1/30/98

AFRL-PR-WP-TM-1998-2002

High Cycle Fatigue (HCF) Science and Technology Program 1997 Annual Report

(1 Jan 97 thru 31 Dec 97)

Prepared by:

Universal Technology Corporation
1270 N. Fairfield Road
Dayton, Ohio 45432-2600

January 1998

Approved for public release; distribution unlimited

PROPULSION DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7251

NOTICE

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

Daniel Thomson, AFRL/PRTC
Components Branch
Turbine Engine Division

Theodore Fecke, AFRL/PRTC
Chief, Components Branch
Turbine Engine Division

Richard J. Hill, AFRL/PRT
Acting Chief, Turbine Engine Division
Propulsion Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1998	1997 Annual Report (1 Jan – 31 Dec 97)

4. TITLE AND SUBTITLE
High Cycle Fatigue (HCF)
Science and Technology Program
1997 Annual Report

5. FUNDING NUMBERS
C - F33615-94-C-5800
PE - 62203F
PR - 3066
TA - 14
WU - 20

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Propulsion Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH
45433-7251

Universal Technology Corporation
1270 N. Fairfield Rd.
Dayton, OH 45432-2600

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Propulsion Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH
45433-7251

POC: Dan Thomson
AFRL/PRTC
937-255-2081

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
AFRL-PR-WP-TM-1998-2002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*
This first annual report of the National Turbine Engine High Cycle Fatigue (HCF) Program is a brief review of work completed, work in progress, and technical accomplishments. This program is a coordinated effort with participation by the Army, Navy, Air Force and NASA. The technical efforts are organized under seven Action Teams including: Materials Damage Tolerance Research, Forced Response Prediction,Component Analysis, Instrumentation, Passive Damping Technology, Component Surface Treatments, and Aeromechanical Characterization. Daniel E. Thomson, AFRL/PRTC, Wright-Patterson AFB, is the Program Manager.

14. SUBJECT TERMS High Cycle Fatigue, Turbine Engines, Instrumentation, Damping, Forced Response, Aeromechanical Characterization, Materials, Surface Treatments, Laser Shock Peening, Component Analysis, Damage Tolerance

15. NUMBER OF PAGES

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

TABLE OF CONTENTS

Preceding Page Blank

TABLE OF CONTENTS (Cont'd)

Page

TABLE OF CONTENTS (Cont'd)

Page

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

FOREWORD

This first annual report of the National Turbine Engine High Cycle Fatigue (HCF) Science and Technology (S&T) Program is a brief summary of the major goals, approaches and technical progress of current ongoing and planned future efforts.

This S&T Program was organized as part of a national effort to help eliminate HCF as a major cause of engine failures. The overall effort is directed by an Air Force led steering committee consisting of representatives from the Air Force, Navy, and NASA along with an adjunct national coordinating committee that includes, in addition, representatives from the Army, Federal Aviation Administration (FAA), Defense Advanced Research Projects Agency (DARPA), industry and major universities. The HCF Integrated Product Team (IPT) organizational structure is shown in Figure 1.

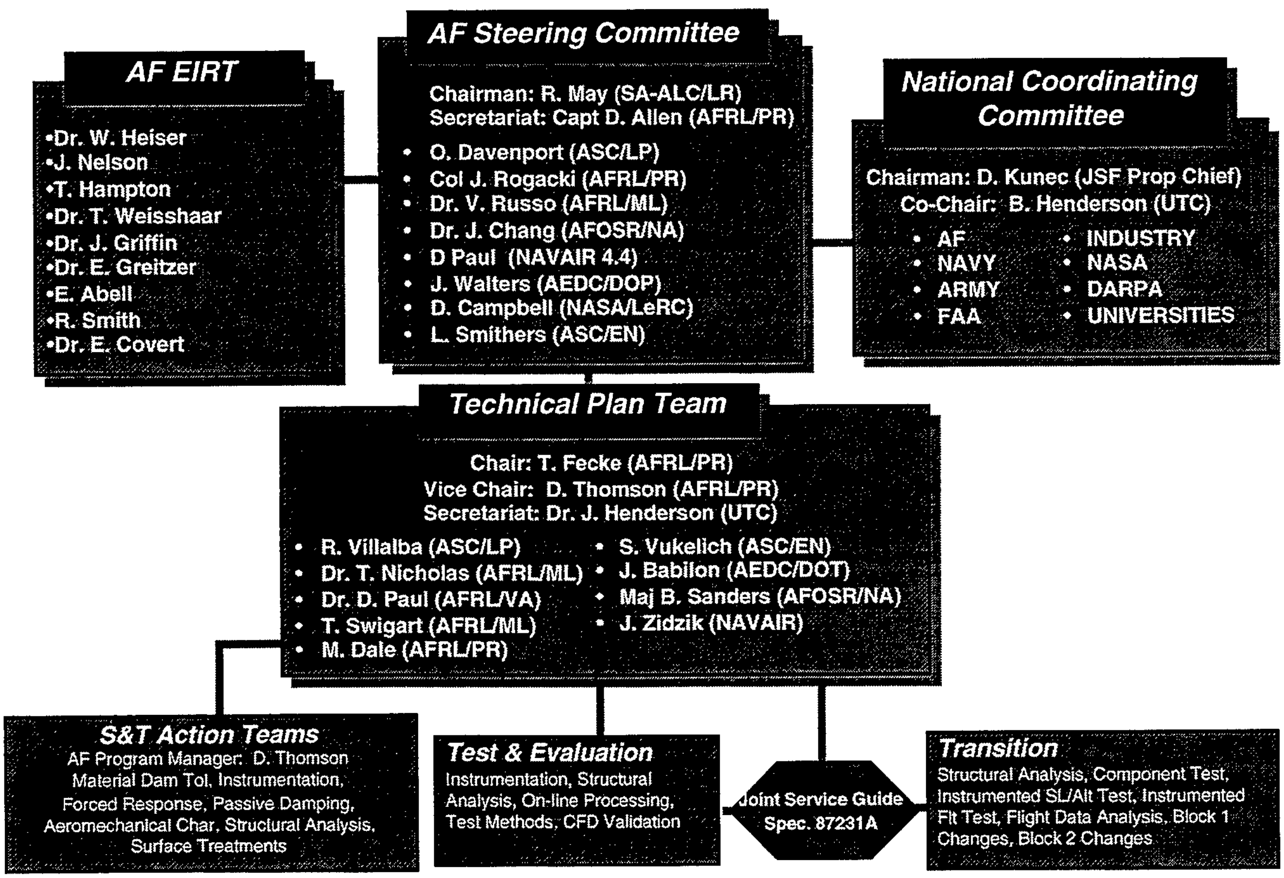


FIGURE 1. HCF Organizational Structure

The S&T Program is specifically directed at supporting the Integrated High Performance Turbine Engine Technology (IHPTET) Program and one of its major goals---to reduce engine maintenance cost. This HCF S&T Program will try to support that goal through technical action team efforts targeted at a 40% reduction of HCF related maintenance costs. In addition, the program could impact the national effort by potentially cutting HCF related "real" development cost by over 50%. When combined with Test and Evaluation (T&E) efforts and future health monitoring approaches, the total national effort should ensure the production of much more damage tolerant, high performance engines---and essentially eliminate engine HCF related aircraft mishaps!

The technical efforts are organized under seven Action Teams including: Materials Damage Tolerance Research, Forced Response Prediction,Component Analysis, Instrumentation, Passive Damping Technology, Component Surface Treatments, and Aeromechanical Characterization. Daniel E. Thomson, AFRL/PRTC, Wright-Patterson AFB, is the Program Manager.

We hope that you will find this report useful. Your comments or questions regarding work reported here are welcome. Action Team Chairs, Co-Chairs and technical contacts are identified in the report.

This technical report has been reviewed and is approved for publication.

Theodore G. Fecke

THEODORE G. FECKE

Chair

HCF Technical Planning Team

1.0 *MATERIALS DAMAGE TOLERANCE RESEARCH*

CHARTER

RESPONSIBILITIES

The Materials Damage Tolerance Research Action Team (Materials AT) is responsible for fostering collaboration between individual HCF materials behavior efforts with the overall goal of reducing the uncertainty in capability of damaged components by 50%. The Materials AT provides technical coordination and communication between active participants involved in HCF life prediction, crack nucleation and propagation, fracture mechanics, and surface treatment technologies. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Materials AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for materials behavior programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the Materials AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in materials behavior technologies applicable to turbine engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT will change as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Mr. Joseph Burns - Chair
U.S. Air Force
AFRL/MLLN, Bldg. 655
2230 Tenth St., Ste. 1, WPAFB, OH 45433-7281
Ph: (937) 255-1360 Fax: (937) 656-4840
burnsjg@ml.wpafb.af.mil

Mr. Michael Kinsella - Co-Chair
U.S. Air Force
AFRL/PRTT, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7251
Ph: (937) 255-6768 Fax: (937) 656-4531
kinselmj@wl.wpafb.af.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

1.1 *IMPROVED HIGH CYCLE FATIGUE LIFE PREDICTION*

This is a 2-year program to develop a new damage tolerant life prediction and design methodology for turbine engine rotating structures subjected to high-stress-ratio, high-cycle-fatigue (HCF) loadings. This program is focused on titanium material characterization issues, and is administrated by the University of Dayton Research Institute (UDRI), which manages and coordinates a team composed of General Electric Aircraft Engines (GEAE), Pratt & Whitney (P&W), AlliedSignal Engines (AE), Southwest Research Institute (SwRI), and Allison Advanced Development Company (AADC).

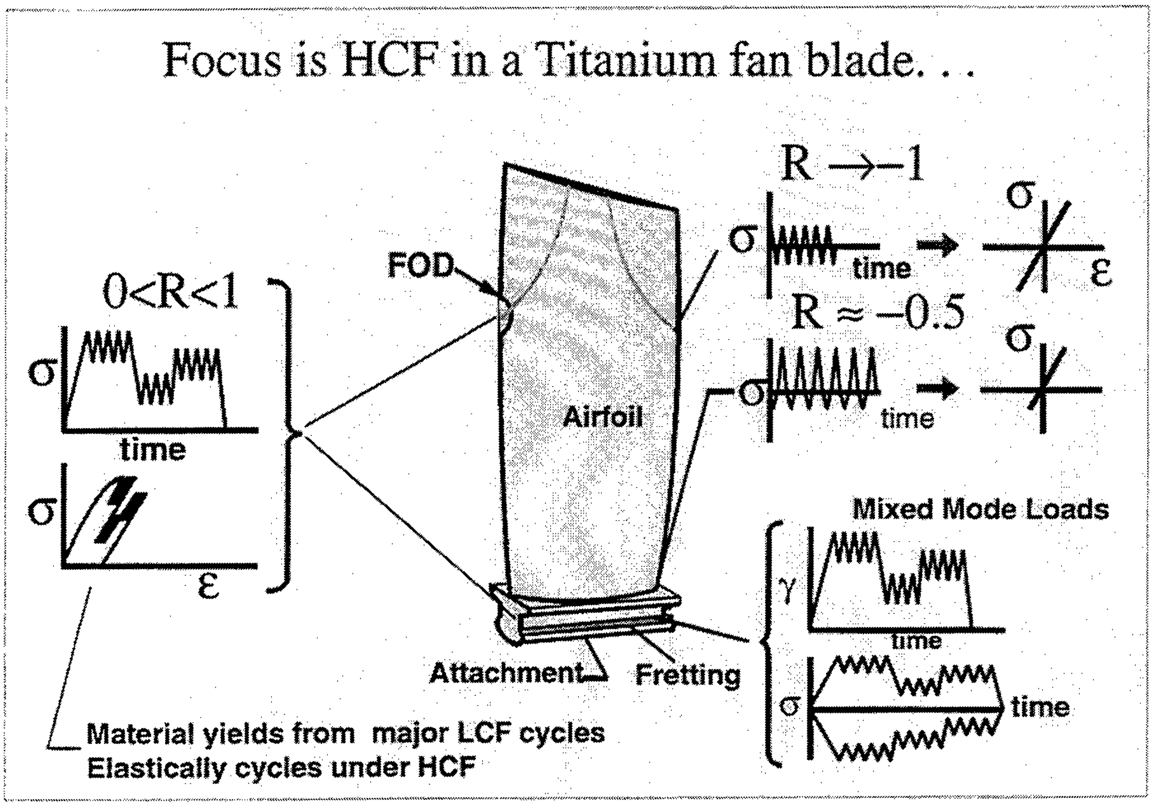


FIGURE 2. Competing Failure Modes on a Typical Fan Blade

The UDRI HCF Team is committed to creating a damage-tolerant-based, fatigue-life design methodology which leads to substantial improvements in predicting and controlling HCF failures, especially those failures which can be associated with service damaged material in turbine engines. The UDRI HCF Team's broadly based program will result in: (1) a substantial database of test results describing all aspects of HCF material behavior, (2) new test methods, (3) new analytical approaches, (4) engineering understanding of the underlying damage mechanisms as they relate to the solutions to the problem, (5) definition of the damage states which increase the potential for HCF failures, (6) total life prediction software, and (7) the framework for addressing HCF problems with a damage tolerant philosophy that relates to the damage states associated with HCF failure experience in engine structures.

The UDRI HCF Team's program will produce results which impact future blade and disk designs, will model life behavior resulting from interactions of low cycle fatigue (LCF) and HCF loading conditions, and will quantify the effects which surface enhancements (such as residual stresses) have on HCF life behavior. The results obtained from this initial program will be integrated into a AFRL/ML sponsored Phase 2 program which will (1) broaden the applicability of the methodology to nickel-base superalloys and (2) result in a new Engine Structural Integrity Program (ENSIP) document that addresses the prevention and control of HCF failures in aircraft turbine engines. This proposed effort supports our four engine-maker teammates' Advanced Turbo Propulsion Plans (ATPP).

POINTS OF CONTACT

Government
Name: Theodore Nicholas, Ph.D.
Organization: U.S. Air Force, AFRL/MLLN
Address: 2230 Tenth St, Suite 1, Bldg. 655
WPAFB, OH 45433-7817
Phone Number: (937) 255-1347
Fax Number: (937) 656-4840
Email: nicholt@ml.wpafb.af.mil

Contractor
Name: Allan P. Berens, Ph.D.
Organization: University of Dayton Research Institute
Address: 300 College Park
Dayton OH 45469
Phone Number: (937) 229-4475
Fax Number: (937) 229-3712
Email: berensap@udri.udayton.edu

1.2 *HIGH CYCLE FATIGUE AND TIME-DEPENDENT FAILURE IN METALLIC ALLOYS FOR PROPULSION SYSTEMS*

This is a 5-year (3-year basic, 2-year optional) program to examine the microstructural damage and micro-mechanical conditions associated with high-cycle fatigue (HCF) in metallic alloys for propulsion systems. The approach involves the definition, microstructural characterization and mechanism-based modeling of the limiting states of damage associated with the onset of HCF failure. It includes the use of new experimental techniques, e.g., thermal imaging, atomic force microscopy, etc., for the in-situ and ex-situ characterization of such damage, and the development of new crystal plasticity models to describe it. The research is being performed primarily on a γ/γ' single crystal Ni-base blade alloy (PWA 1484 or Rene N5) at temperatures between 600° and 1000° C and on an α/β processed Ti-6Al-4V alloy at ambient temperature; additional studies would be carried out on a polycrystalline Ni-base disk alloy and on a lath microstructure in Ti-6Al-4V. Research is focused in three principal areas: a) HCF/LCF interactions, involving the study of fatigue thresholds for long and microstructurally-small cracks at high load ratios ($R \sim 0.9$) and high frequencies ($\nu \sim$ 1-2 kHz) under mode I, mode II and mixed-mode conditions; b) Notches and foreign impact damage, involving the study of such thresholds in the presence of machined notches and indentation damage, before and after surface modification; and c) Fretting fatigue, involving the study of the salient factors controlling fretting relevant to engine applications, and the definition of the critical levels of fretting damage that lead to the onset of HCF failure. A key feature, developed in close association with Allison, GE Aircraft Engines, Pratt & Whitney, the United Technologies Research Center, and Southwest Research Institute, entails access to the extensive database gathered by these organizations, in addition to that of the Industry HCF Program and the "in-house" HCF programs at WPAFB. Jointly planned experimental programs are designed to avoid duplication of effort. The overall objective of the MURI research would be to derive a fundamental microstructural/mechanics based description of the critical phenomena that cause HCF failure in titanium- and nickel-base alloys. This will provide a basis for the development of new structural integrity programs to address the problem of HCF in aircraft engines.

BIBLIOGRAPHY

1. R. O. Ritchie, *Small Cracks and High-Cycle Fatigue*, in Proceedings of the ASME Aerospace Division, J. C. I. Chang, J. Coulter, D. Brei, D. Martinez, W. Hg, and P. P. Freidmann, eds., AMD-Vol. 52, American Society of Mechanical Engineers, New York, NY, 1996, pp. 321-333.

2. A. E. Giannakopoulos and S. Suresh, *A Three-Dimensional Analysis of Fretting Fatigue*, MIT Technical Report, Feb. 1997.
3. J. W. Hutchinson and V. Tvergaard, *Edge-Cracks in Single Crystals under Monotonic and Cyclic Loads*, Harvard University Technical Report No. MECH 307, May 1997.
4. J.M. Morgan and W.W. Milligan, *A 1 kHz Servohydraulic Fatigue Testing System*, in "Fatigue of Materials, Paul C. Paris Symposium", W.O. Soboyejo and T.S. Srivatsan, eds, TMS, Warrendale PA, 1997, in review.

POINTS OF CONTACT

Government
Name: Capt Brian Sanders, Ph.D.
Organization: U.S. Air Force, AFOSR/NA
Address: 110 Duncan Avenue, Suite B115
Bolling AFB, DC 20332-0001
Phone Number: (202) 767-6063
Fax Number: (202) 767-4988
Email: brian.sanders@afosr.af.mil

Contractor
Name: Robert O. Ritchie, Ph.D., Sc.D.
Organization: University of California at Berkeley
Address: Dept. of Materials Science and Mineral Engineering
Berkeley, CA 94720-1760
Phone Number: (510) 486-5798
Fax Number: (510) 486-4995
Email: roritchie@lbl.gov

1.3 *MATERIALS DIRECTORATE IN-HOUSE RESEARCH*

This is an on-going in-house research and development effort for the development of a new damage tolerant life prediction and design methodology for turbine engine structures subjected to high-cycle-fatigue (HCF). The interaction of high cycle fatigue with other damage mechanisms (low cycle fatigue, fretting, foreign object damage, thermomechanical fatigue, creep-fatigue, etc) is the research focus. Also, the development of new test techniques for the determination of HCF effects on structural life is being conducted.

One recent accomplishment is the development of a protocol for an accelerated test procedure to generate constant life or "Goodman" data. Until this procedure had been developed, the Goodman Diagram was generated by determining the stress state where the S-N (stress - life) curve crosses the desired life value for a given value of R (minimum to maximum stress ratio) for a given material / geometry combination. This process was repeated for a (usually small) number of R values, and a Goodman Diagram was generated with linear behavior assumed between data points. This procedure required access to a large amount of data which would be very expensive with regard to time and money to generate if the data were not readily available, particularly where a long-life diagram is required (e.g., $N>10^7$ cycles).

