Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–1998/20 December 1998

Survivability, Structures, and Materials Directorate

Technical Report

Mechanical Vibration Testing Results of Acoustic Test Panels

by

Colin P. Ratcliffe
United States Naval Academy, Mechanical Engineering Department

Roger M. Crane
NSWCCD, Structures and Composites Department

Approved for public release; distribution is unlimited.

NSWCCD-65-TR–1998/20 Mechanical Vibration Testing Results of Acoustic Test Panels

DEPARTMENT OF THE NAVY

NAVAL SURFACE WARFARE CENTER, CARDEROCK DIVISION
9500 MACARTHUR BOULEVARD
WEST BETHESDA MD 20817-5700

9078
Ser 65-34
5 Apr 99

From: Commander, Naval Surface Warfare Center, Carderock Division
To: Chief of Naval Research (ONR 332)

Subj: VIBRATION TESTING OF GRAPHITE REINFORCED COMPOSITE PLATES

Ref: (a) Program Element 0602234N, Seaborne Structural Materials Program for FY96 and Program Element 0602121N, C-Section Task of the BA2 Surface Ship Hull, Mechanical, and Electrical Technology Program for FY96

Encl: (1) NSWCCD-65-TR–1998/20, *Mechanical Vibration Testing Results of Acoustic Test Panels*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to develop procedures to determine the modal damping of various material and geometric configurations. Enclosure (1) describes the mechanical vibration testing of two graphite reinforced composite plates.

2. Comments or questions may be referred to Dr. Roger M. Crane, Code 6553; telephone (301) 227-5126; e-mail, crane@dt.navy.mil.

J. E. BEACH
By direction

Subj: VIBRATION TESTING OF GRAPHITE REINFORCED COMPOSITE PLATES

Copy to:

COMNAVSEASYSCOM WASHINGTON DC
[SEA 03M3 (Ingle), SEA 03M, SEA 03P1 (Kadala), SEA 03P4, SEA 03R, PMS400D, PMS500 (Camponeschi)]

PEOSUB WASHINGTON DC [A. Spero]

NRL WASHINGTON DC [Code 6383 (Badaliance, Gauss)]

CNR ARLINGTON VA [ONR 332 (Kelly), ONR 334 (Barsoum, Fishman, Rajapakse, Tucker, Vasudevan)]

USNA ANNAPOLIS MD [Mechanical Engineering Department (Dr. Colin P. Ratcliffe)]

DTIC FORT BELVOIR VA

Applied Research Laboratory
Pennsylvania State University
Attn: Dr. Kevin Koudela
P.O. Box 30
State College, PA 16804

Assistant Director, CCM
Composites Manufacturing Science Laboratory
Attn Dr. John W. Gillespie, Jr.
University of Delaware
Newark, DE 19716

Newport News Shipbuilding & Drydock Company
Attn Dr. Tom Juska
4104 Washington Avenue
Newport News, VA 23607

NAVSURFWARCEN CARDEROCKDIV
BETHESDA MD [Codes 0112 (Douglas), 0115 (Messick), 3442 (TIC), 60 (w/o encl), 65, 65R (2), 652, 652 (Young), 655, 6551 (Bartlett, Kiviat, Macander, Paraska), 6552 (Bonanni, Loup, Palmer, Rasmussen, Telegadas), 6553 (Crane (10), Coffin, Williams), 72 (Fisher), 7250 (Gershfeld, Maga, Warwick)]

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1998	Final

4. TITLE AND SUBTITLE
Mechanical Vibration Testing Results of Acoustic Test Panels

5. FUNDING NUMBERS
PE 0602234N
PE 0602121N

6. AUTHOR(S)
Colin P. Ratcliffe (USNA) and Roger M. Crane (NSWCCD)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center
Carderock Division
9500 MacArthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-65-TR–1998/20

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief of Naval Research (ONR 332)
Ballston Centre Tower One
800 Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This report describes the mechanical vibration testing of two graphite reinforced composite plates. The plates were tested in a free-free boundary condition up to a frequency of approximately 6 kHz. The plates were designed to assess two different damping treatments. They consisted of a 1.37 inch thick carbon epoxy structural section with a 0.13 in thick region on one side for each treatment. One plate used a conventional constrained layer design, while the other used a thin free layer of fiber reinforced urethane. The results show that while the constrain layer damped plate has a higher energy dissipation potential, it also has a reduced stiffness. There is also some localized modal behavior, which suggests it may also be reduced in strength.

14. SUBJECT TERMS
composite materials graphite

15. NUMBER OF PAGES
19

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Contents

Figures

Tables

Administrative Information

The work described in this report was performed by the Structures and Composites Department of the Survivability, Structures and Materials Directorate, Carderock Division, Naval Surface Warfare Center. The work was funded by the Office of Naval Research, Code 332, under the Seaborne Structural Materials Program (PE 0602234N) and by the Defense Advanced Research Projects Agency under the C-Section Task of the FY96 BA2 Surface Ship Hull, Mechanical, and Electrical Technology Program (PE 0602121N).

