Analysis of Damping Treatments Applied to the MAP Spacecraft

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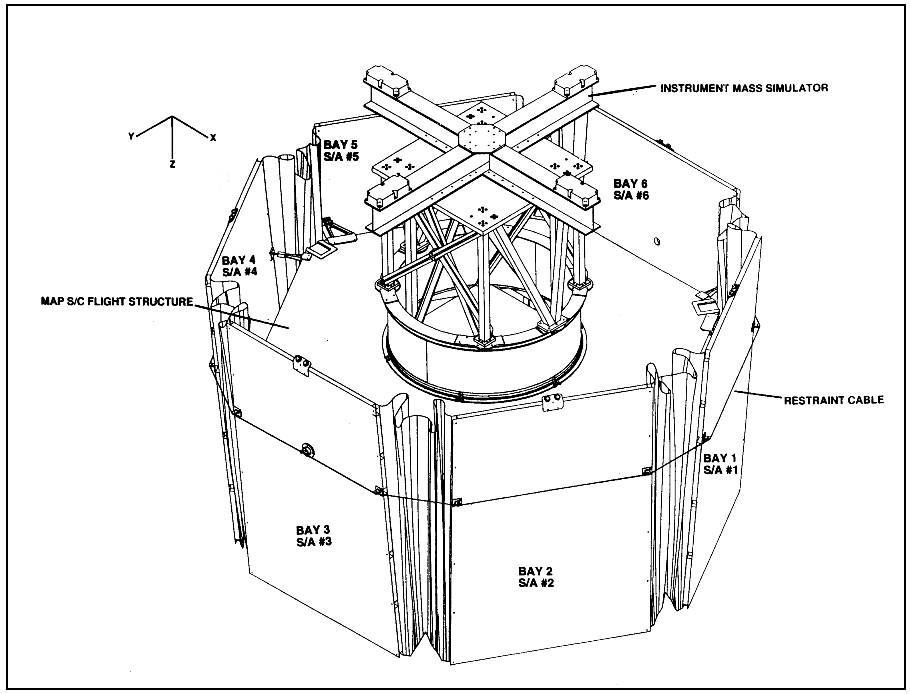
Outline

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

Background

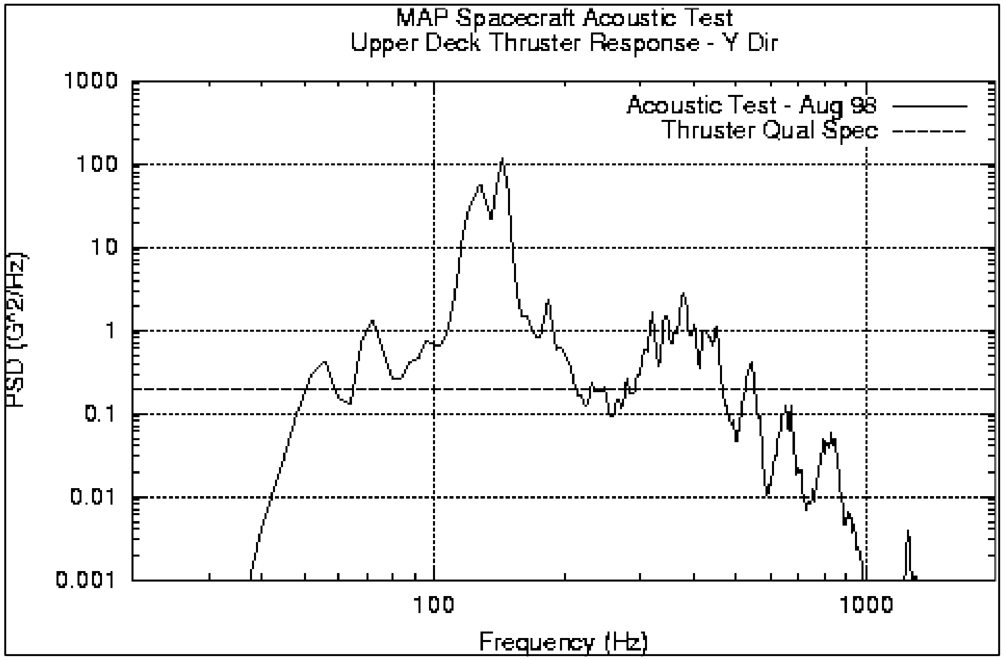
- **MAP = Microwave Anisotropy Probe**
- **MAP Spacecraft Level Acoustic Test - Conducted August, 1998**
  - Flight spacecraft bus with mass mockups
  - No thermal blanketing or electrical harnessing
  - Instrument mass simulator
  - ETU Solar Arrays
- **Acoustic test performed to Delta II 7425-10 protoflight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