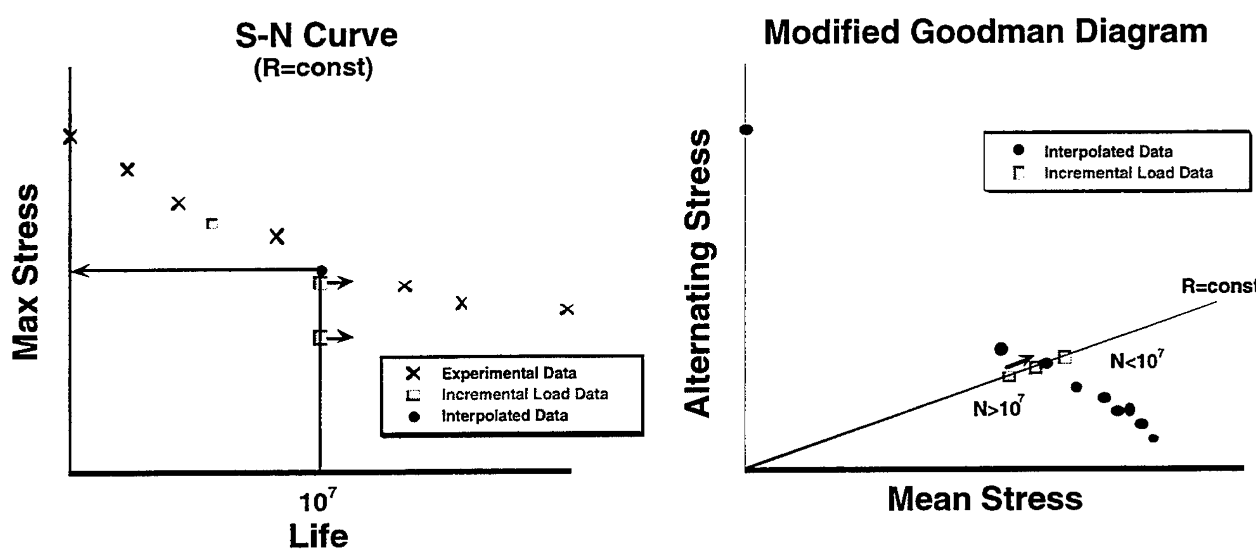


FIGURE 3. Accelerated Test Procedure

With the accelerated procedure, specimens are tested under stress states below those that would produce fatigue failure in a given number of cycles (10^7 in this case). When the target number of cycles is reached, the loads are increased with either R or the mean load held constant (R=const is shown in the figures). When failure finally occurs, it is assumed that all damage occurred at the failure load block. The "Goodman" stress state is then determined by an interpolation between the failure stress state and the stress state of the load block directly preceding in which failure did not occur.

POINTS OF CONTACT

Government

Name: Theodore Nicholas, Ph.D.
Organization: U.S. Air Force, AFRL/MLLN
Address: 2230 Tenth St, Ste 1, Bldg. 655
WPAFB, OH 45433-7817

Phone Number: (937) 255-1347
Fax Number: (937) 656-4840
Email: nicholt@ml.wpafb.af.mil

2.0 *FORCED RESPONSE PREDICTION*

CHARTER

RESPONSIBILITIES

The Forced Response Prediction Action Team (Forced Response AT) has the responsibility of fostering collaboration between individual HCF forced response efforts with the overall goal of combining with the Instrumentation and Component Analysis AT's to better determine alternating stresses to within 20%. The Forced Response AT provides technical coordination and communication between active participants involved in HCF unsteady aerodynamics and blade response technologies. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Forced Response AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for forced response programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the Forced Response AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in forced response technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Maj Greg Minkiewicz, PhD - Chair
U.S. Air Force
AFRL/PRTF, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7253
Ph: (937) 255-8210 Fax: (937) 255-2077
minkiegr@wl.wpafb.af.mil

Mr. George Stefko - Co-Chair
NASA Lewis Research Center
21000 Brookpark Rd., M/S 23-3
Cleveland, OH 44135-3191
Ph: (216) 433-3920 Fax: (216) 977-7051
stefko@lerc.nasa.gov

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

2.1 *FORCED RESPONSE IN MISTUNED BLADED DISKS*

Under this effort a reduced order modeling technique for mistuned bladed disks was developed. Mistuning is a mode localization process in which certain blades vibrate with higher amplitudes than other blades caused by slight variations in blade to blade geometric/material properties. The resulting code, called REDUCE, can calculate natural frequencies and mode shapes for a tuned case or for a single, prescribed mistuning pattern. REDUCE allows the user to obtain a frequency sweep output for the maximum blade response amplitude or a frequency sweep output for response amplitude of all blades. A Monte Carlo analysis can then be performed to determine the maximum blade response amplitude and the mean and standard deviation of maximum response amplitude. In addition, pre- and post-processing capabilities have been developed to allow REDUCE to use NASTRAN and ANSYS output files. REDUCE can also output in Finite Element coordinates for post-processing of mode shapes, forced response displacements and stresses. REDUCE has been validated using the finite element model for an industrial rotor. The REDUCE code has been transferred to the industrial partners in the GUIde Consortium.

REFERENCES

Castanier, M. P. , Ottarsson, G. and Pierre, C., 1997, "A Reduced Order Modeling Technique for Mistuned Bladed Disks," Department of Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, Michigan.

Kruse, M. and Pierre, C., 1997, "Forced Response of Mistuned Bladed Disks Using Reduced-Order Modeling," Department of Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, Michigan.

Kruse, M. and Pierre, C., 1997, "Dynamic Response of an Industrial Turbomachinery Rotor," Department of Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, Michigan.

Pierre, C., Castanier, M. and Kruse, M., 1997, "REDUCE User's Manual," Department of Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, Michigan.

POINTS OF CONTACT

Government

Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor

Name: Dr. Christophe Pierre
Organization: University of Michigan
Address: 3104 G. G. Brown
Department of Mechanical Engineering
and Applied Mechanics
The University of Michigan
Ann Arbor, MI 48109-2125
Phone Number: (313) 936-0401
Fax Number:
Email:

2.2 *TIP MODES IN LOW ASPECT RATIO BLADING*

The scope of the research for this project was to develop a basic understanding of sources of variability in high frequency modes in low aspect ratio blades. This work was divided into two categories:

1. Understanding the effect of taper angle and the bluntness of the leading edge of the airfoil on the vibratory response of high frequency tip modes.
2. Developing an understanding of the manner in which closely spaced modes can interact to produce highly variable response.

The first investigation centered around using a tapered beam as a first ordered approximation for a low aspect ratio blade. It was found that for a truncated beam the magnitude and location of the maximum stress were functions of the truncation factor. A key result of this research is shown below. As can be seen, for small truncation factors, the response of a given high frequency mode would be very sensitive to variations in the tip thickness.

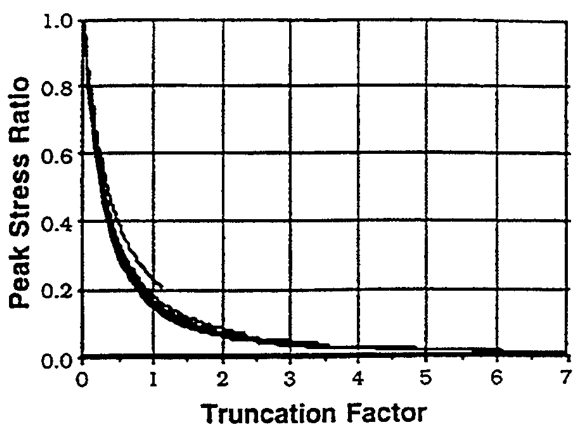


FIGURE 4. Reduction in Stress Participation Factor

The second investigation centered around the concept that if an airfoil has two modes with nearly identical frequencies, then those modes will be highly sensitive to minor variations in blade geometry, and thus there will be significant difference from blade to blade. The issue of how to measure the actual maximum stress in a blade was addressed by developing a theory that the actual modal stress is simply a linear combination of the nominal modes. Since the accuracy of the measurement of modal content is highly dependent upon the placement of the strain gages, a mathematical expression was developed to estimate the error in maximum stress as a function of gage location, gage error and gage placement uncertainty. The expression was developed into the computer code EMIN, which is documented in a separate report, "EMIN, a Computer Program for Optimizing Strain Gage Placement, User Manual" by M.-T. Yang and J. H. Griffin. The program itself has been transferred to the industrial partners in the GUIde Consortium.

REFERENCES

Balaji, G. N., and Griffin, J. H., 1997, "Resonant Response of a Tapered Beam and Its Implications to Blade Vibration," ASME *Journal of Engineering for Gas Turbines and Power*, Vol. 119, pp. 90-95.

Yang, M.-T., and Griffin, J. H., 1997, "Theory and Methodology of Optimally Measuring Vibratory Strains in Closely Spaced Modes," Proceedings of the 1997 International Gas Turbine and Aeroengine Congress and Exposition, June 2-5, 1997, Orlando, FL

POINTS OF CONTACT

Government

Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor

Name: Dr. Jerry Griffin
Organization: Carnegie Mellon University
Address: Department of Mechanical Engineering
Room 414/Scale Hall/5000 Forbes
Carnegie Mellon University
Pittsburgh, PA 15213
Phone Number: (412) 268-3860
Fax Number: (412) 268-3348
Email:

2.3 *NUMERICALLY UNSTEADY AERODYNAMIC SIMULATOR FOR BLADED FORCED RESPONSE PHENOMENA*

Theoretical analyses and computer codes have been developed for predicting compressible unsteady inviscid and viscous flows through blade rows of axial-flow turbomachines. Such analyses are needed to determine the impact of unsteady flow phenomena on the structural durability and noise generation characteristics of the blading. The emphasis here has been placed on developing analyses based on asymptotic representations of unsteady flow phenomena. Thus, high Reynolds number flows driven by small amplitude, unsteady excitations in which viscous effects are concentrated within thin layers have been considered. The resulting analyses should apply in many practical situations and lead to a better understanding of the relevant flow physics. In addition, they will be efficient computationally, and therefore, appropriate for use in aeroelastic and aeroacoustic design studies.

BIBLIOGRAPHY

Verdon, Joseph M., and Ayer, Timothy C., "Unsteady Aerodynamic Models for Turbomachinery Aeroelastic and Aeroacoustic Applications", NASA Contractor Report 4698, November 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253
Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Joseph Verdon
Organization: United Technologies Research Cntr.
Address: United Technologies Research Cntr.
East Hartford, CT 06108

Phone Number:
Fax Number:
Email:

2.4 *HIGH MACH NUMBER FORCING FUNCTIONS*

The purpose of this research was to acquire and analyze data defining forcing functions generated by the wakes from rotor blades operating at high subsonic/transonic Mach numbers. Both near and far wake data were obtained and analyzed to investigate the fundamental modeling inherent in current and advanced forced response unsteady aerodynamic models. Measured rotor wake velocity deficit and semiwake width were found. It was also found that the wake width at 20,000 RPM were extremely large, indicative of highly separated flow.

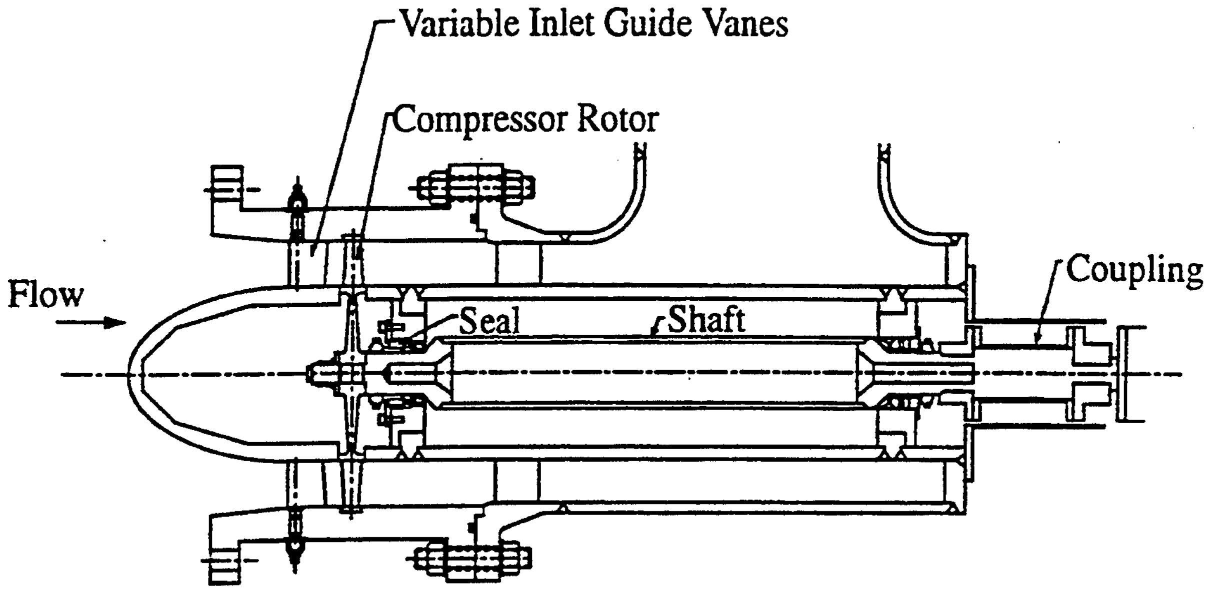


FIGURE 5. Axial Compressor Configuration: 1) Single Stage, 2) 2/3 Hub-Tip Ratio Design, 3) 18 Variable Inlet Guide Vanes, 4) 19 Rotor Blades, 5) Rotor Diameter 30.48 cm (12 in)

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Sandford Fleeter
Organization: Purdue University
Address: Purdue University
Thermal Sciences & Propulsion Center
1003 Chaffee Hall
West Lafayette, IN 47907-1003
Phone Number: (317) 494-1504
Fax Number: (317) 494-0530
Email: fleeter@ecn.purdue.edu

2.5 *UNSTEADY AERODYNAMICS OF IMPELLER BLADES*

Technology trends in centrifugal compressors using vaned diffusers, higher stage loading, thinner blades and smaller impeller-diffuser spacing are presenting challenges in predicting the impeller blade vibratory responses. This task investigated the impeller-diffuser interaction in a centrifugal compressor relevant to impeller blade forced response prediction. The data showed an excellent correlation to a 2-D steady flow analysis. It was found that although the potential forcing function exhibited by a vane diffuser exhibits multiple harmonics, the impeller blades respond primarily to the 1st harmonic. The data also showed much higher responses at close impeller-diffuser spacings.

BIBLIOGRAPHY

Fleeter, Sanford, "Impeller Blade Forced Response Unsteady Aerodynamics," Presentation at the Turbine Engine High Cycle Fatigue Program Forced Response Prediction Action Team Meeting, 9-12 December 1996, Monterey, CA.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Sandford Fleeter
Organization: Purdue University
Address: Purdue University
Thermal Sciences & Propulsion Center
1003 Chaffee Hall
West Lafayette, IN 47907-1003
Phone Number: (317) 494-1504
Fax Number: (317) 494-0530
Email: fleeter@ecn.purdue.edu

2.6 *DYNAMIC ANALYSIS AND DESIGN OF SHROUD CONTACT*

This analysis will enable gas turbine designers the ability to predict blade vibration for rotors incorporating shrouds and/or platform dampers (friction dampers). This task has four objectives. First, a 3-D friction interface model must be developed to allow for not only axial and tangential movement of the blade, but also radial movement. Secondly, a robust nonlinear solver must be developed and integrated into a code called BDAMPER to solve cases in which multiple vibration modes are simultaneously excited and the resulting mode shape and contact motion become very complex. Thirdly, the stabilizing effect of shrouds on blade flutter will be incorporated into BDAMPER. Finally, BDAMPER predictions will be compared with actual test data for verification.

BIBLIOGRAPHY

Menq, C.-H., "Dynamic Analysis of Shrouded Blades and Design of Shroud Contact," Proposal submitted to GUIde Consortium, 15 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Chia-Hsiang Menq
Organization: The Ohio State University
Address: Department of Mechanical Engineering
The Ohio State University
206 West 18th Avenue
Columbus, Ohio 43210-1107
Phone Number: (614) 292-4232
Fax Number: (614) 292-3163
Email: menq.1@osu.edu

2.7 *EVALUATION OF AERO MODELS FOR FORCED RESPONSE PREDICTION SYSTEM*

The purpose of this research is to determine the capability of current state-of-the-art unsteady aerodynamic models to predict the gust and oscillating airfoil response of compressor and turbine airfoils over a range of realistic frequencies and loading levels. The research will evaluate the small perturbation assumption necessary for unsteady flow. Additionally, it will investigate the effect of the aerodynamic forcing function on gust response. Also, three dimensional flow will be investigated as to its effects on gust and airfoil oscillation. Codes being analyzed are primarily NASA Lewis codes, such as Nphase, Sflow, Linflow, and Linflux.

BIBLIOGRAPHY

Capece, V. R., "Evaluation of Current State-of-the-Art Unsteady Aerodynamic Models for the Prediction of Flutter and Forced Vibration Response," Proposal submitted to GUIde Consortium, 10 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Vincent R. Capece
Organization: University of California
Address: Department of Mechanical and
Aeronautical Engineering
University of California
Davis, CA 95616-5294
Phone Number: (916) 752-5019
Fax Number:
Email:

2.8 *NONLINEAR MODELING OF STALL / FLUTTER*

This task is to investigate the possible use of reduced order modeling techniques to linear and nonlinear stall flutter in cascades. Research will be done in three main areas: (1) the development of a time-domain, linearized Navier-Stokes analysis; (2) the development of an efficient eigenmode extraction code for large systems of equations; and (3) the development of reduced order modeling techniques to model nonlinear unsteady flows, especially phenomena such as hard flutter boundaries and limit cycle behavior.

BIBLIOGRAPHY

Hall, K. C., "Nonlinear Reduced Order Modeling of Stall Flutter," Proposal submitted to GUIde Consortium, 14 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253
Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Kenneth C. Hall
Organization: Duke University
Address: Department of Mechanical Engineering
and Materials Science
School of Engineering
P.O. Box 90300
Duke University
Durham, NC 27708-0300
Phone Number: (919) 660-5328
Fax Number: (919) 660-8963
Email: hall@euler.egr.duke.edu

2.9 *AERO/STRUCTURAL SENSITIVITY ANALYSIS*

This research program had three primary goals:

1. To develop realistic computational models to predict the aerodynamic forcing and aerodynamic damping in turbomachinery cascades.

2. To develop analyses for computing the sensitivity of the steady aerodynamic performance and the unsteady aerodynamic and structural dynamic behavior of the cascade due to changes in blade geometry.

3. To develop optimization routines (nonlinear programming algorithms) for computing blade shapes which minimize the aeroelastic response while maintaining high aerodynamic efficiency.

BIBLIOGRAPHY

Hall, K. C., "Sensitivity Analysis of the Coupled Aerodynamic/Structural Dynamic Behavior of Turbomachinery Blade Rows," Proposal submitted to GUIde Consortium, 15 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253
Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Kenneth C. Hall
Organization: Duke University
Address: Department of Mechanical Engineering and Materials Science
School of Engineering
P.O. Box 90300
Duke University
Durham, NC 27708-0300
Phone Number: (919) 660-5328
Fax Number: (919) 660-8963
Email: hall@euler.egr.duke.edu

2.10 *DESIGN GUIDELINES FOR MISTUNED BLADED DISKS*

The goal of this program is to develop a program for analysis and design of mistuned bladed disks that will be based on the code developed under the task *Forced Response of Mistuned Bladed Disks* from the GUIde I effort. Mistuning is defined as a mode localization process in which certain sectors of a bladed disk vibrate at higher amplitudes than surrounding blades. The research has two major areas: 1) analyzing the disk-blade interface and its effect on blade dynamics and representing it in the reduced order modeling code; 2) identifying key design variables using parameter and case studies and developing them into general design guidelines for mistuned bladed disks. Additionally, the code will be updated to allow crude modeling of shrouds and the code will be validated against an experimental test case.

BIBLIOGRAPHY

Pierre C., "Design Guidelines and Realistic Modeling for Vibratory Response of Mistuned Bladed Disks," Proposal submitted to GUIde Consortium, 12 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Christophe Pierre
Organization: University of Michigan
Address: 3104 G. G. Brown
Department of Mechanical Engineering
and Applied Mechanics
The University of Michigan
Ann Arbor, MI 48109-2125
Phone Number: (313) 936-0401
Fax Number:
Email:

2.11 *FRICTION DAMPING OF BLADED DISKS*

The purpose of this research is to investigate the extreme sensitivity of shrouded bladed dynamics to small changes in design. The program will develop an improved understanding of the dynamic response of shrouded bladed disk systems. The ultimate result will be a set of design tools and guidelines to develop robust shrouded bladed disk systems.

BIBLIOGRAPHY

Griffin, J. H., "Predicting Friction Damping in Shrouded Bladed Disk Assemblies," Proposal submitted to GUIde Consortium, 15 April 1995.

