NASA/TM—1998–207685

Measurement of Damping of Composite Materials for Turbomachinery Applications
(MSFC Center Director's Discretionary Fund Final Report, Project No. 94–05)

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March 1998

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Space Administration

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Acknowledgments

The author gratefully acknowledges the efforts of the following individuals in the completion of this task:

Clarissa Love, Summer Teacher Enrichment Program Participant
Brian Vaccaro, Virginia Tech, NASA Space Academy Student
Dr. Jon Goldsby, NASA/LeRC
Jeff Lindner, John Lassiter, Greg Osborn NASA/MSFC

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TABLE OF CONTENTS

LIST OF FIGURES

TECHNICAL MEMORANDUM

MEASUREMENT OF DAMPING OF COMPOSITE MATERIALS FOR TURBOMACHINERY APPLICATIONS (MSFC Center Director's Discretionary Fund Final Report, Project No. 94–05)

I. INTRODUCTION

It has been a widely held assumption that fiber-reinforced composite materials possess more inherent material damping than metals or monolithic composites.[1–2] The objective of this study is to quantify the material damping of fiber-reinforced composite materials that can be used in rocket engine turbomachinery applications. Ceramic matrix composites (CMC's) possess high-strength, low-weight, and high-temperature capability. These are desirable attributes for turbine-end component materials.[3] The additional property of higher damping would allow the components to be less complex and withstand higher dynamic loading.

A NASA Marshall Space Flight Center (MSFC)-sponsored program was developed to investigate the damping properties of composite materials. Material samples were purchased and some were donated from other programs for testing. In the initial phase, beam samples were tested. Later disk specimens, approximately the size of rocket engine turbines, were tested for damping capacity. The results are discussed in the following sections.

A. Beam Tests

1. Ambient Temperature Testing

Beam samples for the initial tests were donated by various manufacturers and Boeing Rocketdyne Division (BRD). BRD was in the process of manufacturing a turbine blisk for a research task and felt damping data would be useful in the materials selection process. There were nine specimens in that round of testing which included:

Table 1. Initial test samples.

Material	Vendor/Provided
8009 Aluminum	Allied Signal Metallic
SiC/C [0/90]	BP Chemical-HITCO
C/C Uninhibited	BP Chemical-HITCO
C/C Inhibited	BP Chemical-HITCO
APC-2/AS4	ICI Fiberite
C/SIC 30% Warp	DuPont/Rocketdyne
C/SiC 40% Warp	DuPont/Rocketdyne
C/SiC 60% Warp	DuPont/Rocketdyne
C/SiC 70% Warp	DuPont/Rocketdyne
Inconel 718	NASA Materials Lab

a. Testing Method. The tests were conducted using standard impact hammer techniques in ambient conditions to excite the samples, which were supported by elastic cords providing a free-free boundary condition. An accelerometer was bonded to the test article and connected to a structural dynamic analyzer which was used to acquire the frequency and damping data. Resonant frequencies were first identified with broad band measurements and later zoom band measurements were used to determine frequency values with high resolution. The damping was calculated from these zoom band frequency response functions.

