TRW

Damping of Precision Metal Matrix Trusses

EAC-1

Presented at : Damping '91
February 13-15, 1991
Catamaran Hotel
San Diego, CA

S. S. Simonian
14 February 1991

AGENDA

- OBJECTIVE
- MOTIVATION
- STRUCTURE CONFIGURATION
- MATERIALS
- TECHNICAL APPROACH
- DISTURBANCES
- DESIGN CONSIDERATIONS
- ANALYSIS RESULTS

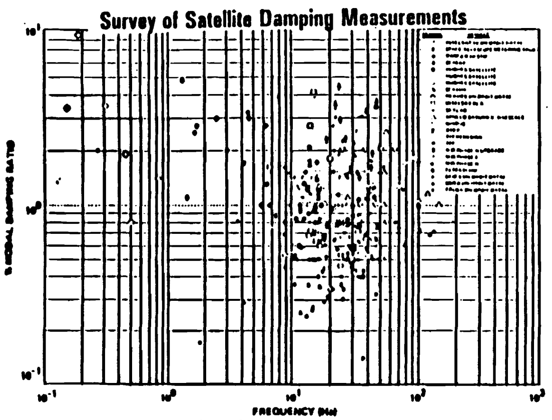
OBJECTIVE

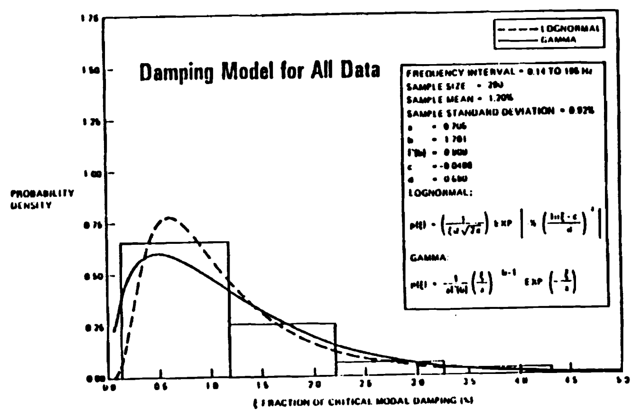
DAMMPS Program :
Damping and metal matrix for precision structures

TO DEMONSTRATE THE DIMENSIONAL PRECISION OF DAMPED AEROSPACE STRUCTURES UNDERGOING DYNAMIC AND THERMAL EFFECTS

MOTIVATION

- **WHY design damping into structures ?**
- **Inherent damping of spacecraft: Is it sufficient ?**





- **Deterministic dynamic performance analysis model :**

Modal damping = 0.5% (mean - 2 sigma)
= 0.2% (mean - 2.5 sigma)

- **Often damping requirements are 5-20% to meet performance measures**
- **This provides the rationale for the need for integral damping design in spacecraft**

WHY MMC & DISCRETE DAMPERS ?

- **Application: Generic Truss Structures**
- **Approaches: Discrete → Links, Joints**
  Distributed → Free layer, Constrained layer
- **Tubular truss structures**

Requirements:
1. **High precision & stability (hysteresis, moisture, CTE)**
2. **High specific stiffness**
3. **High damping**
4. **Simple and reliable design & analysis**

Solution:
- **Items 1 & 2 - MMC Materials**
- **Items 3 & 4 - DISCRETE dampers**

- **Thus for tubular precision truss structures MMC materials and discrete VEM dampers provide the best solution for above requirements**

STRUCTURE CONFIGURATION

- Precision Truss Structures

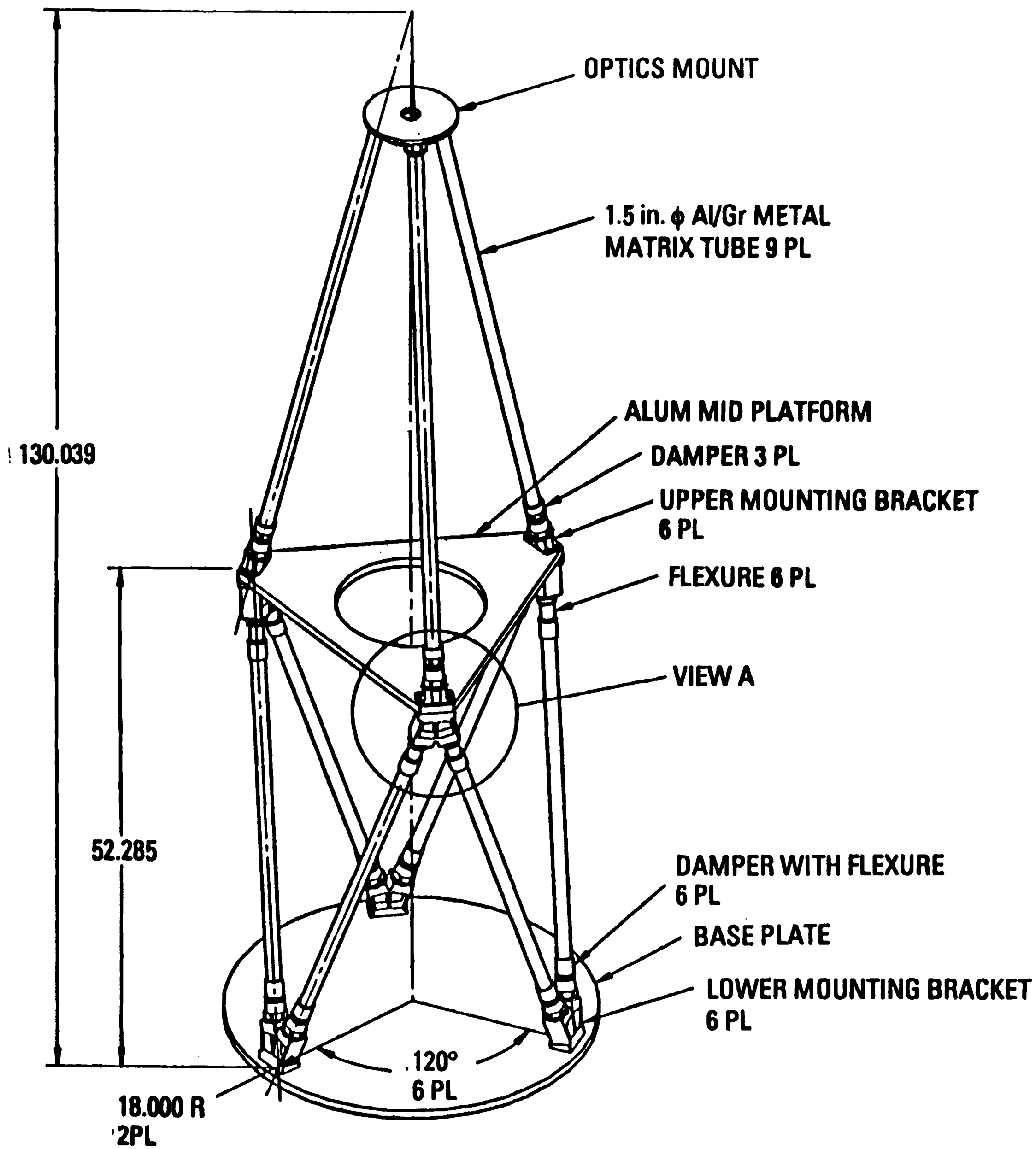
  - Widely used structural system with superior weight-stiffness characteristics