POINTS OF CONTACT

Government
Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor
Name: Dr. Jerry Griffin
Organization: Carnegie Mellon University
Address: Department of Mechanical Engineering
Room 414/Scale Hall/5000 Forbes
Carnegie Mellon University
Pittsburgh, PA 15213-0001
Phone Number: (412) 268-3860
Fax Number: (412) 268-3348
Email:

2.12 *EXPERIMENTAL STUDY OF FORCED RESPONSE IN TURBINES*

The purpose of this research is to develop an understanding of the forcing function, aerodynamic damping and structural damping at actual engine conditions for high frequency vibration of turbine blades. For this research an actual AlliedSignal TFE731-2 HPT will be used to gather data. The original blades, which had a severe high frequency vibration problem, as well as two other blade designs, will be used to gather data. The result of this research will be a database of knowledge which can be used to validate future codes as well as some design guideline information to help avoid high frequency vibrations.

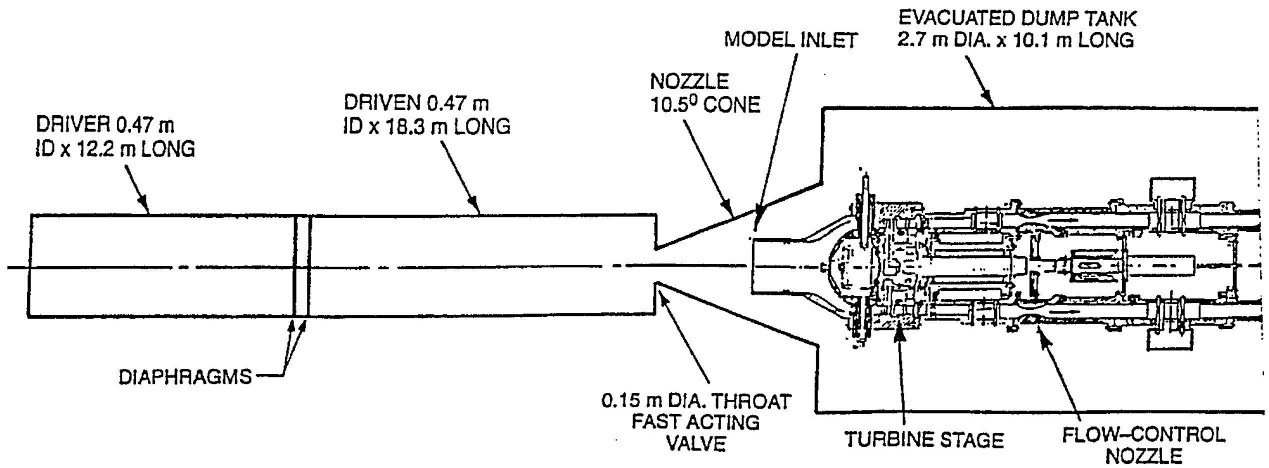


FIGURE 6. Schematic of Experimental Apparatus and Sketch of Wave Diagram

BIBLIOGRAPHY

Abhari, R. and Dunn, M., "Experimental and Numerical Study of Forced Response Excitation for a Full-Scale Rotating Turbine at Actual Engine Conditions," Proposal submitted to GUIde Consortium, 15 April 1995.

POINTS OF CONTACT

Government

Name: Maj Greg Minkiewicz, PhD
Organization: U.S. Air Force
Address: AFRL/PRTF, Bldg 18
1950 Fifth St.
WPAFB, OH 45433-7253

Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email: minkiegr@wl.wpafb.af.mil

Contractor

Name: Dr. Reza Abhari & Mr. Michael Dunn
Organization: Ohio State University
Address: Ohio State University
328 Bowlz Hall
2036 Neil Ave
Columbus, OH 43210-1276
Phone Number: (614) 292-8453
Fax Number: (614) 292-8290
Email:

2.13 *FORWARD SWEPT BLADE AERODYNAMICS*

The purpose of this research is to better understand the aeroelastic behavior of forward swept airfoils in order to prevent high cycle fatigue failures. In order to accomplish this, conventional prediction tools were used to model a rotor with forward swept airfoils. A test was then run to compare against the predictions from the conventional tools. The test showed that the conventional tools were as accurate for forward swept airfoils as they were for conventional airfoils.

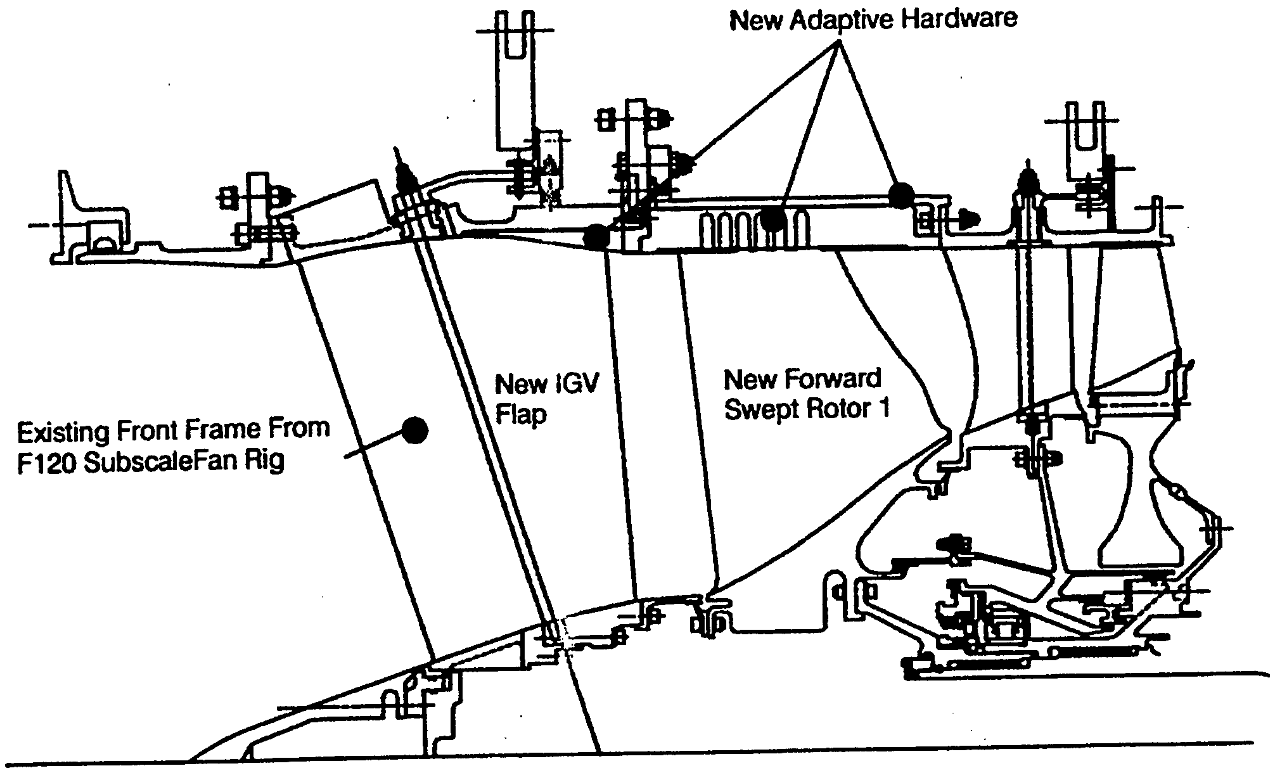


FIGURE 7. GESFAR Fan Rig

BIBLIOGRAPHY

Kielb, Robert," GESFAR Aeromechanics Project", Presentation at the Forced Response Action Team Meeting, Monterey, CA, 9-12 Dec 96.

POINTS OF CONTACT

Government
Name: John Lueke
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-8210
Fax Number: (937) 255-2077
Email:

Contractor
Name: Robert Kielb
Organization: General Electric Aircraft Engines
Address: One Neumann Way, M/D A412
Cincinnati, OH 45215-1988
Phone Number: (513) 243-2821
Fax Number: (513) 243-2944
Email:

2.14 *OSCILLATING CASCADE RIG*

The purpose of this research is to experimentally determine airfoil surface unsteady pressure distributions at large mean incidence angles. This was done using the NASA Lewis Oscillating Cascade shown below. Airfoils representative of a low aspect ratio fan blade tip section were used. Data was gathered at Mach 0.8 at chord incidence angles of 0° and 10°. For the 10° case it was found that a large separation bubble formed near the leading edge. This separation had a dramatic effect on the chordwise distribution of unsteady pressure, especially near the leading edge.

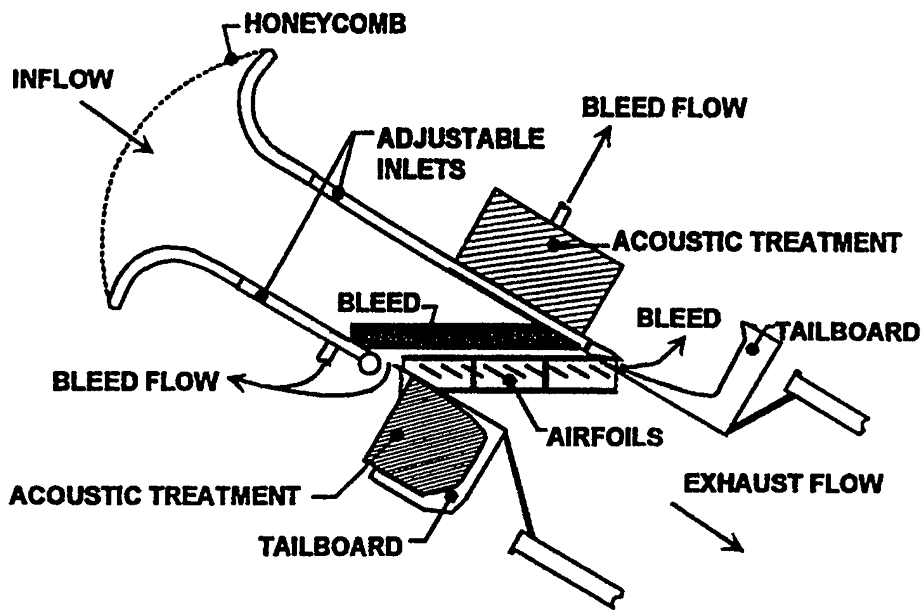


FIGURE 8. NASA Lewis Oscillating Cascade

BIBLIOGRAPHY
Buffman, Daniel, "Oscillating Cascade Experiments at NASA Lewis", Presentation at the Forced Response Action Team Meeting, Monterey, CA, 9-12 Dec 96.

POINTS OF CONTACT

Government
Name: Dr. Daniel H. Buffum

Organization: NASA Lewis Research Center

Address: NASA Lewis Research Center
21000 Brookpark, M/S 77-6
Cleveland, OH 44135-3191

Phone Number: (216) 433-3759

Fax Number:
Email: Daniel.Buffman@lerc.nasa.gov

Contractor
Name: Dr. Vincent Capece and Dr. Aaron King / Dr. Yehia El-Aini
Organization: University of California / Pratt & Whitney
Address: Department of Mechanical and Aeronautical Engineering
University of California
Davis, CA 95616-5294

Pratt & Whitney
P.O. Box 109600
West Palm Beach, FL 33410-9600
Phone Number: (916) 752-5019 / (561) 796-5911
Fax Number:
Email:

2.15 *UNSTEADY STATOR LOADING IN THE F109 ENGINE*

This research focused on unsteady flow in the axial fan of the AlliedSignal F109 engine. As part of the research, a model was developed to explain some phase-map ambiguities which have shown up in several different experiments. The model represents the interaction of the vortical disturbances produced by the rotating blades and the unsteady potential field associated with each blade. Current predictive codes normally do not include the unsteady potential field, and thus ignore the interaction between this field and the vortical disturbances. It has been recommended that this interaction be studied further to better understand it so that it can be incorporated into current predictive codes.

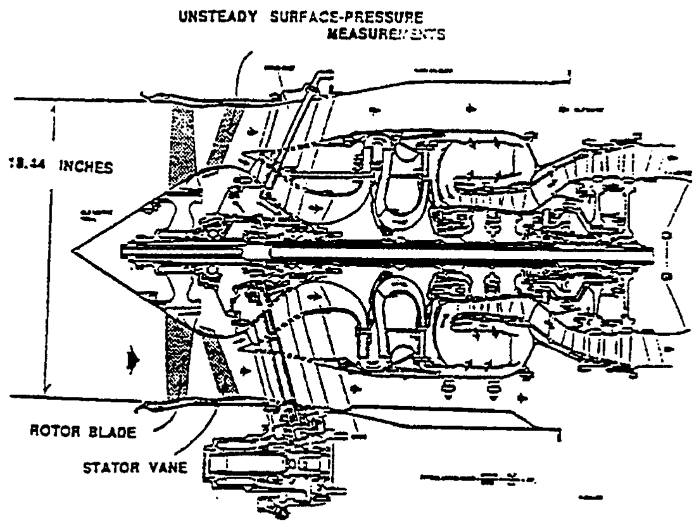


FIGURE 9. Schematic of F109 Engine Showing Location of Pressure-Instrumented Stators.

BIBLIOGRAPHY

Jumper, Eric J, "Preliminary Report: An Experimental Study of Unsteady Forcing on the Stator Row of the Single Stage of Axial Compression in the F109 Turbofan Engine", submitted to USAFA under contract F0561196MV821

POINTS OF CONTACT

Government
Name: Maj Michael K. Fabian
Organization: U.S. Air Force, USAFA
Address: Headquarters USAFA/DFAN
2354 Fairchild Dr., Suite 6H22
United States Air Force Academy
Colorado Springs, CO 80840-6222
Phone Number: (719) 333-4010
Fax Number: (719) 333-4013
Email: fabianmk.dsan@usaf.af.mil

Contractor
Name: Dr. Eric J. Jumper
Organization: University of Notre Dame
Address: Aerospace and Mechanical Engineering
Hessert Center for Aerospace Research
Notre Dame, IN 46556
Phone Number: (219) 631-7680
Fax Number: (219) 631-8355
Email: ejumper@aerosun,aero.nd.edu

2.16 *MSAP2D, AN EULER FLUTTER AND FORCED RESPONSE ANALYSIS CODE FOR MULTISTAGE TURBOMACHINERY*

Most of the current aeroelastic analyses for turbomachines analyze only one blade row, i.e. an isolated blade row. The multistage effects, the effects due to the presence of other blade rows, were neglected or included in an approximate manner. Prediction of flutter and forced response characteristics of the turbomachinery blades requires an accurate analysis of the multi-bladed row turbomachine as a single unit. Towards this goal, an aeroelastic program, Multistage Aeroelastic Analysis Program: 2-D (MSAP2D), has been developed to aid in this analysis. The interface boundary between the blade rows is handled as an additional fluid boundary. The structural model is a typical section with bending and torsional motion degrees of freedom for each blade in the blade row and for all blade rows. The aeroelastic equations are solved in time domain using Newmark's method. The program has been calibrated for several examples. The program can be used for the analysis of unsteady aerodynamic and aeroelastic analysis of multi-blade rows or for an isolated blade row as well.

POINTS OF CONTACT

Government
Name: Oral Mehmed
Organization: NASA Lewis Research Center
Address: 21000 Brookpark Rd., M/S 23-3
Cleveland, OH 44135

Phone Number: (216) 433-6036
Fax Number: (216) 977-7051
Email: oral.mehmed@lerc.nasa.gov

Contractor
Name: T.S.R. Reddy
Organization: University of Toledo
Address: NASA Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135-3191
Phone Number: (216) 433-6083
Fax Number:
Email:

2.17 *ASTROP2, VERSION 2.0: A PROGRAM FOR AEROELASTIC STABILITY ANALYSIS OF MULTIBLADE STRUCTURES*

ASTROP2 (Aeroelastic Stability and Response Of Propulsion systems – 2 dimensional analysis) can perform flutter analysis of rotating blades of propfans, compressors and turbines. ASTROP2 was developed under a project aimed at developing advanced propellers capable of cruising at eight tenths the speed of sound. To formulate the aeroelastic eigenvalue equations, the code combines unsteady aerodynamic forces due to vibrating blades, with the blade structural characteristics using strip theory. The flutter stability information, flutter frequency and damping, is inferred from the eigenvalues obtained from these equations. In ASTROP2, the unsteady aerodynamic forces are obtained from two dimensional cascade theories. The structural characteristics are obtained from a three dimensional structural model.

POINTS OF CONTACT

Government
Name: Oral Mehmed
Organization: NASA Lewis Research Center
Address: 21000 Brookpark Rd., M/S 23-3
Cleveland, OH 44135

Phone Number: (216) 433-6036
Fax Number: (216) 977-7051
Email: oral.mehmed@lerc.nasa.gov

Contractor
Name: T.S.R. Reddy
Organization: University of Toledo
Address: NASA Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135-3191
Phone Number: (216) 433-6083
Fax Number:
Email:

2.18 *GUST AND STRUCTURAL RESPONSE ANALYSIS OF A 2-D CASCADE USING AN EULER AEROELASTIC SOLVER*

The Multistage Aeroelastic Analysis Program MSAP2D was modified to address the problem of gust resulting from upstream blade rows in the calculation of flutter response. The modifications included prescribing the unsteady inflow conditions at the inlet, and using one dimensional non-reflecting boundary conditions. The unsteady aerodynamic forces are obtained from solving two-dimensional Euler equations. The interface boundary between the blade rows is handled as an additional fluid boundary. The structural model is a typical section with bending and torsional motion degrees of freedom for each blade in the blade row and for all blade rows. The aeroelastic equations are solved in time domain using Newmark's method. The program has been calibrated for several examples.

POINTS OF CONTACT

Government
Name: Oral Mehmed
Organization: NASA Lewis Research Center
Address: 21000 Brookpark Rd., M/S 23-3
Cleveland, OH 44135

Phone Number: (216) 433-6036
Fax Number: (216) 977-7051
Email: oral.mehmed@lerc.nasa.gov

Contractor
Name: T.S.R. Reddy
Organization: University of Toledo
Address: NASA Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135-3191
Phone Number: (216) 433-6083
Fax Number:
Email:

3.0 *COMPONENT ANALYSIS*

CHARTER

RESPONSIBILITIES

The Component Analysis Action Team (Component Analysis AT) has the responsibility of fostering collaboration between individual HCF component analysis efforts with the overall goal of combining with the Instrumentation and Forced Response AT's to better determine alternating stresses to within 20%. The Component Analysis AT provides technical coordination and communication between active participants involved in HCF component analysis technologies. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Component Analysis AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for component analysis programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the Component Analysis AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in component analysis technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Mr. Paul Zimmerman - Chair
Naval Air Systems Command
AIR 4.4.7.2 Bldg. 106
22195 Elmer Road, Unit #4
Patuxent River, MD 20670-1534
Ph: (301) 757-0500 Fax: (301) 757-0562
zimmerman_paul%pax4a@mr.nawcad.navy.mil

Ms. Kathleen Sargent - Co-Chair
U.S. Air Force
AFRL/PRTC, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7251
Ph: (937) 255-2081 Fax: (937) 255-2660
sargenka@wl.wpafb.af.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

3.1 *ASSESSMENT OF TURBINE ENGINE COMPONENTS*

The University of Dayton Research Institute (UDRI) is performing several tasks in support of the HCF S&T Plan as part of DOD contract F33615-96-C-2604, *Assessment Of Turbine Engine Components*. The term of the contract is from September 1996 to September 2001.

Phase II, Task 1, *Accuracy of Finite Element Frequency Predictions,* addresses the issue of structural analysis accuracy. Accuracy assessments for all of the solid elements in ABAQUS, ANSYS, and MSC/NASTRAN have been performed to guide the analyst in selecting the proper element type for a particular vibration problem. Error estimation procedures have been developed which can be applied as a postprocessing operation. Dialogues have been initiated with FEA software vendors to explore the possibility of integrating such a procedure into the software once the task is complete.

Phase III, Task 1, *Nonlinear Interface Modeling*, deals with nonlinear joints such as snap rings and bolted connections. Analytical procedures are being developed to incorporate the essential aspects of nonlinear joint response into routine design analysis when necessary.