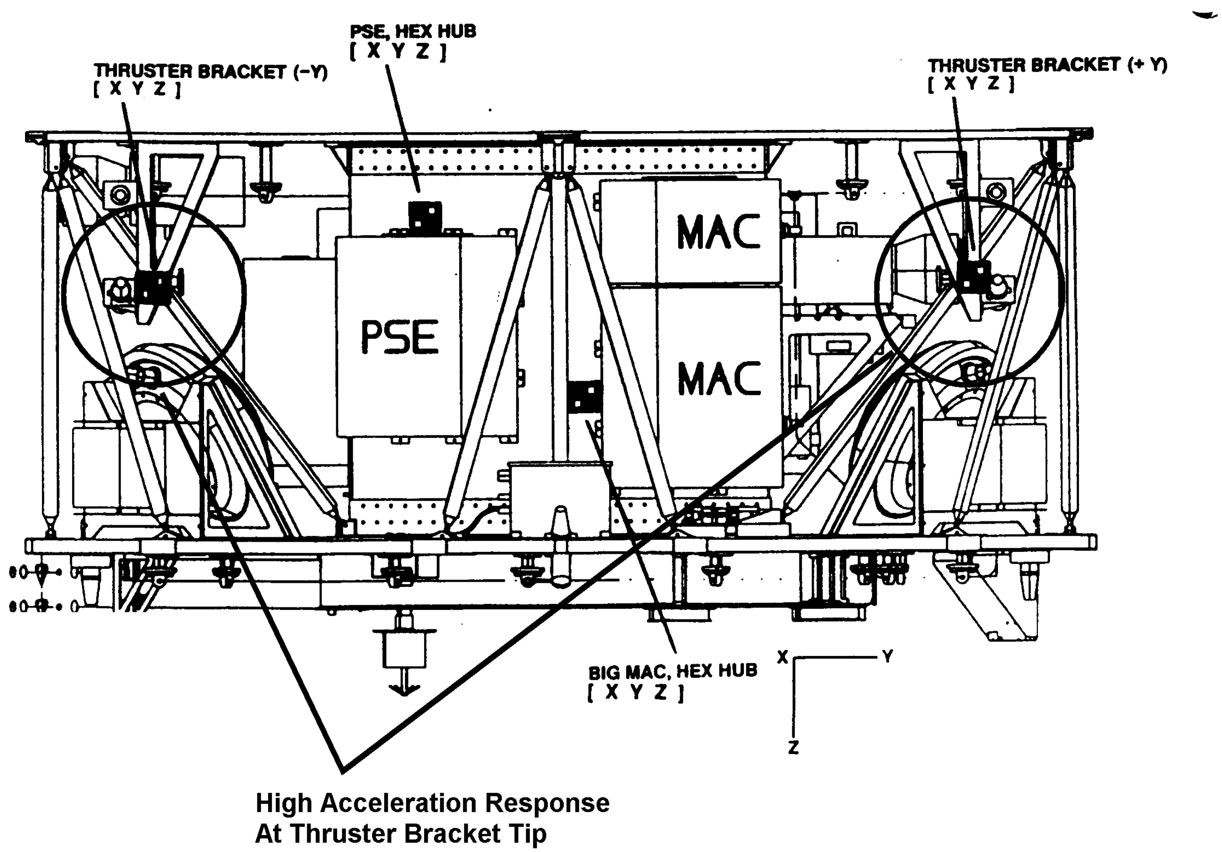
MAP Acoustic Test Configuration

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**

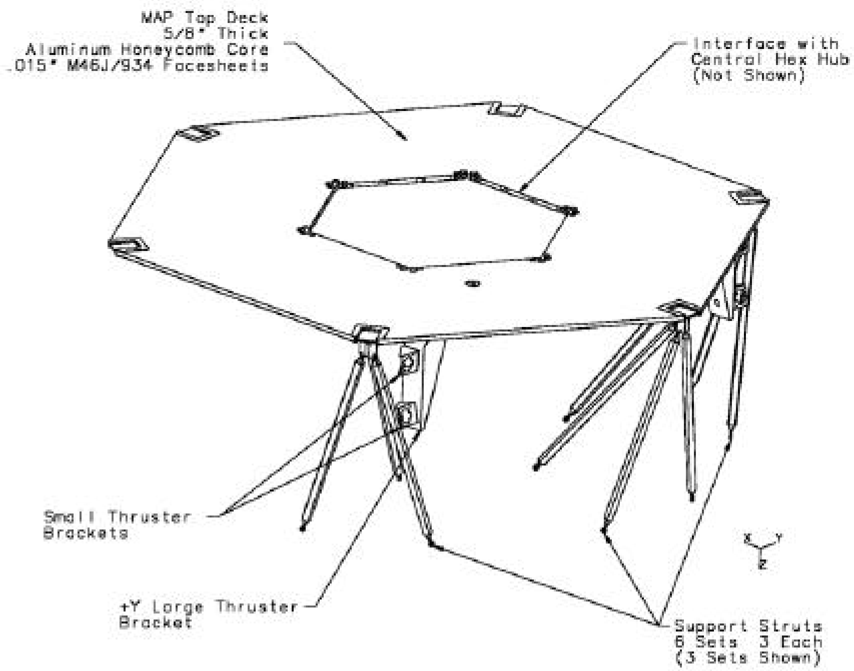


Spacecraft Configuration



Spacecraft Configuration - Cont.