- Traceable to large number military and scientific space projects

Truss Assembly

DAMMPS

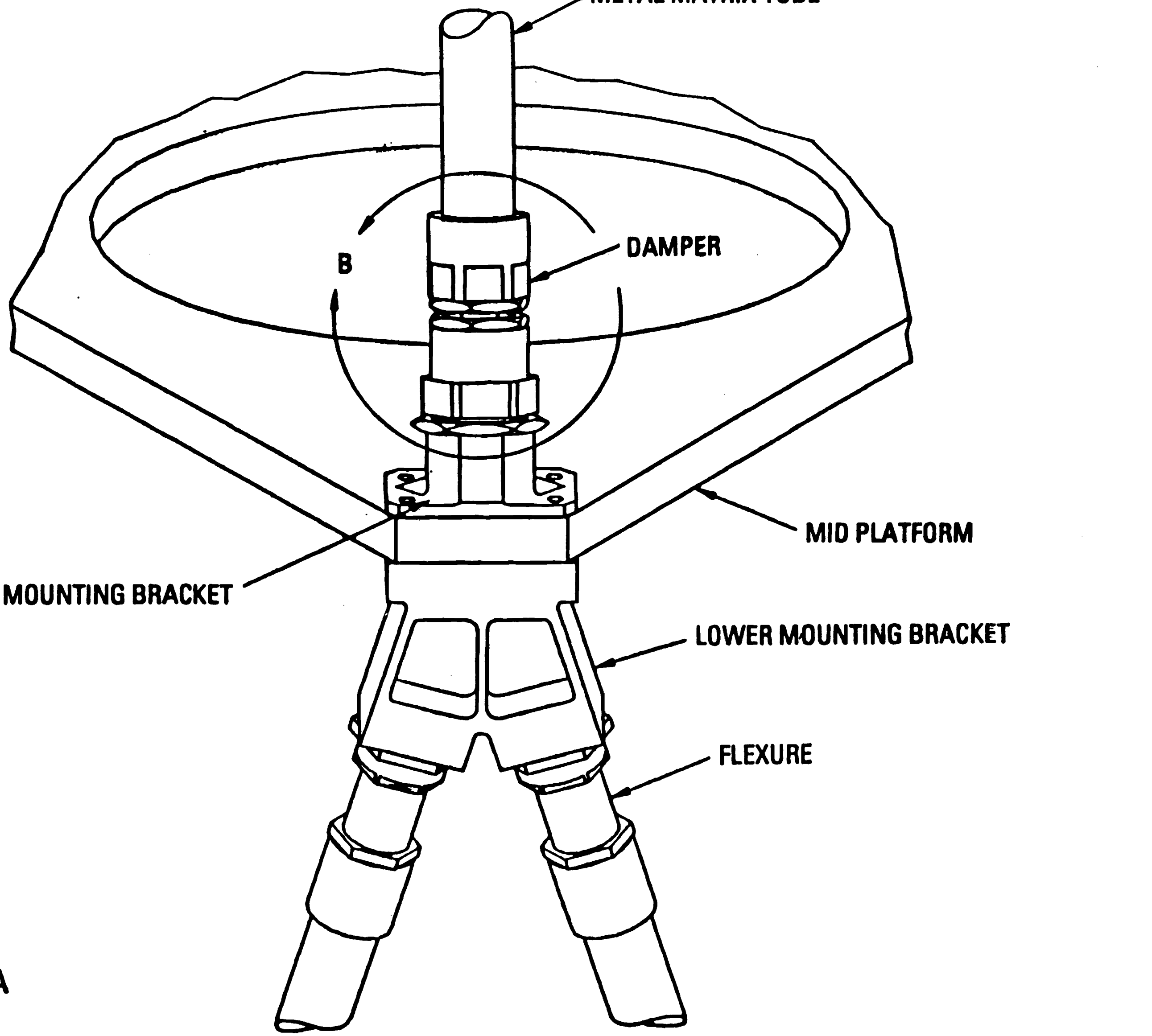
TRW



DAMMPS DEMONSTRATION
STRUCTURAL ARTICLE (DSA)

Mid Platform

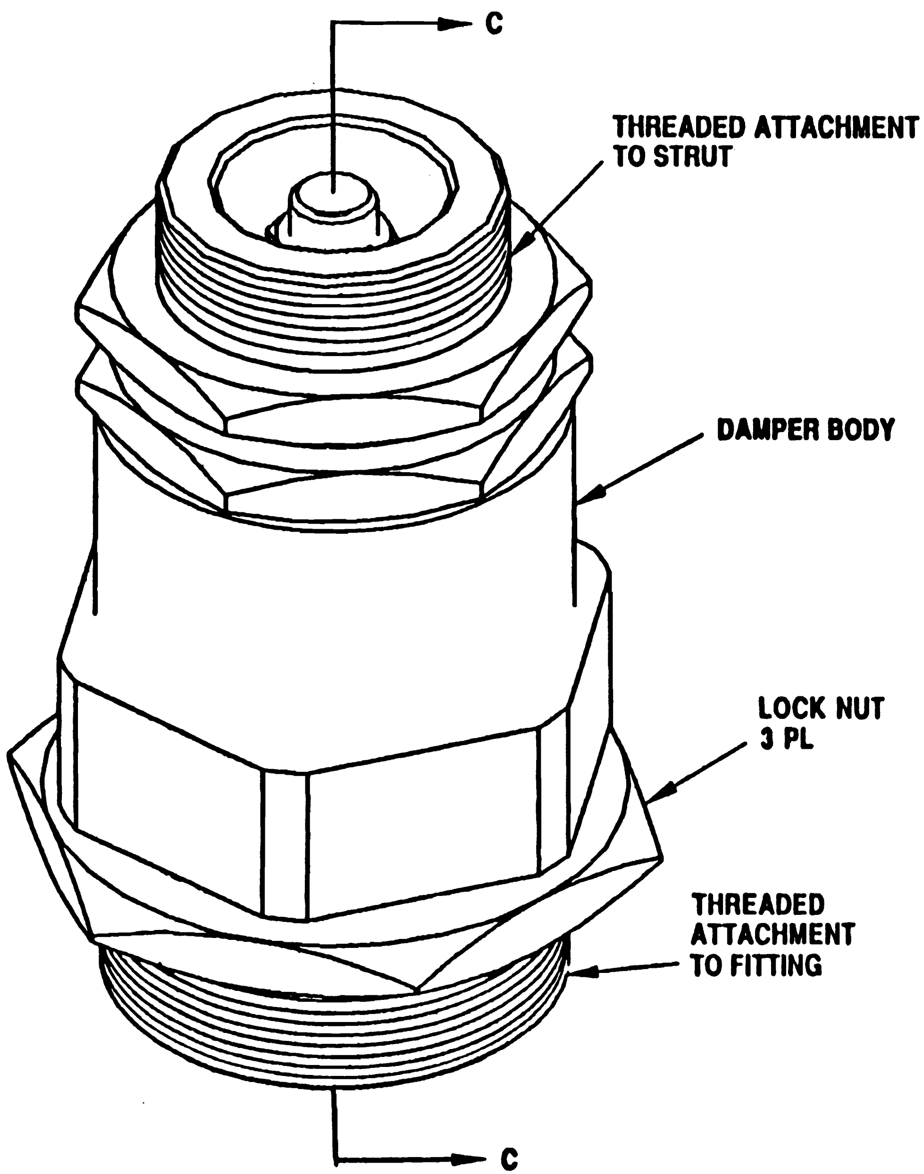
TRW



VIEW A

DAMMPS

Damper

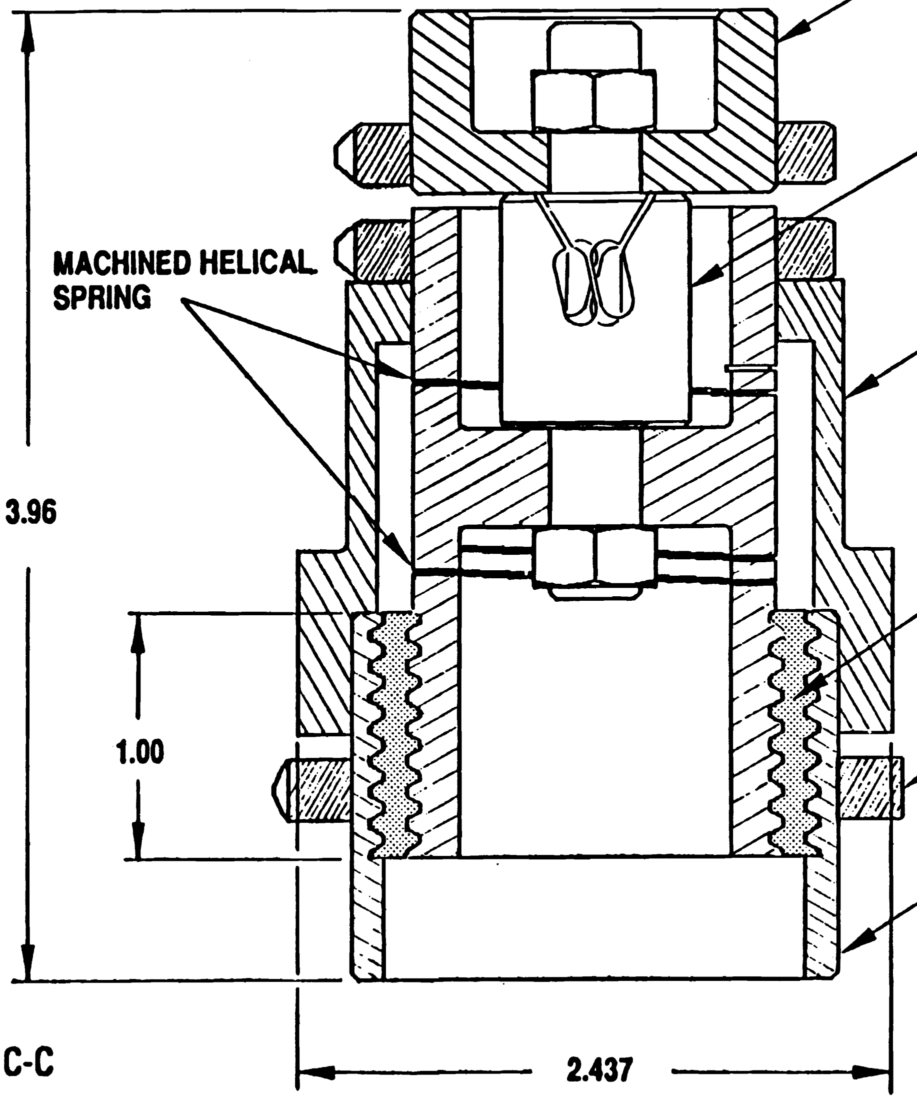


VIEW B

DAMMPS

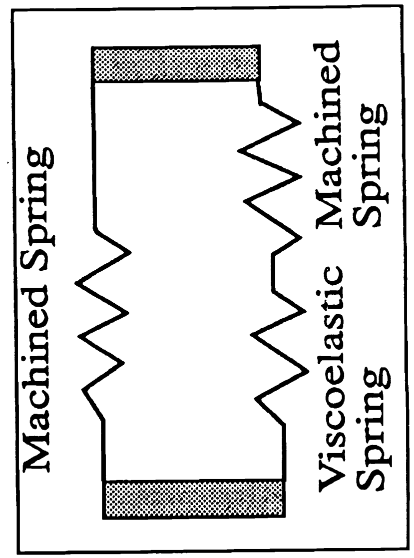
Damper Section View

TRW



SECTION C-C

*REPLACED WITH STIFF ROD FOR DAMPERS WITHOUT BUILT-IN FLEXURES



Mechanical Model

MATERIAL REQUIREMENTS

- MMC Material Considerations
  - SSS (Strength, Stiffness, Stability)

