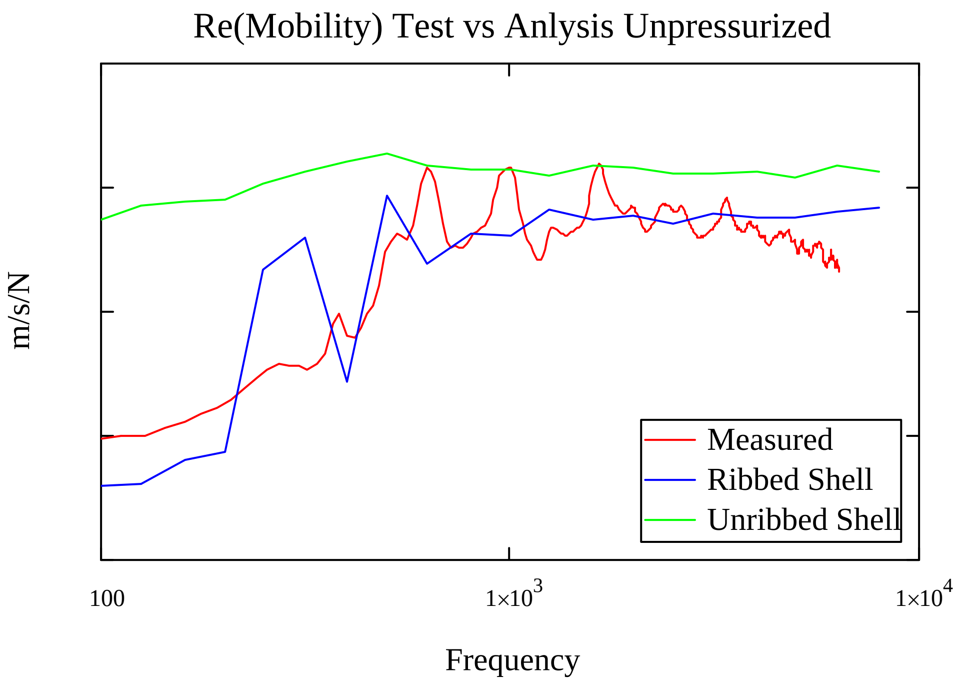
Receiver – Subsystem Characterization
Modal Density

Typically measured:

1. Input Mobility, $Re\{Y_{00}\} = G$

$$G_r = \frac{\pi}{2}\frac{n_r(\omega)}{M_r}$$

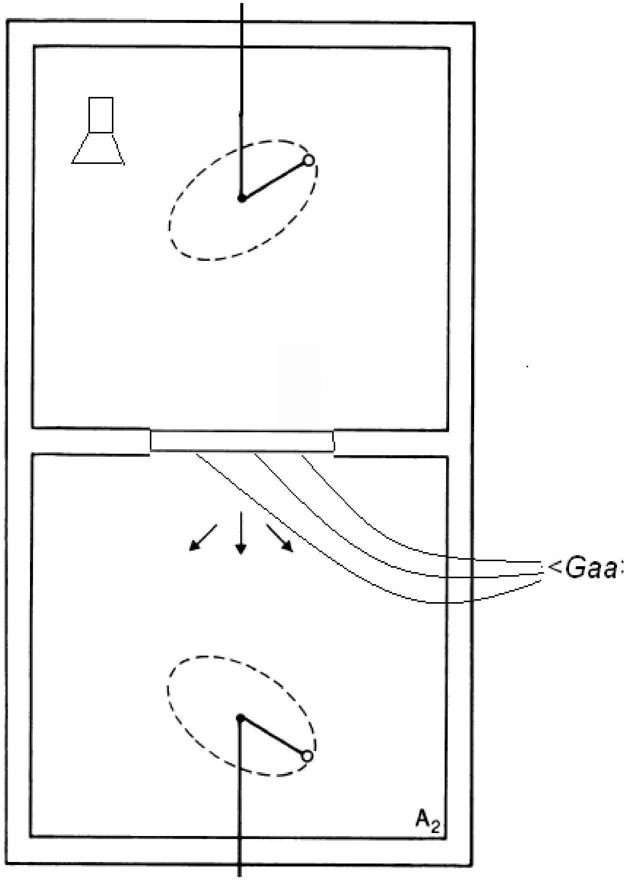
CROWN



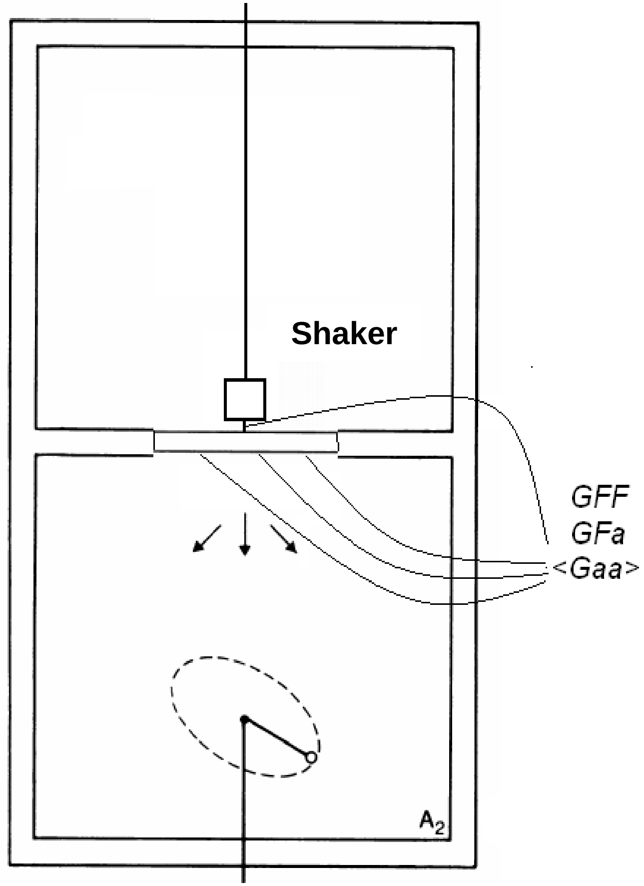
Pre-production Testing Opportunities

A series of tests can be performed on a representative structure in a transmission loss suite to gather the data required for tuning the SEA model:

Transmission Loss



Radiation Efficiency & Mechanical Conductance



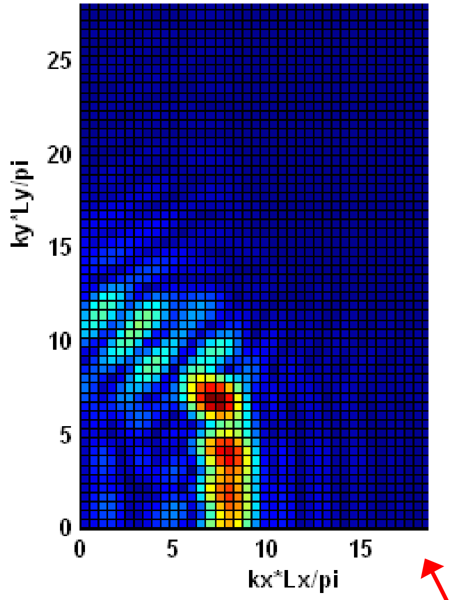
$$\sigma_{rad} = \frac{W_{rad}}{\langle v^2 \rangle \rho_0 c_0 S}$$