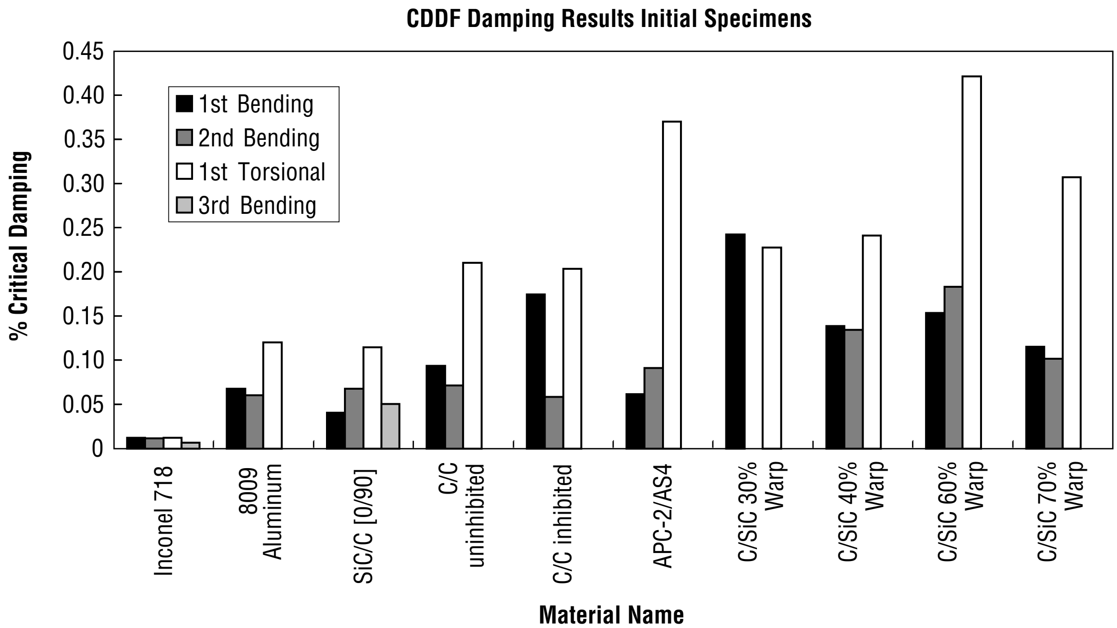

Figure 1. Damping results initial testing.

Depicted in figure 1 are the results from the first series of tests. Inconel 718 is the baseline sample to which all the others will be compared. The other samples tested had higher damping than the baseline. All the other samples were composites except for the 8009 Aluminum which is a new aluminum alloy. The C/SiC samples, provided by BRD, had different amounts of fibers in the warp direction than the fill direction for a [0/90] layup. It can be seen that just by producing an unbalanced layup with a [0/90] architecture, different damping values can be obtained for different modes. It was also observed that the first torsional mode produced the most damping in all specimens.

The next round of testing began after procuring monolithic silicon nitride, Blackglas/Nicalon from Allied Signal and SiC/SiC samples from DuPont. These samples were cut to the same dimensions, 20.32 cm × 2.54 cm × 0.3175 cm (8 in. × 1 in. × 0.125 in.). A 10:1 length-to-width ratio is preferred from a theoretical standpoint, but it would have been much more expensive to procure samples in 25.4 cm lengths. Therefore, the samples were cut from 20.32 cm × 20.32 cm square plates that the vendors produce for their own specimen testing. This provided an 8:1 length-to-width ratio. During this round of testing it was possible to investigate the effect of fiber architecture on the damping. Previous testing showed that changing the number of fibers in one direction as opposed to another for a [0/90] layup produced different amounts of damping. Therefore, architectures including off-axis fibers should also produce varied amounts of damping. Quasi-Isotropic and [0/90] layups of SiC/SiC and Blackglas/

Nicalon were tested. Additionally, nominal (32 percent) and high (40 percent) volume fraction Blackglas/Nicalon samples were tested again with quasi-isotropic and [0/90] layups.

From figure 2 we note that the most damping was observed in the first torsional mode. The three silicon nitride samples provided very little damping in the bending modes, about the same amount as the Inconel 718 baseline sample. The C/SiC [0/90] balanced (50-percent warp) provided the most damping for any specimen during this phase of tests. The Blackglas materials seemed to vary a bit with the changes in volume fraction and fiber architecture but they still provided at least 0.1 percent critical damping for each mode evaluated. The SiC/SiC samples showed the same trend, increases in damping for the modes in the following order: first bending, second bending, and first torsional. The [0/90] seemed to provide the most damping of the pair, but in bending was close to the Inconel sample.

2. Composite Integrally Bladed Turbine Disk (CBLISK) Materials

The third and final round of beam sample testing was conducted for the CBLISK program, a task that will test a composite blisk in a rocket engine turbopump designed to provide oxidizer to a hybrid rocket engine. The CBLISK program wanted to evaluate the damping capacity of the materials under review. Two samples each of C/SiC quasi-isotropic, C/SiC [0/90], C/SiC [0/90] with a 15-degree offset and SiC/alumina [0/90] were tested.

