Analysis of Damping Treatments Applied to the MAP Spacecraft

Scott Gordon
Code 542
Goddard Space Flight Center

Presented at
FEMCI Workshop
May 18, 2000
Outline

• Background/Problem Description
• Modal Survey
• Damping Treatments
• Analysis Methodology
• Analysis Results
• Comparison with Test Data
• Conclusions
Background

- MAP = Microwave Anisotropy Probe
- MAP Spacecraft Level Acoustic Test
  - Conducted August, 1998
    - Flight spacecraft bus with mass mockups
    - No thermal blanketing or electrical harnessing
    - Instrument mass simulator
    - ETU Solar Arrays
- Acoustic test performed to Delta II 7425-10 protoflight levels (142.9 OASPL)

MAP Acoustic Test Configuration
Problem Description

- High acceleration response measured at thruster locations on top deck
- Acceleration levels exceeded the qualification levels for the thrusters
- Thruster Qual Levels
  - .2 G^2/Hz 20-2000 Hz
  - 20 Grms
- Measured test levels
  - 44 Grms
  - 116 G^2/Hz @ 140 Hz
- Problem addressed by adding damping treatments to spacecraft
Spacecraft Configuration
Spacecraft Configuration - Cont.

- **MAP Top Deck Configuration**
  - 5/8” thick aluminum honeycomb panel
  - .015” M46J/934 facesheets
  - Hexagonal shape
    - 94” across hexagon points
    - 36” central cut-out
  - Center supported at hex-hub
  - Outer corners supported by truss members
• **Upper Deck Thrusters**
  - 4 identical 1-lb thrusters mount to MAP upper deck
  - 2 thrusters per thruster bracket (upper and lower)
  - Each thruster mounts to small bracket which attaches to large bracket
  - Large and small brackets built up from T800/EX1515 laminate flat stock
  - Mounting faces are .072”, remaining faces are .036”

Detail of MAP Upper Deck Thruster Bracket
Modal Survey

- A modal survey was performed to determine mode shapes contributing to high thruster response
- 5 x 5 mesh of single axis accelerometers used on the top deck
- Triaxial accelerometers at each of the mounting bracket locations and at tip of large bracket
- Results were correlated with FEM model
Modal Survey - Cont.

- Test data showed several candidate modes in the 120-200 Hz range which excited high thruster response
- Candidate modes showed a combination of deck deflection and local bracket deformation
- FEM results did not match test data exactly but had sufficient accuracy to capture contributing modes
Modal Survey - Cont.

- Acoustic test analytically simulated
- Good correlation with X and Y response
- Z response did not show same degree of correlation
- Not as critical because Z response is significantly lower below 200 Hz
- Conclusion: Model and loading conditions could be used to define damping treatments
Damping Treatments - Thruster Brackets

- 3M Scotchdamp ISD-242 applied to thruster brackets
- GSFC Heritage: Scotchdamp used by TRW on EOS-PM spacecraft
- FEM analysis used to determine size and placement of damping treatments
- .004” layer of scotchdamp with Gr/Ep constraint layer
- Constraint layer material and thickness selected to match thruster bracket surface
Damping Treatments - Top Deck

- Lockheed-Martin SMRD strips applied to deck edges
- GSFC Heritage: Used on XTE spacecraft
- .4” thick SMRD strip with honeycomb constraint layer
- SMRD strips designed to target deck modes driving thruster response
- Scotchdamp applied to top and bottom surfaces of top deck
- Scotchdamp targeted at higher frequency response (300-500 Hz)
Damping Treatments - Cont.