Introduction

Two graphite reinforced composite plates were manufactured to the same nominal dimensions of 10 x 16 inches x 1.5 inches thick. The plates were designed by ARL Penn State and were designated as “Plate 2” and “Plate 3”. Both plates consisted of a 1.37-in thick structural layer, with a 0.13-inch thick damping treatment on one side. Plate 2 is essentially uniform in construction, with a thin area of carbon fiber reinforced urethane used as the damping treatment. Plate 3 contains a constrained layer damping treatment, although it was not visible in the panel as fabricated. Since the panels were manufactured with an equivalent structural region, no other information will be provided concerning these plates. In essence, they were identical with the exception of the treatment used.

The objectives of the tests were to determine the modal loss factors for each plate and assess the treatment performance for use on a composite structure. The modal testing was also done to confirm that the structural stiffnesses of the two plates were the same.

Test Method

The test method used for both test panels was the procedure detailed in Ratcliffe and Crane [1998]. The following were the specific details of the test.

A square mesh with a one-inch side was placed on each plate. The mesh was shifted a half inch from the edge of the plate, as shown below. There was a total of 40 grid points in the mesh.

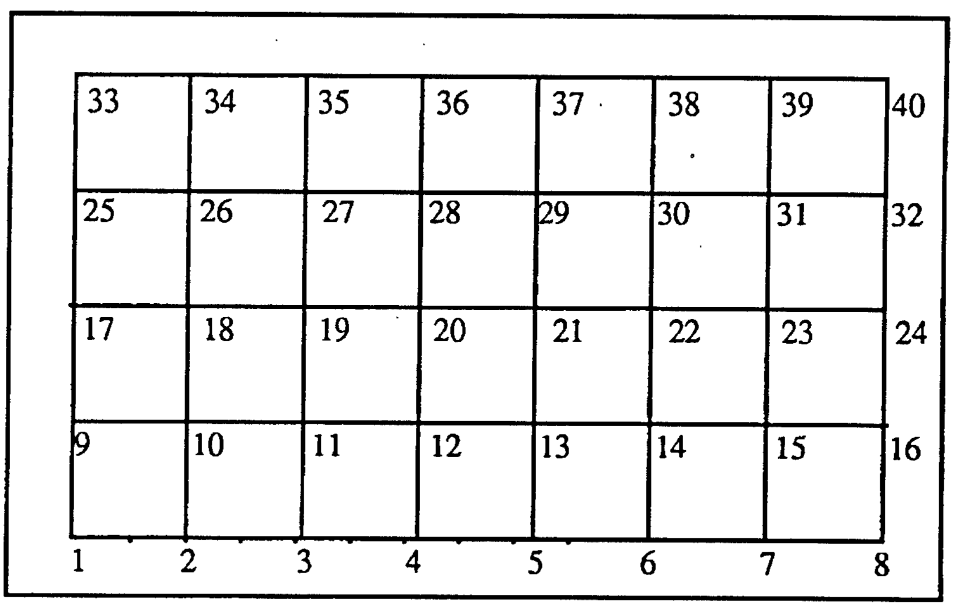

Figure 1. Grid Mesh for Impact Excitation.

The plate was supported horizontally on bubble wrap. The bubble wrap was placed on a hard, smooth surface, with the holes upwards.

Provisional testing of the panel indicated that data should be obtained up to 6.25 kHz. In this frequency range, representative frequency response function plots showed there were about ten resonant peaks.

A modally tuned PCB ICP model 086B03 force hammer was used for all testing. Data obtained using a nylon tip showed a significant drop-out in the force signal's auto power spectrum near 3.9 kHz, with a second drop out at 4.4 kHz. Data obtained using a steel tip did not show any significant dropout in the 0-6.25 kHz frequency range. A steel tip was therefore used on the hammer.

A PCB type ICP 609A accelerometer was secured with beeswax to grid point 1. This accelerometer is used to monitor the panel response from the impulse excitation at the other grid locations.

Signal conditioning for both the force gage and accelerometer was with PCB ICP battery powered amplifiers. This is used so that line noise is minimized.

The same transducer pair and grid pattern was used for testing both panels.

Transducers were used uncalibrated, and therefore the dynamic functions are referenced to an arbitrary datum.

The analyzer was set up in accordance with Ratcliffe and Crane [1998]. Both ICP conditioning amplifiers were set with a x 10 gain. The pre-trigger was set to 5 ms.

The data were captured using a HP3562A analyzer. The force signal window was set at 25 ms. For the frequency range of 0-6.25 kHz, the length of the time record is given by the machine as 128 ms. Previous testing of the lighter-damped panel (Plate 2) showed that the viscous damping ratio is of the order 1-2%, with the fundamental natural frequency being about 1100 Hz. Combined, the (ζ_r, f_r, T) term for the fundamental mode of the plate is about 2.1. The nomograph in Ratcliffe and Crane [1998] indicates that no exponential window is required. The longest exponential window time constant available in the HP3562A (1,000 seconds) was therefore used. The correction to modal damping required for this window is insignificant.