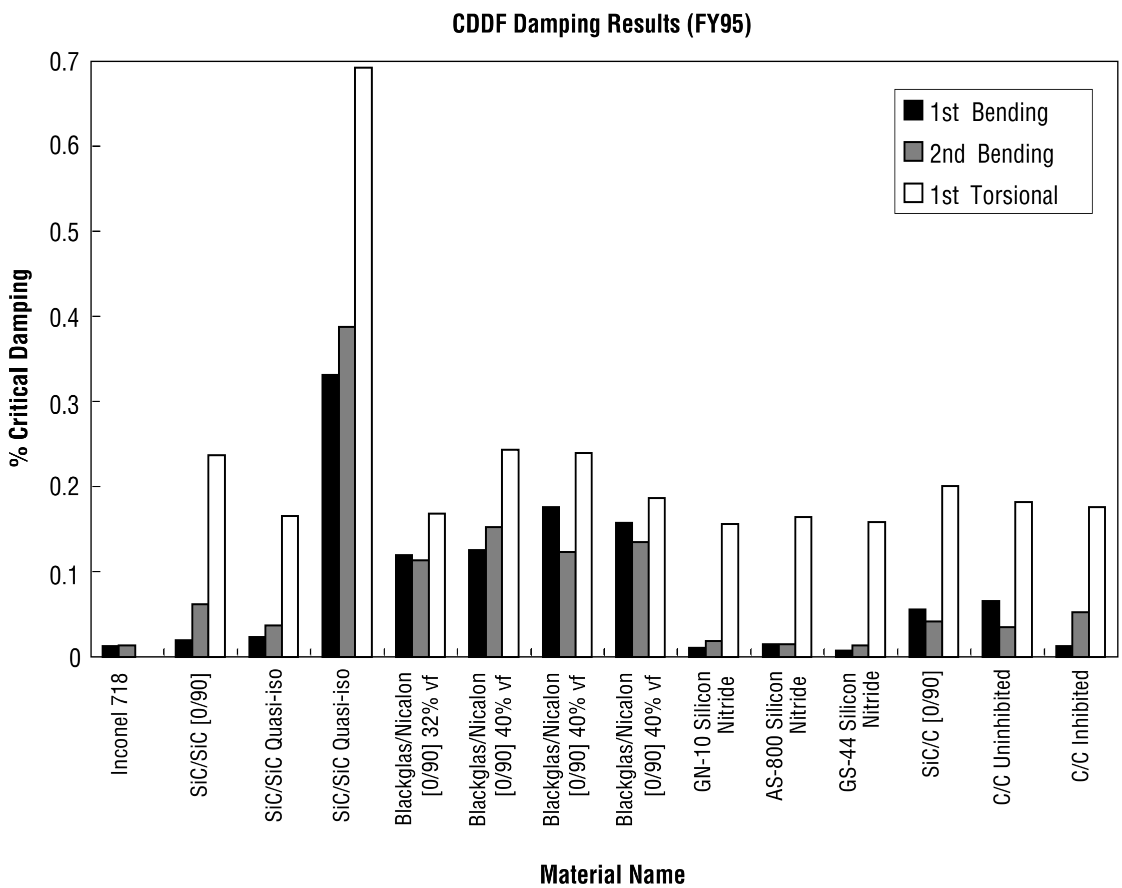

Figure 2. Phase 2 test results.

The results of the damping tests are shown in figure 3. All the composite materials tested showed much higher damping than in the Inconel 718 sample. As with the other tests, the first torsional mode had the most damping for each sample. The C/SiC [0/90], 15-degree offset, sample B, was slightly damaged right before testing. Perhaps additional microcracking of the matrix produced higher damping in the bending modes due to the damage.

3. High Temperature Testing

Dr. Jon Goldsby of the Materials Directorate at the NASA/Lewis Research Center tested the Blackglas and C/SiC samples at temperatures ranging from 20 to 1,200 °C. Most rocket engine turbines currently run at about 650 °C, but engine designers want to run at even higher temperatures to improve the engine efficiency and performance. Data indicates that ceramic matrix composites are good candidates for turbines that will be operating at temperatures above 650 °C. The samples used for this level of testing were smaller in size (100 × 4 mm) than the previous samples.