$$W_{rad} = \frac{\langle p_{rec}{}^2 \rangle A_r}{4 \rho_0 c_0}$$

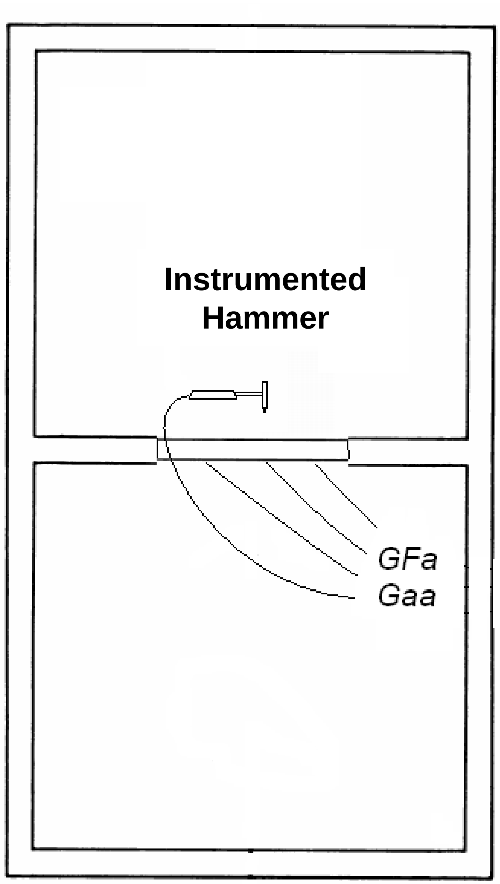
$$G = \mathrm{Re}\{Y_{00}\}$$

Pre-production Testing Opportunities

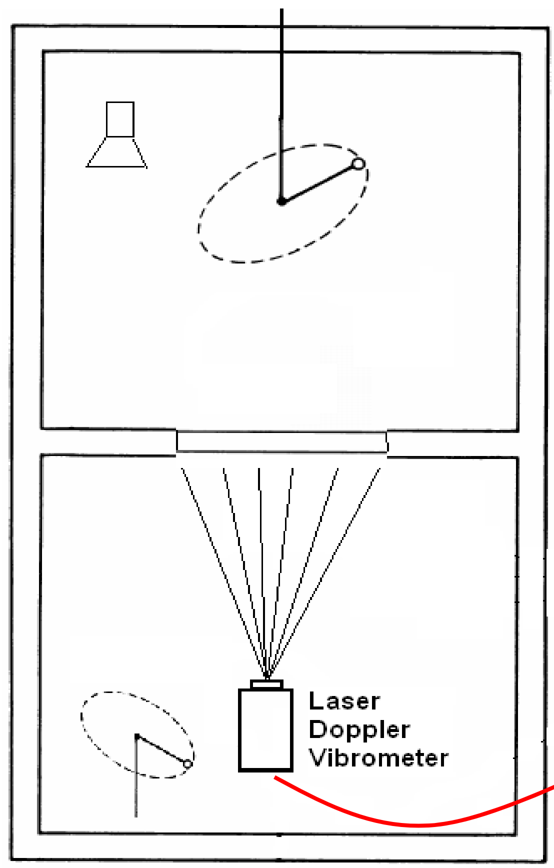
A series of tests can be performed in a transmission loss suite to gather the data required for tuning the SEA model:

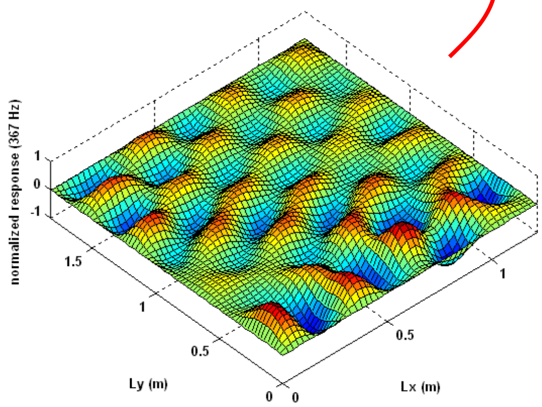


IRDM Loss Factor Estimation



Full Plate/Shell Scan – wavenumber characteristic





Pre-production Testing Opportunities

Transmission Loss

- Used to validate SEA model and other post processed data

Radiation Efficiency - σ

- Provides information of resonant vs. non-resonant radiation
- In general describes how well the panel radiates noise

Damping Loss Factor - η

- Required for the SEA model, typically difficult to estimate without experiment
- The ratio of resonant to non-resonant transmission is proportional to σ^2/η

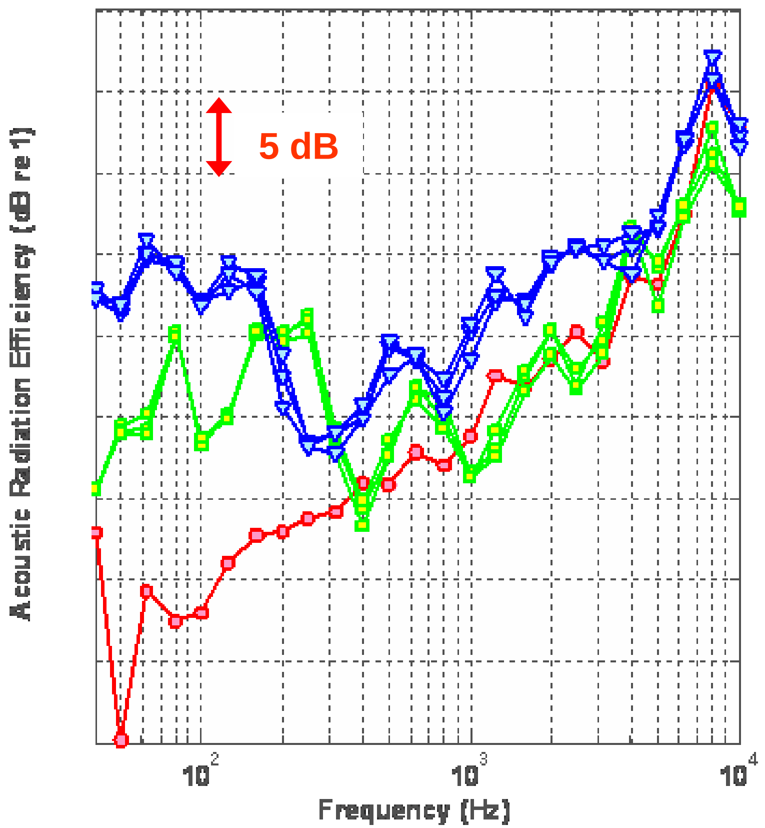
Wavenumber Characteristic

- Can help the SEA modeller during subsystem division
- Describes the structure's acceptance to loading (TBL) and vicinity to the sonic disk