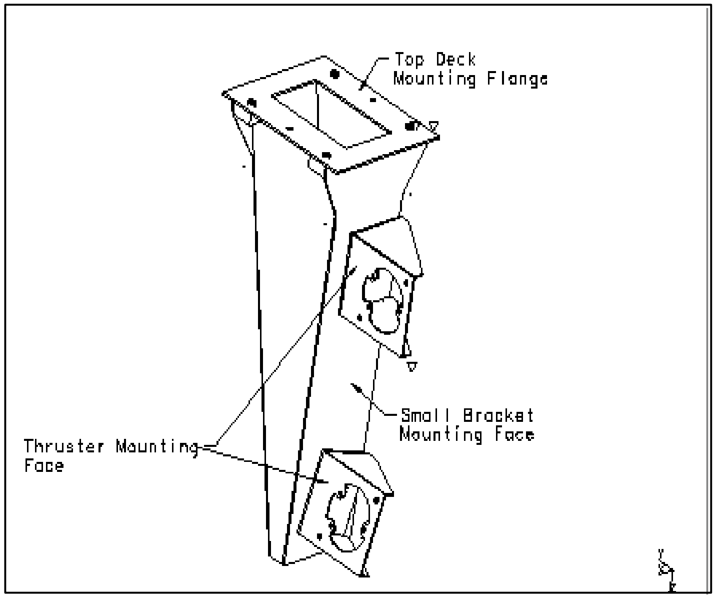
- **MAP Top Deck Configuration**
  - 5/8” thick aluminum honeycomb panel
  - .015” M46J/934 facesheets
  - Hexagonal shape
    - 94” across hexagon points
    - 36”central cut-out
  - Center supported at hex-hub
  - Outer corners supported by truss members



MAP Top Deck with Thruster Brackets

Spacecraft Configuration - Cont.

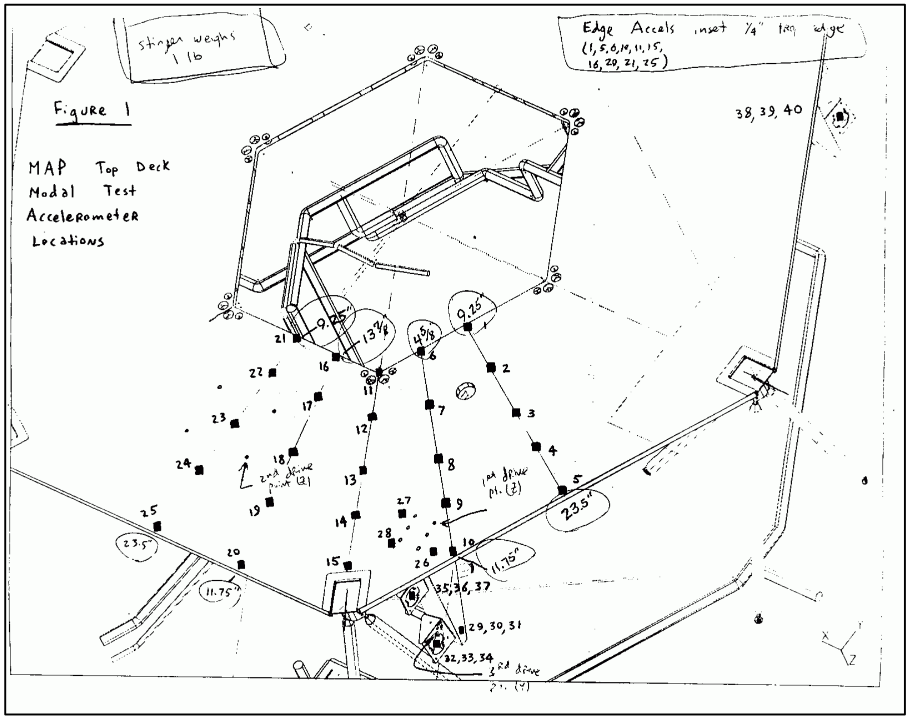
- **Upper Deck Thrusters**
  - 4 identical 1-lb thrusters mount to MAP upper deck
  - 2 thrusters per thruster bracket (upper and lower)
  - Each thruster mounts to small bracket which attaches to large bracket
  - Large and small brackets built up from T800/EX1515 laminate flat stock
  - Mounting faces are .072”, remaining faces are .036”