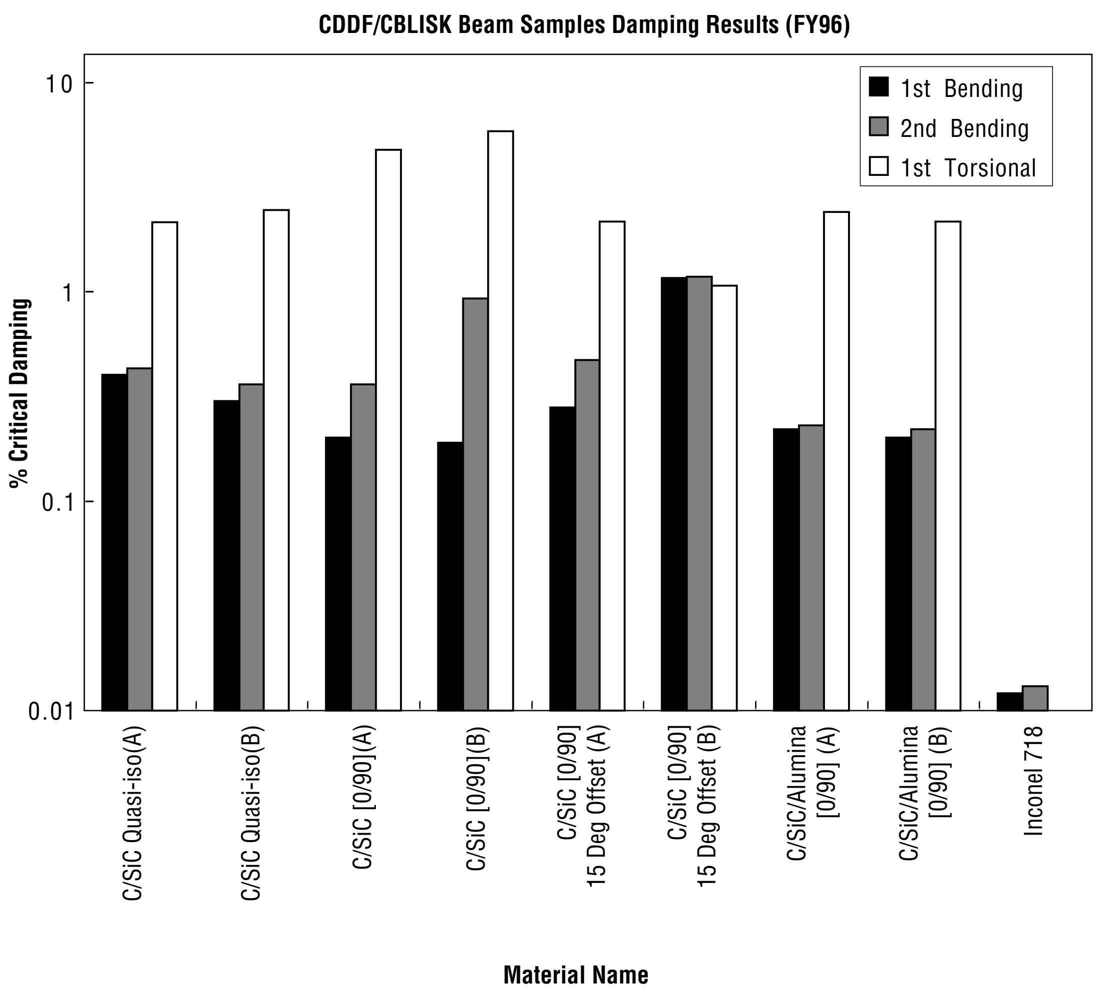

Figure 3. CBLISK program damping test results.

