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A Craig-Bampton Experimental Dynamic Substructure using the Transmission Simulator Method

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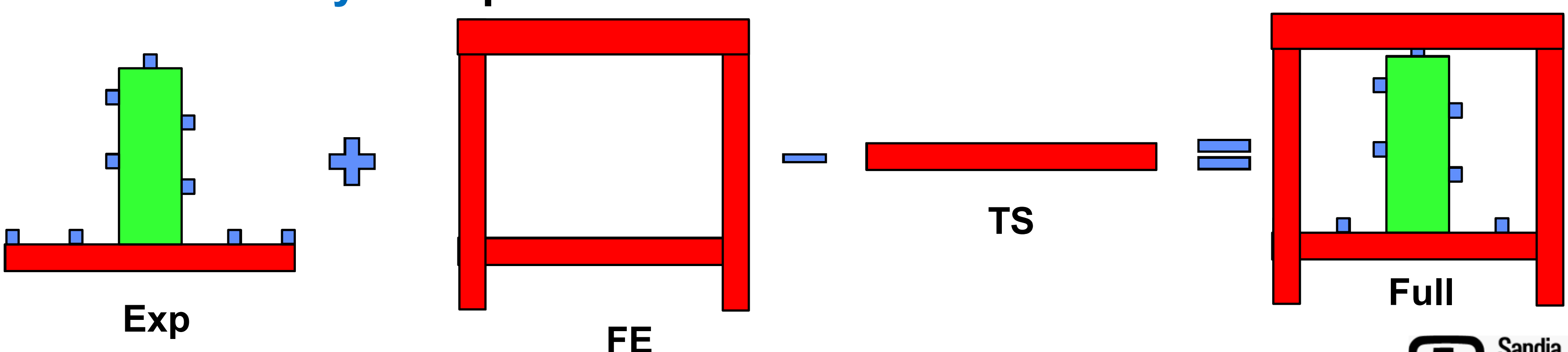
Outline of Presentation

- The motivation for the work is described
- An experimental substructure, based on the transmission simulator method, that fits in the Craig-Bampton matrices form is developed
- An overview of the theory is presented
- Examples are provided
  - Analytical Beam Example
  - Industrial Example

Motivation for a Craig-Bampton Experimental Substructure

- Our goal is to couple an experimental substructure with a FE substructure in a FE code such as NASTRAN, ABAQUS, ANSYS, Sierra Structural Dynamics (Sandia code)
- Currently this is usually done by adding physical dof/springs/masses/dampers to represent generalized dof and coupling them with multi-point constraints (MPCs) to physical dof of the FE substructure – awkward
- Many codes already have capability to implement Craig-Bampton substructures, so if we can match this form, it will be easy to implement



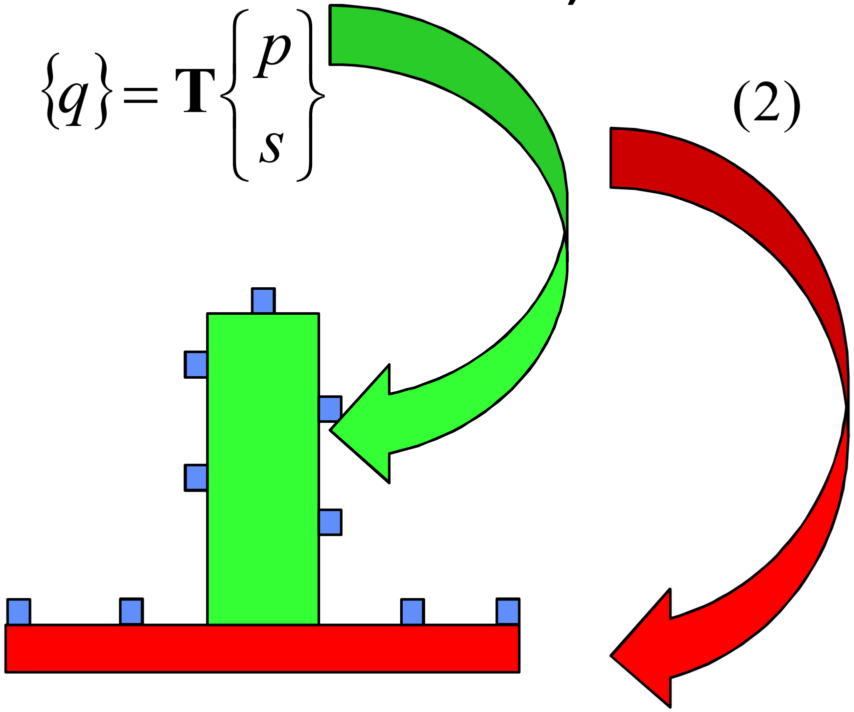
Equations for Transmission Simulator CB approach

Beginning with the experimental model as

$$\left[\omega^2{}_{free} - \omega^2 I\right]\{q\} = \{0\} \qquad (1)$$

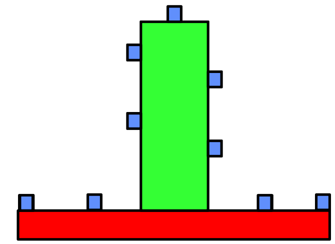
Find a square transformation $\mathbf{T}$ that relates *q* to *p* (fixed base modal dof) and s (free modal dof of fixture)

$$\{q\} = \mathbf{T}\begin{Bmatrix} p \\ s \end{Bmatrix} \qquad (2)$$



Equations for Transmission Simulator Modal CB approach

The transformation is derived in the paper as



$$\mathbf{T} = \left[\mathbf{L}_{fix}\mathbf{\Gamma}_{fix} \quad \Phi_b^+\Psi_b\right] \qquad (3)$$

A property of a transformation is that it does not change the results of the eigenvalue analysis.