Detail of MAP Upper Deck Thruster Bracket

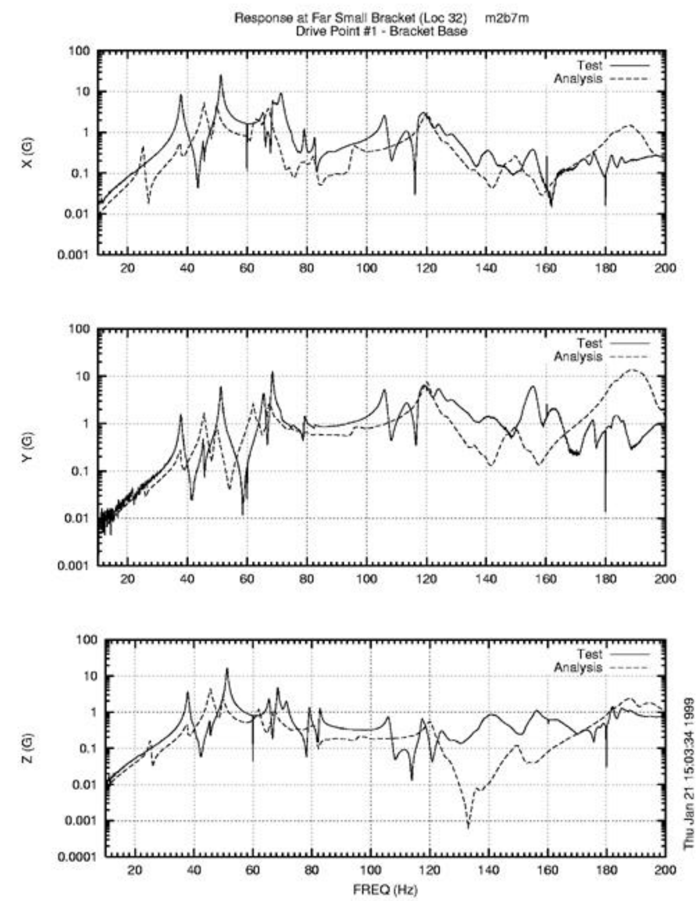
Modal Survey

- **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**



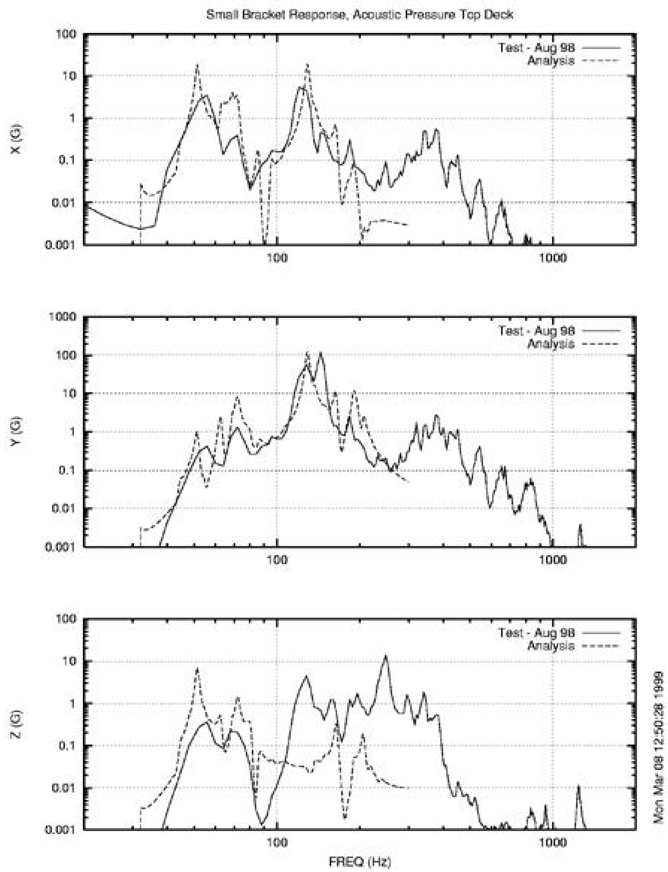
Modal Survey - Cont.