Results General

The coherence statistics are shown in the Table 1. The average and standard deviation are computed for all frequencies, at all test points. The sample size is thus 32,040 (40 points x 801 lines per spectrum). The results for both tests show a good confidence that the data are of high quality.

Table 1. Coherence Results for Modal Testing of Acoustic Test Panels.

Plate	Average Coherence (%)	Standard Deviation of Coherence
2	98.7	0.070
3	98.9	0.064

The frequency response functions for each plate were subject to a modal analysis using two different commercial modal analysis packages; The STAR System (Spectral Dynamics, Inc.), and ME'scope (Vibrant Technology, Inc.) The natural frequencies and mode shapes are shown in the Table 2. In Table 2, the mode shape descriptor is an estimate of the measured mode shape compared to the mode shape for a theoretical uniform plate. The first number gives the number of phase changes along the shorter side (10 inch) of the plate, and the second number gives the number of phase changes along the length (16 inch) of the plate. Thus, (0, 2) represents the first lengthwise bending mode.

Table 2. Modal Test Results for Plates 2 and 3.

Mode Shape Descriptor	Natural Frequency (Hz)				Loss Factor (%)			
	Plate 2		Plate 3		Plate 2		Plate 3	
	STAR	ME'scope	STAR	ME'scope	STAR	ME'scope	STAR	ME'scope
(0, 2)	1248	1248	1206	1208	1.88	1.86	3.75	3.67
(0, 3)	2906	2906	2427	2430	1.53	1.50	10.0	10.15
(0, 4)	5000	5003	4126	4127	1.69	1.60	5.51	5.32
(1, 1)	1081	1081	1166	1166	1.29	1.30	2.13	2.15
(1, 2)	2338	2337	2207	2207	1.13	1.13	7.10	7.10
(1, 3)	3865	3865	3534	3534	1.48	1.48	6.25	6.20
(1, 4)	5615	5615	5026	5024	1.71	1.75	5.42	5.75
(2, 0)	2993	2993	2594	2593	1.17	1.17	6.36	6.40
(2, 1)	3468	3468	3111	3111	1.19	1.19	5.38	5.38
(2, 2)	4409	4408	3870	3870	1.35	1.37	7.39	7.34
(2, 3)	5788	5788	5134	5134	1.52	1.57	5.16	5.48
(3, 0)	6213	6213			1.52	1.42		
ill defined			5737	5732			2.63	3.85

Comparison of Modal Analysis Packages

Table 3 shows the difference between the natural frequencies and loss factors determined by the two different software packages.

Table 3. Comparison of Consistency of Test Results from Star and ME'scope Modal Packages.

Mode Shape Descriptor	Natural Frequency Difference (STAR - ME'scope) (Hz)		Loss Factor Difference (STAR - ME'scope) (%)	
	Plate 2	Plate 3	Plate 2	Plate 3
(0, 2)	0	-2	0.02	0.08
(0, 3)	0	-3	0.03	-0.15
(0, 4)	-3	-1	0.09	0.19
(1, 1)	0	0	-0.01	-0.02
(1, 2)	1	0	0.00	0.00
(1, 3)	0	0	0.00	0.05
(1, 4)	0	2	-0.04	-0.33
(2, 0)	0	1	0.00	-0.04
(2, 1)	0	0	0.00	0.00
(2, 2)	1	0	-0.02	0.05
(2, 3)	0	0	-0.05	-0.32
(3, 0)	0		0.10	
ill defined		5		-1.22

The natural frequencies estimated by the two software packages are in remarkable agreement. The average magnitude of the difference between the natural frequencies is only 0.01 % for Plate 2, and 0.04 % for Plate 3. The biggest difference is 5 Hz, which is for the ill-defined 5737 Hz mode of Plate 3.

Damping estimates are a little more variable, but still show remarkable agreement. For the lighter damped plate, Plate 2, all the estimated loss factors are within less 0.1% of each other. For the heavier damped plate, Plate 3, there is more variability. However, the biggest variation is about 0.33%, except for the ill defined (3, 0) mode.

This work suggests that, regardless which analysis package is used, there is an insignificant difference between the natural frequencies and modal damping.

Results - Loss Factors

The loss factors for the two analyses of each plate are shown in Figure 2. Note that the repeatability between different analysis packages means that the two curves for each plate almost overlay, and are difficult to distinguish in this figure.