The resulting transformed equations of motion are

$$\left[\begin{bmatrix} \diagdown\omega_{fix}^{2}\diagdown & K_{ps} \\ K_{ps}^{T} & K_{ss} \end{bmatrix} - \omega^2 \begin{bmatrix} I & M_{ps} \\ M_{ps}^{T} & M_{ss} \end{bmatrix}\right] \begin{Bmatrix} \bar{p} \\ \bar{s} \end{Bmatrix} = 0 \qquad (4)$$

Subtract the TS (fixture)

$$\left[\begin{bmatrix} \diagdown\omega_{fix}^{2}\diagdown & K_{ps} \\ K_{ps}^{T} & K_{ss} - \diagdown\omega_{TS}^{2}\diagdown \end{bmatrix} - \omega^2 \begin{bmatrix} I & M_{ps} \\ M_{ps}^{T} & M_{ss} - I \end{bmatrix}\right] \begin{Bmatrix} \bar{p} \\ \bar{s} \end{Bmatrix} = 0 \qquad (5)$$

The CB matrices separate the component and the fixture (TS)

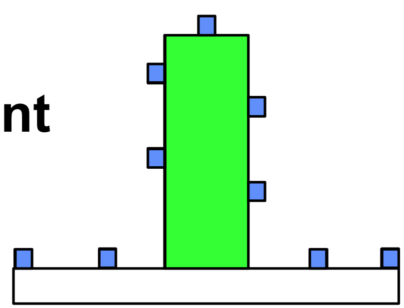
Write a transformation to expand the modal dof of fixture out to physical boundary dof

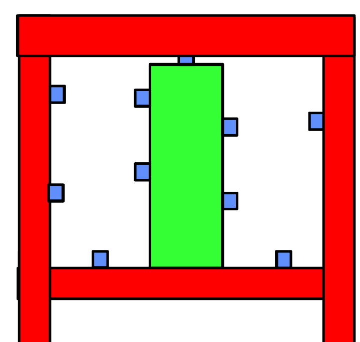
$$\begin{Bmatrix} \bar{p} \\ \bar{s} \end{Bmatrix} = \begin{bmatrix} I & 0 \\ 0 & \Psi_b^+ \end{bmatrix} \begin{Bmatrix} \bar{p} \\ \bar{x}_b \end{Bmatrix} \qquad (6)$$

To obtain the final experimental substructure in a form that fits in Craig-Bampton matrices

$$\left[\begin{bmatrix} \omega_{fix}^2 & K_{ps} \\ K_{ps}^T & \Psi_b^{+^T} \left[K_{ss} - \omega_{TS}^2 \right] \Psi_b^+ \end{bmatrix} - \omega^2 \begin{bmatrix} I & M_{ps} \\ M_{ps}^T & \Psi_b^{+^T} \left[M_{ss} - I \right] \Psi_b^+ \end{bmatrix} \right] \begin{Bmatrix} \bar{p} \\ \bar{x}_b \end{Bmatrix} = 0 \qquad (7)$$

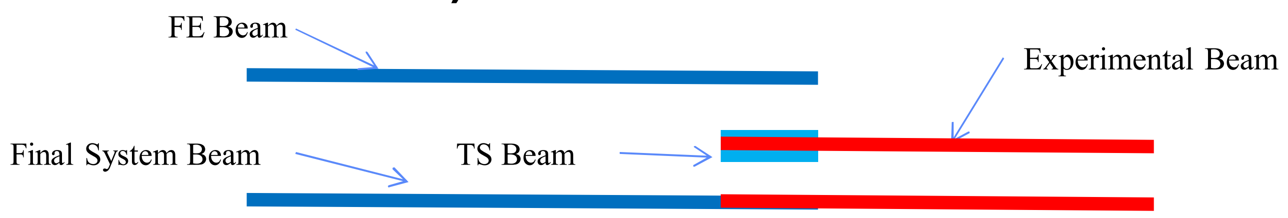
Matrices will be rank deficient for substructure alone





Analytical Beam Example

- **Blue beam is FE Substructure (FE model)**
- **Red beam with cyan fixture is experimental substructure (7 modes to 5876 Hz)**
- **Cyan beam is transmission simulator (3 rigid body modes and one elastic mode)**



Truth Frequency (Hz)	Substructured Frequency (Hz)	Error in Frequency (%)
212.0	209.7	-1.1
574.6	571.5	-0.5
1,121.0	1,131.4	0.9
1,867.3	1,877.4	0.5
2,750.2	2,782.4	1.2
3,341.7	3,398.4	1.7
3,949.6	4,034.7	2.2
5,115.9	5,167.6	1.0
5,965.5	5,946.9	-0.3

Industrial Example

Shell with dozens of internal components