- Viscoelastic Material (VEM) Considerations
  - High Loss Factors with broad temperature response
  - Desirable stiffness over temperature and frequency
  - Low outgassing properties

DSA Tube Requirements and MMC Material Objectives

Tubes are Part of Precision Structure -

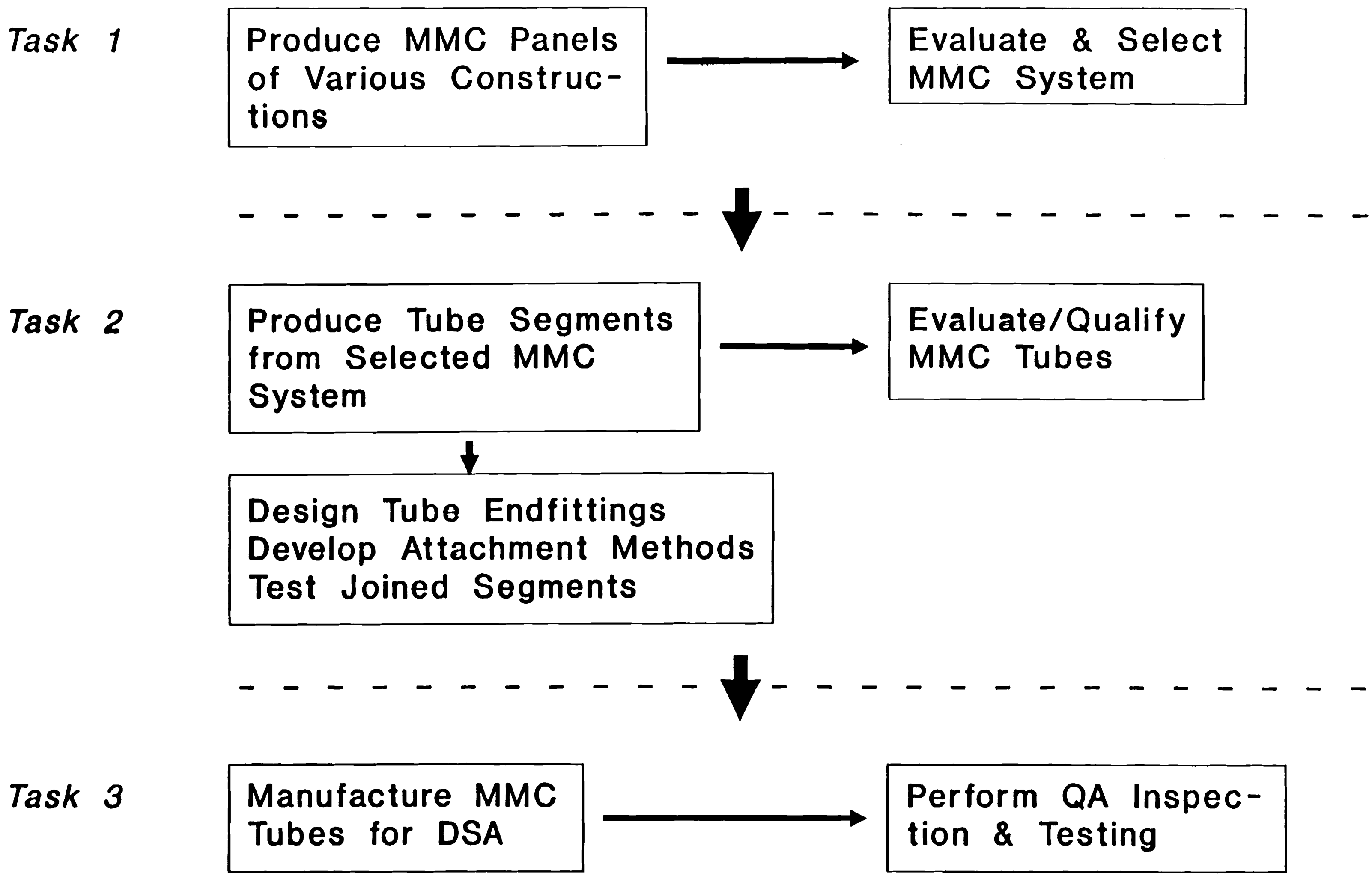
- o High axial specific stiffness
- o Near zero axial CTE
- o Dimensionally stable

Structure Must Withstand Loads Induced During Assembly and Launch

Desired Material Features -

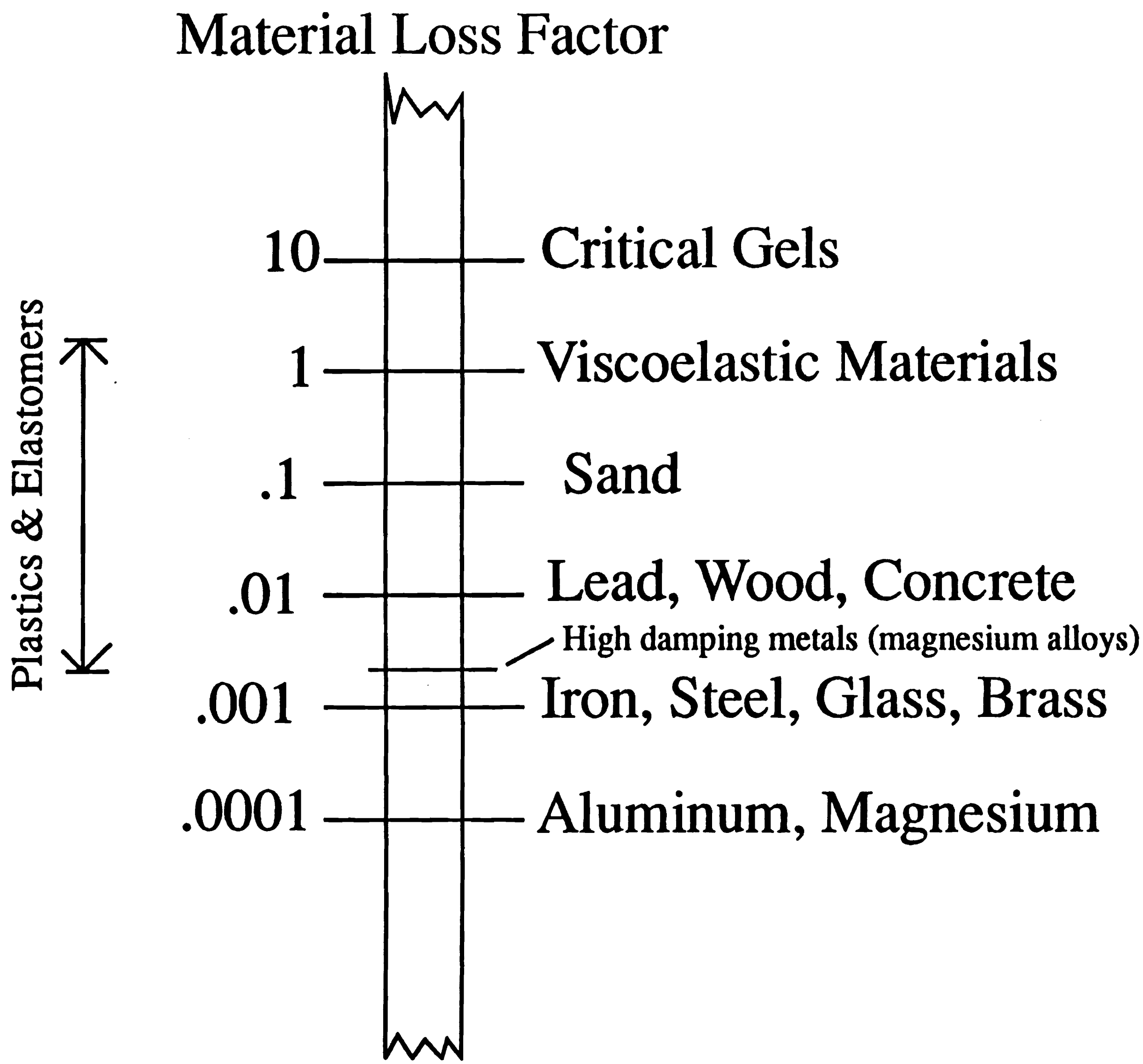
- o Unidirectional ultra-high modulus graphite fiber (Dupont E120), with high fiber loading and Mg matrix, for high stiffness, low density, and near zero CTE
- o Consistent fiber loading and impregnation for consistent property performance
- o Fine matrix grain structure for increased composite transverse and shear strength

Program Approach for MMC Tube Development



WHY VISCOELASTIC MATERIALS ?