Notes:
1) SWRD strip width = 1"
2) FM73 film adhesive used to assemble SMRD strips
3) EA9309-3NA paste adhesive used to bond SMRD assembly to top deck
Analysis Methodology


• Approach uses standard NASTRAN elements to model VEM damping treatments
  – Solid elements (HEXA and PENTA) for the VEM Layer
  – Thin shell elements (QUAD4) for the constraint layer

• Equivalent modal damping developed based on % strain energy in VEM for a particular mode

• Equivalent modal damping can then be used in standard NASTRAN dynamic solutions to calculate damped response.
Analysis Procedure

- Add solid elements representing VEM and shell elements representing constraint layer to FEM structural model
- Run normal modes solution and recover % strain energy in the solid elements representing the VEM
- Calculate modal damping associated with the VEM for each mode by applying the following equation

\[
\zeta_v = 0.5 \eta_v \sqrt{\frac{G_v(f)}{G_{v_{ref}}}} \left( \frac{SE_{vem}}{SE_{total}} \right)
\]

Where
- \( \eta_v \) = VEM damping loss factor. This quantity is temperature and frequency dependent
- \( G_v(f) \) = Shear modulus of the VEM at the specific frequency of the mode of interest
- \( G_{v_{ref}} \) = VEM shear modulus at the frequency at which the damping treatment is being targeted. This is the shear modulus used in NASTRAN for the normal modes analysis
- \( SE_{vem}/SE_{total} \) = Ratio of strain energy in the VEM to the total strain energy for the specific mode of interest
Analysis Procedure - Cont.

- The VEM modal damping ($\zeta_v$) is added to the nominal modal damping to get the total damping for that mode.
- For the MAP dynamic analysis, nominal modal damping was 1.6% of critical based on spacecraft acoustic test.
- The VEM material properties used in the analysis are shown in the table below:

<table>
<thead>
<tr>
<th>VEM Material Properties used to Calculate Damping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties @ t=70 F and f=140 Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Damping Loss Factor</th>
<th>Shear Modulus $G_{vref}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M Scotchdamp ISD-242 (1)</td>
<td>1.0</td>
<td>1050</td>
</tr>
<tr>
<td>Lockheed-Martin SMRD 100F-90C (2)</td>
<td>1.0</td>
<td>4000</td>
</tr>
</tbody>
</table>

Notes:
(1) Material data from nomograph supplied by 3M
(2) Material data from Lockheed-Martin
Analysis Verification*

- Beam coupons with and without scotchdamp were tested to verify methodology
- Analytical predictions showed good correlation with test data

*Data from Steve Hendricks at Swales Aerospace
Analysis Results

• Total reduction of 17 dB predicted due to Scotchdamp on bracket and SMRD on deck

• This still does not meet manufacturers thruster qual levels

• Several additional factors
  – Blanketing & harnesses (10dB)
  – Rubber shims at small bracket interface (3-9 dB)
  – Scotchdamp on top deck (3 dB)
Intermediate Acoustic Test

- Acoustic test performed July 1999 to assess effectiveness of damping treatments
- Flight MAP spacecraft bus, most spacecraft electronics, electrical harnesses and blanketing as close to flight as possible, ETU solar arrays, no instrument or simulator
- Measured reductions sufficient to show thrusters qualified for flight environment
Damping Prediction - Test vs Analysis

- Analytical prediction within 3 dB of peak test response at 120 Hz
- Overpredicts response above and below target frequency
- Analysis does not account for reduction in input or other factors
- Analysis shows poor correlation with data from spacecraft acoustic test
Damping Predictions - Test vs Analysis

- Several factors may have accounted for poor correlation between analytical predictions and test data
  - NASTRAN model may not have sufficient resolution to accurately predict damping for the complicated mode shapes driving the thruster response
  - Analytical technique for predicting modal damping was not verified for SMRD
  - Low level (-7 dB) acoustic data was scaled to full level. Damping may not be fully effective until higher levels of input
  - Expected acoustic reductions may not be cumulative.
  - Expected acoustic reductions may not be fully effective for localized thruster response.
Conclusion

• Addition of damping treatments successfully reduced acceleration response at thruster mounting locations to acceptable levels
• Methodology used was straightforward to implement and could be used with existing NASTRAN models
• Modal damping technique used to optimize damping treatments as well as predict response
• Technique did not accurately predict peak acceleration response
• Predictions of dynamic response should be verified by testing the structure under representative loading conditions.