- **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**



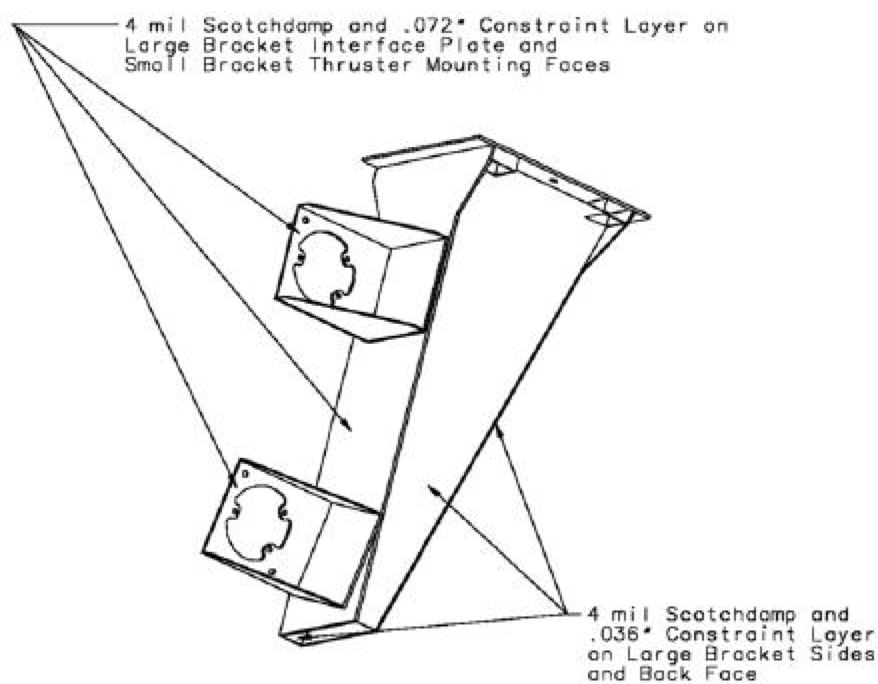
Modal Survey - Cont.