- Unlike Metals Viscoelastic Materials (VEM) Have High Loss Factors



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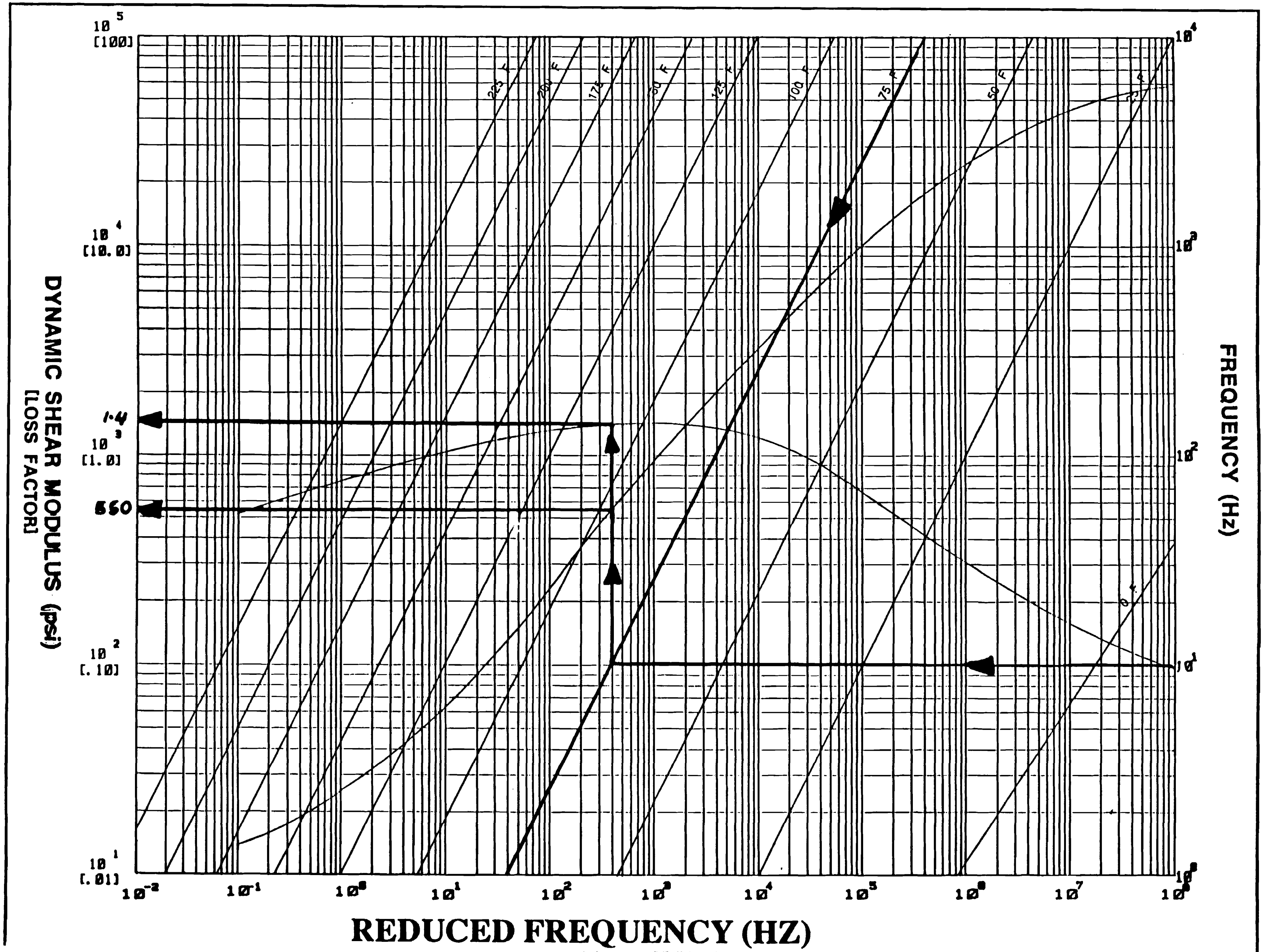
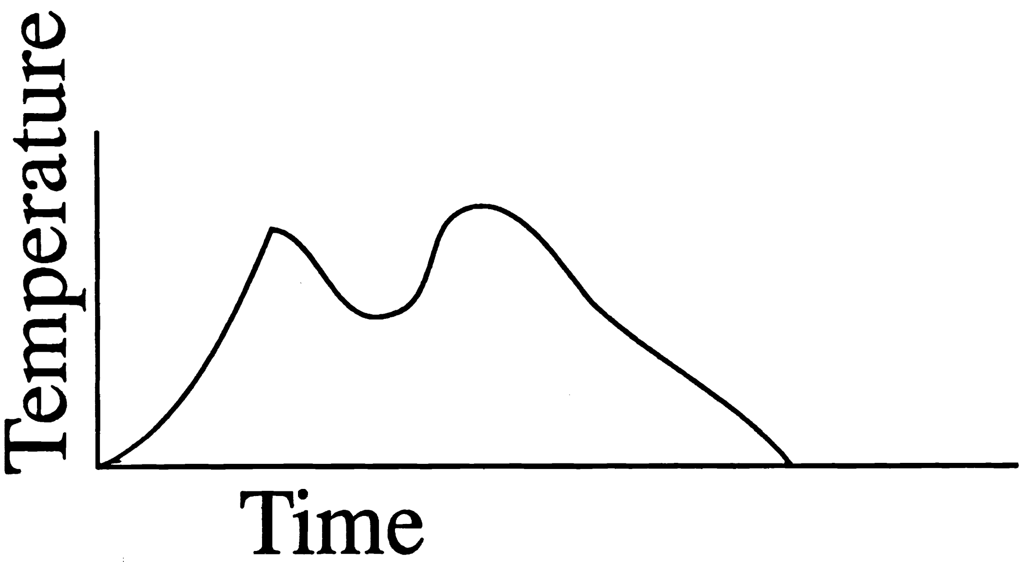
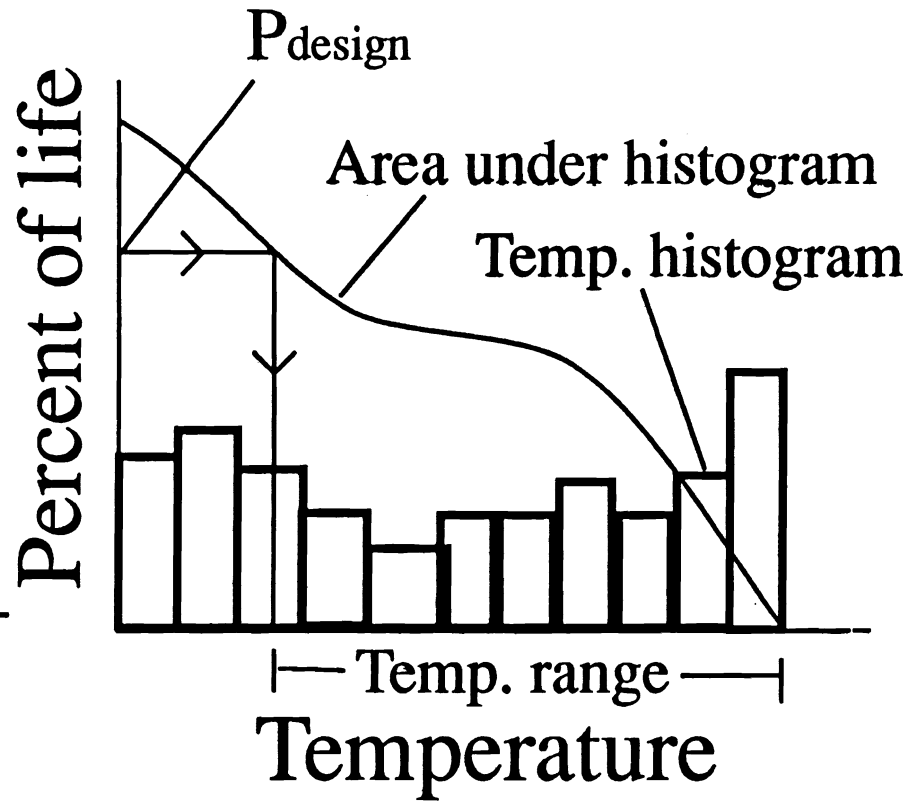
VEM DYNAMIC PROPERTIES
Scotchdamp SJ-2015X Type 110



DESIGN TEMPERATURE RANGE for VEM





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Recommended VEM Materials for DAMMPS