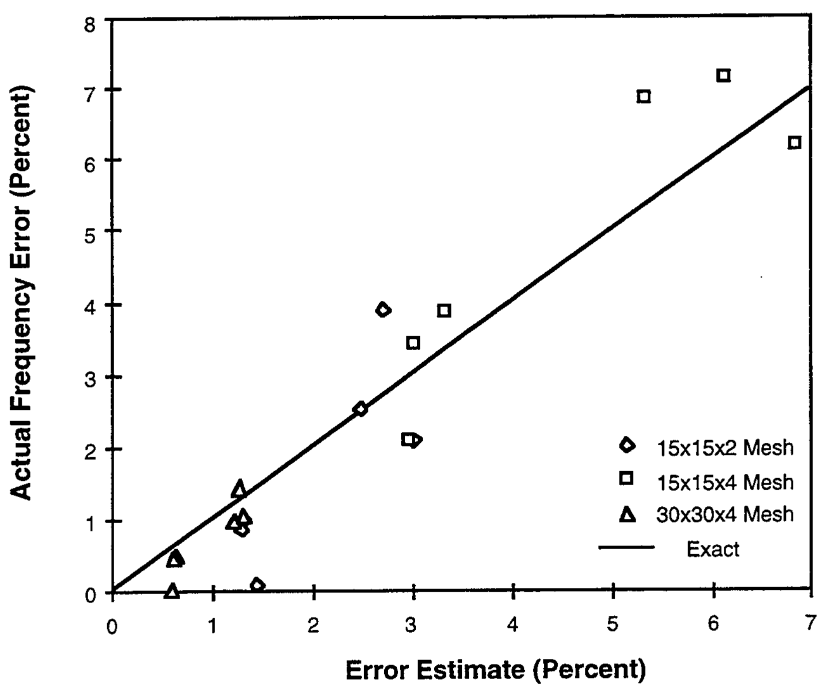


FIGURE 10. Natural Frequency Error Estimates for Bending and Torsion Modes

BIBLIOGRAPHY

1. D. E. Thomson, R. A. Brockman, J. W. Fielman, and W. R. Braisted, *Accuracy of Mid-Range Frequency Predictions for Turbine Engine Blades*, AIAA Paper 97-3155, 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Seattle, Washington, July 6-9, 1997.

2. D. Thomson, M. Huffman, W. Braisted, and R. Brockman, *Effects of Differing Analysis Philosophies on Joint Design Projects*, 13th ISABE Conference, Chattanooga, Tennessee, September 7-12, 1997.

POINTS OF CONTACT

Government

Name: Kathleen A. Sargent
Organization: U. S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2081
Fax Number: (937) 255-2660
Email: sargenka@wl.wpafb.af.mil

Contractor

Name: Dr. Robert A. Brockman
Organization: University of Dayton Research Inst.
Address: 300 College Park
Dayton, OH 45469-0110
Phone Number: (937) 229-3484
Fax Number: (937) 229-4251
Email: brockman@udri.udayton.edu

3.2 *PROBABILISTIC DESIGN FOR TURBINE ENGINE AIRFOILS*

This program, initiated through PRDA 98, will fund the development of a probabilistic design system for turbine engine airfoils. It will provide the necessary integration of the HCF technical areas defined within six other Science and Technology Action Teams and produce rigorous and efficient statistical methods for computational procedures. The probabilistic methodologies will be validated against past failures of actual engine components and design/qualification during demonstrator engine programs.

An announcement was released in the 25 August 1997 Commerce Business Daily for proposals. Evaluations are underway and the expected award dates are 1 June 1998 to 31 August 1998.

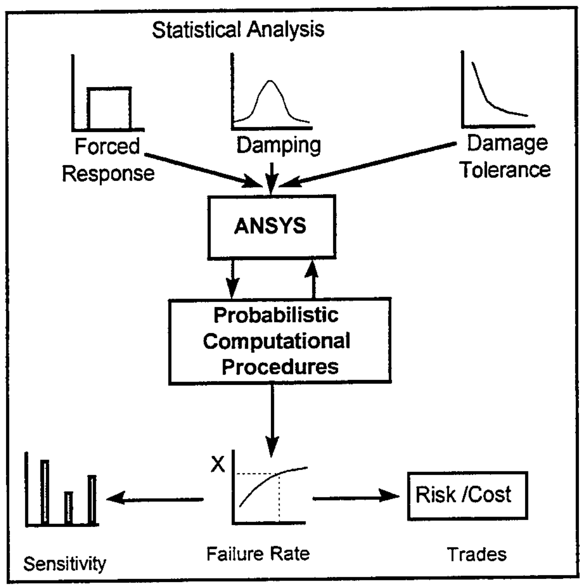


Figure 11. Conceptual Approach for Probabilistics

POINTS OF CONTACT

Government
Name: Kathleen A. Sargent
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251

Phone Number: (937) 255-2081
Fax Number: (937) 255-2660
Email: sargenka@wl.wpafb.af.mil

3.3 *FRACTURE SCREENING*

The applicability of probabilistics to disk design has been demonstrated under the USAF Probabilistic Rotor Design System Contract (PRDS --F33615-90-C-2070). Probabilistic Fracture Mechanics (PFM) methodology for assessing the impact of statistically distributed flaws (inclusions, pores, etc.) has been developing at GE Aircraft Engines for over a decade and a half and was integrated several years ago into GEAE's design process for PM components. The PRDS contract substantially augmented experimental validation of PFM with push-pull hourglass and cyclic spin disk tests. It also demonstrated the ability to roll into PFM analyses other statistical components (dimensional variability, flaw distribution lot-to-lot differences and scatter in inclusion behavior), and to incorporate failure probability as a constraint in a design optimization of the XTC-76/3 high pressure turbine disk.

Work has started with preliminary calculations for the F110-129 Stage 1 Fan based on empirical distributions of flow defect intensity, damping, blade-to-blade response, and mode shape. In particular, it should be noted that the distribution of blade-to-blade response was estimated from strain gage and light probe measurements on a limited number of engines. As was described above, it is intended that this distribution be generated from more fundamental distributions using a mistuning algorithm.

POINTS OF CONTACT

Government
Name: Chris Lykins
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251

Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lykinscd@wl.wpafb.af.mil

Contractor
Name: Paul G. Roth
Organization: GE Aircraft Engines
Address: 1 Neumann Way
Mail Drop K105
Cincinnati, OH 45215
Phone Number: (513) 243-4445
Fax Number: (513) 243-4886
Email: paul.roth@ae.ge.com

4.0 ***INSTRUMENTATION***

CHARTER

RESPONSIBILITIES

The Instrumentation Action Team (Instrumentation AT) has the responsibility of fostering collaboration between individual HCF instrumentation efforts with the overall goal of combining with the Forced Response and Component Analysis AT's to better determine alternating stresses to within 20%. The Instrumentation AT provides technical coordination and communication between active participants involved in HCF measurement, sensor, data processing, and engine health monitoring technologies. Technical workshops have been organized on at least an annual basis and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Instrumentation AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for instrumentation and engine health monitoring programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the Instrumentation AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in instrumentation technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Mr. Bill Stange - Chair
U.S. Air Force
AFRL/PRTC, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7251
Ph: (937) 255-2351 Fax: (937) 255-2660
stangewa@wl.wpafb.af.mil

Mr. Henry Jones - Co-Chair
Sverdrup Technology Inc.
1103 Avenue B, M/S 1400
Arnold AFB, TN 37389-1400
Ph: (615) 454-7750 Fax: (615) 454-6187
jonesht@hap.arnold.af.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

4.1 *NSMS DEVELOPMENT FOR HCF*

Approach: Improve NSMS Accuracy and Sensor Capability

Description: This program, initiated through PRDA V, funds the Propulsion Instrumentation Working Group (PIWG) to develop the front-end hardware for a Fourth Generation Noncontacting Stress Measurement System (NSMS). The PIWG, which brings together the strengths and capabilities of the four major engine manufacturers (General Electric, Pratt & Whitney, Allison, AlliedSignal), as well as NASA and the USAF, will develop a NSMS which has five-fold greater deflection resolution, multiple integral order mode capability, improved timing and data processing capabilities, and reduced probe and data acquisition costs.

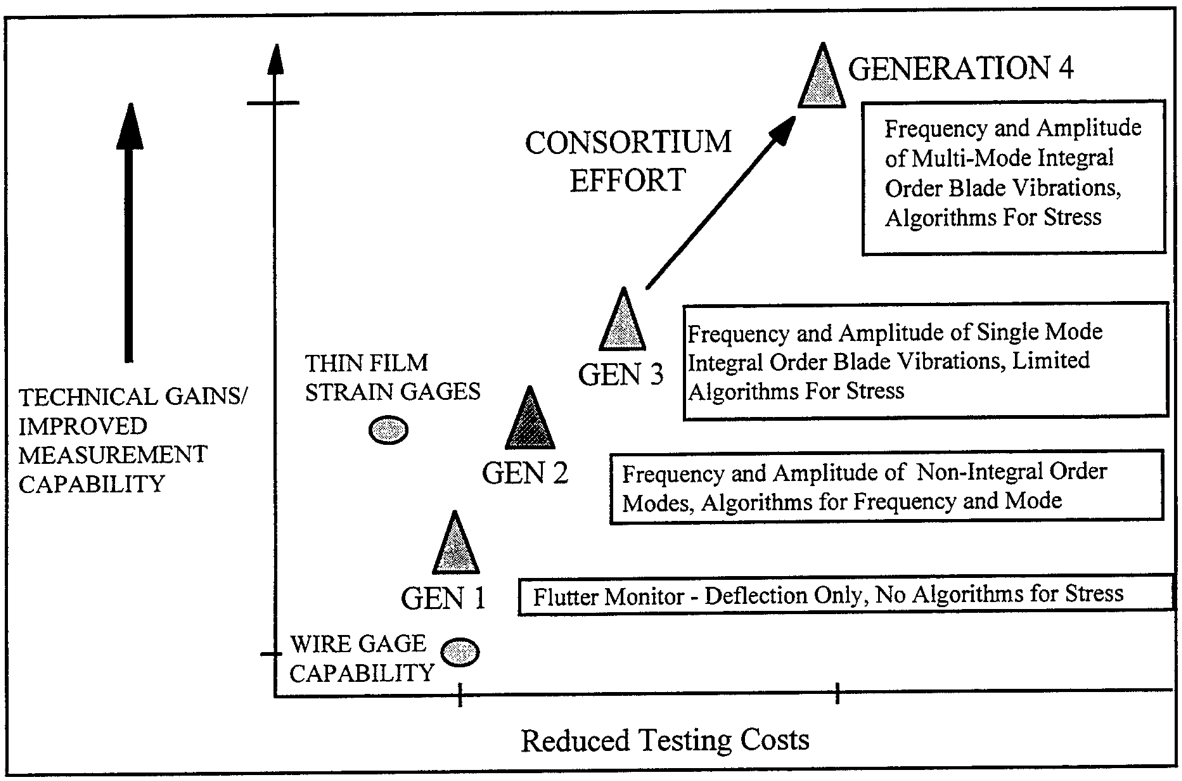


Figure 12. NSMS The Next Generation

POINTS OF CONTACT

Government
Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

Contractor
Name: Mr. Wally Rakowski
Organization: Ohio Aerospace Institute
Address: 22800 Cedarpoint Rd.
Cleveland, OH 44142
Phone Number: (216) 962-3126
Fax Number: (216) 962-3200
Email:

4.2 *GEN 4 NSMS ALGORITHM DEVELOPMENT*

Approach: Provide Improved Algorithm Capability for NSMS

Description: The Gen 4 NSMS algorithm development effort will produce algorithms and software for processing blade-tip deflection information produced by the Gen 4 NSMS Front-End Hardware System (currently being developed under a PRDA V contract). The host computer will be selected to be fully compatible with the Gen 4 NSMS Front-End System and comply with government/industry processor guidelines. The Processing System will receive data in real time from the Front-End System or from archived data. Processing algorithms will characterize individual blade and bladed disk system vibration modes at multiple, simultaneously occurring, integral and nonintegral frequencies. The system will process data from multiple line and/or spot probes arranged in various configurations on multiple engine stages, and provide on-line real time analysis capability at an update rate of at least twice a second. Time and frequency domain analysis defining blade-tip vibration amplitudes, phases, frequencies, damping, and blade untwist in a variety of display formats will be provided. Data will be formatted to interface with blade-tip-deflection to stress conversion algorithms. Fully interactive software tools will be provided to facilitate system setup, calibration, and analysis with simultaneous processes displayed on screen windows.

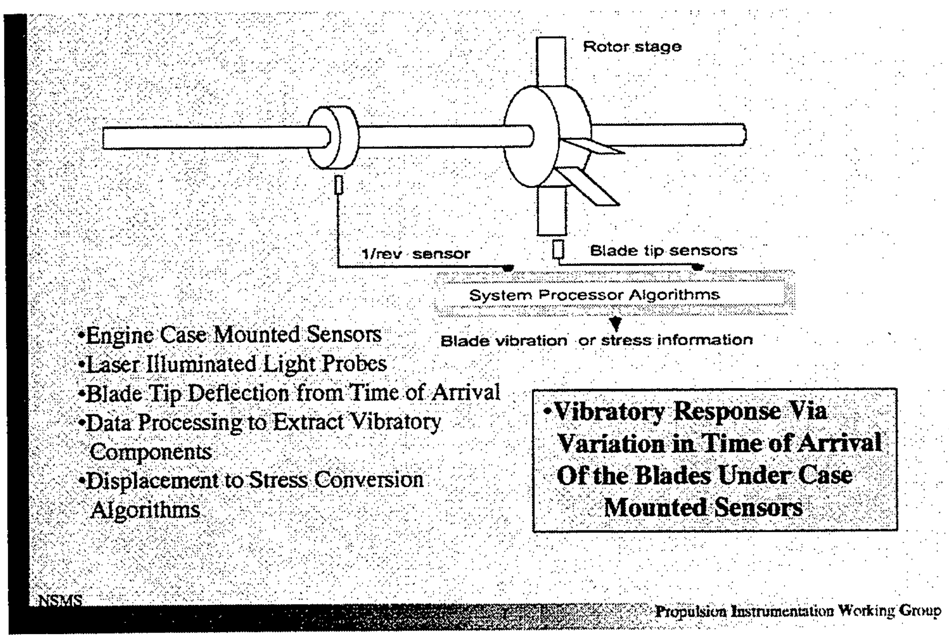


Figure 13. Fundamentals of NSMS

POINTS OF CONTACT

Government
Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

4.3 *GEN 5 NSMS DEVELOPMENT*

Approach: Provide Improved Stress Measurement Capability for NSMS

Description: Gen 5 NSMS will build in, and further develop, the capabilities of the Gen 4 hardware and software systems. The Gen 4 system will be reviewed to ascertain the feasibility and trade offs of utilizing alternate tip deflection sensors (i.e., non-light probes). Based on the results of this review, new deflection sensors will be designed and fabricated which will have the requisite temperature capability to operate successfully in the HPT. The tip deflection sensors and processing system will also be modified to allow deflection data to be taken at any point on the blade span leading or trailing edge. This modification will drastically improve the accuracy of NSMS in those cases where a node of vibration is close to or at the tip leading edge. The Gen 4 NSMS processing algorithms will be expanded to optionally include data from other reliable instrumentation sources (e.g., strain gage measurements, accelerometers, pressure transducers, and MEMS sensors), to improve the definition and accuracy of blade displacement, frequency, and stress determination. NSMS and information from alternate sensors will be combined in the processing to better define the deflection and stress for all blades in each instrumented stage. Improved bladed-disk and stress distribution vs. tip deflection models will be developed by optionally providing the results of bench testing (e.g., holographic interferometry, strain gage, laser vibrametry, and SPATE/Thermal Stress Analysis) and other test experience as inputs to the finite element analysis library, which the processing system uses to calculate stress distribution. The Gen 5 NSMS will provide on-line analysis and modeling to define all blade characteristics using interactive processing with graphical and animated model displays.

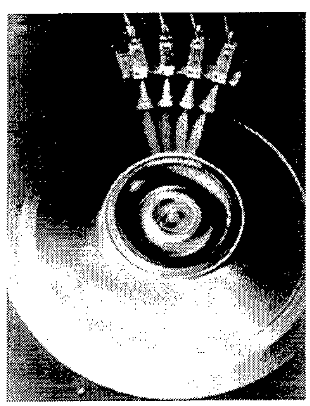


Figure 14. Spin Pit Validation of Advanced NSMS System

POINTS OF CONTACT

Government
Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

4.4 *PRESSURE/TEMPERATURE SENSITIVE PAINT*

Approach: Develop Environmental Mapping System

Description: This program investigates the use of Pressure Sensitive Paints (PSP) for the optical measurement of dynamic pressures in a rotating turbomachinery environment. PSPs use compounds which fluoresce at varying light amplitudes depending upon the local oxygen concentration, a parameter which can be related to local static pressure. Temperature Sensitive Paints (TSP) are virtually identical to PSPs chemically, but are insensitive to pressure fluctuations. TSPs can therefore be used to provide the temperature distributions necessary to accurately calibrate the PSP readings. Other PSP limitations which need to be addressed include frequency response, temperature limitations, paint life, and environmental degradation due to the rotating environment.

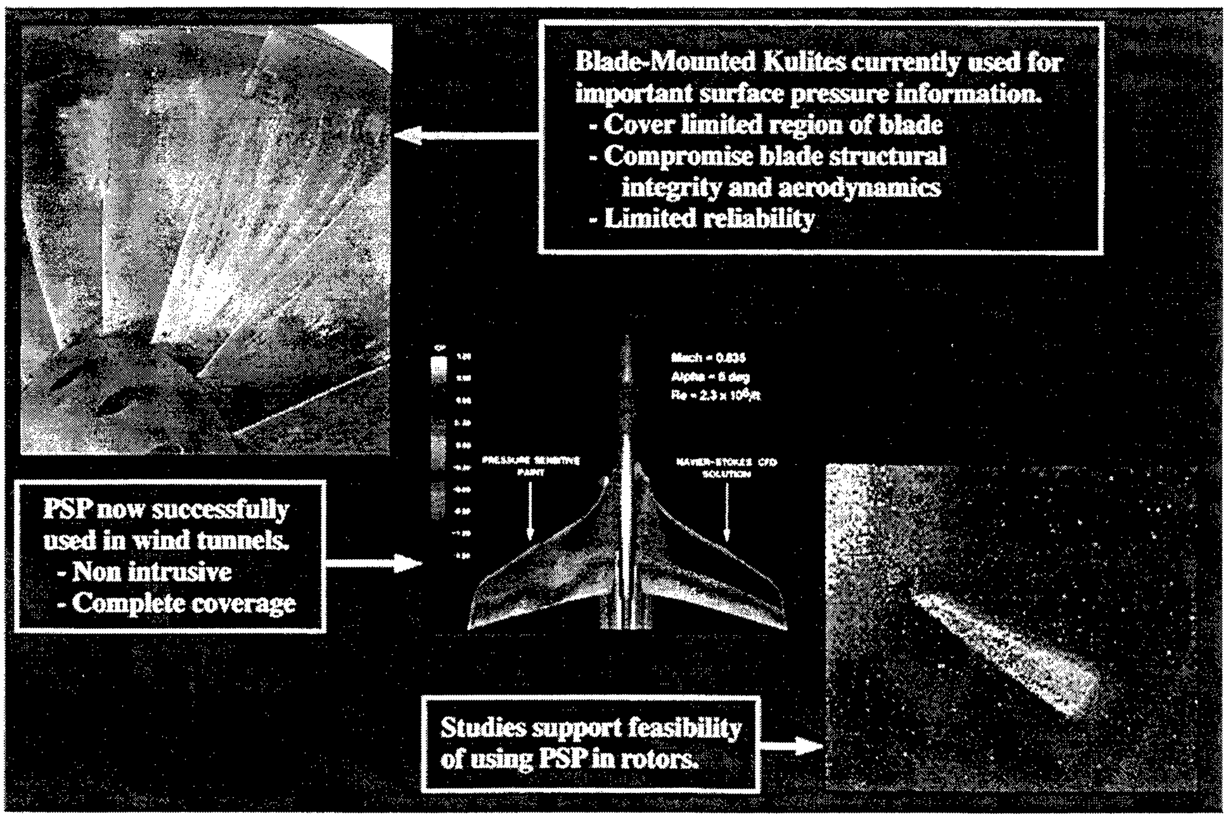


Figure 15. Pressure Sensitive Paint

POINTS OF CONTACT

Government
Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

Contractor
Name: Kelly Navarra
Organization: Innovative Scientific Solutions, Inc.
Address: 2786 Indian Ripple Road
Dayton, OH 45440-3638
Phone Number: (937) 255-6802 ext. 225
Fax Number: (937) 255-0898
Email: navarra@crf.wpafb.af.mil

4.5 *OPTICAL AIRFOIL PRESSURE MAPPING SYSTEM*

Approach: Develop Environmental Mapping System

Description: Optical 2-D pressure mapping has been identified as an essential part of the HCF Compressor Instrumentation S&T Plan. In support of the S&T plan, this PRDA V program investigates the use of thin film air etalons for the optical measurement of dynamic pressures in a rotating turbomachinery environment. After laboratory R&D activities have been completed, this program will conduct a detailed rig test and evaluation of etalon technology versus the most promising pressure sensitive paint formulations available at that time. It is anticipated that a downselection and additional development activities will be conducted on the more promising technique.