- **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**



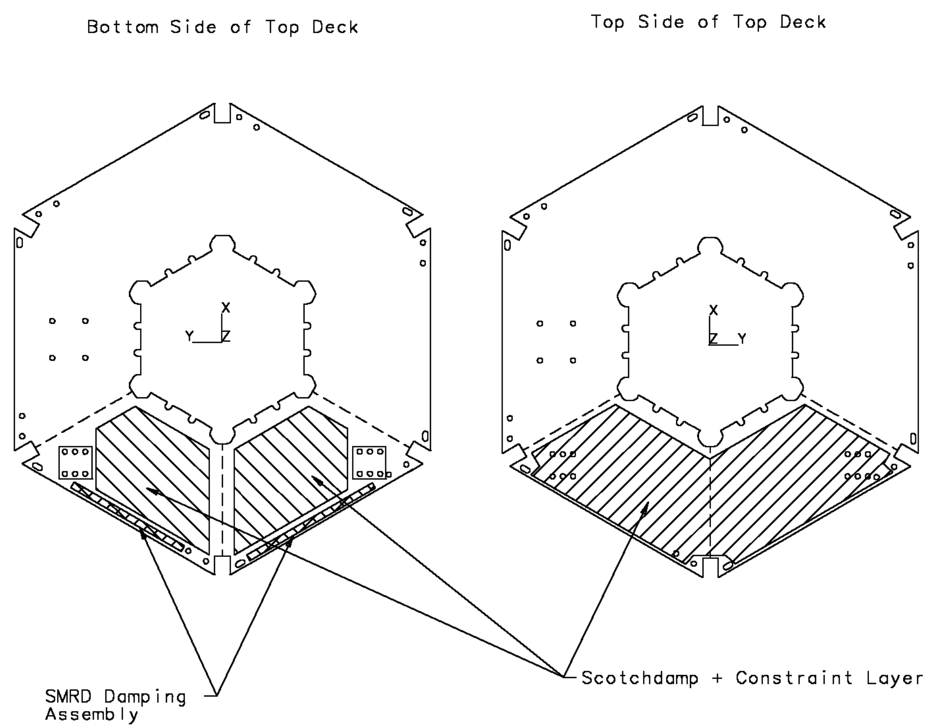
Damping Treatments - Thruster Brackets

- **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**

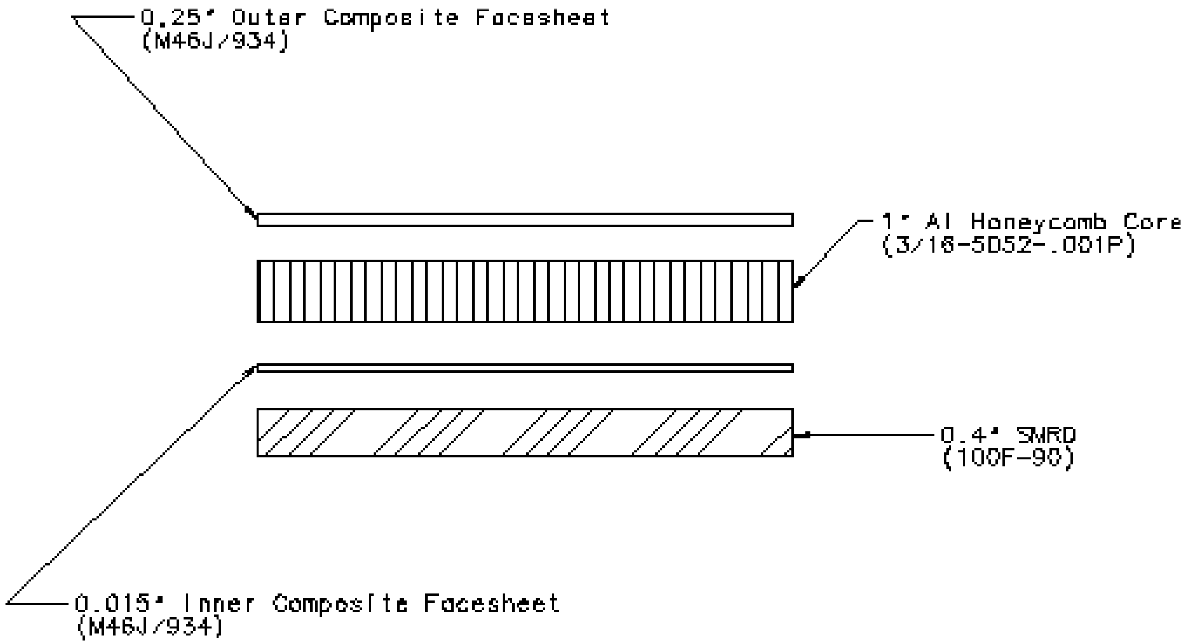


Damping Treatments - Top Deck

- **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) SMRD strip width = 1"
2) FM73 film adhesive used to assemble SMRD stripe
3) EA9309-3NA paste adhesive used to bond SMRD assembly to top deck

Analysis Methodology

- **Methodology outlined in "Finite Element Prediction of Damping in Structures with Constrained Viscoelastic Layers", C.D. Johnson and D.A. Kienholz, AIAA Journal, Vol. 20, No. 9, Sept 1982, pp. 1284-1290**
- **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**

$$z_v = .5 * h_v * \sqrt{G_v(f) / G_{vref}} * \left(SE_{vem} / SE_{total} \right)$$

Where

ζ_v	=	Ratio of critical damping due to VEM
η_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_{vref}	=	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.

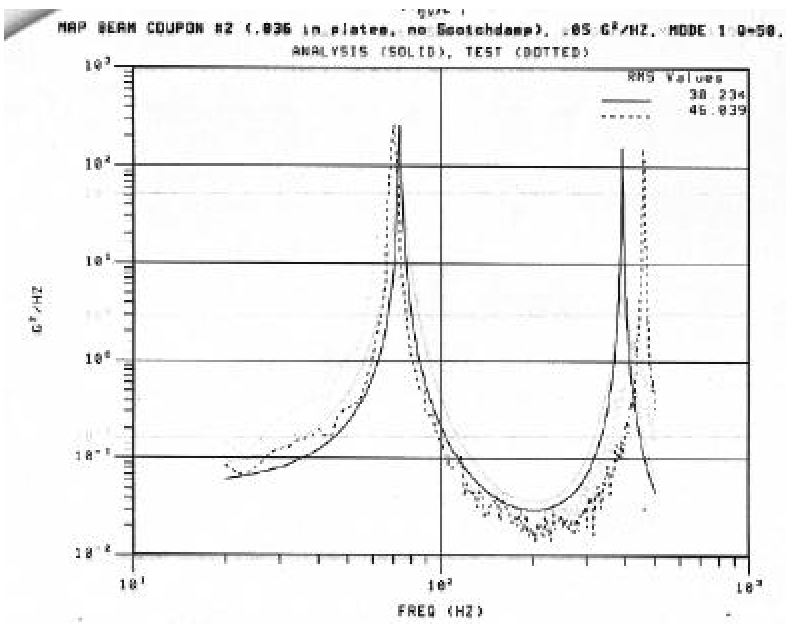
- **The VEM modal damping (z_v) is added to the nominal modal damping to get the total damping for that mode**
- **For the MAP dynamic analysis, nominal modal damping was 1.6% of critical based on spacecraft acoustic test**
- **The VEM material properties used in the analysis are shown in the table below:**