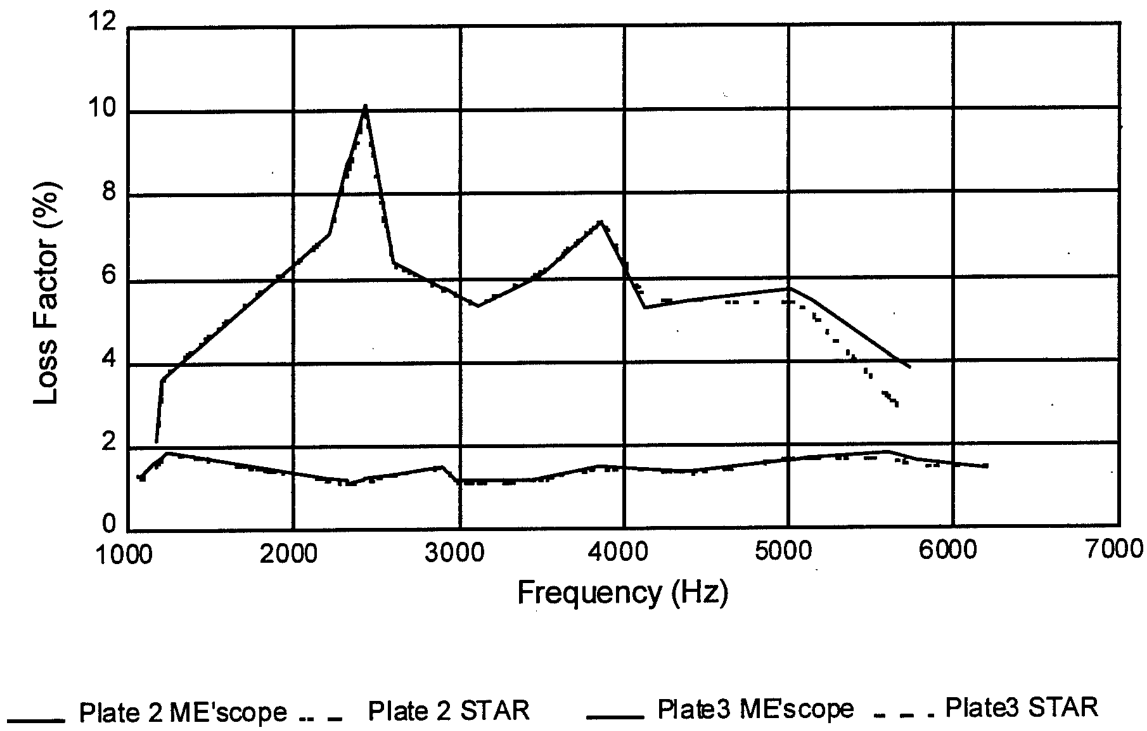

Figure 2. Comparison of Damping Performance Using Star Modal and Me'scope.

The damping for the urethane system, Plate 2, is essentially constant with frequency, including the lowest modes. Damping for the constrained layer plate, Plate 3, is higher than for Plate 2. However, the low frequency damping is significantly lower than that at moderate frequencies. Also, the damping generally reduces with increasing frequency.

Under an unreported trial, Plate 2 had been previously tested to 5 kHz. The damping obtained from that trail, USNA T3, is compared to the ME'scope damping obtained under this trial in Figure 3. The trial USNA T3 was not in accordance with the standardized procedure. Overall, there is good agreement between these tests.

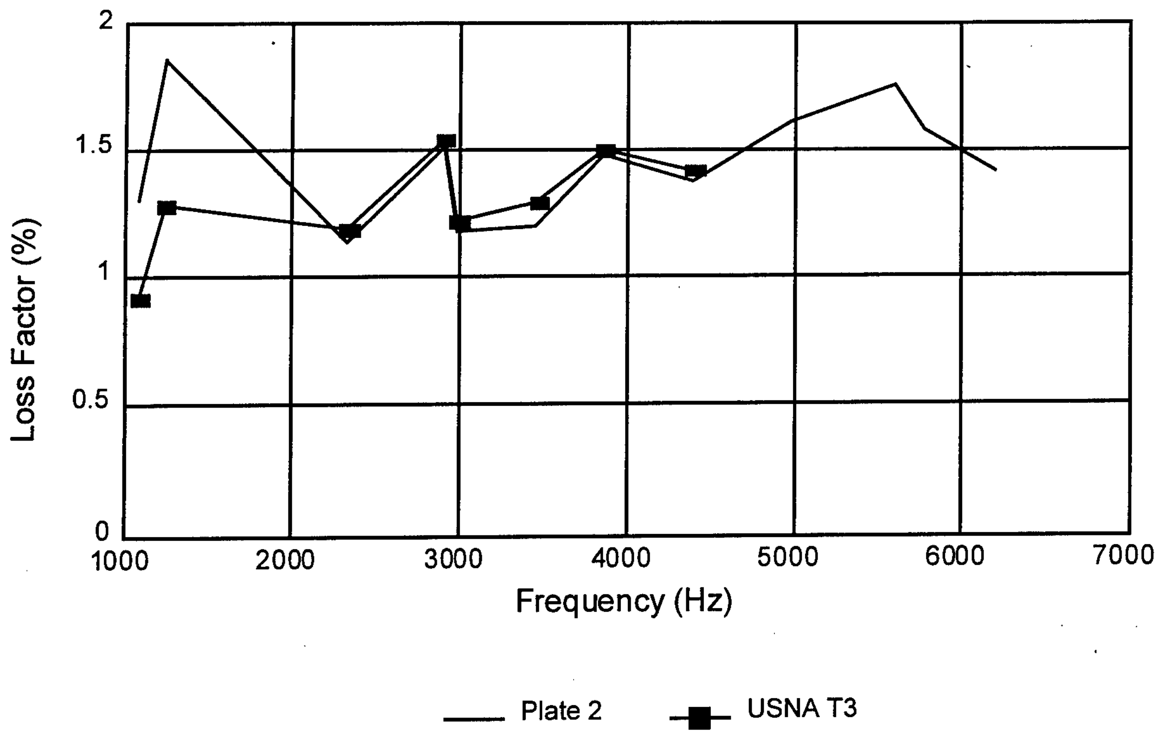

Figure 3. Comparison of Test Results of Plate 2.