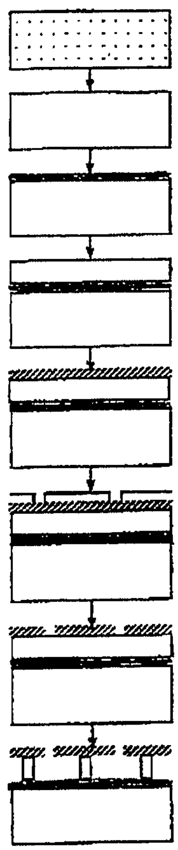


Figure 16. Air Gap Etalon Fabrication Methodology

POINTS OF CONTACT

Government
Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

Contractor
Name: Tom Bonsett
Organization: Allison Engine Company
Address: P.O. Box 420, S/C-W03A
Indianapolis, IN 46206-0420
Phone Number: (317) 230-3448
Fax Number: (317) 230-4236
Email: tbonsett@iquest.net

4.6 *2-D TEMPERATURE MAPPING BY THE LASER INDUCED FLUORESCENCE (LIF) OF THERMOGRAPHIC PHOSPHORS*

Approach: Develop Requisite Algorithms, Probes, & Methodologies for Implementing 2-D Rotational LIF on TBC & CMC Components

Description: The Air Force has identified non-contact 2-D temperature mapping as part of its HCF Instrumentation Turbine S&T plan. To achieve this S&T goal and to achieve the full potential of the Laser Induced Fluorescence (LIF) of Thermographic Phosphors (TP) technique it is necessary both to develop methodologies for 2-D rotational measurements and also to extend the LIF technique to advanced high temperature materials, e.g. TBC and CMC materials. The proposed effort will focus on developing fiber optics delivery and collection probes for 2-D rotational measurements, developing methods to deposit phosphors on TBC and CMC materials, formulating data analysis algorithms, and implementing methods to prolong phosphor life in the harsh engine environment.

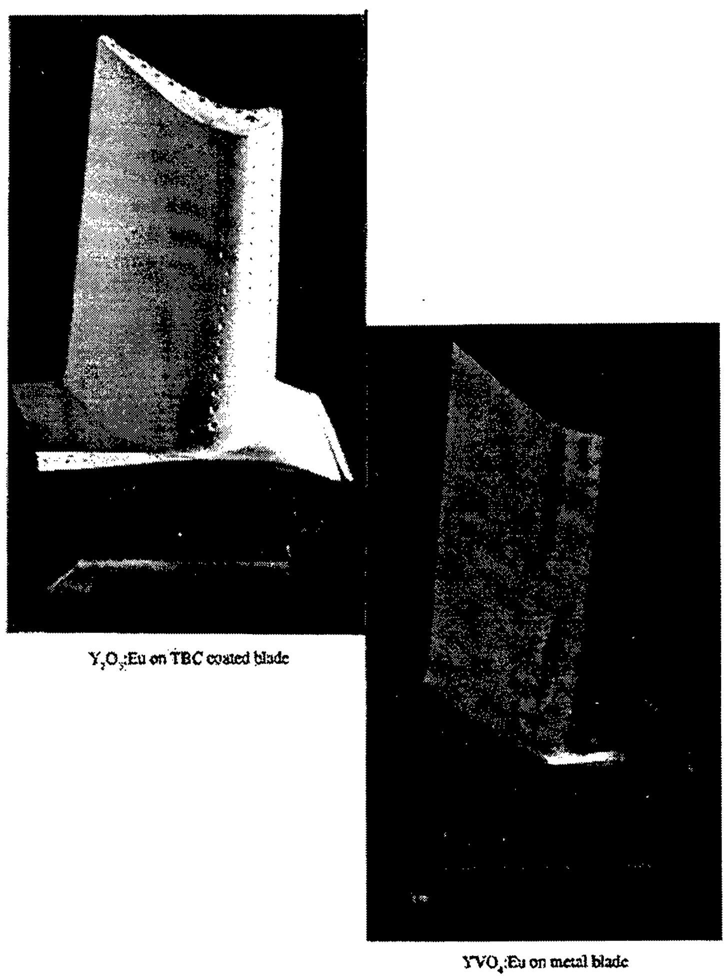


Figure 17. Two Pre-Test ATEGG E-Beam Coated Blades Illuminated by UV Light Source

Additionally, the Air Force has identified non-contact 2-D pressure mapping as part of its HCF Compressor Instrumentation Turbine S&T plan. Two of the candidate pressure mapping technologies (pressure sensitive paint and thin film etalons) have a marked temperature artifact. In order to successfully apply either of these pressure mapping technologies in an engine environment it will be necessary to have some means of measuring the sensor temperature. It is proposed that thermographic phosphors be incorporated in both pressure sensitive paints and thin film etalons in order to utilize LIF techniques to measure the pressure sensor temperature.

POINTS OF CONTACT

Government

Name: Bill Stange
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth St., Bldg. 18
WPAFB, OH 45433-7251

Phone Number: (937) 255-2351
Fax Number: (937) 255-2660
Email: stangewa@wl.wpafb.af.mil

4.7 *ADVANCED THIN FILM DYNAMIC STRAIN GAGES*

Approach: Develop Advanced Thin Film Dynamic Strain Gages

Description: The objective of this program is to develop thin film strain gages with increased life and greater temperature capability. In order to achieve this goal, efforts are underway in-house to develop and utilize the already successful LeRC PdCr static strain gauge for dynamic strain measurement and to investigate the use of ceramic strain gauge materials at the University of Rhode Island.

POINTS OF CONTACT

Government

Name: Dr. Jih-Fen Lei
Organization: NASA LeRC
Address: 21000 Brookpark Rd., M/S 77-1
Cleveland, OH 44135

Phone Number: (216) 433-3922
Fax Number: (216) 433-8643
Email: jlei@lerc.nasa.gov

5.0 ***PASSIVE DAMPING TECHNOLOGY***

CHARTER

RESPONSIBILITIES

The Passive Damping Technology Action Team (Damping AT) has the responsibility of fostering collaboration between individual HCF passive damping efforts with the overall goal of damping component resonant stress by 60% for fans and turbines. The Damping AT provides technical coordination and communication between active participants involved in HCF passive damping technology. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair and selected Damping AT members meet as required (estimated quarterly) to review damping activities, develop specific goals for passive damping programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the Damping AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in damping technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Don Zabierek - Chair
U.S. Air Force
AFRL/VASF, Bldg. 24C, Rm. 218
2145 Fifth St., WPAFB, OH 45433-7006
Ph: (937) 255-5200 x304 Fax: (937) 255-6684
zabierdw@msmail.fibg.wpafb.af.mil

Dr. David Barrett - Co-Chair
U.S. Navy
NAVAIR SYSCOM
Structures Division
Bldg. 2187, Ste. 2340, Unit 5
48110 Shaw Road
Patuxent River, MD 20670-1906
Ph: (301) 342-9360 Fax: (301) 342-9412
barrett_dave%pax5@mr.nawcad.navy.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

5.1 *DAMPING SYSTEMS FOR IHPTET*

Goals: Address the design, fabrication, instrumentation, bench testing and spin testing of various damping systems applicable to both fan and compressor blisks. Improve design baseline of compaction effects on particle damping.

Approach: This is a thirty-five month effort with two phases. The first phase will investigate the feasibility of using a viscoelastic system. The second phase will evaluate the use of particle systems as damping systems on fan/compressor blisks.

FY97 Progress:

XTE45 Blisk selected as first component

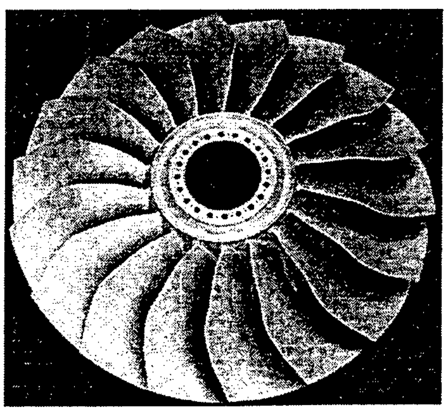
Particle damping concept selected as damping approach

Drill and screw concept and small cavity with insert are the two concepts being considered

Advanced Core Compression System (ACCS) blisk selected as other component

Viscoelastic damping system selected for this component

Particle compaction investigation initiated



GEAE XTE45 Fan Blisk

FIGURE 18. GE Component Selected

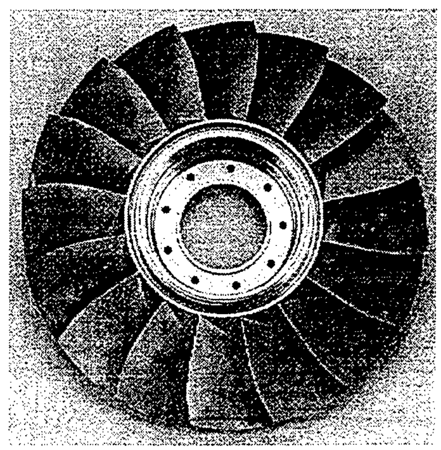


FIGURE 19. Allison Component Selected

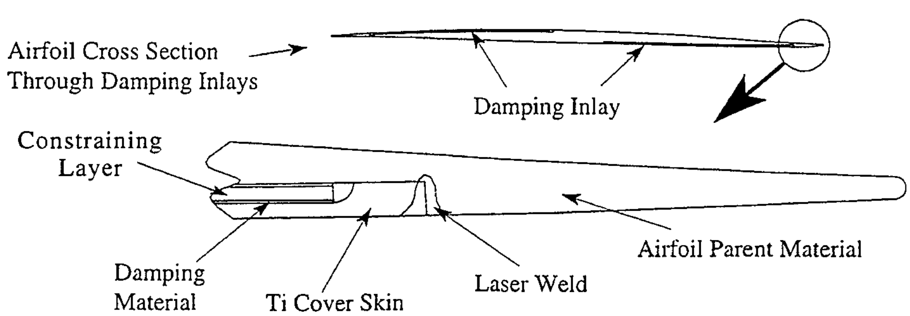


FIGURE 20. Blisk Damping Concept

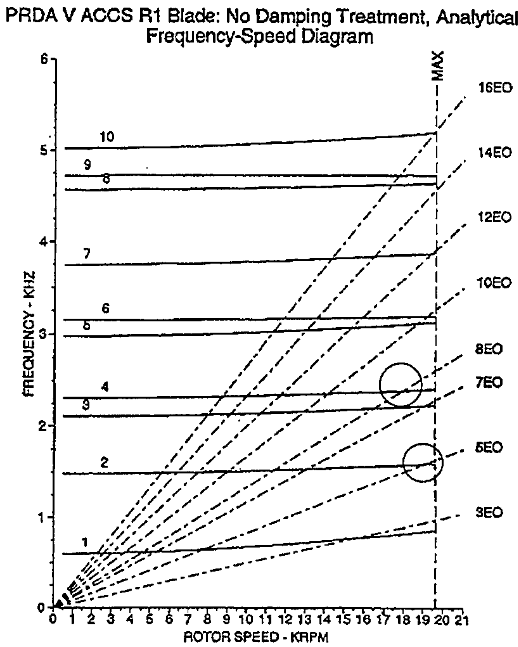


FIGURE 21. Design Area

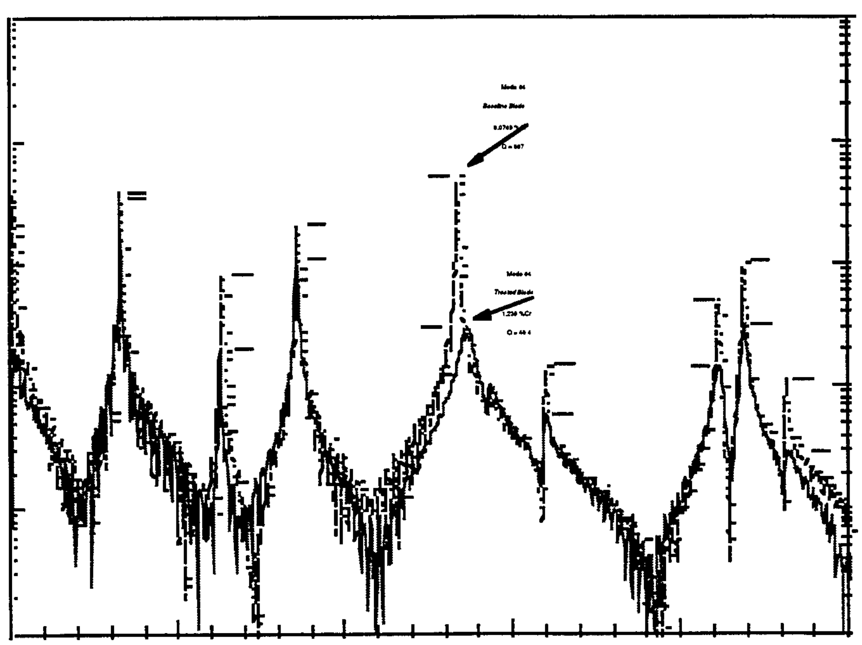


FIGURE 22. Damped vs Undamped Compressor Blade

POINTS OF CONTACT

Government
Name: Mr. Frank Lieghley Jr.
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lieghlfw@wl.wpafb.af.mil

Contractor
Name: Mr. Robert Kielb
Organization: General Electric Aircraft Engines
Address: One Nuemann Way
Cincinnati, OH 45215-1988
Phone Number: (513) 243-2821
Fax Number: (513) 243-2944
Email: robert.re.kielb@ae.ge.com

5.2 *ADVANCED DAMPING CONCEPTS TO REDUCE HCF*

Goals: Design damping into two fan/compressor components. Validate this design system with a spin test.

Approach: During the initial portion of the contract, several damping concepts will be evaluated. There will then be a down select to one concept. The selected component will be redesigned using this concept to increase damping in that component. The new design will be validated in a spin test.

FY97 Progress:

Literature search completed

Damping materials are being identified and trade studies are being performed to select the systems and designs that have the best opportunity of supplying effective damping

Test specimen configurations have been developed for the NASA Lewis spin pit

A detailed test plan is being developed for damping tests in the NASA Lewis spin pit

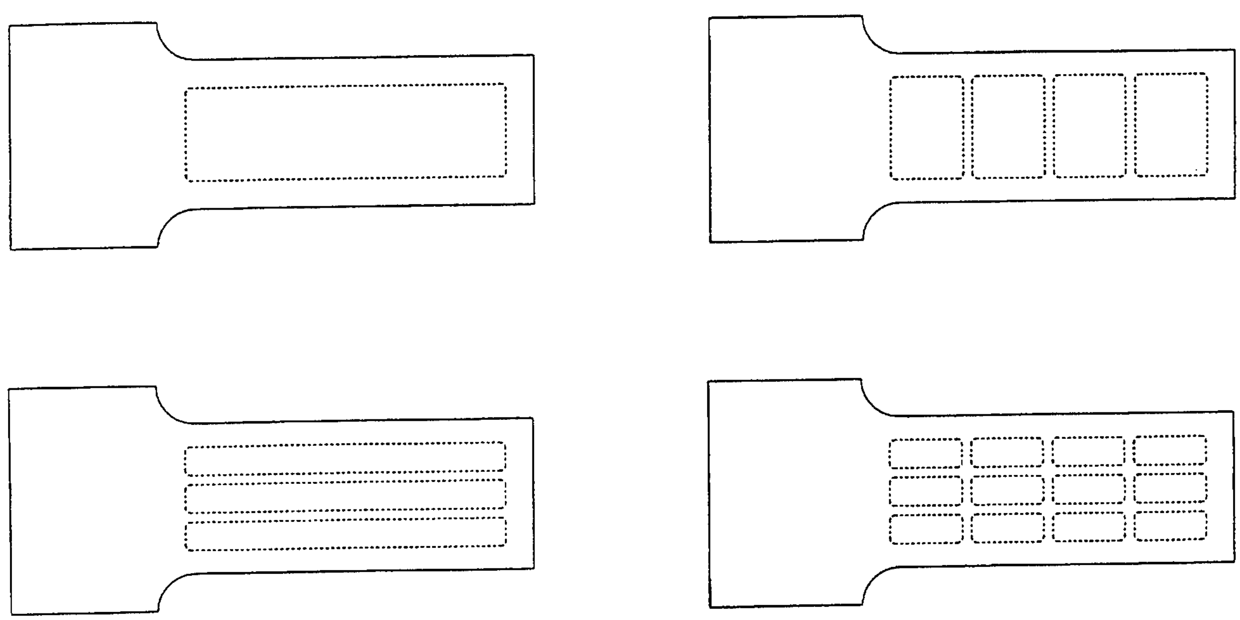


FIGURE 23. UDRI Spin Pit Blade Configurations

POINTS OF CONTACT

Government
Name: Mr. Frank Lieghley, Jr.
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lieghlfw@wl.wpafb.af.mil

Contractor
Name: Mr. Mike Drake
Organization: University of Dayton Research Inst.
Address: 300 College Park Ave
Dayton, OH 45469-4251
Phone Number: (937) 229-2654
Fax Number: (937) 229-4251
Email: drakeml@udri.udayton.edu

5.3 *WL/FI DAMPING INVESTIGATIONS*

Goals: Contribute to the state-of-the-art in damping technology by providing critical in-house research in areas that will provide the needed information to optimize a design system that accurately predicts damping in components.

Approach: As items are identified that are within the scope of in-house capabilities and there are sufficient funds available, a task will be established to perform the work. To date there have been four tasks established.

FY97 Progress:

- Experimental study of fan blade damping with viscoelastic materials in internal cavities completed
- Numerical study defining the behavior of bladed disks with non-uniform damping performed

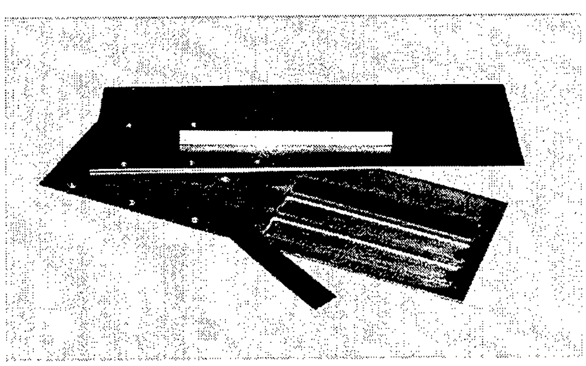


FIGURE 24. VEM Blade Structure

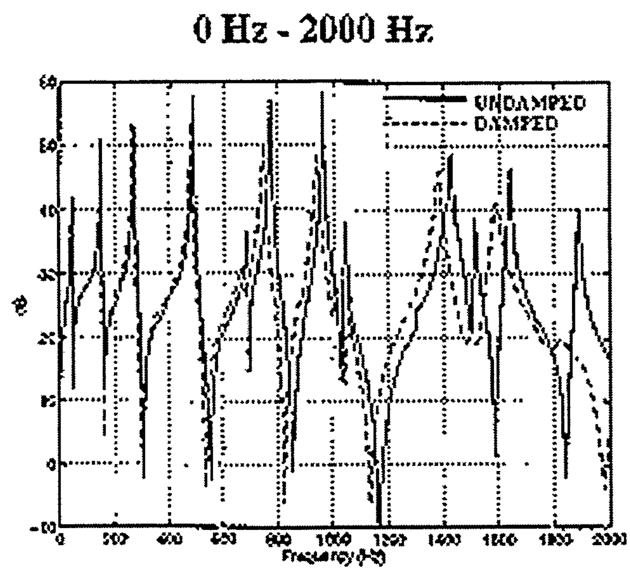


FIGURE 25. Test Results

POINTS OF CONTACT

Government
Name: Mr. Robert Gordon
Organization: U.S. Air Force, AFRL/VASV
Address: 2145 Fifth Street, Ste. 2
Bldg. 24C, RM 214A
WPAFB, OH 45433-7006

Phone Number: (937) 255-5200 ext. 402
Fax Number: (937) 255-6684
Email: bob@msmail.fibg.wpafb.af.mil

5.4 *VISCOELASTIC HYDROSTATIC DAMPING TECHNOLOGY*

An in-house study at Wright-Patterson AFB found that hydrostatic pressure generated by the internal damping material is a concern. In response to this, CSA was tasked to investigate the influence of hydrostatic pressure on viscoelastic materials in cavities of gas turbine engine airfoils. The objectives are as follows:

1. Develop an approach for accurately measuring the Poisson's ratio of viscoelastic materials.
2. Understand the behavior of viscoelastic damping materials in enclosed cavities subject to large centrifugal loads.
3. Experimentally verify that finite element analysis can accurately model the hydrostatic pressure in VEM on the surrounding structures.