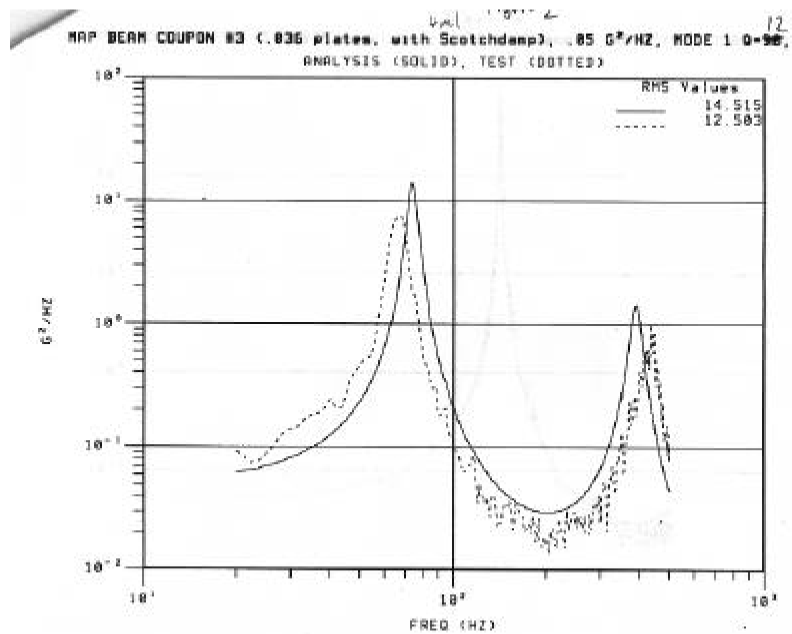
VEM Material Properties used to Calculate Damping		
	Properties @ t=70 F and f=140 Hz	
Description	**Damping Loss Factor** h_v	**Shear Modulus** G_{vref} **(psi)**
3M Scotchdamp ISD-242 (1)	1.0	1050
Lockheed-Martin SMRD 100F-90C (2)	1.0	4000

