INFLUENCE OF STRUCTURAL FLEXIBILITY ON THE DYNAMIC PRECISION OF A VEHICLE-MOUNTED EQUIPMENT SYSTEM

Paramsothy Jayakumar, Dave Mechergui, Ronald Renke
U.S. Army RDECOM TARDEC
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</table>
1. Problem Statement 3
2. Rigid Vehicle Model 4
3. Rigid Model Simulation Results 8
4. Component Mode Synthesis (CMS) 11
5. Craig-Bampton CMS Method 12
6. Craig-Chang CMS Method 13
7. Flexible Vehicle Model 14
8. CMS of Equipment 16
9. Equipment CMS Results 17
10. Frame CMS Results 20
11. Equipment Enclosure CMS Results 23
12. Influence of CMS Method on the Vehicle Dynamics 24
13. Influence of Flexibility on the Vehicle Dynamics 26
14. Conclusions 30
Current project is to develop a precision equipment system

- Equipment system needs to be reliable for use from vehicle platform
- Equipment system is placed in enclosure attached to cargo bed
- For the equipment system to work properly, vibration should be minimized
- Vibration coming from the road through suspension is suppressed by isolators
- Excessive vibration can cause the system to miss performance, and in severe cases can cause mechanical failure
- Need to know vehicle motion accurately to design isolators
- Rigid and flexible vehicle models are developed and simulation results compared
Rigid Vehicle Model

- **Adams/Car Model**
Rigid Vehicle Model

- Suspension System
  - Springs and dampers
  - Bumpstops
  - Tierod
  - Drive shaft

Double wishbone suspension
Rigid Vehicle Model

- Pacejka 2002 tires
  - Unloaded radius: 516 mm
  - Tire width: 317 mm
  - Vertical stiffness: 525 N/mm
  - Vertical damping: 3.15 N-s/mm

- Steering System
  - Idler
  - Pitman arm
  - Center link
- Idle engine speed
- Max engine speed
- Max throttle
- Final drive ratio
Rigid Model Simulation Results

• Time Histories, Accelerations
  - Low random RMS road, vehicle speed is 31 mph
  - High random RMS road, vehicle speed is 20 mph
Rigid Model Simulation Results

- **Acceleration Histograms**

- Random road RMS 3.5" excites higher accelerations
Rigid Model Simulation Results

Power Spectral Densities

- No low frequencies in response
Component Mode Synthesis

- Component mode synthesis (CMS) is a technique that allows to analyze structure by dividing it into different substructures. The substructures are analyzed separately, then assembled together
  - This technique used for large and complex structures
  - When FE components are built in different locations
- High modes in the modal analysis are truncated there is no loss in resolution, the CMS technique will capture them with the static deformation shapes
- CMS technique reduces significantly the model complexity, computational time
Craig-Bampton Method

Craig-Bampton Method *

Fixed-Interface normal modes

Constraint modes

Fixed-Interface normal mode of fixed interface

(k-ω²m)φ = 0

Constraint modes of cantilever beam

u₁ = 1
u₂ = 0

u₁ = 0
u₂ = 1

Method is used when parts are connected with joints

Craig-Chang Method

Craig-Chang Method *

Free-Interface normal modes

\[ F = 1 \]

Attachment modes

\[ M = 1 \]

Fundamental normal mode of free-interface

Method is used when parts are connected with
- joints that are partially constrained
- Bushings that do not have high stiffness

Attachment modes of cantilever beam

Adams/car Flexible Model

Flexible frame

34 attachment nodes
Flexible Vehicle Model

16 attachment nodes

Equipment Enclosure

4 attachment nodes

Equipment
Equipment was meshed and run for model analysis using different CMS techniques, the analysis was done using Radioss software.