Results - Natural Frequencies and Mode Shapes

One of the aims of the trial reported here was to verify that the two plates had comparable stiffness. The comparison was done by comparing the natural frequencies. Consistently, the natural frequencies for Plate 3 are lower than those for Plate 2. The following figures show the comparison.

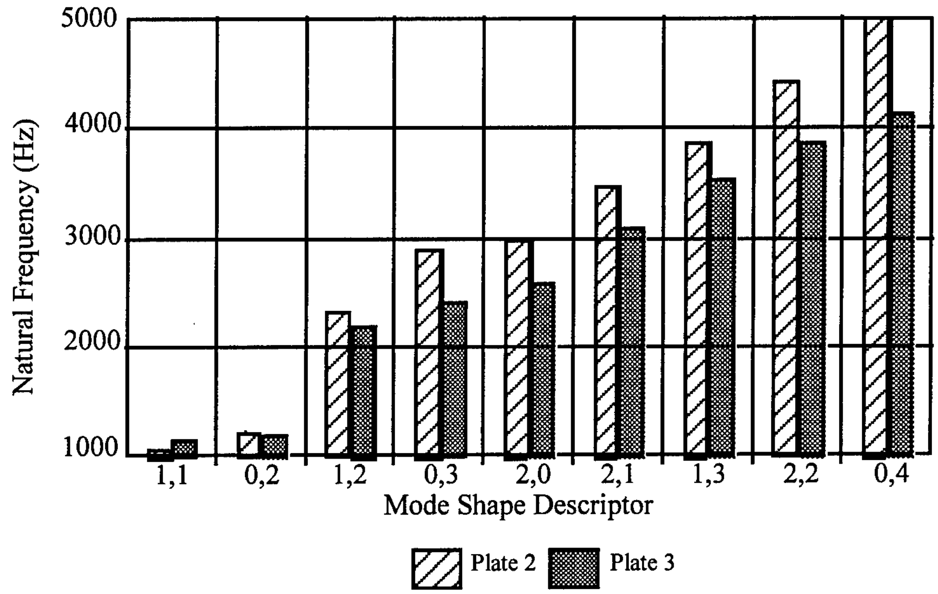

Figure 4. Comparison of Natural Frequencies of Acoustic Test Panels 2 and 3 for Various Mode Shapes.

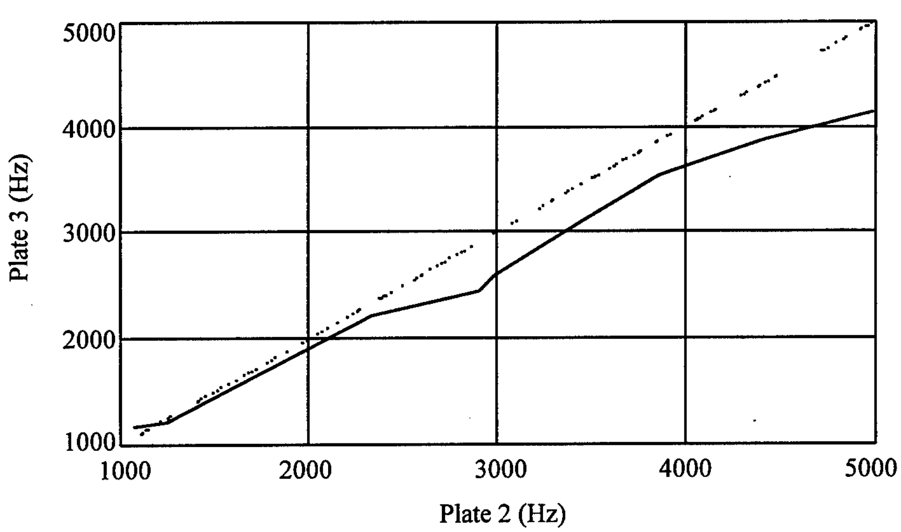

Figure 5. Comparison of Natural Frequencies of Acoustic Test Panels 2 and 3.

The figures comparing natural frequencies show that the plates have comparable stiffness at lower frequencies. However, as the frequency increases, Plate 3 shows a rapidly reducing dynamic stiffness. This suggests there may be 'weak spots' in Plate 3, which act as local resonators at higher frequencies. This effect is noticeable in some of the mode shapes, shown and discussed below.