Material	Vendor
Isoloss HD	EAR
Isodamp C-1002	EAR
Isodamp C-1105	EAR
Isodamp C-1100	EAR
Hidamp II	Barry Controls
SPE/D	LORD
Scotchdamp Type 110	3M
DENSIL 2078 I	DENSIL
DENSIL 2078 III	DENSIL
Structural Adhesive 2216	3M
Vitron Rubber	Vitron
Kalrez 1058	DuPont

TECHNICAL APPROACH:

ANALYSES & TESTS

- TWO UNDAMPED BASELINE STRUCTURES WILL BE STUDIED: MMC & GR/EP
- DETAILS OF DYNAMIC ANALYSIS AND TESTS

ITEM	BASELINE 1 (*)	BASELINE 2 (**)
MATERIAL	GR/EP	MMC
PERFORMANCE ANALYSES ● COOLENT FLOW DISTURBANCE ● REACTION WHEEL INDUCED DISTURBANCES ● SETTLING TIME - SLEW MANEUVER	YES	YES
TESTING ● COMPONENT ● MODAL SURVEY ● PERFORMANCE	NA	YES
TEST/ANALYSIS CORRELATION ● UPDATED MODELS AND PERFORMANCE ASSESSMENT	NA	YES

(*) PAPER STUDY ONLY
(**) TWO SETS OF TESTS AND ANALYSES: WITH AND WITHOUT INTEGRALLY DESIGN DAMPING.

TECHNICAL APPROACH (CONT.)

MODULAR JOINT DESIGN

- THE MMC DSA WILL INCORPORATE MODULAR JOINT DESIGNS WHICH WILL INCORPORATE REMOVABLE VISCOELASTIC MATERIALS (VEM)
- SINCE THE VEM ELEMENTS ARE REMOVABLE, THE SAME MMC STRUCTURE WILL BE TESTED WITH AND WITHOUT DAMPING ELEMENTS
- SEVERAL JOINT DESIGNS HAVE BEEN IDENTIFIED

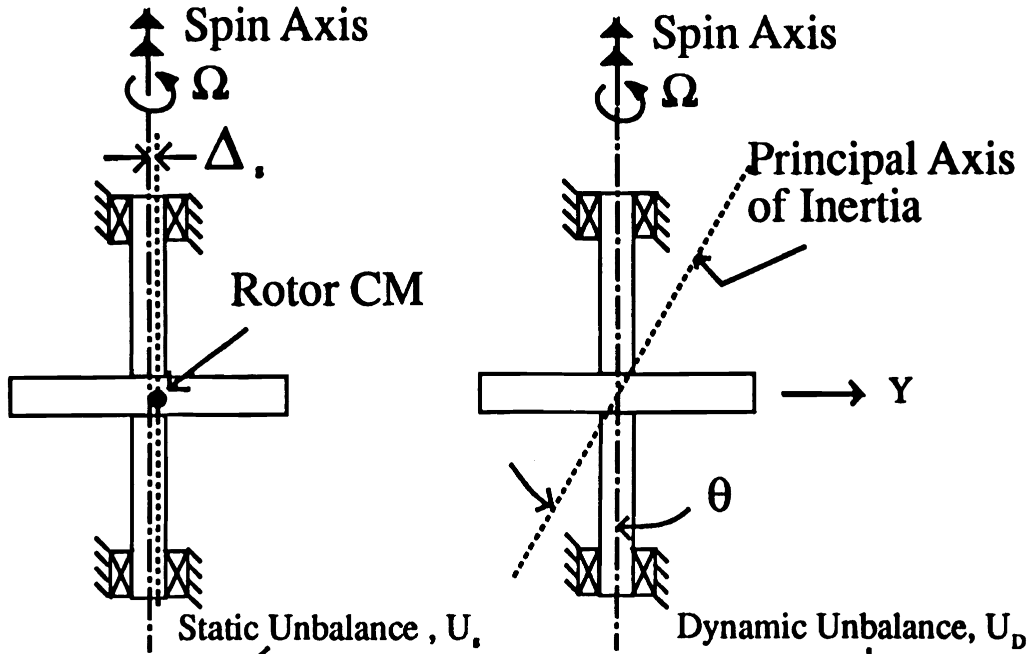
DISTURBANCES

- Rotating Equipment : Reaction Wheels (RWA)
- Flow Induced Disturbances
- Slew Maneuvers : Settling Time
- Thermal History

ROTOR STATIC & DYNAMIC UNBALANCE

- Force or Moment : $F = \delta M \Omega^2$

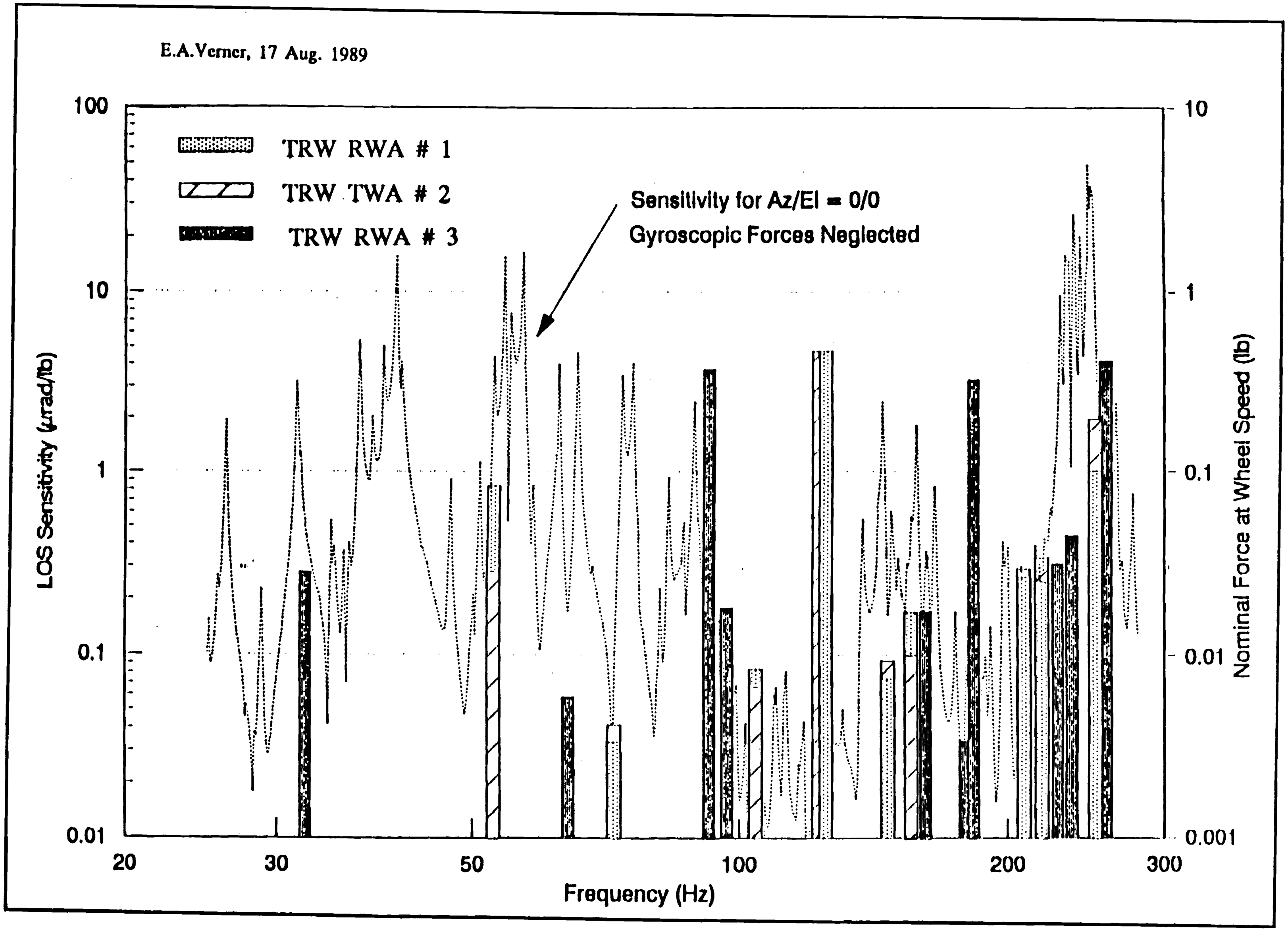
F = Force or Moment (lb or in-lb)
M = Rotor Mass (lb-sec^2/in)
Ω = Wheel Speed (Rad/sec)
δ = Disturbance Amplitude (in. or in.^{2} tabulated)



$$F = m\Delta_s\Omega^2 = \boxed{w\Delta_s}\frac{\Omega^2}{g}$$

$$T_x = (J_p - J_{xx})\theta\Omega^2 = \boxed{(J_p - J_{xx})g\theta}\frac{\Omega^2}{g}$$