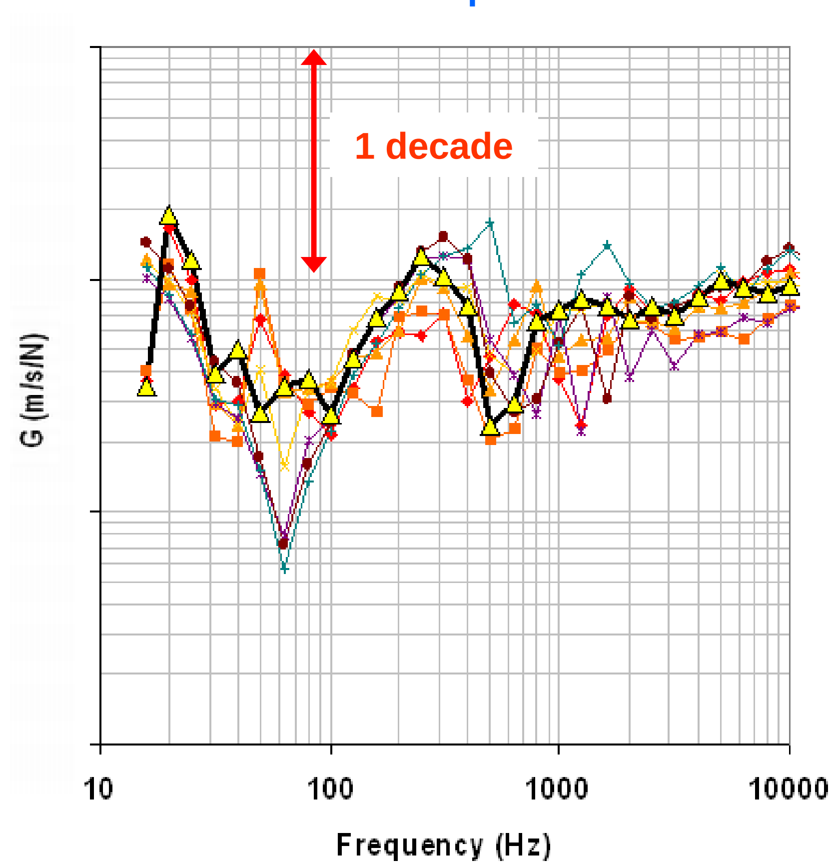
Pre-production Testing Opportunities

Examples of measured data:

Radiation Efficiency of three test panels



Point Conductance at multiple locations on one panel



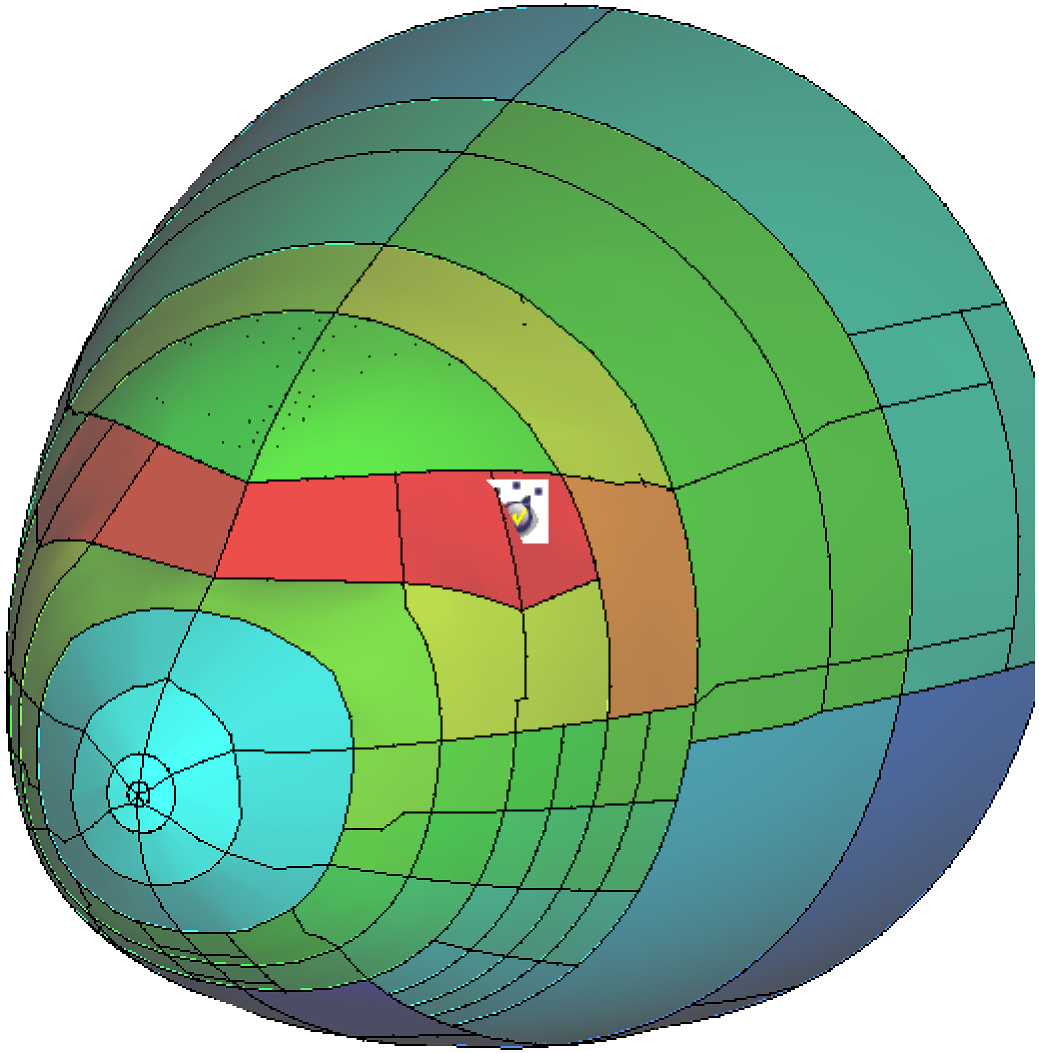
Path Information

Point to Point Transfer Functions:

$$\frac{a_r}{\dot{Q}_s} = \frac{p_s}{F_r}$$

The measured acceleration normalized by the volume acceleration is the same as the pressure at the source location due to a force at the measured accelerometer position.

Statistical Energy Analysis Model Validation



777 Flight Deck SEA Model

Acoustic Volumes

Response at 1600 Hz

Source: Pilots Seat

Path Information - Power Transfer Functions

Change of variables: $\beta_{i,j} = \omega n_i(\omega)\eta_{i,j} = \omega n_j(\omega)\eta_{j,i}$ $\quad W_i = E_i / n_i(\omega)$

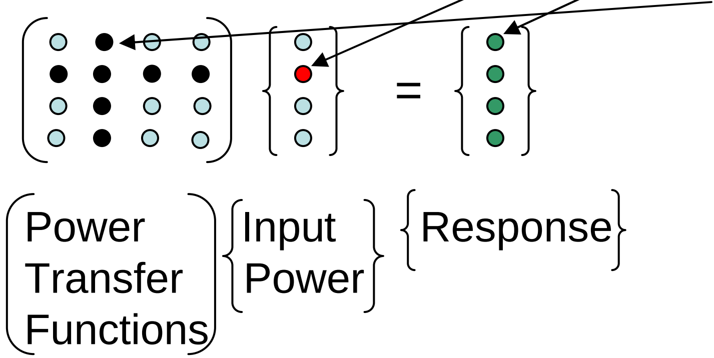
Symmetric Matrix: $$\left[b_{i,j}\right]\left\{W_i\right\} = \left\{W_i^{in}\right\}$$

$$\left[b_{i,j}\right]^{-1}$$ Is observable!

$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\} = \left\{W_i\right\}$$

Process

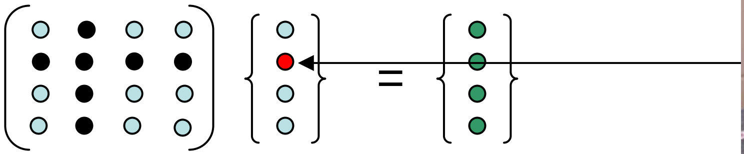
- Apply external power to one subsystem
- Measure the response on all subsystems
- Compute power transfer functions
- Repeat for other source locations



Power Transfer Function Measurement

Step 1: Apply External Power to single subsystem
(turn on speaker)