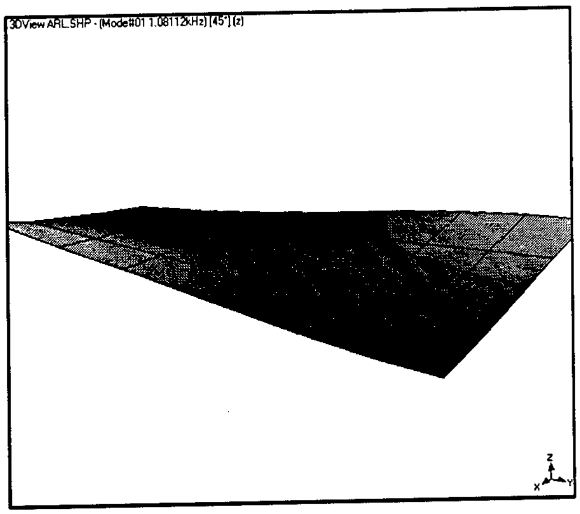

Figure 6. Plate 2, Mode (1, 1), 1081 Hz.

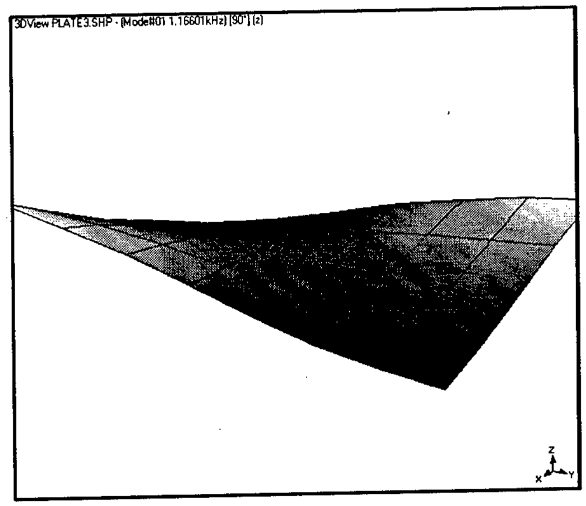

Figure 7. Plate 3, Mode (1, 1), 1166 Hz.

Mode (1, 1) is the lowest frequency structural mode of both plates. Both plates exhibit 'clean' mode shapes, comparable to that expected for a theoretical uniform plate.

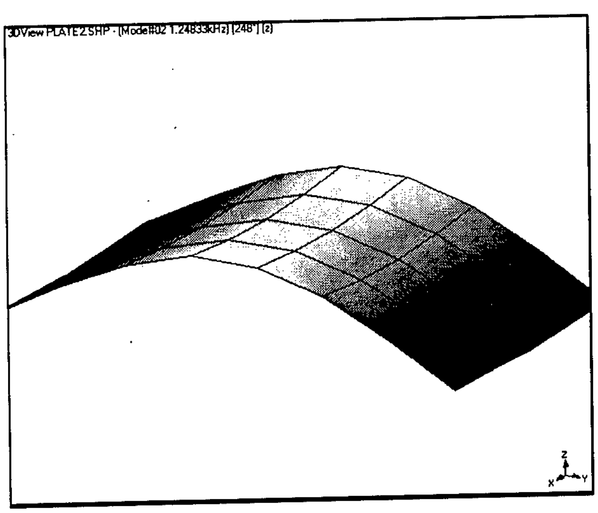

Figure 8: Plate 2, Mode (0, 2), 1248 Hz.

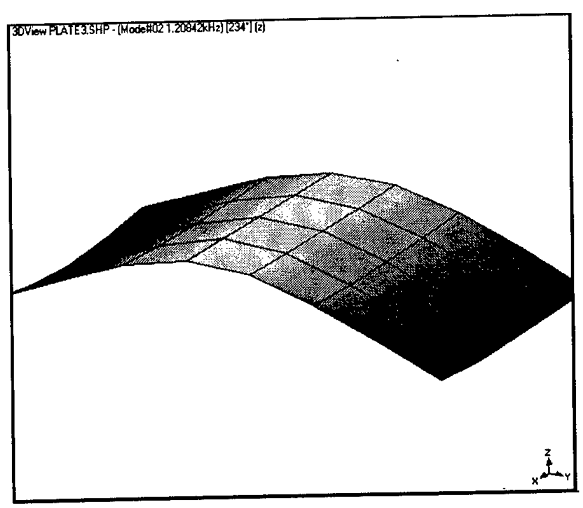

Figure 9: Plate 3, Mode (0, 2), 1208 Hz.

Mode (0, 2) is the second lowest frequency structural mode of both plates. Both plates exhibit mode shapes comparable to that expected for a theoretical uniform plate.