- Cutoff frequency is 200 Hz
- There are 4 attachment nodes
### Craig-Bampton Method

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<tr>
<th>Mode Shape</th>
<th>Natural Frequency (Hz)</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
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- 24 static modes
- 8 normal modes

### Craig-Chang Method

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- 24 static modes
- 12 normal modes

### CMS Modes

- 32 orthonormalized modes
Equipment Mode Shapes and Natural Frequencies

**Craig-Bampton**

Mode Shape 1
\[ \omega_1 = 39.6 \text{ Hz} \]

Mode Shape 2
\[ \omega_2 = 89.2 \text{ Hz} \]

**Craig-Chang**

Mode Shape 1
\[ \omega_1 = 39.6 \text{ Hz} \]

Mode Shape 2
\[ \omega_2 = 89.7 \text{ Hz} \]
Equipment Mode Shapes and Natural Frequencies

**Craig-Bampton**

Mode Shape 3  
$\omega_3 = 135.7$ Hz

Mode Shape 4  
$\omega_4 = 170.4$ Hz

**Craig-Chang**

Mode Shape 3  
$\omega_3 = 134.4$ Hz

Mode Shape 4  
$\omega_4 = 158.9$ Hz
Frame CMS Results

Craig-Bampton Method

<table>
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- 204 static modes
- 53 normal modes

CMS Modes

- 257 orthonormalized modes

Craig-Chang Method

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- 204 static modes
- 72 normal modes

CMS Modes

- 276 orthonormalized modes
Frame Mode Shapes and Natural Frequencies

**Craig-Bampton**

Mode Shape 1  
$\omega_1 = 19.8$ Hz

Mode Shape 2  
$\omega_2 = 22.5$ Hz

**Craig-Chang**

Mode Shape 1  
$\omega_1 = 18.9$ Hz

Mode Shape 2  
$\omega_2 = 22.5$ Hz
Frame Mode Shapes and Natural Frequencies

**Craig-Bampton**

Mode Shape 3
\[ \omega_3 = 28.1 \text{ Hz} \]

Mode Shape 95
\[ \omega_{95} = 382.0 \text{ Hz} \]

**Craig-Chang**

Mode Shape 3
\[ \omega_3 = 28.0 \text{ Hz} \]

Mode Shape 95
\[ \omega_{95} = 355.4 \text{ Hz} \]
## Equipment Enclosure CMS Results

### Craig-Bampton Method

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<td>Highest</td>
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</table>

- 96 static modes
- 97 normal modes

**CMS Modes**
- 179 orthonormalized modes
Influence of CMS Method on the Model Dynamics Random Road RMS 3.5"

Frame Acceleration

Cargo Bed Cradle Acceleration
Influence of CMS Method on the Model Dynamics
Random Road RMS 3.5"

**Craig-Bampton**
- Max: 4.5 g
- Min: -6.4 g

**Craig-Chang**
- Max: 4.4 g
- Min: -6.3 g
Influence of Flexibility on the Model Dynamics
Random Road RMS 1.0"

Frame Acceleration

Cargo Bed Acceleration
Flexible components were obtained using Craig-Bampton method.
Influence of Flexibility on the Model Dynamics
Random Road RMS 3.5"

Rigid acceleration
Max Min
2.8 g -1.9 g

Flex acceleration
Max Min
3.0 g -2.0 g

Rigid acceleration
Max Min
3.3 g -1.4 g

Flex acceleration
Max Min
3.4 g -2.2 g
Influence of Flexibility on the Model Dynamics
Random Road RMS 3.5"

<table>
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<th>Equipment Enclosure Acceleration</th>
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<th>Equipment Acceleration</th>
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<tbody>
<tr>
<td>Rigid Model</td>
</tr>
<tr>
<td>Flexible Model</td>
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Rigid acceleration
Max   Min
3.4 g  -1.4 g

Flex acceleration
Max   Min
3.6 g  -2.3 g

Rigid acceleration
Max   Min
3.6 g  -4.2 g

Flex acceleration
Max   Min
4.5 g  -6.6 g
Conclusions

• Developed a vehicle model that carries a precision equipment, the latter can be reliably used. In order to function properly, its vibration is minimized; the vibration coming through the suspension is suppressed by isolator mounts.
• Integrated flexible components (frame, equipment enclosure, and equipment) into the vehicle rigid model using CMS.
• Equipment system vibration was not affected by the type of CMS method.
• Equipment acceleration increased by 50 % when the model is flexible, for rough roads (3.5" rms).