$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\}=\left\{W_i\right\}$$

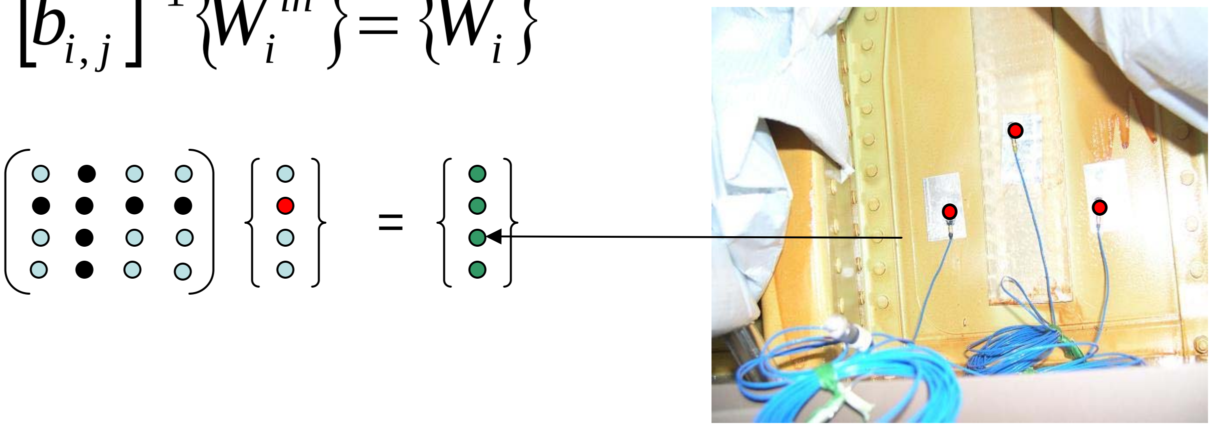


$$W_i^{in}=\rho_{air}\dot{Q}_i^{\,2}/8\pi c$$

Power Transfer Function Measurement

Step Two: Measure the response of the structure.

$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\} = \left\{W_i\right\}$$

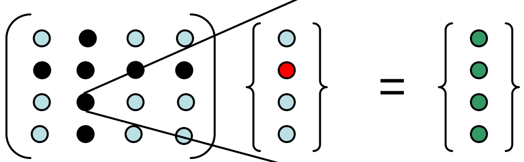


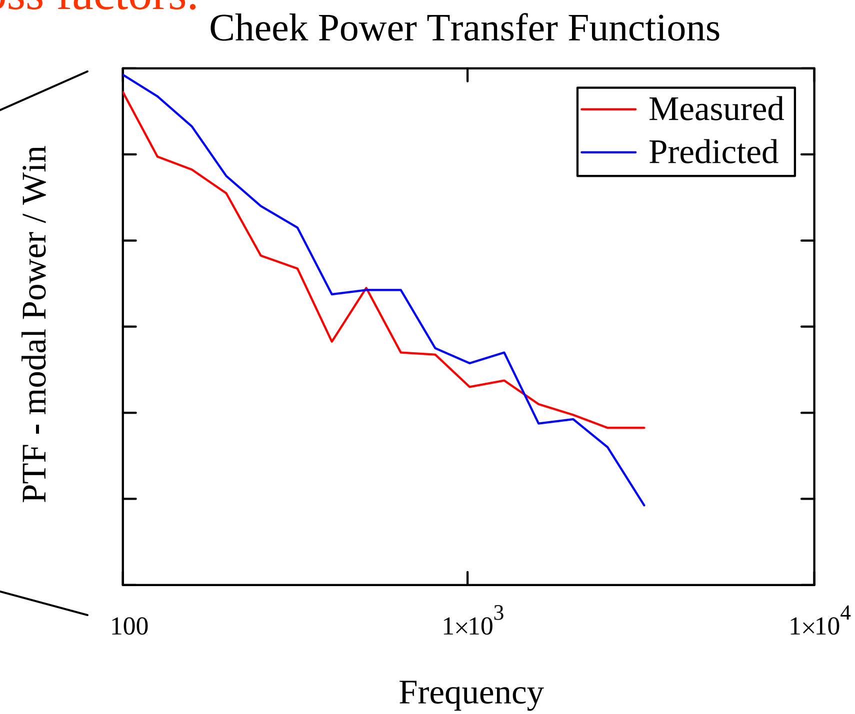
$$W_j = \left\{\frac{\pi}{2G_j}\right\}\left\{\frac{a_j^{\,2}}{\omega^2}\right\}$$

Power Transfer Function Measurement

Step Three: Calculate the off diagonal terms. These are the power transfer functions. They are related to the coupling loss factors.