COMPARISON OF WHEEL RADIAL DISTURBANCES



MEASURED REACTION WHEEL DISTURBANCE MODELS

- ## PROPORTIONALITY CONSTANTS FOR TWO TRW REACTION WHEELS

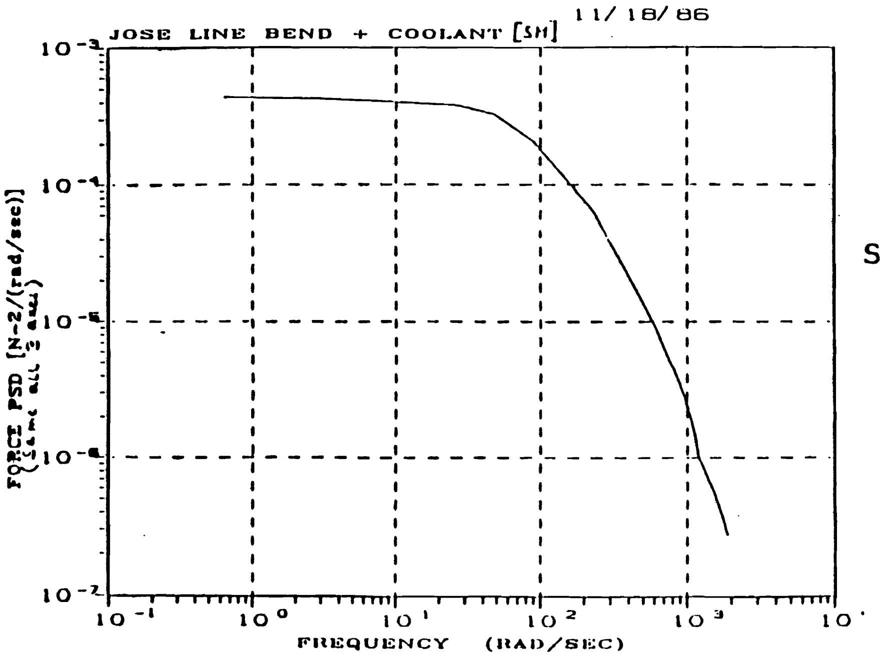
Disturbance	Harmonic	Axial Force	Lateral Force (Y)	Lateral Force (Z)	Radial Force (avg)	Lateral Moment (Y)	Lateral Moment (Z)	Radial Moment (avg)
		$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$
Ball Group / Outer Race	1	0.061	0.150	0.200	0.175	6.0	5.0	5.5
(0.418 x Wheel Speed)	2	0.081	0.040	0.040	0.040	1.5	5.0	3.3
	3	0.098	0.040	0.080	0.060	3.0	3.0	3.0
	4	0.175	0.150	0.200	0.175	1.5	3.0	2.3
Ball Group / Inner Race	1	0.051	0.030	0.020	0.025	2.0	2.0	2.0
(0.582 x Wheel Speed)	2	0.177	0.020	0.090	0.055	2.0	4.0	3.0
	3	0.179	0.200	0.200	0.200	4.0	4.0	4.0
Inner / Outer Race	1	13.500	1.300	1.800	1.550	550.0	500.0	530.0
(1.000 x Wheel Speed)	2	1.180	0.800	1.500	1.150	20.0	20.0	20.0

Disturbance	Harmonic	Axial Force	Lateral Force (Y)	Lateral Force (Z)	Radial Force (avg)	Lateral Moment (Y)	Lateral Moment (Z)	Radial Moment (avg)
		$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$	$(in^2 \cdot 10^{-6})$
Ball Group / Outer Race	1	0.015	0.500	0.500	0.500	6.0	6.0	6.0
(0.418 x Wheel Speed)	2	0.010	0.030	0.070	0.050	3.0	0.7	1.9
	3	0.091	0.090	0.110	0.100	2.0	6.0	4.0
	4	0.371	0.200	0.110	0.155	2.0	1.5	1.8
Ball Group / Inner Race	1	0.026	0.020	0.020	0.020	3.0	3.0	3.0
(0.582 x Wheel Speed)	2	0.382	0.040	0.050	0.045	4.0	4.0	4.0
	3	0.383	0.200	0.100	0.150	7.0	7.0	7.0
Inner / Outer Race	1	1.230	3.000	2.500	2.750	400.0	400.0	400.0
(1.000 x Wheel Speed)	2	1.450	0.500	0.700	0.600	10.0	10.0	10.0

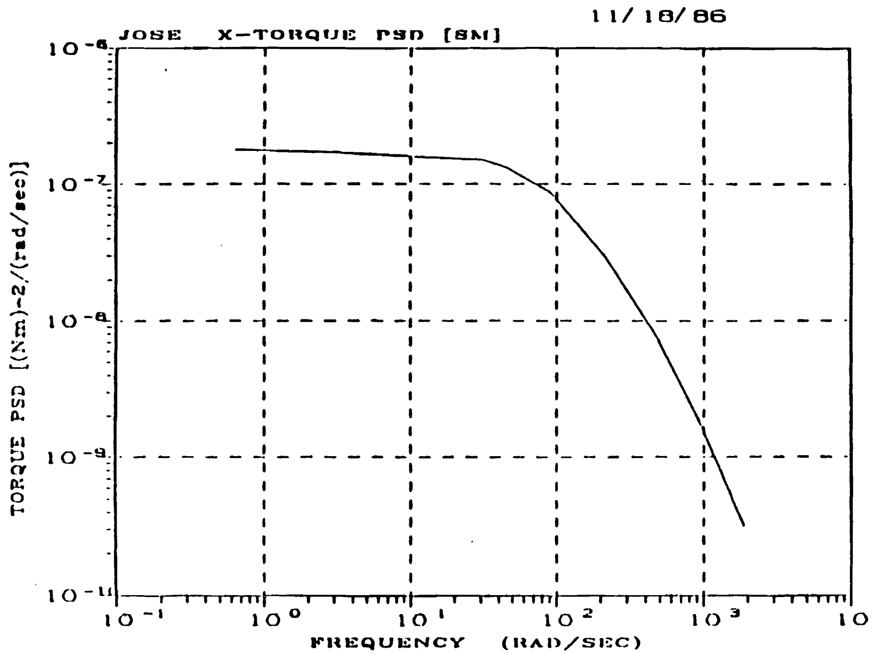
COOLENT FLOW INDUCED FORCE/MOMENTS

(JOSE)

SECONDARY MIRROR FORCE PSD



SECONDARY MIRROR X–TORQUE PSD



THERMAL LOAD CASES

CASE	GEO								LEO							
	Inside				Outside				Inside				Outside			
	With Heaters		Without Heaters		With Heaters		Without Heaters		With Heaters		Without Heaters		With Heaters		Without Heaters	
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
1	X															
2		X														
3			X													
4				X												
5					X											
6						X										
7							X									
8								X								
9									X							
10										X						
11											X					
12												X				
13													X			
14														X		
15															X	
16																X

Definitions:

GEO : Geosynchronous orbit
LEO : Low Earth orbit
Inside : DAMMPS DSA inside spacecraft
Outside : DAMMPS DSA outside spacecraft
L : Low thermal coupling with spacecraft
H : High thermal coupling with spacecraft

DAMMPS Thermal Modeling

- TRASYS surface model was developed to provide radiation exchange factors and orbital heat fluxes for different seasons and optical properties.

- A 75 node SINDA thermal model was used to provide predicted temperatures for two sample cases:

  (1) For summer solstice with S13GLO white paint at EOL
  (2) For equinox with leafing aluminum paint at BOL

- Other assumptions:

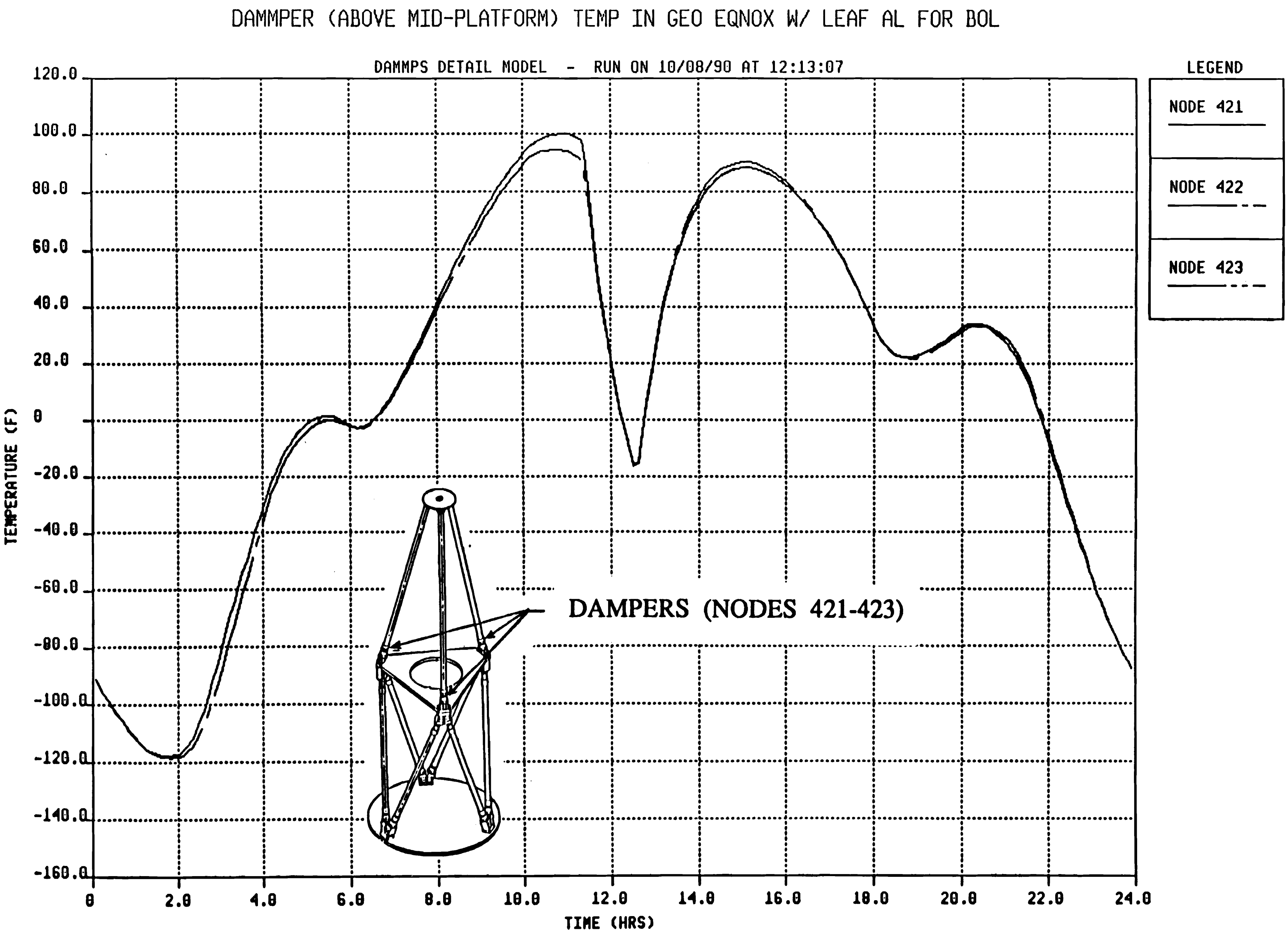
(a) Thermal control on the structure by using different coatings.

(b) The structure is mounted outside a spacecraft.

(c) Thermal conductivity of the tubes, K = 110 Btu/hr-ºF-ft.

(d) Tube material is 50% graphite/50% magnesium alloy.

(e) Interface conductance of 0.50 Btu/hr.-ºF between spacecraft and DAMMPS DSA.



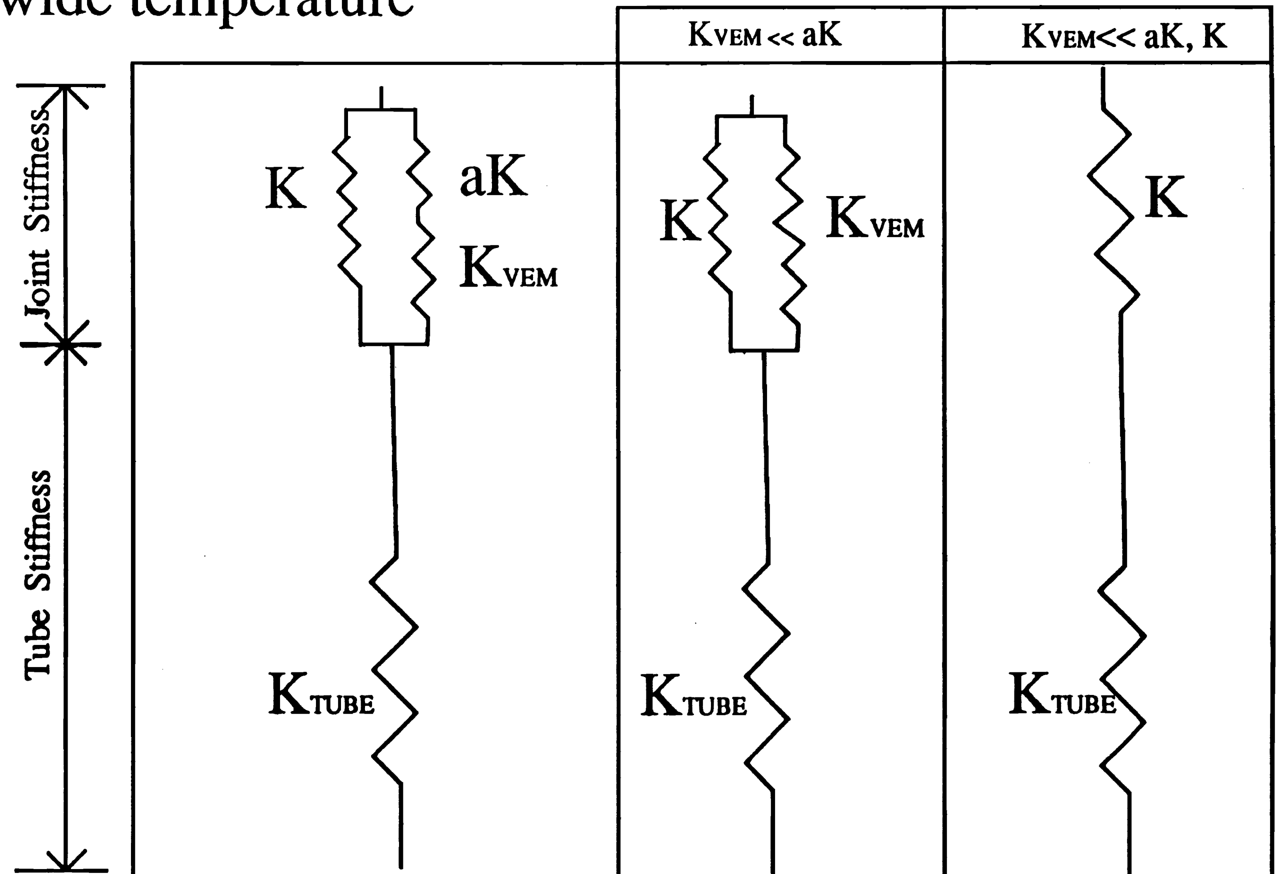
DAMMPER (ABOVE MID-PLATFORM) TEMP IN GEO EQNOX W/ LEAF AL FOR BOL
DAMMPS DETAIL MODEL - RUN ON 10/08/90 AT 12:13:07
LEGEND
NODE 421
NODE 422
NODE 423
TEMPERATURE (F)
120.0
100.0
80.0
60.0
40.0
20.0
0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
TIME (HRS)
DAMPERS (NODES 421-423)

DESIGN CONSIDERATIONS

- Damper Stiffness Properties
- Design Sensitivity to Thermal History
- Thermal Data Requirements and Control

TRUSS ELEMENT STIFFNESS

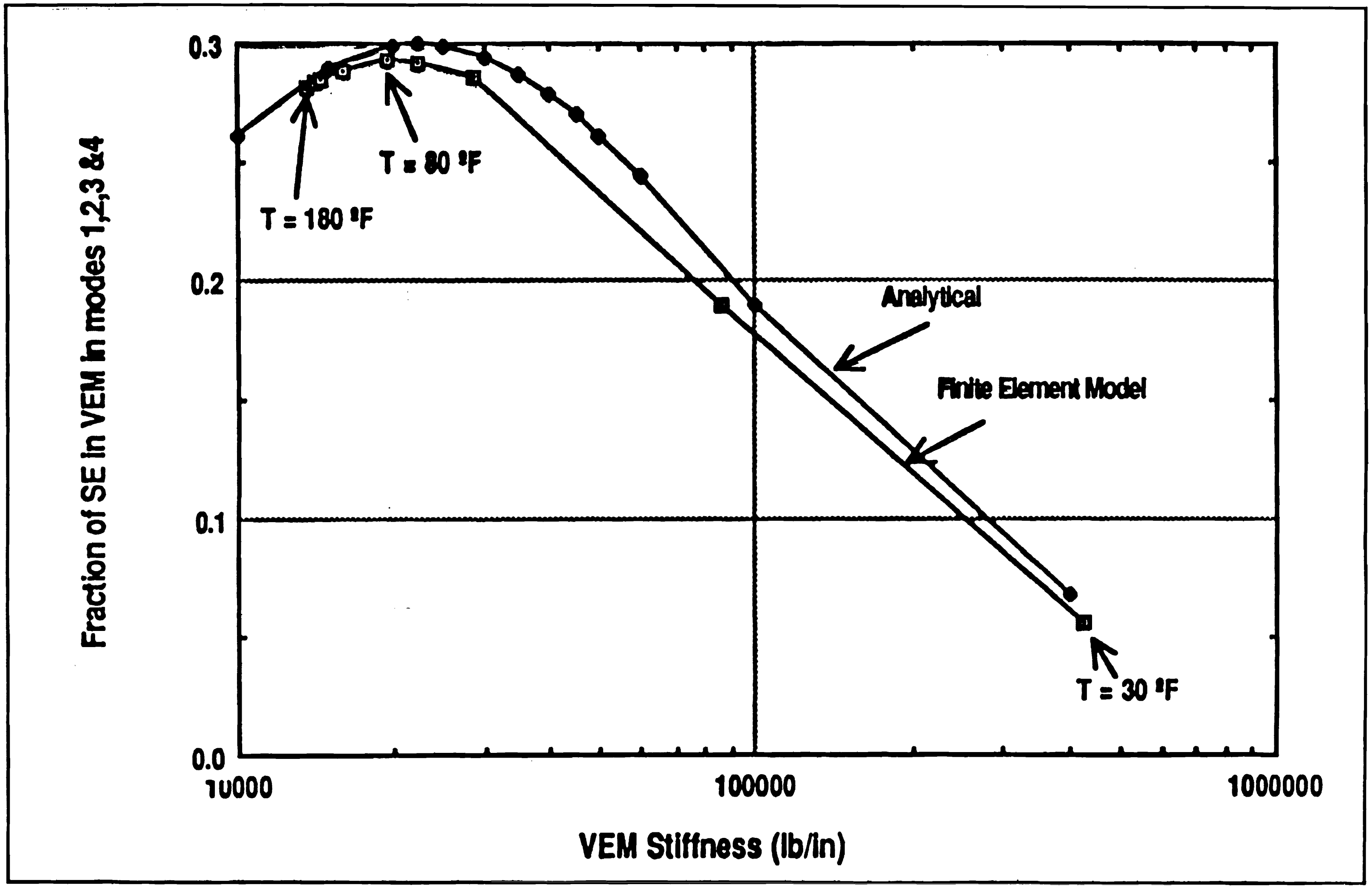
- Three Element Damper : Stiffness not very sensitive to wide temperature variations



Cases	JOINT STIFFNESS : K_{JOINT}		
Nominal	$K + \frac{aK\,K_{VEM}}{aK + K_{VEM}}$	$K + K_{VEM}$	K
I : $K_{VEM} << K, aK$	K } Design independant of K_{VEM}	K } Design dependant on K_{VEM}	K
II : $K_{VEM} >> K, aK$	K + aK	K_{VEM}	K
Damping	Mod.-High	High	Low

DESIGN DAMPING LEVEL

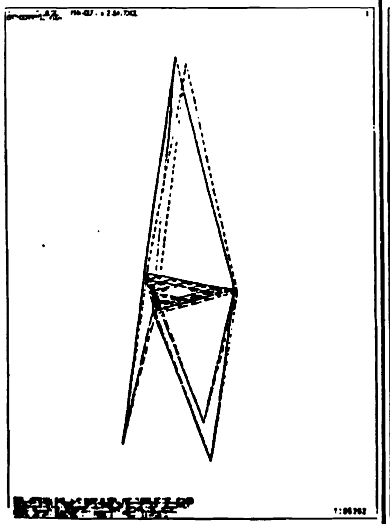
- Damper Parameters Have Been Optimized



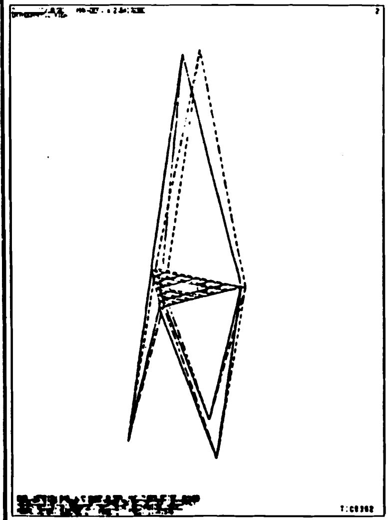
DSA DYNAMIC CHARACTERISTICS

DSA Finite Element Model : Model 220 A   Orthographic View

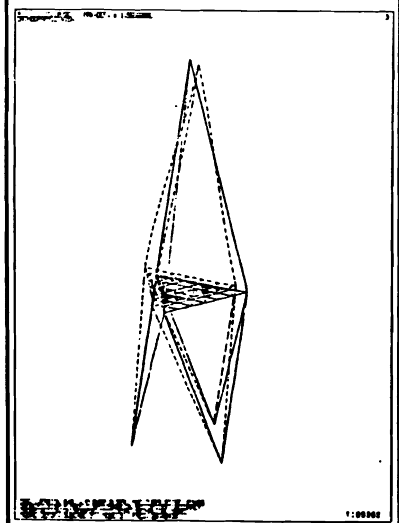
Mode 1 : 11.4 Hz



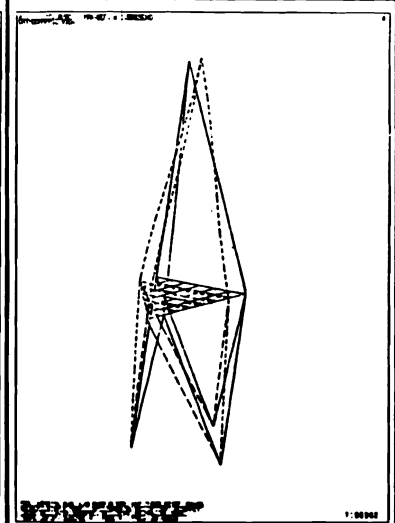
Mode 2 : 11.4 Hz

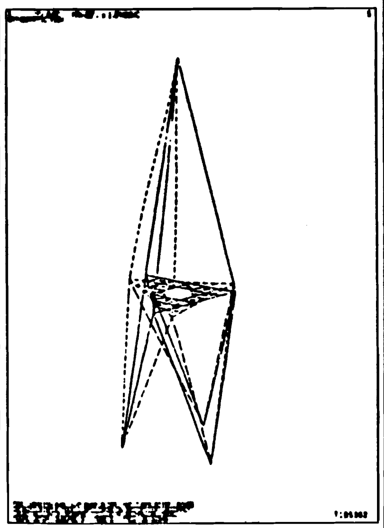


Mode 3 : 29.4 Hz

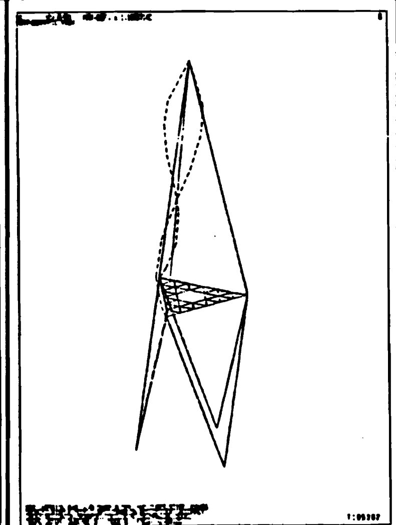


Mode 4 : 29.4 Hz

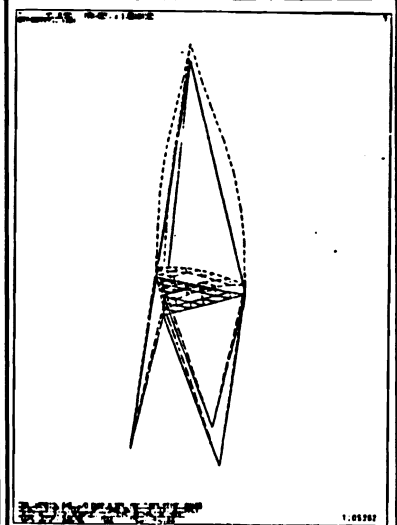




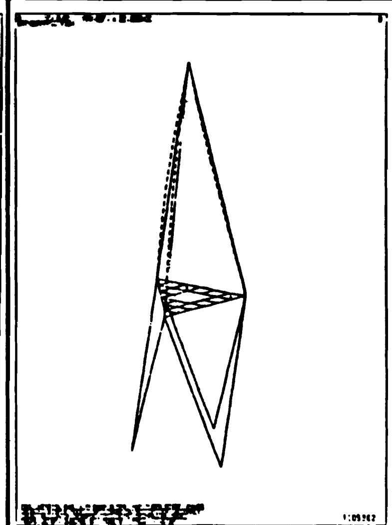
Mode 5 : 35.5 Hz



Mode 6 : 72.7 Hz



Mode 7 : 74.0 Hz



Mode 8 : 77.6 Hz

RESPONSE ANALYSES

- Response Levels Due to RWA Disturbances

    -Amplitude Reduction by a Factor of 10 to200 Hz Over Undamped Structure (Goal:Factor of 5)

- Response Levels Due to Slew Maneuvers

    - Undamped Settling Time > 10 Sec.

    -Damped Settling Time = .35 Sec.

    - Goal: Factor of Ten

RESPONSE ANALYSES

- RMS Response Levels Due to Coolant Flow Disturbance

Quantity	Undamped	Damped
Pointing X (μin)	1049	225
Pointing Y (μin)	1112	271
Pointing Z (μin)	16.34	2.116
LOS X (μrad)	6.993	2.263
LOS Y (μrad)	6.273	1.867
LOS Z (μrad)	.1828	.0649

- Response Reductions to 1000 Hz : By Factors 2.8 to 7.7