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**

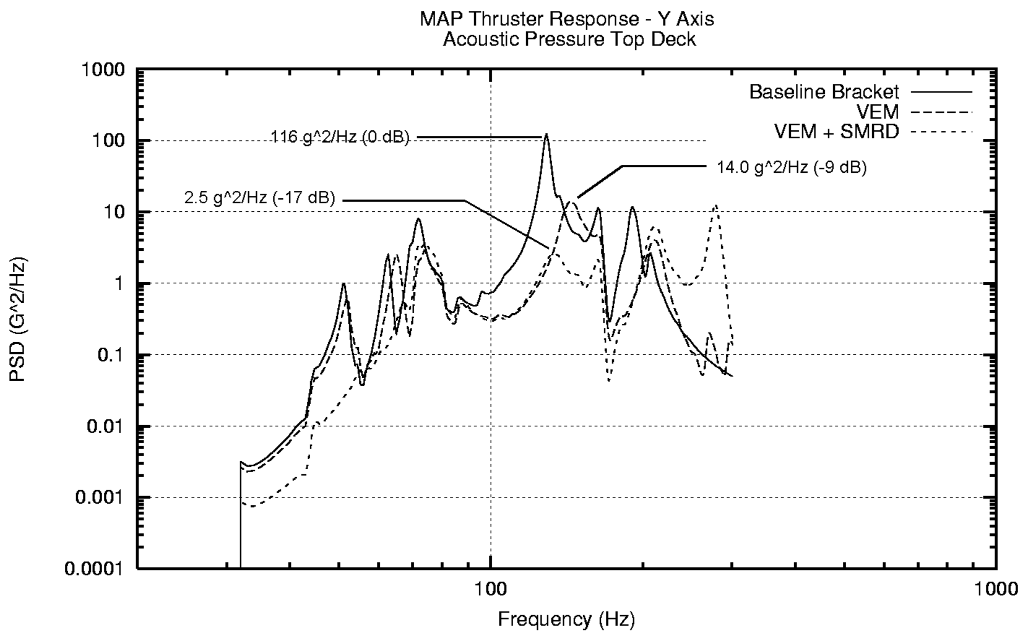




*Data from Steve Hendricks at Swales Aerospace

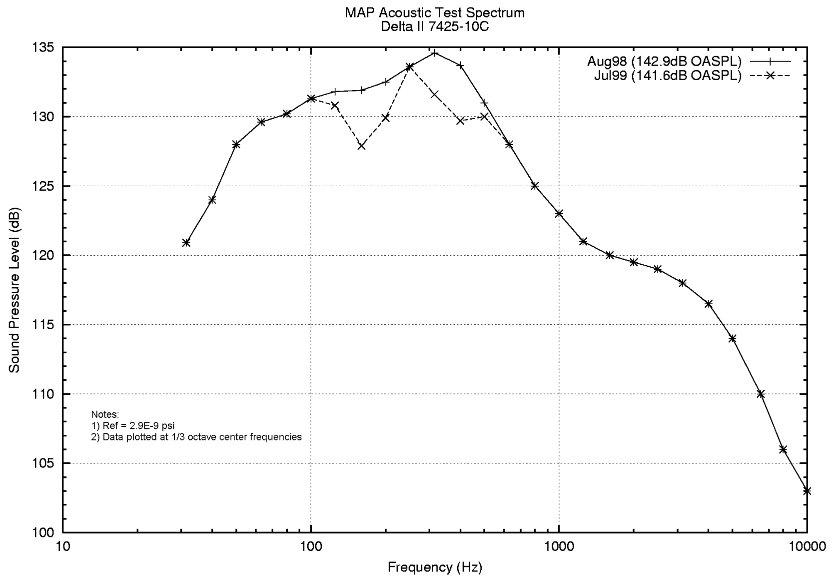
Analysis Results

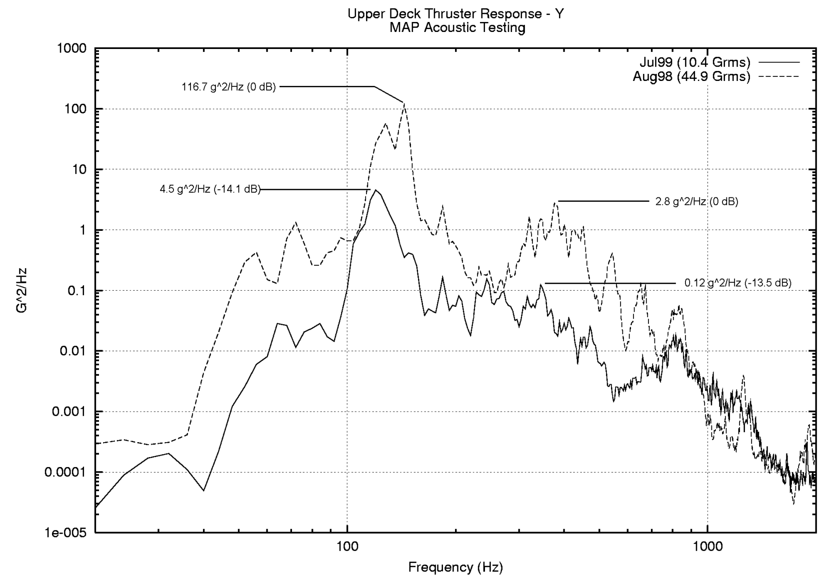
- **Total reduction of 17 dB predicted due to Scotchdamp on bracket and SMRD on deck**
- **This still does not meet manufacturers thruster qual levels**
- **Several additional factors**
  - Blanketing & harnesses (10dB)
  - Rubber shims at small bracket interface (3-9 dB)
  - Scotchdamp on top deck (3 dB)



Intermediate Acoustic Test

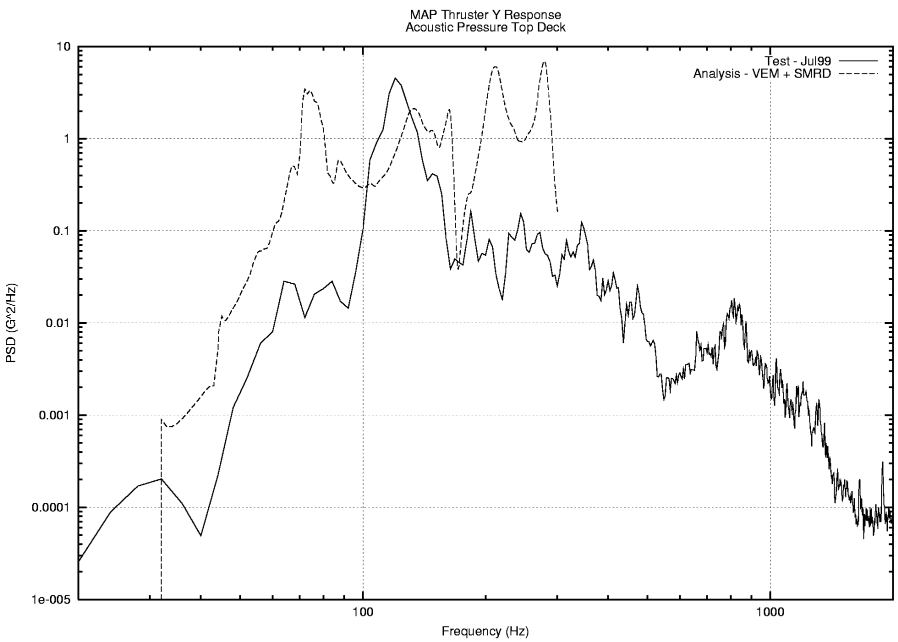
- **Acoustic test performed July 1999 to assess effectiveness of damping treatments**
- **Flight MAP spacecraft bus, most spacecraft electronics, electrical harnesses and blanketing as close to flight as possible, ETU solar arrays, no instrument or simulator**
- **Measured reductions sufficient to show 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.**