$$[b_{i,j}]^{-1}\{W_i^{in}\} = \{W_i\}$$





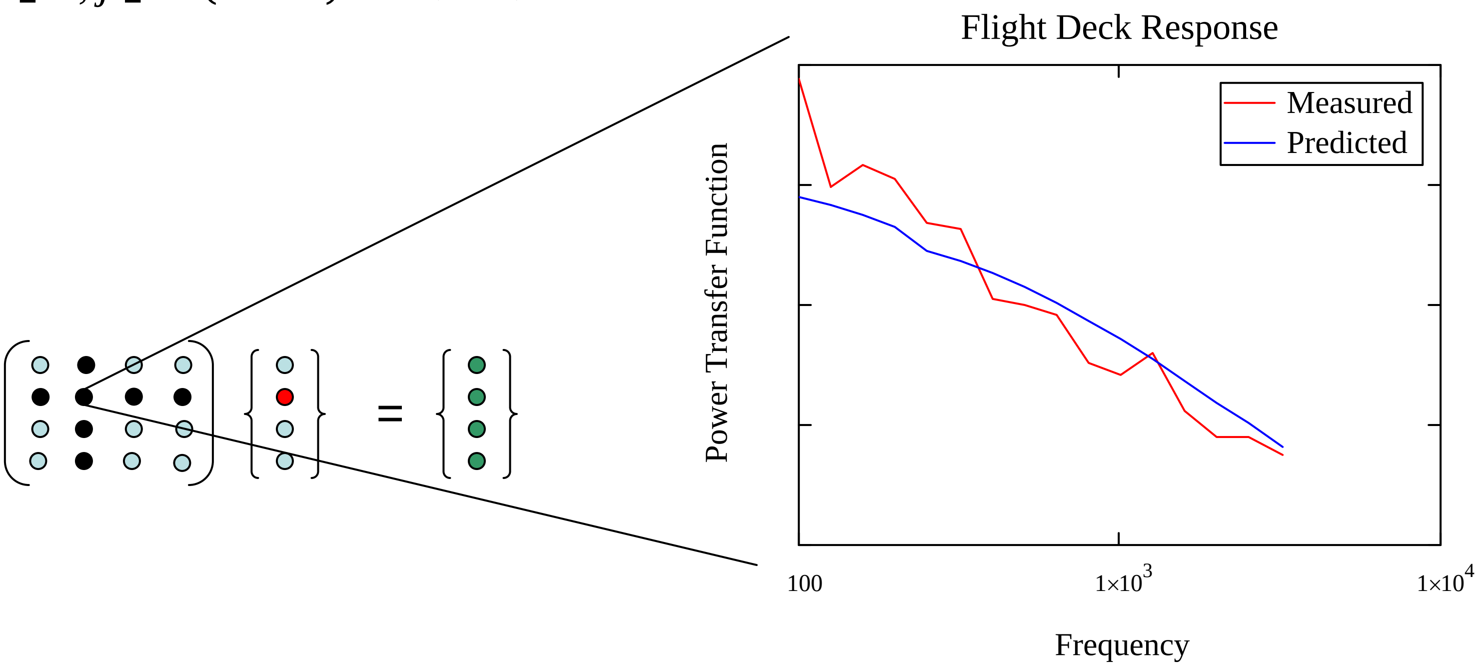
Result:

$$\frac{W_j}{W_i^{in}} = \frac{4\pi^2 c}{\rho_{air}\omega^2 G_j}\left\{\frac{a_j^{\,2}}{\dot{Q}_i^{\,2}}\right\}$$

Power Transfer Function Measurement

Step Four: The diagonal term is related to the total loss factor

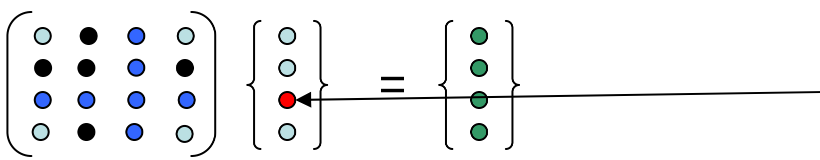
$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\} = \left\{W_i\right\}$$



Power Transfer Function Measurement

Step Five: Repeat for other source locations.

$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\} = \left\{W_i\right\}$$



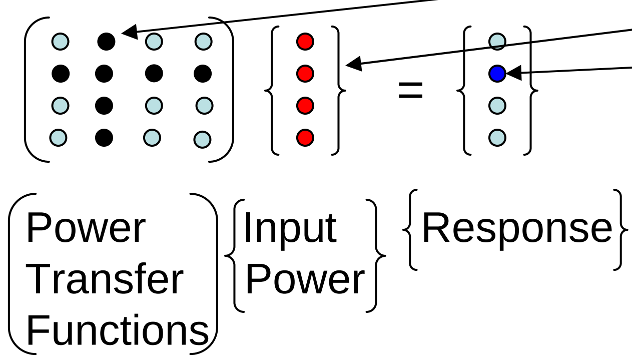
Just another way to look at SEA model validation.

Power Transfer Function Measurement

Opportunity: If you are only interested in one acoustic response, it is possible to build a test based SEA model using a single acoustic reciprocity measurement and an independent source determination.

$$\left[b_{i,j}\right]^{-1}\left\{W_i^{in}\right\} = \left\{W_i\right\}$$

- Acoustic Reciprocity Measurement
- Source Determination
- Calculate Operational Response



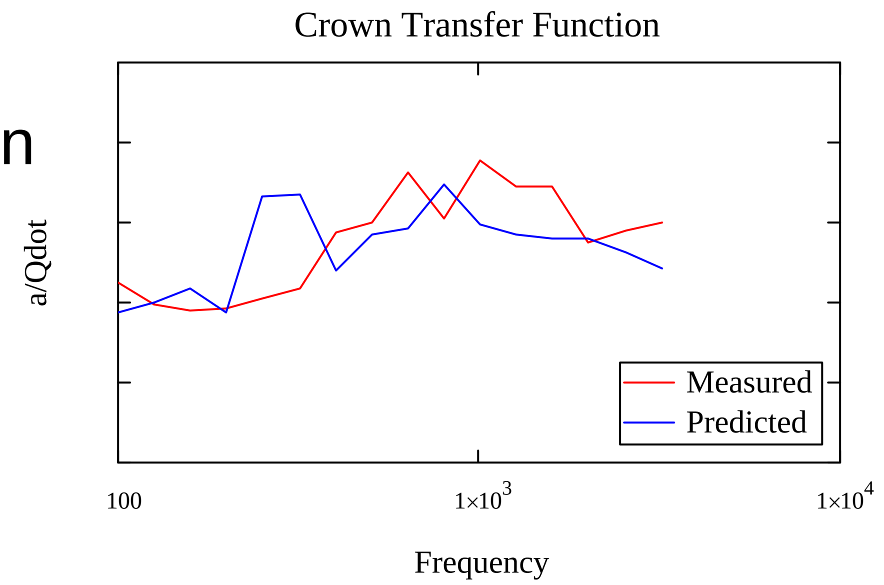
Comparison

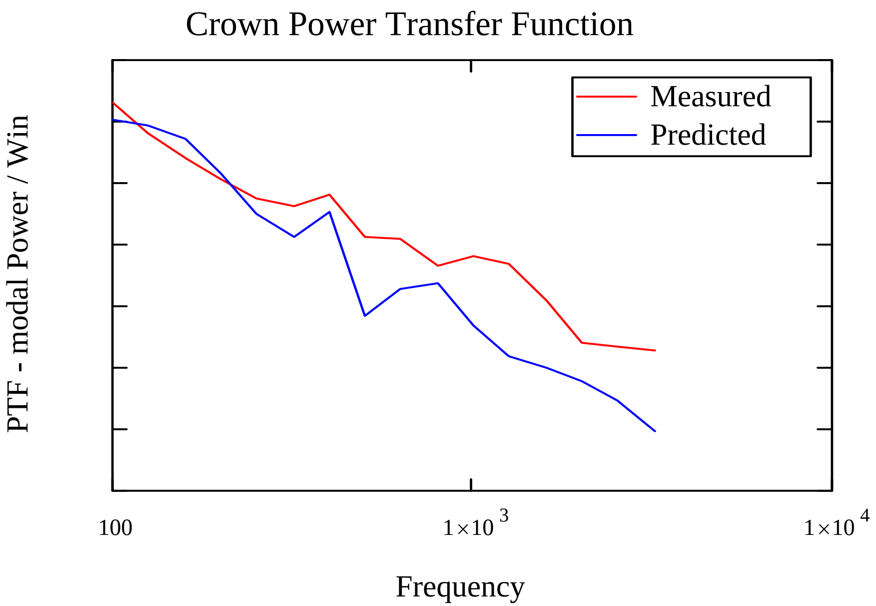
Point to Point Transfer Function

$$\frac{a_r}{\dot{Q}_s} = \frac{p_s}{F_r}$$

Power Transfer Function

$$\frac{W_j}{W_i^{in}} = \frac{4\pi^2 c}{\rho_{air}\omega^2 G_j}\left\{\frac{a_j^{\ 2}}{\dot{Q}_i^{\ 2}}\right\}$$





Comparison

The estimate of the transfer function in SEA involves both the source and receive subsystem conductances. SEA uses it's estimates of the conductance to convert from the internally calculated power transfer function to the response transfer function. This has the potential to affect the perceived performance of the model.

$$\left|TF_{i,j}\right|^2 = \frac{2}{\pi} G_i G_j \frac{Wi}{W_j^{in}}$$

Conclusions

- Testing is required to do SEA model development
- Tests need to be structured to provide information on all elements of the SEA model: Source, Path and Receiver
- Power Transfer Functions can provide a look at solver performance