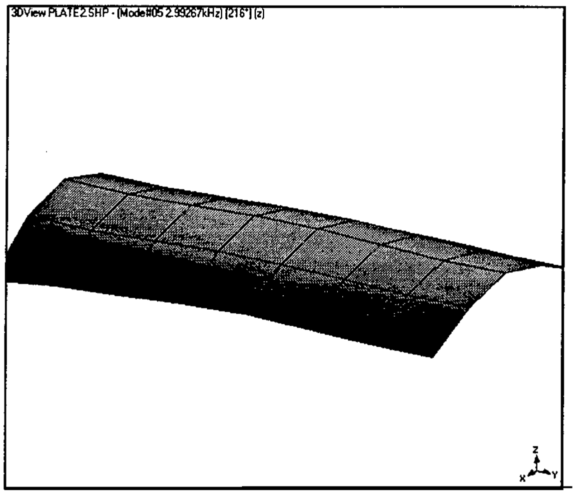

Figure 10. Plate 2, Mode (2, 0), 2993 Hz.

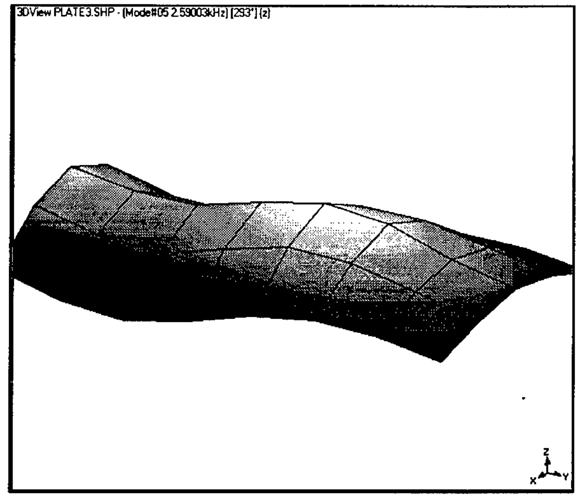

Figure 11. Plate 3, Mode (2, 0), 2593 Hz.

Mode (2, 0) is the 5th structural resonance. The mode shape for Plate 2 is typical of the shape for a theoretical uniform plate. Plate 3 is starting to show some unusual behavior. There is some unexpected lengthwise bending, and the mode shape across the width shows some 'sharpening' near the middle.

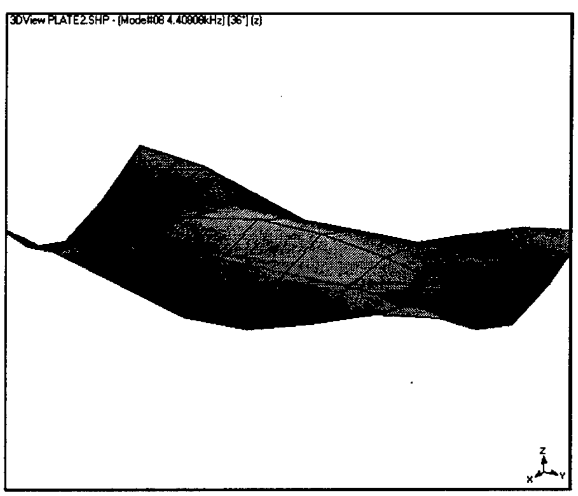

Figure 12. Plate 2, Mode (2, 2), 4408 Hz.

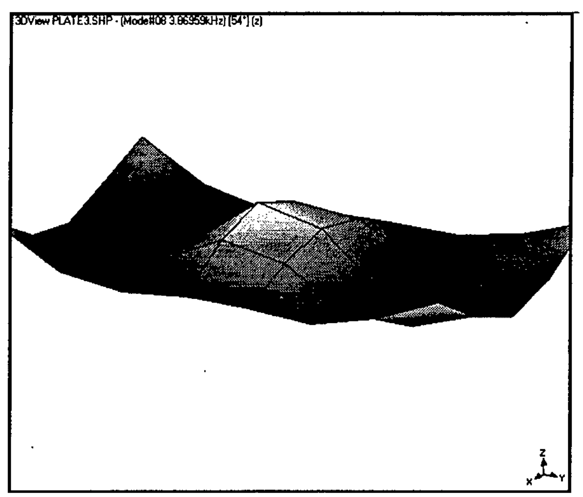

Figure 13. Plate 3, Mode (2, 2), 3870 Hz.

For mode (2, 2), Plate 2 continues to show a mode shape comparable to that expected for a theoretical uniform plate. For Plate 3, there is significant activity near the middle. The shape suggests a lack of uniformity along the length of the plate.

