NASA/TM—2010-215671

High Temperature Damping Behavior of Plasma-Sprayed Thermal Barrier and Protective Coatings

Dongming Zhu and Robert A. Miller
Glenn Research Center, Cleveland, Ohio

Kirsten P. Duffy
University of Toledo, Toledo, Ohio

Louis J. Ghosn
Glenn Research Center, Cleveland, Ohio

February 2010

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 443–757–5803

- Telephone the NASA STI Help Desk at 443–757–5802

- Write to:
  NASA Center for AeroSpace Information (CASI)
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2010-215671

High Temperature Damping Behavior of Plasma-Sprayed Thermal Barrier and Protective Coatings

Dongming Zhu and Robert A. Miller
Glenn Research Center, Cleveland, Ohio

Kirsten P. Duffy
University of Toledo, Toledo, Ohio

Louis J. Ghosn
Glenn Research Center, Cleveland, Ohio

Prepared for the
33rd International Conference and Exposition on Advanced Ceramics and Composites
sponsored by the American Ceramic Society
Daytona Beach, Florida, January 18–23, 2009

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

February 2010

This work was sponsored by the Fundamental Aeronautics Program
at the NASA Glenn Research Center.

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available electronically at http://gltrs.grc.nasa.gov

High Temperature Damping Behavior of Plasma-Sprayed Thermal Barrier and Protective Coatings

Dongming Zhu and Robert A. Miller
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Kirsten P. Duffy
University of Toledo
Toledo, Ohio 43606

Louis J. Ghosn
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

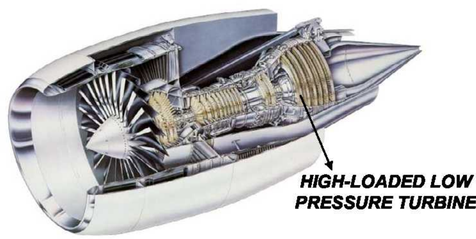
Abstract

A high temperature damping test apparatus has been developed using a high heat flux CO_2 laser rig in conjunction with a TIRA S540 25 kHz Shaker and Polytec OFV 5000 Vibrometer system. The test rig has been successfully used to determine the damping performance of metallic and ceramic protective coating systems at high temperature for turbine engine applications. The initial work has been primarily focused on the microstructure and processing effects on the coating temperature-dependence damping behavior. Advanced ceramic coatings, including multicomponent tetragonal and cubic phase thermal barrier coatings, along with composite bond coats, have also been investigated. The coating high temperature damping mechanisms will also be discussed.

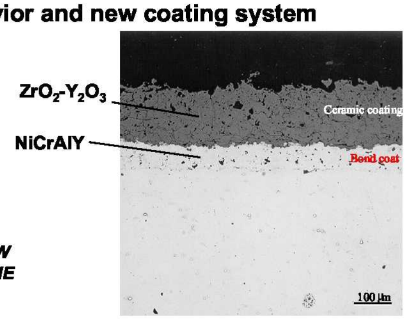
National Aeronautics and Space Administration

Introduction

- **High cycle fatigue (HCF) becomes of increased concern for highly-load turbine systems**
- **Integrated turbine blade coatings may offer viable solutions to improved blade vibration damping, surface erosion and oxidation protections**
- **Current high temperature turbine damping efforts emphasizing low pressure turbine (LPT) systems**
- **High temperature damping testing and modeling methodologies aiming at understanding coating damping behavior and new coating system development**



(a) Turbine Engine



(b) Plasma- Sprayed TBC coating

www.nasa.gov

National Aeronautics and Space Administration

Outline

- **High temperature material damping testing approach**
  - Laser damping rig fixture design and modeling
  - Modal analysis
- **Experimental setup**
- **High temperature damping testing**
- **Damping behavior of ceramic coating**
- **Summary and Conclusions**

www.nasa.gov

National Aeronautics and Space Administration

Coating and Material Damping Testing Approach

- Electromagnetic shaker (TIRA S540 25 kHz Shaker, peak force 90 N)
  - Initially tested at 1 and 2 g acceleration
- Polytec OFV 5000 Vibrometer system
- High power CO_2 laser for specimen heating
- Coating specimens designed using ASTM standard E756-05
- FEM and analytical solutions used for vibration modal analysis
- FEM used for test rig optimization

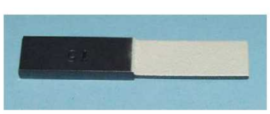
CO_2 Laser

www.nasa.gov

National Aeronautics and Space Administration

Experimental

- Coating and substrate material systems
  - CMSX4+Y single crystal superalloy substrate (25 X 10 X 1 mm)
  - CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)
  - CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)/t' low k TBC*
  - CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)/cubic low k TBC**
- Initially 14 mm diameter uniform laser beam with minimum specimen cooling (very low thermal gradients across the specimen thickness)
- Maximum testing temperature 1230 °C with a heating cooling cycle
- Resonance peak data collected at steady-state heating conditions
- Resonance peak width used for determining loss factors $1/Q = \Delta f/f$ at -3dB

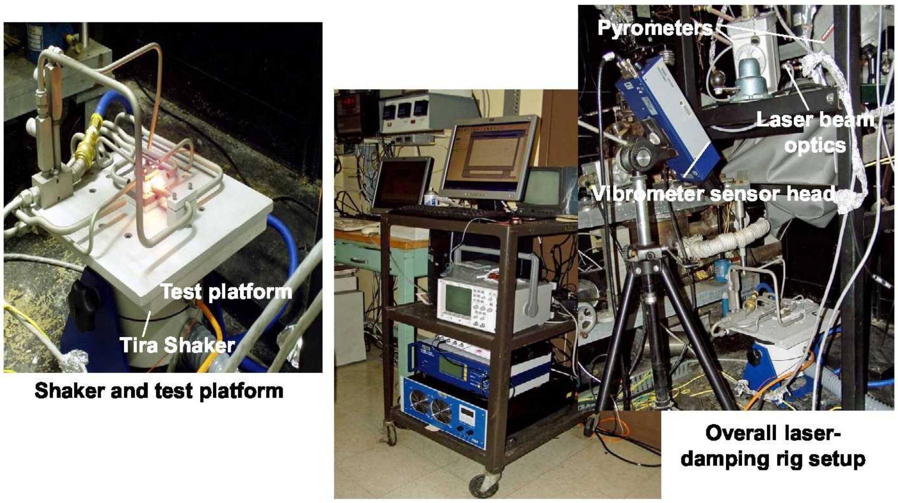


* Plasma-sprayed ZrO_2-4mol% $(Y,Gd,Yb)_2O_3$
** Plasma-sprayed ZrO_2-10mol%$(Y,Gd,Yb)_2O_3$

www.nasa.gov

National Aeronautics and Space Administration

Experimental Setup



Shaker and test platform

Overall laser-damping rig setup

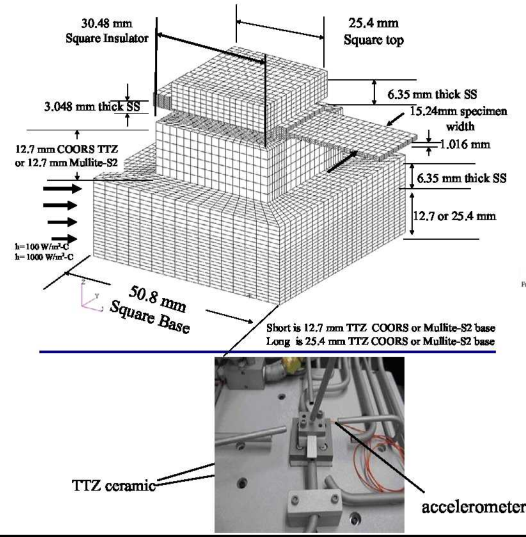
Control and data acquisition unit

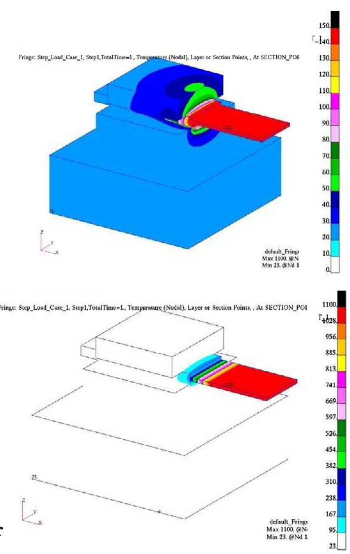
www.nasa.gov

National Aeronautics and Space Administration

Damping Test Rig Fixture

- FEM modeling of cooling requirements



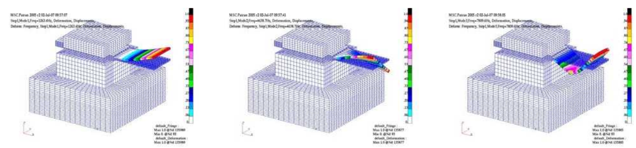


www.nasa.gov

Damping Test Rig Fixture (Continued)

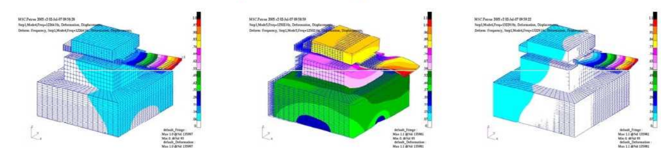
- FEM resonance frequency modeling

COORS TTZ   Short Fixture, 41.148 mm total height



Mode I 1263.4 Hz Specimen 1st Bend | Mode II 4638.7 Hz Specimen 1st Twist | Mode III 7809.6 Hz Specimen 2nd Bend

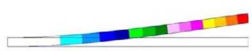
Specimen frequencies



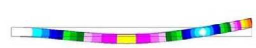
Mode IV 12264 Hz | Mode V 12502 Hz | Mode VI 13229 Hz

Fixture frequencies

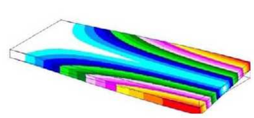
Test Specimen Mode Shapes and Resonance Frequencies
(uncoated; HVOF bond coated; Ceramic TBC/HVOF bond coated)



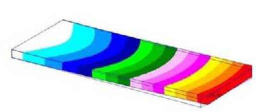
1st Bending mode: 994; 1,212; 1,226Hz



2nd Bending mode: 6,180; 7,565; 7,665Hz

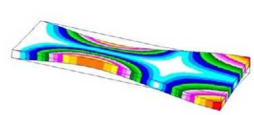


1st Twisting mode: 7,787; 8,599; 8,580Hz



1st Stiff-wise Bending mode: 9,230; 9,770; 9,554Hz

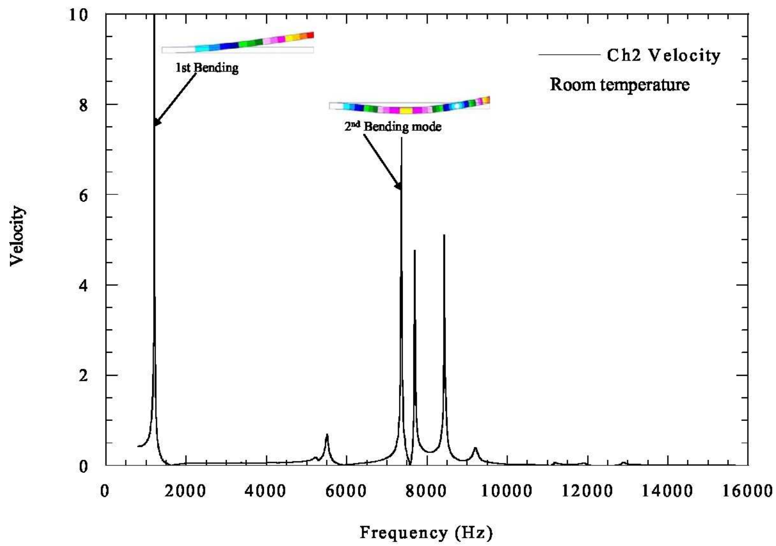
3rd Bending mode: 17,385; 21,233; 21,509Hz



2nd Twisting mode: 23,857; 26,536; 26,496Hz

National Aeronautics and Space Administration

Damping Mode Characterizations of a Ceramic TBC Coated Specimen

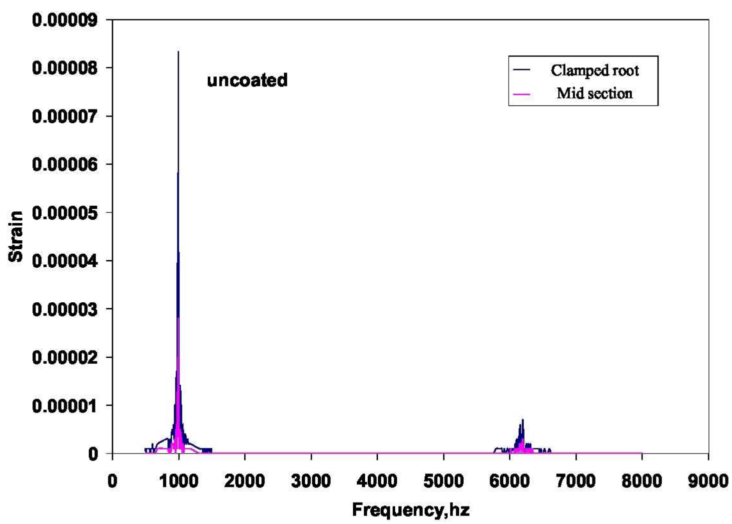


www.nasa.gov

National Aeronautics and Space Administration

Strains Associated with The 1st and 2nd Bending

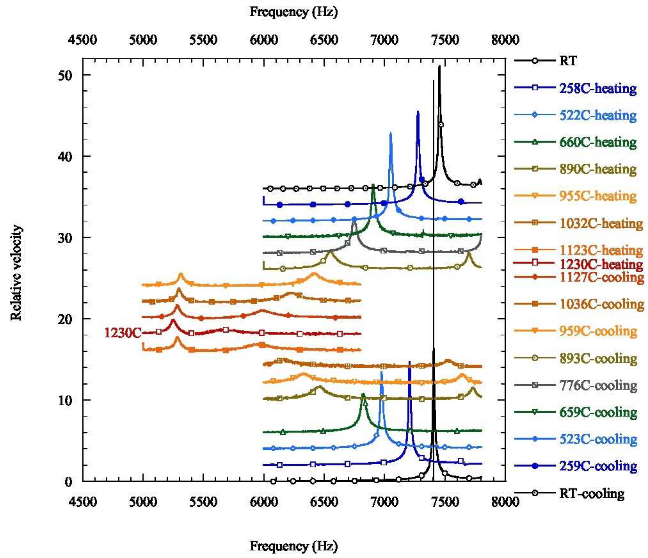
- Modeled for 1 g acceleration; higher strain testing planned for future studies



www.nasa.gov

National Aeronautics and Space Administration

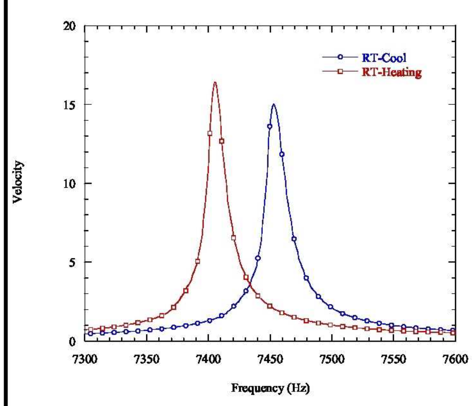
Damping Characterization of a Cubic Phase Low Conductivity Thermal Barrier Coatings

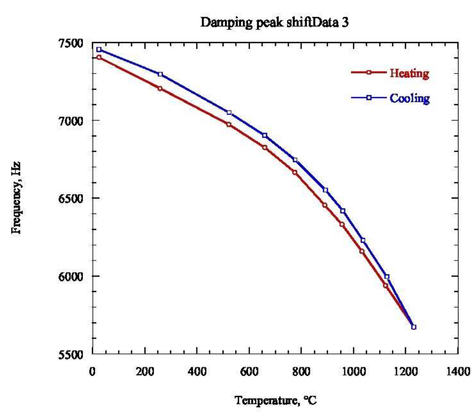


www.nasa.gov

National Aeronautics and Space Administration

Resonance Peak Shift Observed During the Heating Cooling Cycle

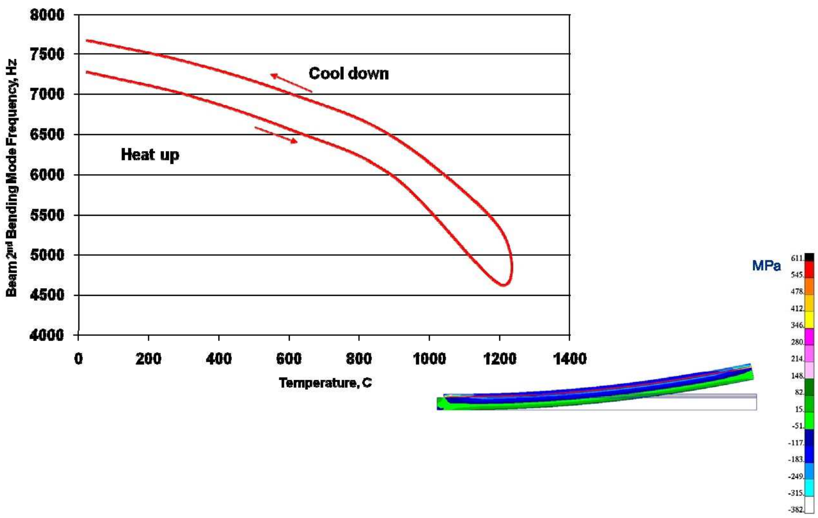




www.nasa.gov

National Aeronautics and Space Administration

FEM Modeling of Peak Shift for a Stiffened Beam System



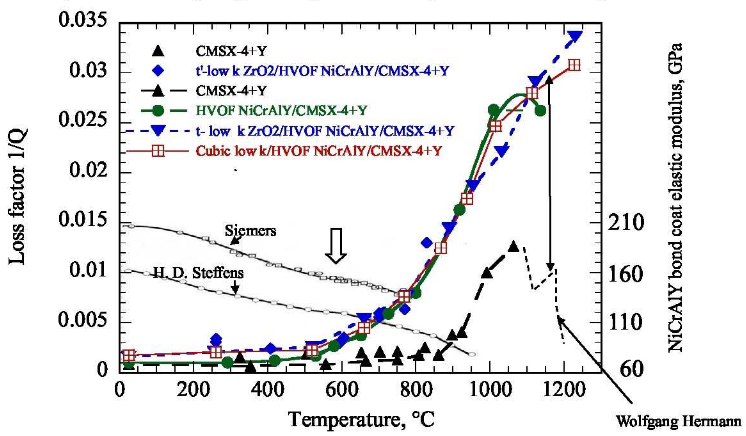
www.nasa.gov

National Aeronautics and Space Administration

Damping Behavior of Thermal Barrier and Protective Coating Systems

— The coated systems showed significant damping improvements compared to the CMSX-4 substrate

— Ceramic thermal barrier helped improve damping at low temperatures (below 600 °C) and at very high temperatures (above 1000 °C)



www.nasa.gov

National Aeronautics and Space Administration

Conclusions

- Laser rig based high temperature damping rig demonstrated
- HVOF NiCrAlY bond coat significantly improved damping performance of turbine alloy systems
- Ceramic thermal barrier coatings showed slightly improved damping at lower temperature and very high temperatures compared to the metal bond coat-substrate system
- The coating damping temperature dependence corresponded to the materials Young's modulus changes
- Resonance peak shifts to higher frequency observed due to possible residual stresses that stiffened cantilever beam systems
- Coatings demonstrated a viable approach for vibration control and high cycle fatigue reduction for turbine blade systems

www.nasa.gov

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-02-2010

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
High Temperature Damping Behavior of Plasma-Sprayed Thermal Barrier and Protective Coatings

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Zhu, Dongming; Miller, Robert, A.; Duffy, Kirsten, P.; Ghosn, Louis, J.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WBS 561581.02.08.03.15.02

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-17013

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

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM-2010-215671

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Categories: 23, 24, 26, and 27
Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A high temperature damping test apparatus has been developed using a high heat flux CO_2 laser rig in conjunction with a TIRA S540 25 kHz Shaker and Polytec OFV 5000 Vibrometer system. The test rig has been successfully used to determine the damping performance of metallic and ceramic protective coating systems at high temperature for turbine engine applications. The initial work has been primarily focused on the microstructure and processing effects on the coating temperature-dependence damping behavior. Advanced ceramic coatings, including multicomponent tetragonal and cubic phase thermal barrier coatings, along with composite bond coats, have also been investigated. The coating high temperature damping mechanisms will also be discussed.

15. SUBJECT TERMS
Thermal barrier coating; NiCrAlY bond coat; Damping; Vibration; Resonance peak frequency; Loss factor; Young's modulus

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	15	STI Help Desk (email:help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(include area code)* 443-757-5802