Currently, CSA is conducting three activities. They are bench testing, spin testing and conducting analysis pertinent to this topic. The bench testing and spin testing are underway, and the spin testing will take place at Test Devices within the next few months. There are no firm results or data to report at this time.

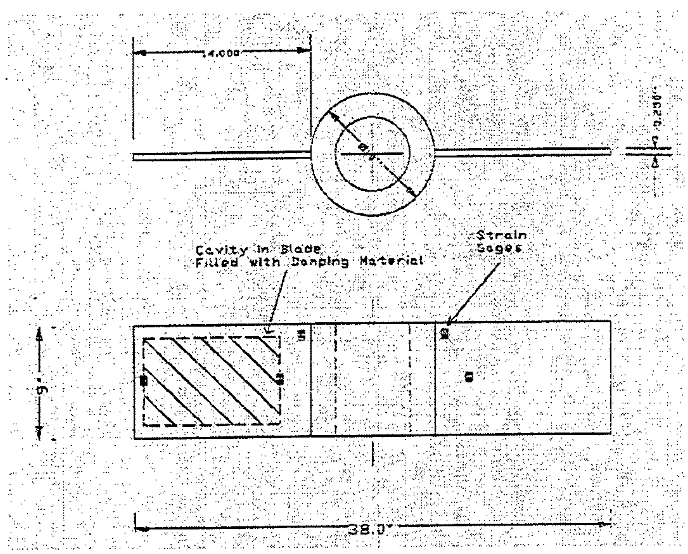


FIGURE 26. Test Blade

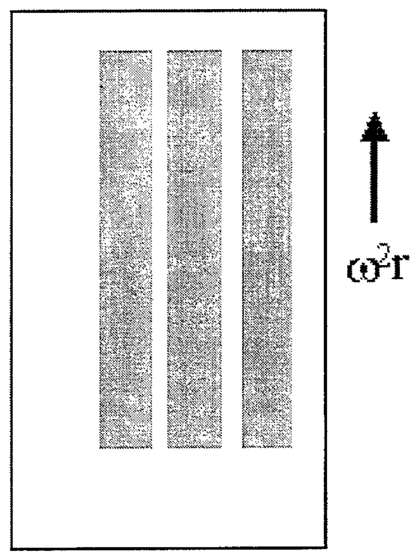


FIGURE 27. VEM Orientation

POINTS OF CONTACT

Government
Name: Lt Michael Bettencourt
Organization: U.S. Air Force, AFRL/VASV
Address: 2145 Fifth Street, Ste. 2
Bldg. 24C, RM 214
WPAFB, OH 45433-7006
Phone Number: (937) 255-5200 ext. 453
Fax Number: (927) 255-6684
Email: bettenmv@msmail.fibg.wpafb.af.mil

Contractor
Name: Dr. Coner Johnson
Organization: CSA Engineering, Inc.
Address: 2850 West Bayshore Rd.
Palo Alto, CA 94303-3843

Phone Number: (415) 494-7351
Fax Number: (415) 494-8749
Email: cjohnson@csaengr.com

5.5 *POWDER DAMPING TECHNOLOGY*

Goal: Characterize damping mechanism of encapsulated fine metal-oxide powders and their ability to damp a turbine engine component under centrifugal loads or extreme pressure. Apply this technology to Aircraft Exhaust Washed Structures.

Approach: This program has three major tasks. The first task is the characterization of the powder damping system's ability to damp various HCF modes on the component. The next task is the testing of this system under centrifugal loads and extreme pressure. The final task is taking what has been learned from the first two tasks and applying it to an Aircraft Exhaust Washed Structures.

FY97 Progress:

Mohawk has completed the design, analysis and test of the TiO_2 powder damping system

CSA has initiated, using different testing apparatuses, their own independent evaluation of the Mohawk powder damping system

Final report should be out in early FY98

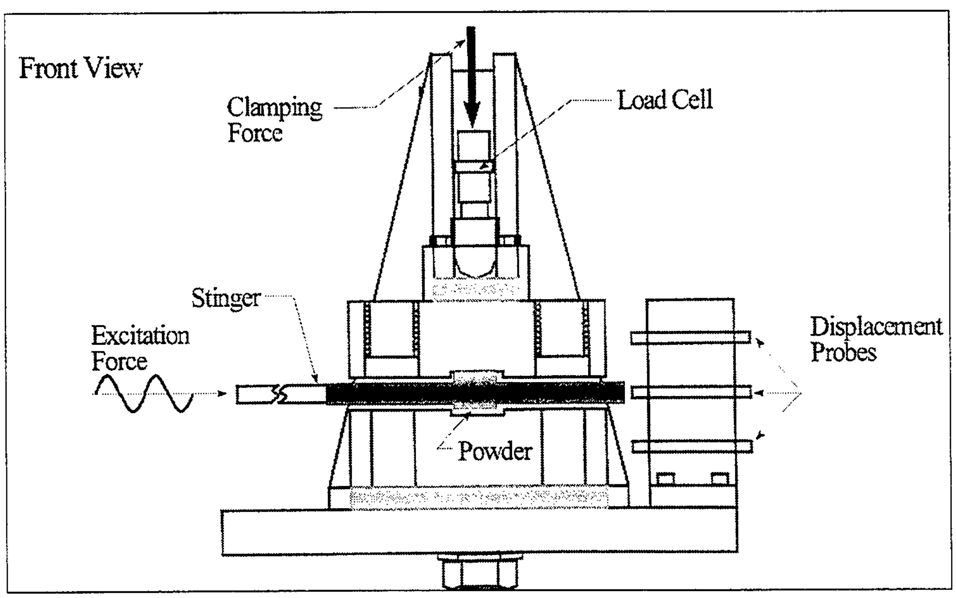


FIGURE 28. Test Bed

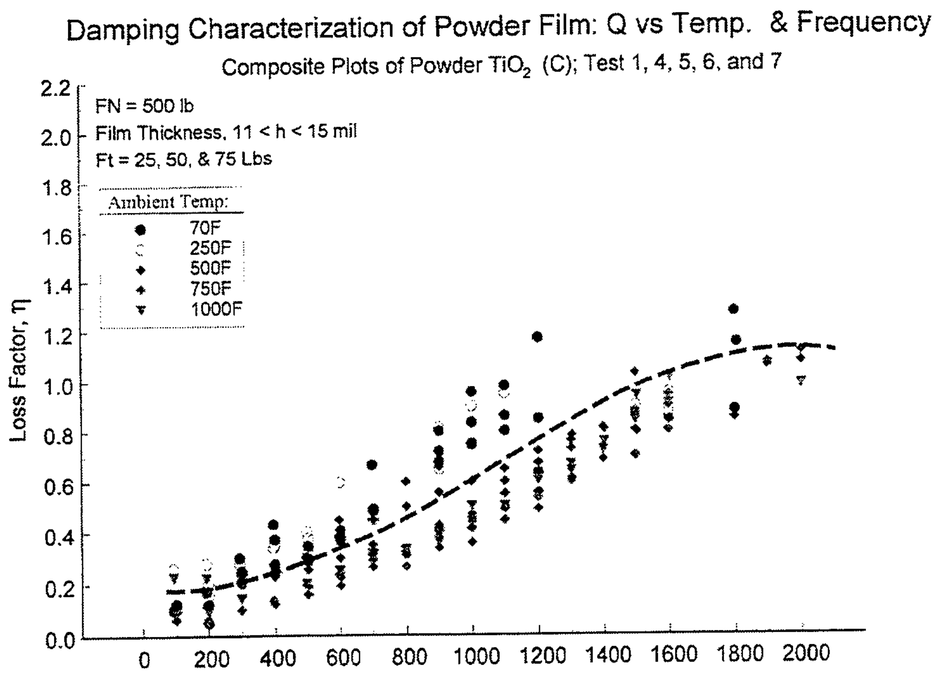


FIGURE 29. Test Results

POINTS OF CONTACT

Government
Name: Capt Cindy Hustedde
Organization: U.S. Air Force, AFRL/VASV
Address: 2145 Fifth Street, Ste. 2
Bldg. 24C, RM 214
WPAFB, OH 45433-7006
Phone Number: (937) 255-5200 ext. 408
Fax Number: (927) 255-6684
Email: hustedcl@msmail.fibg.wpafb.af.mil

Contractor
Name: Dr. Conor Johnson
Organization: CSA Engineering, Inc.
Address: 2850 West Bayshore RD
Palo Alto, CA 94303-3843

Phone Number: (415) 494-7351
Fax Number: (415) 494-8749
Email: cjohnson@csaengr.com

5.6 *COMPACTION EFFECTS ON PARTICLE DAMPING*

Goal: Develop and validate an analytical model for effects of compaction on particle damping.

Approach: An analytical model will be developed that incorporates the effects of compaction on a particle damping system. A series of tests will be performed to provide the needed data for the model. The final proof of the model will be a spin test.

FY97 Progress:

Contract awarded to General Electric

Work will be accomplished in IHPTET damping program

POINTS OF CONTACT

Government
Name: Mr. Frank Lieghley Jr.
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lieghlfw@wl.wpafb.af.mil

Contractor
Name: Dr. Robert Kielb
Organization: General Electric Aircraft Engines
Address: One Neumann Way
Cincinnati, OH 45215-1988
Phone Number: (513) 243-2821
Fax Number: (513) 243-2944
Email: robert.re.kielb@ae.ge.com

5.7 *MECHANICAL DAMPING CONCEPTS*

Goal: Develop composite blades with a co-cured viscoelastic damping material. Demonstrate other new damping approaches.

Approach: There are four major tasks in this program.

- Design and analyze a composite blade with the co-cured viscoelastic damping material
- Spin test blades to verify damping characteristics
- Design, analyze and fabricate impact damping systems
- Test verification of impact damping systems

FY97 Progress:

- Composite blades successfully spin tested
- Impact damping systems designed and fabricated
- Initial spin test on impact damping systems started

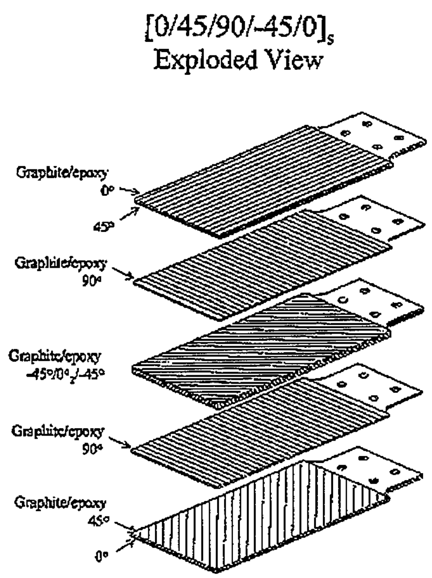


FIGURE 30. Undamped Blade

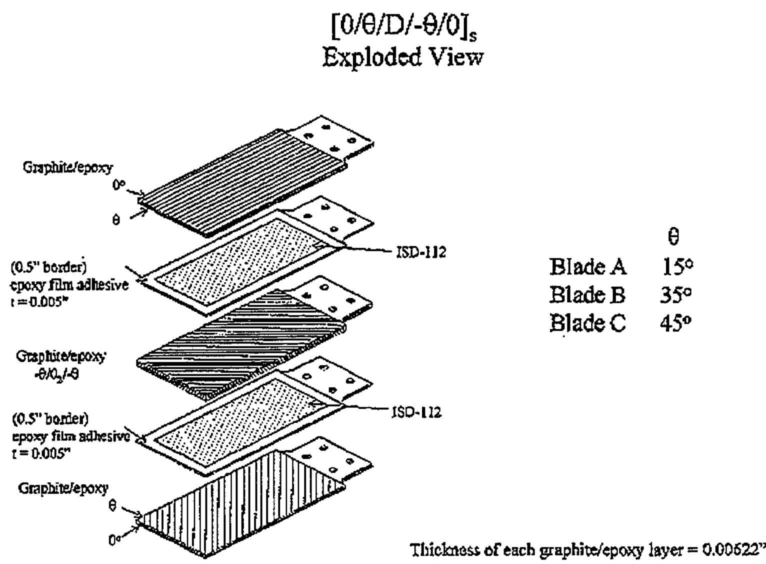


FIGURE 31. Damped Blade

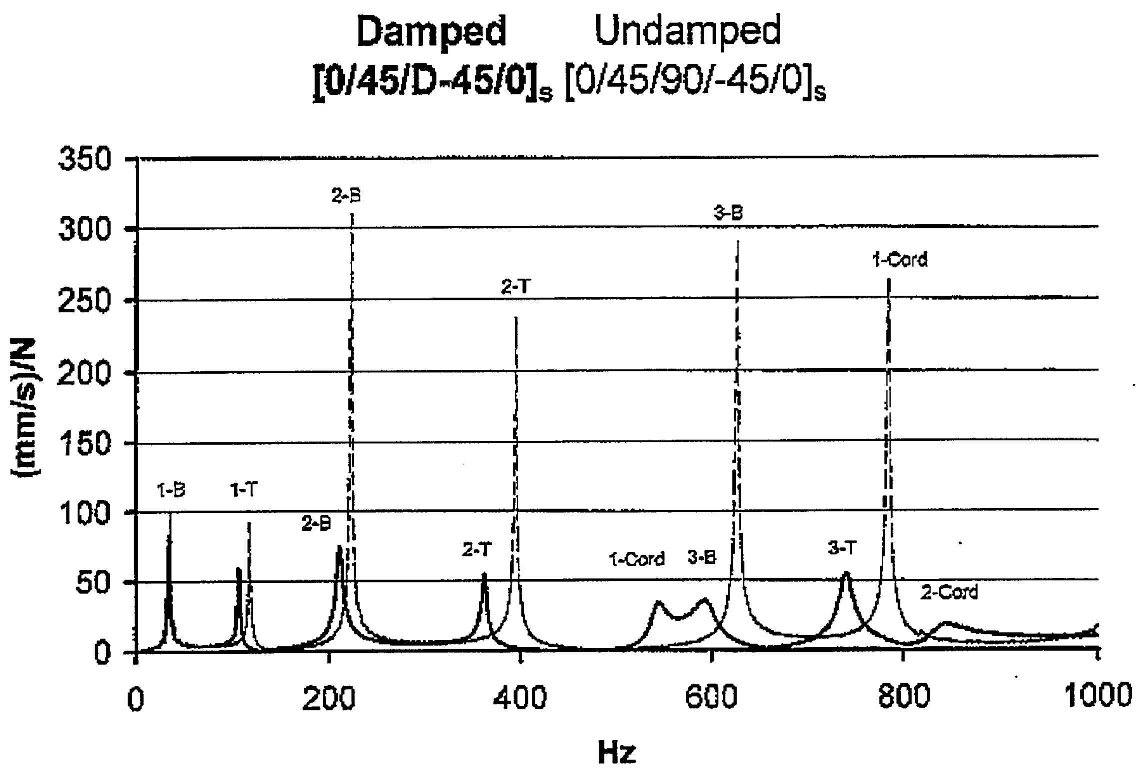


FIGURE 32. Spin Pit Test Results

POINTS OF CONTACT

Government
Name: Mr. Oral Mehmed
Organization: NASA Lewis Research Center
Address: 21000 Brookpark Rd
Cleveland, OH 44135
Phone Number: (216) 433-6036
Fax Number: (216) 977-7051
Email: oral.mehmed@lerc.nasa.gov

Contractor
Name: Mr. John Kosmatka
Organization: University of California
Address: 9500 Gilman Dr 0085
San Diego, CA 92093-0085
Phone Number: (619) 534-1779
Fax Number: (619) 534-6373
Email: kosmatka@ames.uscd.edu

5.8 *EVALUATION 0F INTERNAL DAMPERS*

This is a contract extension on contract "Experimental Evaluation of Reinforced Swept Airfoils." The goal of this program is to develop an internal friction damping system in a fan component.

Approach: The internal friction damper will be designed and analyzed to maximize damping characteristics of the system. Under a different task of the program (not considered HCF money) the system will then be installed into the fan component and spin tested and its damping characteristics verified.

FY97 Progress:

- The finite element model for the system was completed
- The damping model for the finite element model was developed and added
- A damping prediction analysis was performed on the component
- Analytical model verified with test data

POINTS OF CONTACT

Government
Name: Lt Jeff Brown
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-2734
Fax Number: (937) 255-2660
Email: brownjm@wl.wpafb.af.mil

Contractor
Name: Dr. Yehia El-Aini
Organization: Pratt & Whitney
Address: P.O. Box 109600, MS 714-03
West Palm Beach, FL 33410-9600
Phone Number: (561) 796-5911
Fax Number: (561) 796-8993
Email: elainiye@pwfl.com

5.9 *DAMPING FOR EXTREME ENVIRONMENTS*

Submitted as an SBIR proposal to the topic of damping for extreme environments, this SBIR was awarded and initiated on June 11, 1997. The objectives of this program are:

1. Develop a multi-particle impact damping (MPID) material characterization test procedure to enhance the understanding of the damping mechanisms and obtain MPID damping properties.
2. This methodology will be validated in "proof-of-methodology" testing on a structural component in the Phase I program.
3. The validated MPID design methodology will then be used to perform preliminary damping treatment design for a Pratt & Whitney hot engine component to be tested in Phase II.

The focus of this program is on non-rotating structures which allows the contractor to concentrate on the fundamental technical issue currently limiting the use of MPID – lack of a validated design methodology. In the latter part of the Phase I effort an appropriate high temperature structural component from a Pratt & Whitney gas turbine engine will be identified for MPID treatment in the Phase II effort. The intent of the Phase II demonstration will be to validate the MPID design methodology for this and other high temperature non-rotating engine components. (Nozzle guide vanes are given as an example).

Currently, this project is underway and CSA has pulled in UDRI as a subcontractor. They have completed preliminary particle damper parameter characterization testing, constructed finite element models of the beam configurations, and completed a test plan.

POINTS OF CONTACT

Government
Name: Lt Michael Bettencourt
Organization: U.S. Force, AFRL/VASV
Address: 2145 Fifth Street, Ste. 2
Bldg. 24C, RM 214
WPAFB, OH 45433-7006
Phone Number: (937) 255-5200 ext.453
Fax Number: (937) 255-6684
Email: bettenmv@msmail.fibg.wpafb.af.mil

Contractor
Name: Dr. Conor Johnson
Organization: CSA Engineering, Inc.
Address: 9500 Gilman Dr 0085
Palo Alto, CA 94303-3843
Phone Number: (415) 494-7351
Fax Number: (415) 494-8749
Email: cjohnson@csaengr.com

6.0 *COMPONENT SURFACE TREATMENTS*

CHARTER

RESPONSIBILITIES

The Component Surface Treatments Action Team (Surface Treatments AT) has the responsibility of fostering collaboration between individual HCF surface treatment efforts with the goal of increasing leading edge defect tolerance by 15x (5 mils to 75 mils). The Surface Treatments AT provides technical coordination and communication between active participants involved in Laser Shock Peening (LSP) and related technologies. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Surface Treatments AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for LSP programs, and coordinate with the Technical Plan Team (TPT) and National Coordinating Committee (NCC). The Chairman (or Co-Chair) of the Surface Treatments AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in surface treatment technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Mr. Tim Swigart - Chair
U.S. Air Force
AFRL/MLMP, Bldg. 653
2977 P St., Ste. 6, WPAFB, OH 45433-7739
Ph: (937) 255-2413 Fax: (937) 656-4420
swigartc@ml.wpafb.af.mil

Mr. Chris Lykins - Co-Chair
U.S. Air Force
AFRL/PRTC, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7251
Ph: (937) 255-1867 Fax: (937) 255-2660
lykinscd@wl.wpafb.af.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

6.1 *LSP COMPONENT EVALUATION*

This effort compared shot peening to the LSP process. First stage F101 blades were processed, notched and fatigue tested. Crack growth was arrested in the LSP airfoils, but the shot peened airfoils failed below the designated life cycles.

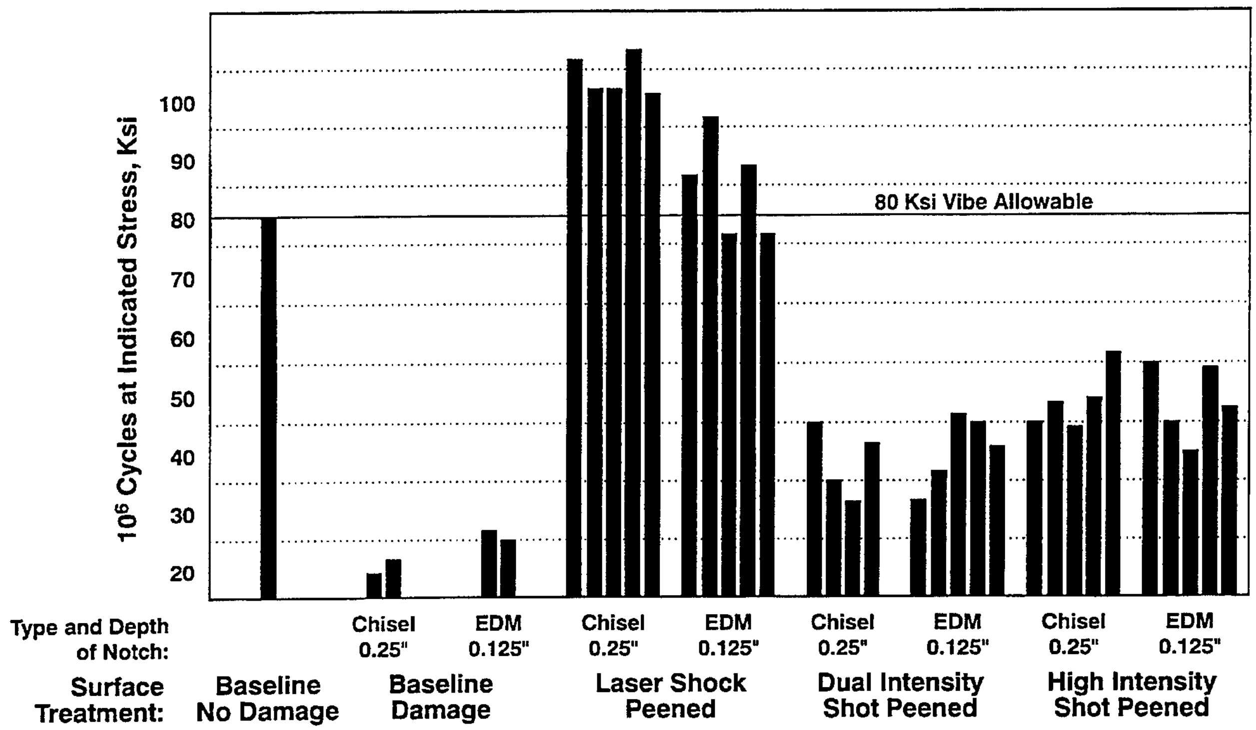


FIGURE 33. Siren Testing Device Heated 24 Hr at 400°F Before Testing at Room Temperature

POINTS OF CONTACT

Government
Name: Chris Lykins
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lykinscd@wl.wpafb.af.mil

Contractor
Name: Dennis Corbly
Organization: GE Aircraft Engines
Address: One Neumann Way, M/D G407
Cincinnati, OH 45215-6301
Phone Number: (513) 243-5832
Fax Number: (513) 243-1647
Email:

6.2 *LSP COMPETITION*

In September 1995, a comparative study between a new surface treatment technology, termed laser shock peening (LSP), and an established surface treatment technology, termed shot peening, was conducted. This effort was designed to evaluate the damage tolerance improvements of these processes; specifically, rating their influence for enhancing the fatigue life of foreign object damaged turbine engine fan blades. Critical blade characteristics, such as surface finish and changes in aerodynamics profile, as well as manufacturability, were factored into the evaluation. The test matrix was configured to make the assessment as realistic and objective as possible. Results indicate that LSP'd blades which were then damaged exhibited better than or equal fatigue strength properties compared to undamaged baseline blades.

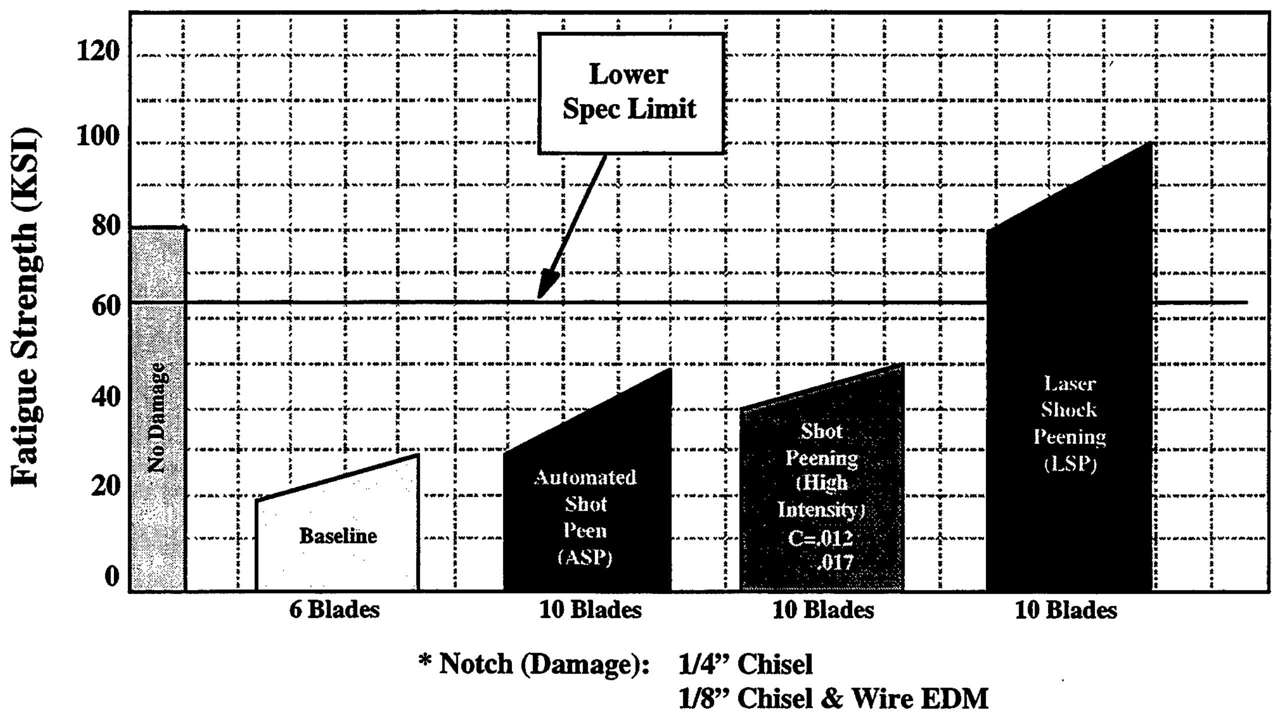


FIGURE 34. Damage Tolerance Information Indicating LSP'd Blades Provide the Same Fatigue Strength as Undamaged, Baseline Blades

POINTS OF CONTACT

Government
Name: David W. See
Organization: U.S. Air Force, AFRL/MLMP
Address: 2977 P Street, Ste. 6, Bldg. 653
WPAFB OH 45433-7739
Phone Number: (937) 255-3612
Fax Number: (937) 656-4420
Email: seedw@ml.wpafb.af.mil

Contractor
Name: Paul Sampson
Organization: GRC International, Inc.
Address: 2940 Presidential Drive, Ste. 390
Fairborn, OH 45324-6223
Phone Number: (937) 429-7773
Fax Number: (937) 429-7769
Email: psampson@grci.com

6.3 *LSP OPTIMIZATION SBIR I*

The objective was to try and optimize the spot shape in order to get an improvement in the residual stress profile and decrease processing time. Elliptical spots were compared to the standard round spots. In addition, the contractor investigated laser system modifications. They were able to increase the rise time and sharpen the laser pulse.

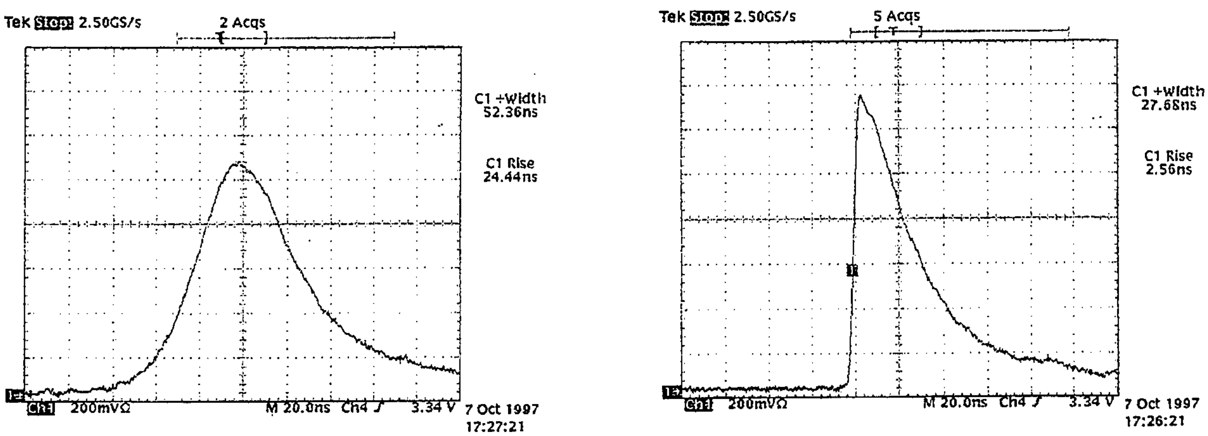


FIGURE 35. Peak Rise Time Before & After Laser System Modifications

POINTS OF CONTACT

Government
Name: Chris Lykins
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lykinscd@wl.wpafb.af.mil

Contractor
Name: Allan H. Clauer, PhD.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272
Phone Number: (614) 718-3000, ext 12
Fax Number: (614) 718-3007
Email: allan.clauer-lspt@worldnet.att.net

6.4 *LSP OPTIMIZATION SBIR II*

The primary objective of this Phase II Small Business Innovative Research effort is to develop a prototype laser peening facility capable of peening production volumes of "small parts," such as turbine engine blades. The focus of the effort is the design and development of a 200 Joule pulsed Nd:Glass laser capable of 1/2 Hz processing speed. Also of major importance is the development of a workstation, which will consist of a five axis articulated robot for parts positioning and an appropriate containment chamber. System acceptance testing is scheduled for late October 1997.

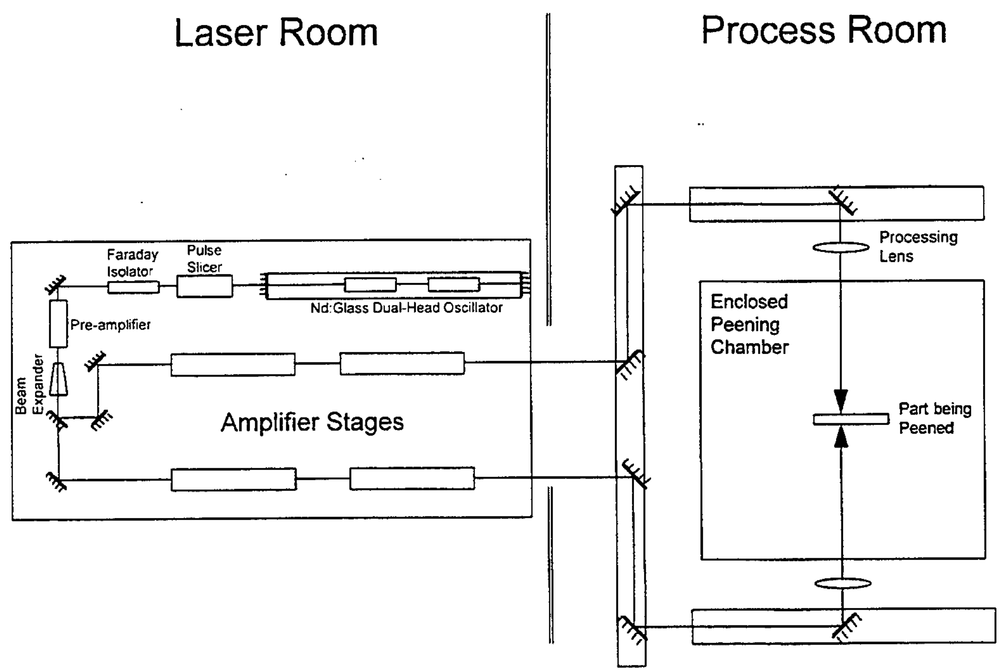


FIGURE 36. Schematic of Laser System Operations

POINTS OF CONTACT

Government
Name: Timothy C. Swigart
Organization: U.S. Air Force, AFRL/MLMP
Address: 2977 P Street, Ste. 6, Bldg. 653
WPAFB OH 45433-7739
Phone Number: (937) 255-3612
Fax Number: (937) 656-4420
Email: swigartc@ml.wpafb.af.mil

Contractor
Name: Jeff L. Dulaney, Ph.D.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272
Phone Number: (614) 718-3000 ext 11
Fax Number: (614) 718-3007
Email: jeff.dulaney-lspt@worldnet.att.net

6.5 *PROCESS MODELING LSP STTR I*

The objective of this effort was to model the LSP impact event. One spot processing was modeled by placing improved constitutive relations into a finite element code built for dynamic modeling. The residual stress predicted was compared to existing x-ray diffraction data. A Phase II STTR has been awarded to carry forward these concepts to predict multiple spot processing residual stress profiles.

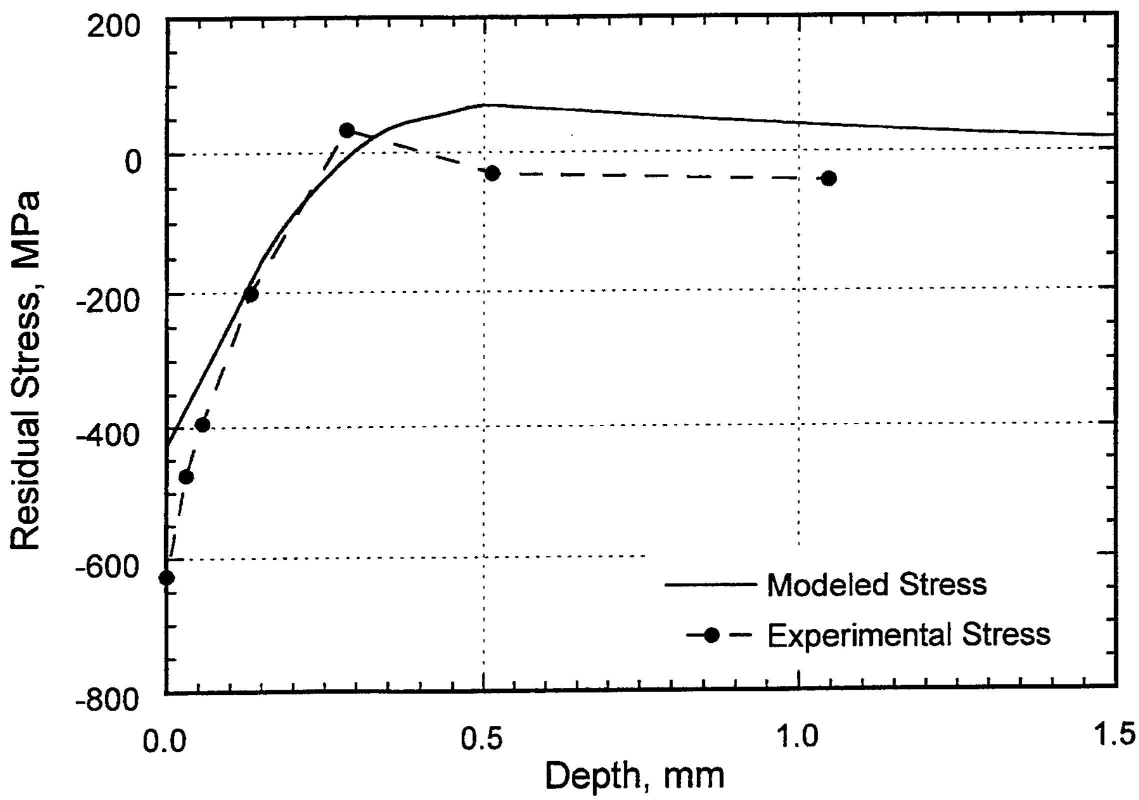


FIGURE 37. Comparison of Modeled and Experimental Residual Stresses for Estimated Similar Pressure Conditions (LSP Technologies, Inc.)

POINTS OF CONTACT

Government
Name: Joseph Burns
Organization: U.S. Air Force, AFRL/MLLN
Address: 2230 Tenth Street, Ste. 1, Bldg. 655
WPAFB OH 45433-7281
Phone Number: (937) 255-1360
Fax Number: (937) 255-4840
Email: burnsjg@ml.wpafb.af.mil

Contractor
Name: Allan H. Clauer, PhD.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272
Phone Number: (614) 718-3000, ext 12
Fax Number: (614) 718-3007
Email: allan.clauer-lspt@worldnet.att.net

6.6 *PROCESS MODELING LSP STTR II*

The objective of this effort is to develop a predictive capability for the compressive stress distribution produced in a part or structure by laser shock peening. Such a predictive capability would substaintially shorten the development time and costs for new applications and alloys. With predictive tools of this type, the effectiveness and implementation of laser peening can be improved rapidly beyond what has already been demonstrated.

In this Phase II STTR effort, the modeling effort developed in Phase I will be extended in greater detail in directions of significant importance to the application of laser shock peening. Specific tasks are: 1) Determine the residual stress distributions for a wider range of laser peening parameters applied to both thick and thin sections; 2) Determine the changes in the residual stresses caused by geometric features such as holes, edges, and curved surfaces, and peening conditions such as overlapping spots; 3) Develop the data into a design curve utility that can be used to easily look up residual stress profiles to be expected from various laser peening conditions; 4) Broaden the materials base from Ti-6AI-4V to other metals and alloys, and 5) Structure the model outputs so they can be used as inputs to other analytical models.

POINTS OF CONTACT

Government
Name: Joseph Burns
Organization: U.S. Air Force, AFRL/MLLN
Address: 2230 Tenth Street, Ste. 1, Bldg. 655
WPAFB OH 45433-7281
Phone Number: (937) 255-1360
Fax Number: (937) 255-4840
Email: burnsjg@ml.wpafb.af.mil

Contractor
Name: Allan H. Clauer, PhD.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272
Phone Number: (614) 718-3000, ext 12
Fax Number: (614) 718-3007
Email: allan.clauer-lspt@worldnet.att.net

6.7 *LSP RAPID OVERLAY SBIR I*

In the early stage of the application of laser shock peening, the manufacturing aspects of the process have not been developed to an acceptable level. One of the significant shortcomings of the current process is the slow rate of processing. The major factor in this slow processing rate is the application and removal of the opaque overlay system, in this case, paint. Current practice requires the application and removal of the paint outside of the laser workstation. For a part that requires a number of shots, this necessitates placement into and removal from the laser workstation several times. This drastically slows the processing rate.

This Phase I Small Business Innovative Research effort addresses this problem by developing a concept to apply and remove the paint in real time, on-line for each shot. This will enable a part to remain in the workstation, being processed to completion without interruption.

This effort started on 5 May 1997 and is scheduled to be completed by 4 November 1997. A Phase II contract has been announced to carry on this work to ruggedize the proof of concept system and integrate it into the robust laser processing workstation funded through SBIR effort.

POINTS OF CONTACT

Government
Name: Timothy C. Swigart
Organization: U.S. Air Force, AFRL/MLMP
Address: 2977 P Street, Ste 6, Bldg. 653
WPAFB OH 45433-7739
Phone Number: (937) 255-3612
Fax Number: (937) 656-4420
Email: swigartc@ml.wpafb.af.mil

Contractor
Name: Allan H. Clauer, Ph.D.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272
Phone Number: (614) 718-3000 ext 12
Fax Number: (614) 718-3007
Email: allan.clauer-lspt@worldnet.att.net

6.8 *LSP RAPID OVERLAY SBIR II*

This is a follow on effort to the successful Phase I concept demonstration to apply and remove the opaque layer automatically while processing a component in the laser workstation. This effort will also confirm the viability of using diffractive optics to deliver a square beam to the surface of a part and implement it into the Production Prototype Laser workstation. The result of this Phase II effort will be a rapid and more efficient laser peening system with the flexibility to accommodate a wide range of both Air Force and commercial applications.

POINTS OF CONTACT

Government
Name: Timothy C. Swigart
Organization: Manufacturing Technology
Address: AFRL/MLMP, Bldg. 653
2977 P. Street, Suite 6
WPAFB, OH 45433-7739
Phone Number: (937) 255-3612
Fax Number: (937) 656-4420
Email: swigartc@ml.wpafb.af.mil

Contractor
Name: Allan H. Clauer, PhD.
Organization: LSP Technologies, Inc.
Address: 6145B Scherers Place
Dublin, OH 43016-1272

Phone Number: (614) 718-3000, ext 12
Fax Number: (614) 718-3007
Email: allan.clauer-lspt@worldnet.att.net

6.9 *MT FOR AFFORDABLE LSP*

This FY98 new start will focus on investigating and implementing advanced monitoring and control techniques that will improve the effectiveness of laser shock peening and reduce the cost to process a part. Also required will be a business plan on how to commercialize LSP beyond the aerospace sector creating an industry capability either by providing an LSP service or the sale of equipment or both.

Anticipated award is mid-April 1998.

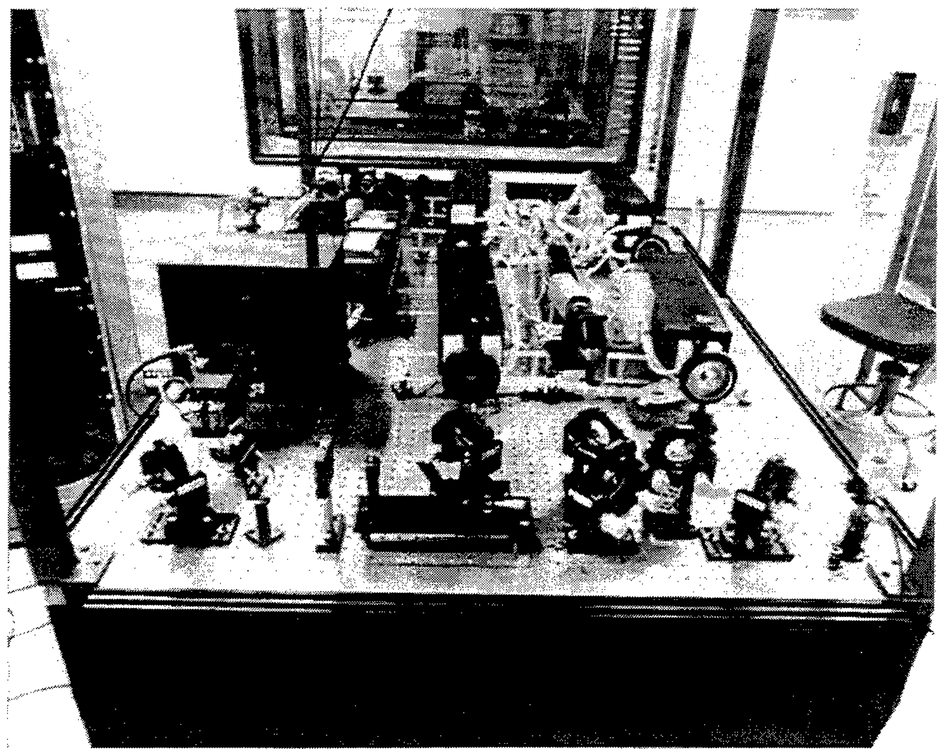


FIGURE 38. Prototype Laser Forming Table with Processing Room in the Background

POINTS OF CONTACT

Government

Name: Timothy C. Swigart
Organization: U.S. Air Force, AFRL/MLMP
Address: 2977 P Street, Ste. 6, Bldg. 653
WPAFB OH 45433-7739

Phone Number: (937) 255-3612
Fax Number: (937) 656-4420
Email: swigartc@ml.wpafb.af.mil

7.0 *AEROMECHANICAL CHARACTERIZATION*

CHARTER

RESPONSIBILITIES

The Aeromechanical Characterization Action Team (Aeromechanical AT) has the responsibility of fostering collaboration between individual HCF aeromechanical characterization efforts with the overall goal of providing the required design and test verification focus for the entire program. This AT provides technical coordination and communication between active participants involved in HCF testing technologies and the additional Test and Evaluation Plan, hosted by Arnold Engineering Development Center (AEDC). Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for test and evaluation programs, and coordinate with the TPT and NCC. The Chairman (or Co-Chair) of the AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis.

STRUCTURE

This AT includes members from government agencies, industry, and universities who are actively involved in Test and Evaluation technologies applicable to turbine engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related programs.

ACTION TEAM CHAIRMEN

Dr. Doug Rabe - Chair
U.S. Air Force
AFRL/PRTX, Bldg. 18
1950 Fifth St., WPAFB, OH 45433-7251
Ph: (937) 255-6802 x231 Fax: (937) 255-0898
rabedc@wl.wpafb.af.mil

Mr. Joe Babilon - Co-Chair
U.S. Air Force
AEDC/DOT, M/S 9011
1099 Ave. E, Arnold AFB, TN 37389-9011
Ph: (615) 454-3720 Fax: (937) 454-3559
babilon@hap.arnold.af.mil

INTRODUCTION

The following sections summarize goals, approaches and technical progress for some of the major current ongoing and planned efforts under this action team.

7.1 *HCF DESIGN VERIFICATION PROTOCOL COMMITTEE*

Approach: Provide guidelines for evaluating turbine engines for HCF.

Description: The development of the accepted engineering practice to evaluate turbomachinery components and full turbine engines for HCF has become the mission of the HCF Design Verification Protocol Committee. This committee was established in the summer of 1997 and has active industry and government participation. The recommended practices and guidelines developed by this committee will identify parameters requiring verification, detail verification techniques, recommend instrumentation, and link the verification with the design cycle. Currently the committee is scheduled to develop a formal charter by 1 November 1997 and identify initial practices by the first quarter of 1998.

POINTS OF CONTACT

Name: Dr. Doug Rabe
Organization: U.S. Air Force, AFRL/PRTX
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-6802 x231
Fax Number: (937) 255-0898
Email: rabedc@wl.wpafb.af.mil

Name: Dr. Kurt Nichol
Organization: Sverdrup Technology, Inc.
Address: 935 Avenue C, M/S 9800
Arnold AFB, TN 37389-9800
Phone Number: (615) 454-6929
Fax Number: (615) 454-3629
Email: nicholkl@hap.arnold.af.mil

7.2 *AEROMECHANICS TECHNOLOGY*

Approach: Determine appropriate techniques to measure inlet flow field distortion for HCF evaluation.

Description: When turbomachinery components and full turbine engines are evaluated for HCF resistance, the inlet flow field is frequently distorted to provide aerodynamic forcing similar to what would be present in aircraft installations. This inlet flow distortion is typically measured with 40 fixed probes that are arranged in five radial immersions at eight circumferential positions. This pattern of instrumentation has been found to adequately measure inlet flow distortion when compressors have been evaluated for stall margin sensitivity. However, for HCF evaluation, the flow field has to be more finely resolved. In order to determine the proper techniques, the inlet flow of test compressors in the Compressor Research Facility are to be evaluated in detail. From these detailed investigations and the resulting blade vibratory response, a new standard of inlet flow field measurement will be established. The figure shows a 3/rev distortion measured with a single rake of five radial immersions that has been circumferentially traversed. While the probe was traversed, pressure measurements were acquired at 0.5 degree increments. Therefore, this contour plot represents approximately 3600 data points. The frequency spectra for this data set shows that indeed the predominate frequency is 3/rev; however, it also shows significant energy is present at 1/rev, 9/rev and 15/rev which could also excite the component being evaluated. This new measurement technique identified these additional drivers which could adversely influence the results of an HCF evaluation of the component being tested. Ultimately this new measurement concept will lead to improved HCF evaluation techniques and more reliable turbine engines.

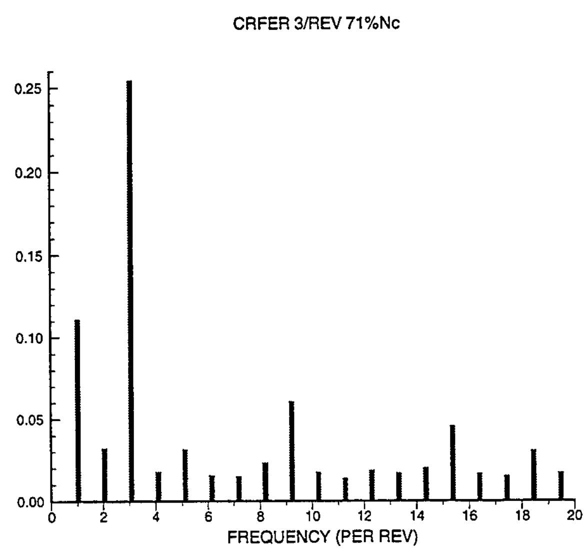


FIGURE 39. Frequency Spectra of Inlet Total Pressure

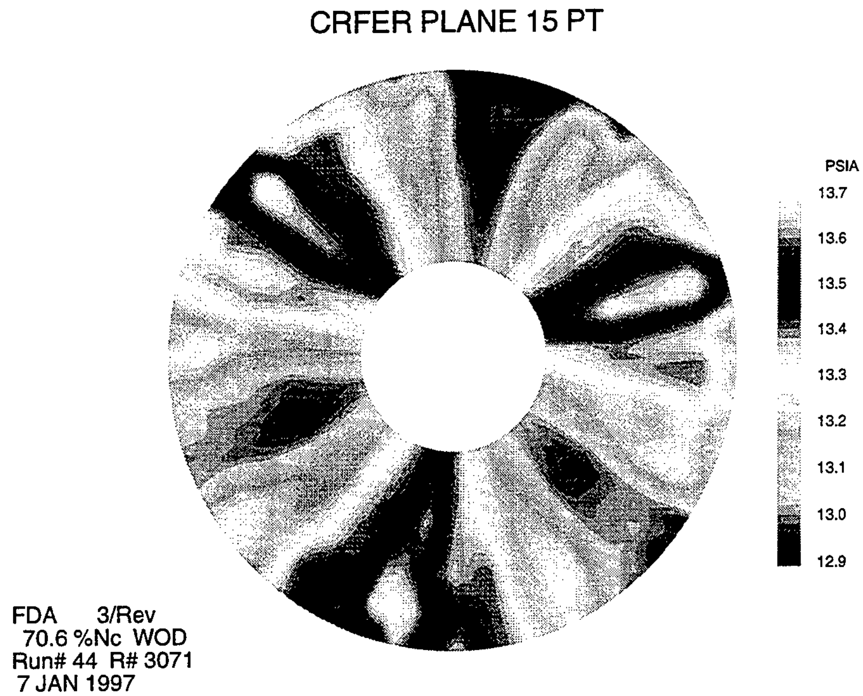


FIGURE 40. High Resolution Inlet Total Pressure Contour

POINTS OF CONTACT

Government

Name: Dr. Doug Rabe and Carl Williams
Organization: U.S. Air Force, AFRL/PRTX
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251

Phone Number: (937) 255-6802 x231
Fax Number: (937) 255-0898
Email: rabedc@wl.wpafb.af.mil
williac@terc.wpafb.af.mil

7.3 *COMPRESSOR AERO AND STRUCTURAL MISTUNING*

Goal: Characterize mistuning in a compressor rotor in which blade coupling through disk deflection is small. This allows the effects of aerodynamic damping on blade-to-blade stress variations to be examined because this is the major parameter which couples blades in such a rotor.

Approach: The first portion of this project is analysis of data acquired under the CRFER test program to determine response frequency, peak stress, and total damping for each blade at resonance. This data is used to determine whether blade-to-blade stress variations in the rotor can be attributed to aerodynamic damping. The effects of throttle condition are also investigated to determine how system-wide changes in aerodynamic blade loading affect blade-to-blade variations. The effect of blade-mounted pressure transducers is examined for two blades to determine if aerodynamic data can be acquired for each blade without disrupting the structural response. Finally, a reduced-order model which is the first to account for unsteady aerodynamics is tested in comparison to the experimental results.

Accomplishments: The project is nearing completion. All experimental data analysis is complete, and the reduced-order model has been run. The results from the reduced-order model are currently being correlated with experimental results.

POINTS OF CONTACT

Government
Name: Mr. James Kenyon
Organization: U.S. Air Force, AFRL/PRTE
Address: 1950 Fifth Street, Bldg. 18D
WPAFB, OH 45433-7251
Phone Number: (937) 255-6802
Fax Number: (937) 255-0898
Email: kenyonja@terc.wpafb.af.mil

7.4 *TURBINE ENGINE FATIGUE FACILITY (TEFF)*

7.4.1 *TEFF - COMPONENT INTEGRITY*

Research is conducted in this area in order to understand the 3-dimensional effects of material behavior. These effects can be introduced through multiaxial states of stress, complex load interaction or geometrically dependent processing effects.

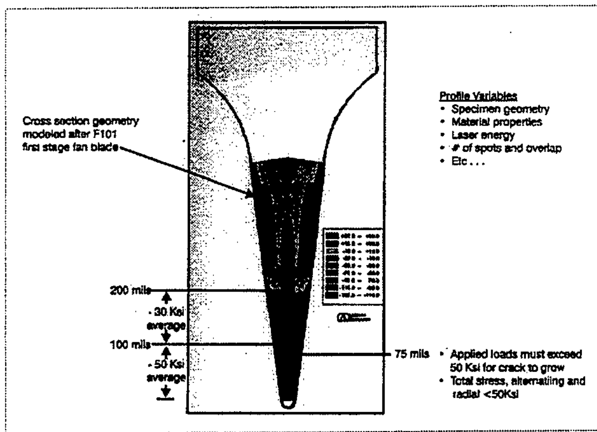


FIGURE 41. 3-Dimensional Nature of Compressive Residual Influence on Crack Growth Studied in the TEFF on Real Airfoils

7.4.2 *TEFF - VIBRATION*

Research is conducted in this area in order to conduct vibration assessments and to control the vibration response. Vibration assessment is carried out through deterministic and probabilistic methods. The control of the vibratory response is carried out by investigating and developing active and passive damping techniques.

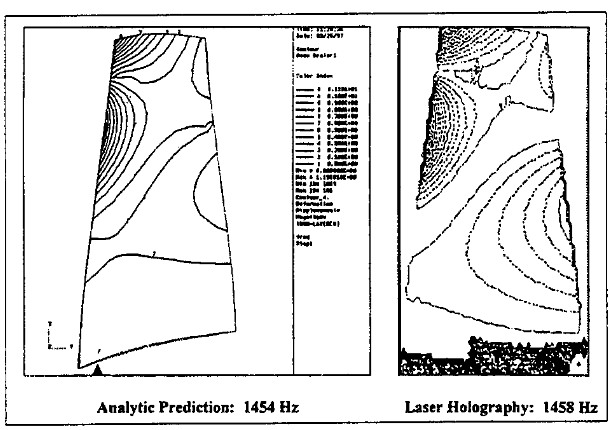


FIGURE 42. Finite Element Analysis - Prediction, as Compared to the Measured Response From Real Time Laser Holography

7.4 *TURBINE ENGINE FATIGUE FACILITY (TEFF) - (Cont'd)*

7.4.3 *TEFF - HCF EXCITATION*

Research is conducted in this area to improve the methods of testing components in a bench environment where the load paths are consistent with those seen by an individual part in the engine. Also, research is conducted in methodologies to excite rotors in an evacuated spin pit and to acquire data in this environment.

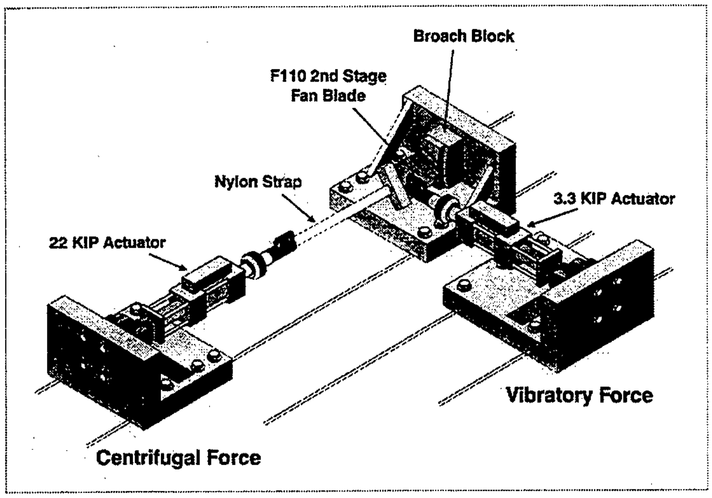


FIGURE 43. Artist Concept of the Push-Pull Machine: Centrifugal and Vibratory Loads Applied Through Hydraulic Actuation

POINTS OF CONTACT

Government
Name: Mr. Chris Lykins
Organization: U.S. Air Force, AFRL/PRTC
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-1867
Fax Number: (937) 255-2660
Email: lykinscd@wl.wpafb.af.mil

7.5 *COMPRESSOR AERO DAMPING*

To accurately predict vibration of turbine engine blades, one part of the equations of motion which must be obtained is the aerodynamic damping. Therefore, this program is set up to obtain aero damping of turbine engine blades from compressor rig tests. These tests will be conducted with axial flow compressors in the subsonic and transonic aerodynamic regime. Low and high order modes will be evaluated and compared against predictions using NASA LeRC's aero-elastic code, Turbo-AE. Blades on this research compressors will be instrumented with high frequency responding pressure transducers and strain gages.

POINTS OF CONTACT

Government
Name: Dr. Doug Rabe
Organization: U.S. Air Force, AFRL/PRTX
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-6802 x231
Fax Number: (937) 255-0898
Email: rabedc@wl.wpafb.af.mil

7.6 *IMPROVED COMPRESSOR AERO DAMPING*

Damping of blades in the turbine engine stems from material, structural, friction and aerodynamic damping. This program is set up to improve the turbine engine community's ability in measuring and predicting aerodynamic damping. Tests will be conducted on full scale rotors at the Compressor Research Facility (CRF) and Turbine Research Facility (TRF) to measure the overall damping associated with the blades of these rotors. To separate out the aerodynamic effects from those of the material and structure, tests will be conducted in an actual compressible flow environment and repeated in an evacuated environment (vacuum). The vacuum will remove the aero loading and will allow for the measurement of the structural and material damping.

POINTS OF CONTACT

Government

Name: Dr. Doug Rabe
Organization: U.S. Air Force, AFRL/PRTX
Address: 1950 Fifth Street, Bldg. 18
WPAFB, OH 45433-7251
Phone Number: (937) 255-6802 x231
Fax Number: (937) 255-0898
Email: rabedc@wl.wpafb.af.mil