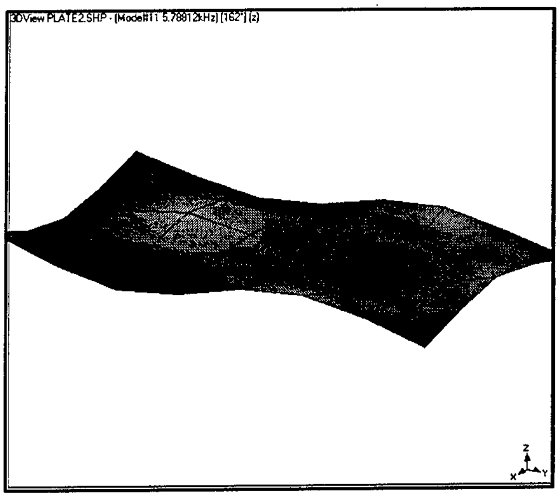

Figure 14: Plate 2, mode (2, 3), 5788 Hz

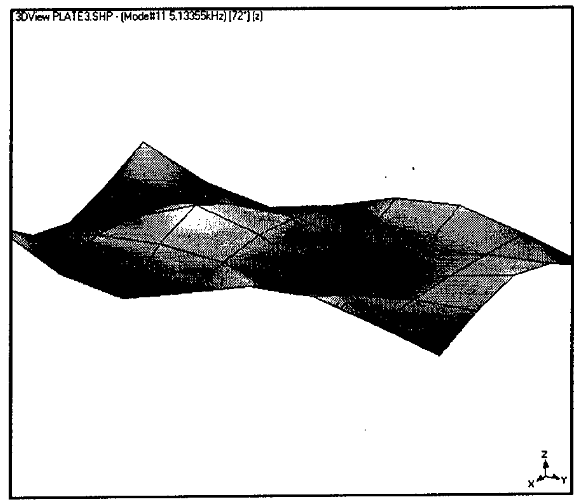

Figure 15: Plate 3, mode (2, 3), 5134 Hz

Plate 3 continues to show a high-curvature mode shape when compared to Plate 2 and theoretical mode shapes.

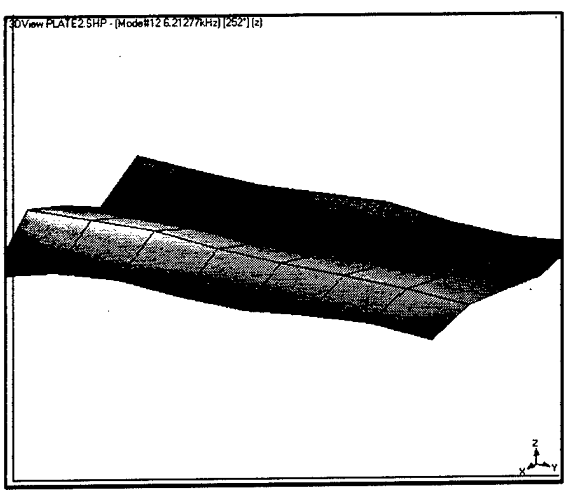

Figure 16. Plate 2, mode (3, 0), 6213 Hz.

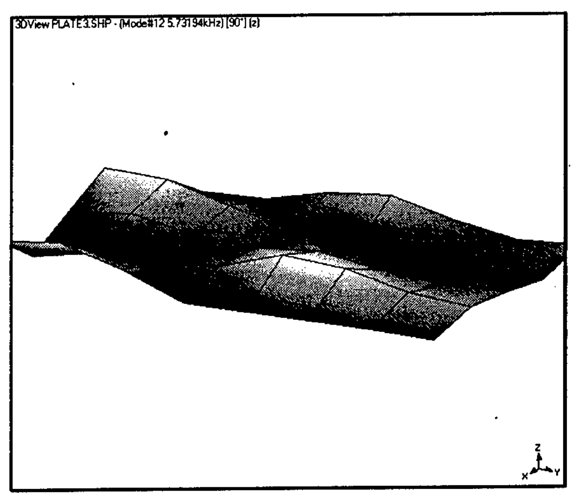

Figure 17. Plate 3, Mode (ill defined), 5732 Hz.

The above figures are for the highest resonant frequency measured for each plate. Based on the trend in natural frequencies, the two shapes should be for the same mode shape. Plate 2 is still consistent with a theoretical uniform-plate shape. The shape for Plate 3 is not.

Conclusions

A standardized procedure was used to measure the natural frequencies and modal loss factors for two graphite reinforced composite damping test plates. Based on the differences between the natural frequencies of the two plates, the plate identified as Plate 3 was less stiff. The mode shapes suggested Plate 3 had some structural performance that was not consistent with a uniform plate, with unexpectedly large localized motion near the middle. The behavior of the plate identified as Plate 2 was consistent with that of a uniform plate.

Damping for Plate 2 was essentially independent of frequency, being equally good at low frequencies as at high. Damping for Plate 3 was always higher than that for Plate 2. However, the damping in Plate 3 varied with frequency. It was less at low frequencies, and also showed a reducing trend at high frequencies.

Recommendations

It is recommended that the unusual dynamic behavior of Plate 3 be investigated further, since this may cause unexpected in-service problems.

Since Plate 2 appeared to be a structurally sounder configuration, it is also recommended that Plate 2 be reconfigured and tested with a thicker urethane layer. The thickness should be increased so that the dynamic stiffness is reduced to a value comparable with that for Plate 3.

Reference

Ratcliffe, Colin P. and Roger M. Crane [1998]. NSWCCD-65-TR–1998/21, *Standardized Procedure for Experimental Vibration*, Naval Surface Warfare Center, Carderock Division, West Bethesda, Maryland.