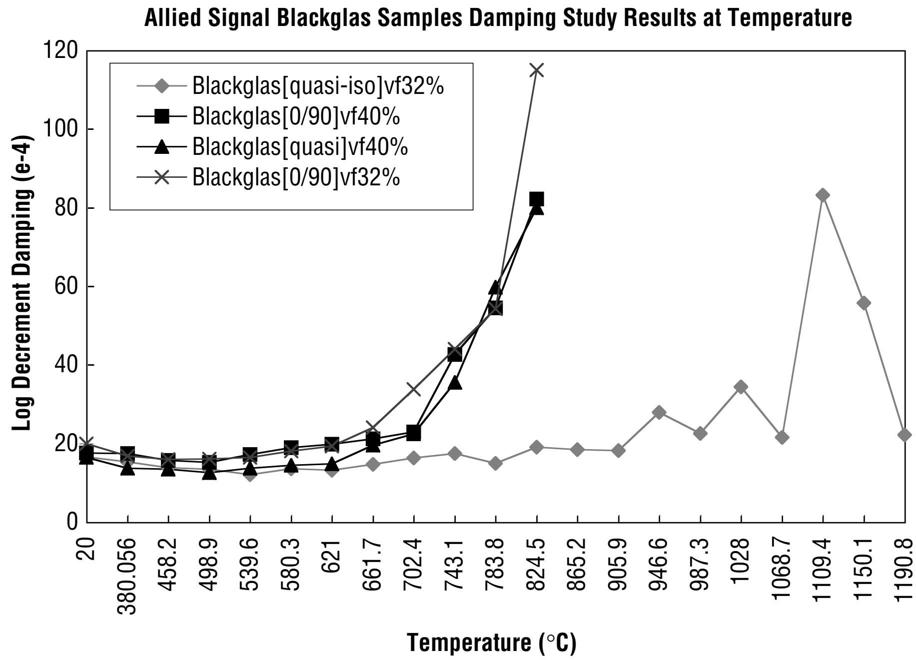

Figure 4. Blackglas damping results at elevated temperture.

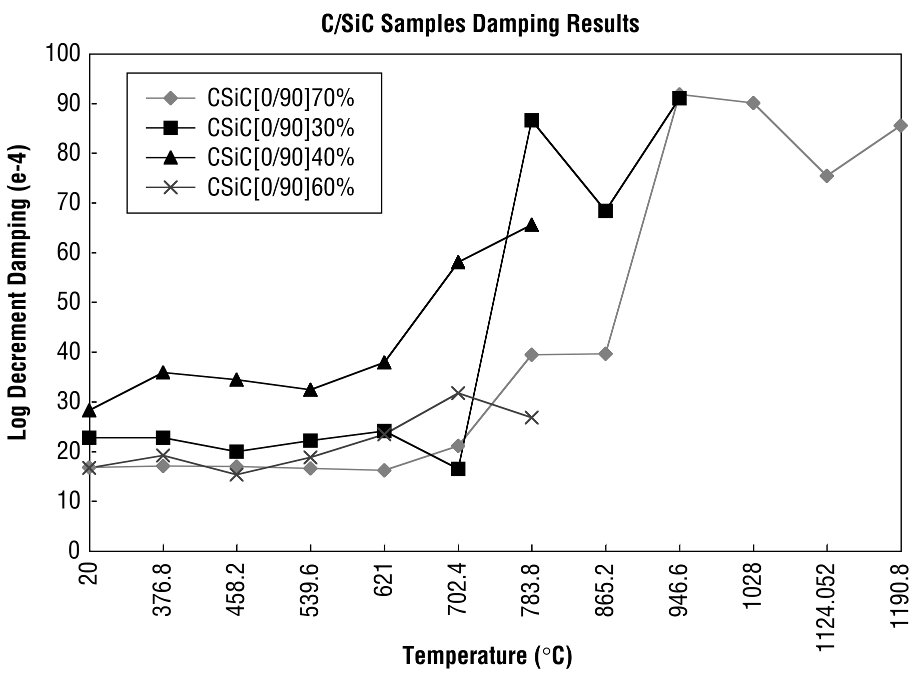

Figure 5. C/SiC damping results at elevated temperature.

The data from these tests show that for the Blackglas materials, the damping is fairly constant to about 1,000 °C, where we note some increase. The C/SiC samples have a similar trend but the increase occurs around 600 °C. This data shows that the level of damping would be constant in the operating range of the turbine. If the level of damping is enough to reduce the amplitude of some primary modes of a turbine blade, the high cycle fatigue life of the part can be increased. Dependable damping throughout the usable temperature range could be useful information to a turbine designer.

B. Disk Testing

Two disks were procured from Oak Ridge National Laboratory (ORNL) made of SiC/SiC, in two different fiber architectures. These were polar woven and quasi-isotropic cloth layup. These materials were chosen due to their availability and usefulness in turbine applications. Additionally, ORNL developed a process called forced flow chemical vapor infiltration (FF-CVI) that can produce thick parts in a matter of days, instead of months, as the normal CVI process would take. It was important to test components using this process because of the benefits of the faster production process. The disks were 24.76 cm in diameter, a size that is close to that of production rocket engine turbines. These disks, along with an Inconel 718 and 304 stainless steel disk, were tested. The results are depicted in figure 6.

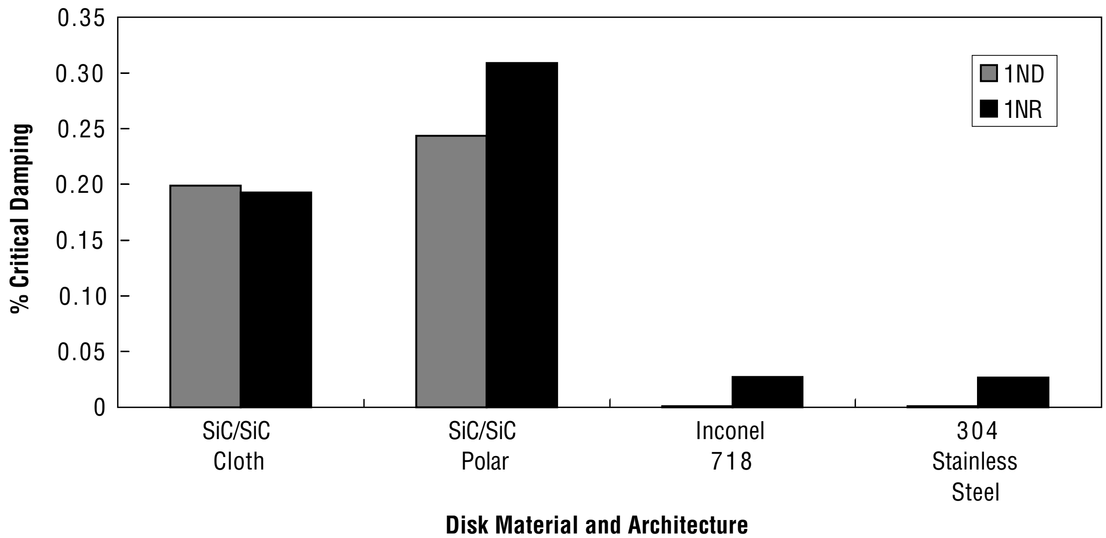

Figure 6. Disk damping.

The two metal disks seem to have about the same amount of damping for the first nodal diameter (1ND) mode and first nodal ring (1NR) mode, while the ceramic matrix composite disks seem to have much more. Note the increased damping in the polar specimen as compared to the cloth layup. Perhaps the polar architecture provides more fibers for the interfacial slip between fiber and matrix, which would provide greater surface area, causing greater amounts of friction-releasing energy in the form of damping.

There does seem to be more damping in a CMC disk than in metallic. These tests, while not at operating conditions or using the exact turbine configuration, i.e., no blades, do quantify the higher material damping in CMC’s. Additional testing would be required at operating conditions to truly evaluate the amount of damping and its capacity to dampen blade bending and disk modes.

BRD, under a U.S. Air Force-sponsored task, will be testing a NASA/MSFC bladed disk from the CBLISK program to determine the damping in the blades under simulated operating conditions.

II. CONCLUSIONS AND RECOMMENDATIONS

This program was developed to determine if composite materials suitable for rocket engine turbine applications provide more inherent material damping than their superalloy counterparts. The blade and disk tests do show a higher level of material damping in the composites. The Air Force and BRD are evaluating the damping capacity of a CMC blisk under simulated operating conditions.

NASA/MSFC will be testing a CMC blisk in a rocket engine turbopump. This is the level of testing required to determine if this class of materials can really provide adequate damping during operation. More coupon testing is also needed to provide design data. Just as strength properties can be tailored in a composite for its proposed use, it may be possible to dial in the damping needed in a given application. This may also be applied to areas such as sound suppression for commercial applications.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1998	Technical Memorandum

4. TITLE AND SUBTITLE
Measurement of Damping of Composite Materials for Turbomachinery Applications (MSFC Center Director's Discretionary Fund Final Report, Project No. 94–05)

5. FUNDING NUMBERS

6. AUTHORS
D.L. Harris

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M–861

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TM—1998–207685

11. SUPPLEMENTARY NOTES
Prepared by Structures and Dynamic Laboratory, Science and Engineering Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Nonstandard Distribution
Subject Category 24
Unclassified–Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The scientific community has felt that ceramic matrix composite (CMC) materials possess more material damping than the superalloys used in the production of rocket engine turbomachinery turbine-end components. The purpose of this NASA/MFSC study is to quantify the damping in CMC's as compared to a typical super-alloy, Inconel 718. It was observed through testing of beam coupons and disk specimens that the CMC's do indeed possess more material damping than the baselined alloy Inconel 718.

14. SUBJECT TERMS
Blisk, Composite Turbine, Damping

15. NUMBER OF PAGES
16

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited