

Study of Catalytic Methane Combustion in Microtubes as an Ignition System for Oxygen and Methane Propulsion Devices

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Program Description:

This study seeks to both computationally and experimentally examine the capability of an igniter using the catalytic reactions of oxygen and methane on platinum to cause ignition. The tests will be conducted under the range of pressures and fuel rich mixture conditions typical of rocket engines. Methane will be one of the fuels of choice in this new era of exploration through in-situ resource utilization as the capability of producing it on Mars exists. The development of such a system will prove useful as mankind returns to the moon and expands beyond our own planet.

The experimental work comprises of testing for ignition under the appropriate conditions. The studies are done with a mixture of fuel and oxidizer simulating the mixture in a rocket combustion chamber flowing against the ignition stream under a stagnation condition. The ignition stream is either a heated inert gas for a basis of comparison or the products of the catalytic reaction. The catalytic reaction is carried out by flowing a premixed fuel and oxidizer mixture through heated platinum microtubes which then is directed against an opposed flow of premixed methane and oxygen. This process studies ignition characteristics of premixed methane and oxygen when directed in a jet against an opposing heated jet. The influence of replacing an inert opposing jet with hot products of combustion from the catalyst will be investigated. The studies shall be conducted over a wide range of equivalence ratios and thermodynamic parameters. With the completion of the experimental work in the high pressure test cell in the Combustion Diagnostics Laboratory at Case Western Reserve University, a torch igniter will be developed using the results and tested at the NASA Glenn Research Center in the Research Combustion Laboratory.

Computational trials are carried out using codes that each simulates specific aspects of the study. The reacting flow within the catalytic tube will be simulated using the PLUG code and shall include both surface and gas phase chemistry. The ignition of the premixed methane oxygen jet when directed against another heated jet will be investigated using a second code, which is a two point flame controlling counterflow code of the Smooke formulation and modified by Nishioka. For the case where the inert jet is substituted by the heated products of combustion, the results from the PLUG code are used as the inlet conditions to parametrically study the behavior and provide a basis for comparison with the experimental work.

Program Relevance to NASA:

With the retirement of the space shuttles in 2010, a new period in exploration begins with the development of the Orion crew exploration vehicle, the return to the moon, and the goal of putting mankind on Mars. For this final step, some reconsideration of how space travel is conducted is required. Mars is far enough away where it would require a great deal of fuel to go and return. If all the propellant is carried for the full trip, the mass would be rather large, requiring a great deal of fuel to transport that which is required to return to Earth. Rather than carry all the required fuel as all exploration has done so far, methane can be produced on the planet.

Since new craft are being developed for this exploration, a change in propellants from what has traditionally been used is possible. In the past generation, our nation's space shuttle and rockets have used a variety of fuels, but primarily hydrogen and solid fuels. Methane has not been used as a fuel that often as it has properties that are drawbacks and consequently; it has been less studied than other fuels for this type of application. One of these properties is that it requires more energy and time to ignite than other fuels, such as hydrogen. In considering an ignition system, rather than using another fuel to start ignition or just creating a larger spark, one of the solutions to these problems that readily comes to mind is using a catalyst which would reduce the energy required.

This project seeks to expand the knowledge base of premixed fuel-rich methane and oxygen mixtures. This study will not only result in the development of an ignition system but provide data for future systems that may require knowledge into these components under these extreme conditions.

Program Benefits to Society:

The results of this study will be published and made available to the science and engineering community in general. The project will establish a proof of concept for a proven and practical catalytic igniter for these conditions. The computational and experimental results for the counterflow will also provide more data for high pressure ignition of premixed methane in this extreme range. The project will verify the computational results for the catalytic reactions under these conditions with the

experiments and establish a basis of comparison for further work in this regime of conditions.

Program Goals:

The primary result of this project is to fully study and develop a catalytic ignition system for methane and oxygen mixtures. The subdivisions are as follows.

- Using PLUG, computationally study the methane/oxygen reactions on platinum for a set of pressures, temperatures, equivalence ratios and residence times in order to determine temperature and concentration profiles and dependencies for the above conditions
- Using the counterflow ignition code, establish a baseline for the temperature required for ignition by heated inert gas under the required conditions, pressures, strain rates, and equivalence ratios.
- Using the counterflow ignition code and the results from the studies in PLUG, conduct a parametric study to examine the ignition of the methane oxygen mixtures across the aforementioned conditions by the products and exhaust temperatures of the catalytic reaction
- Conduct experiments across the requisite ranges of the catalyst and counterflow conditions to study the ignition capabilities and map out the behavior
- Develop and test a torch igniter to be tested at NASA Glenn

Program Accomplishments:

Though the project is ongoing as part of Master's and Ph.D. work: progress is being made in both the computational and experimental work.

- The new high pressure test cell and experimental station has been designed and machined and is now in the final stages of construction, to be welded and hard anodized prior to experiments being carried out
- Computational studies have begun using the PLUG code to establish what will become the range of inlet conditions for the catalytic ignition trials with the counterflow code
- Computational studies using the counterflow code have been carried out and are being continued using the heated nitrogen inert for the baseline comparisons

Student Accomplishments:

I have finished taking my classes for the Master's degree that this program is funding and have begun taking classes for the Ph.D. I have continued to work on both sides of the study, experimental and computational. I have designed the high pressure vessel myself for the purposes of this experiment and future work and am overseeing the progress of the construction through all phases. I have begun to compile data and ready for publication and presentation at conferences.

Justin Littell

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GSRP student 2007
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PROGRAM DESCRIPTION

The subject matter of Justin Littell's GSRP award are as follows:

- Test composite material constituents for the development of constitute models used by researchers at NASA GRC.
- Test triaxial braided composite materials to study the deformation and failure mechanisms in triaxial braided composite materials.
- Create a computer model that will predict the composite material response under static and impact loading.

PROGRAM RELEVANCE TO NASA

This award is funded under NASA's Aging Aircraft Directorate (AAD) and directly pertains to scope of the AAD's work. AAD is currently investigating the effects of composite material aging when used in high performance airplane components, such as fuselage and engine materials. While this work is being conducted on unaged materials, the results of this work attempt to define critical areas in the composite materials which will suffer the greatest effects (material property degradation, interfacial weakening, etc.) of the aging process. Knowing what areas of the composite materials will be most affected by the aging process will allow NASA researchers and scientists explore and mitigate potential problems which could arise when using such composite materials in the future.

PROGRAM BENEFITS TO SOCIETY

The GSRP program for Justin Littell has helped to identify potential problems that could arise when using aged composite materials in airplane structures. Identifying potential problems with composite materials used in airplanes has the benefit of making airplanes safer to the general public, while also allowing other researchers and scientists identify potential solutions to the problems presented.

PROGRAM GOALS

The research goals of Justin Littell's GSRP award was to study the behavior of triaxial braided composite materials by testing them under static and impact loading. Also, by using the collected data from the tests, a computer model used to simulate composite material behavior was created.

STUDENT ACCOMPLISHMENTS

Justin Littell has accomplished the following items under his GSRP award:

- Create a test method capable of testing the composite matrix constituent, the epoxy resin, under a variety of loading conditions for data collection. The data collected is currently being used in computer material models by researchers

here at NASA GRC.

- Identified potential failure mechanisms in triaxial braided composite materials which led to material degradation and strength reduction
- Collected triaxial braided composite material test data for the rapid screening of different composite material systems.
- Created a computer finite element model using data collected on the composite materials which accurately predicted test data to within 10%
- Created a computer model for the prediction of impact strength for the above tested composite materials. Models are currently under verification.

GSRP

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Damage Detection and Life Prediction Methodology for Ceramic Matrix Composites:
Experiments and modeling

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PROGRAM DESCRIPTION

This research, supported under the Graduate Student Research Program, focuses on developing a correlation between damage accumulation and electrical resistance change in SiC fiber reinforced SiC matrix composites.

Woven silicon carbide fiber-reinforced silicon carbide (SiC/SiC) ceramic matrix composites (CMC) possess unique properties such as high thermal conductivity, excellent creep resistance, improved toughness, and good environmental stability (oxidation resistance), making them particularly suitable for hot structure applications. In specific, CMCs could be applied to hot section components of gas turbines, aerojet engines, thermal protection systems, and hot control surfaces. The benefits of implementing these materials include reduced cooling air requirements, lower weight, simpler component design, longer service life, and higher thrust. It has been identified in NASA High Speed Research (HSR) program that the SiC/SiC CMC has the most promise for high temperature, high oxidation applications.

One of the critical issues in the successful application of CMCs is on-board or in-situ assessment of the damage state and an accurate prediction of the remaining service life of a particular component. This is of great concern, since most CMC components envisioned for aerospace applications will be exposed to harsh environments and play a key role in the vehicle's safety. On-line health monitoring can enable prediction of remaining life; thus resulting in improved safety and reliability of structural components. Monitoring can also allow for appropriate corrections to be made in real time, therefore leading to the prevention of catastrophic failures. Most conventional nondestructive evaluation (NDE) techniques such as ultrasonic C-scan, x-ray, thermography, and eddy current are limited since they require structural components of complex geometry to be taken out of service for a substantial length of time for post-damage inspection and assessment. Furthermore, the typical NDE techniques are useful for identifying large interlaminar flaws, but insensitive to CMC materials flaws developed perpendicular to the surface under tensile creep conditions. There are techniques such as piezoelectric sensor, and optical fiber that could be used for on-line health monitoring of CMC structures. However, these systems involve attaching an external sensor or putting special fibers in CMC composites, which would be problematic at high temperature applications.

Most composite materials are multifunctional materials in which the damage is coupled with the material electrical resistance, providing the possibility of real-time information about the damage state through monitoring of resistance. Electrical resistance has been shown to be a sensitive measure of internal damage in a number of composite systems such as carbon fiber reinforced polymer (CFRP), silicon carbide-fiber reinforced glasses and 2D carbon fiber-reinforced silicon carbide. In such composites, the fibers are the conductive material, while the matrix acts as an insulator by comparison. This allows

for detection mainly of fiber breakage by measuring the resistance change of the materials. In contrast, for the SiC/SiC composites, the resistivity of the matrix is on the same order of magnitude as that of the fibers. The resistance may be sensitive to matrix cracks which are far more important to mechanical properties of CMC materials. However, little study on SiC/SiC composites has been reported to our knowledge. This project aims to demonstrate that the electrical resistance closely correlates with matrix cracking in the SiC/SiC composites, and that real-time information about the damage state can be obtained through monitoring of the resistance.

PROGRAM RELEVANCE TO NASA

SiC/SiC CMC has been identified by NASA's high speed research program as having the most promise for high temperature, high oxidation environments. Development of a life monitoring and prediction method which is effective at high temperature would serve to advance the implementation of these materials in real world applications.

PROGRAM BENEFITS TO SOCIETY

As stated previously, the implementation of SiC/SiC CMC in aerospace applications is limited by the ability to monitor crack growth. The development of a model based on electrical resistivity will potentially solve this problem. As a result, aircraft could reap the benefits of reduced cooling air requirements, lower weight, simpler component design, longer service life, and higher thrust. Such improvements will have far reaching effects on the aerospace industry.

PROGRAM GOALS

The goal of this project is to develop a non-destructive evaluation (NDE) method that can be used for on-board or in-situ assessment of the damage in CMCs and life predictions. The objective is to experimentally and analytically determine the relationship between the damage and electrical resistance such that the internal damage and life of the composites can be predicted by measuring the resistance change during/after service. The proposed NDE method will first consist of the development of an electro-mechanical model of CMC's. This model can then be used to quantify the relationship between electrical resistance and damage accumulation for a variety of fiber alignments and loading conditions. Material testing will provide empirical data relating the electrical resistance to stress and strain. Upon analysis of the material microstructure, the change in resistance will be related to the actual damage accumulation. Correlating the theoretical and experimental results will allow for verification and/or improvement of the models.

PROGRAM ACCOMPLISHMENTS

Thus far, experiments have been successfully conducted in which samples were tensile tested, while simultaneously monitoring the change in resistance. The results have demonstrated that self-sensing using matrix conductivity can effectively detect matrix damage which is critical to the life of high-temperature CMC structures. Specifically, we have shown that the resistance change in SiC/SiC composite systems is very sensitive to the matrix cracking and closely related to the damage evolution. We also show that it is possible to detect the largest inadvertent overloads in CMC materials by measuring the residual resistance after a mission is completed.

STUDENT ACCOMPLISHMENTS

The findings from this project, which are described above, were presented as a poster at the American Ceramics Society conference on advanced ceramics and composites in January of 2008. Also, a paper is currently in press in the journal *Scripta Materialia* documenting the initial findings from room temperature tensile tests coupled with resistance measurement.

Flame Stabilization in Counter-current Dump Combustors

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Project Description

Three novel concepts have been used to explore methods of achieving a stable flame without requiring a continuous ignition source. Control strategies such as counter-current shear (suction) flow, a sloped step extension, and microjets are used to alter the flow-field properties while minimizing the strain rate penalty. Counter-current shear flow has been shown to increase the generation of turbulence and reduce ignition delay time. Modifications to a step extension have been shown to alter the recirculation zone characteristics and affect energy production. Microjets, traditionally used as a noise reduction technique in supersonic jets, produce a reduction in large-scale structures and decreases turbulent kinetic energy within the flow-field. However, in this research, microjets are explored as a new shear control strategy. Microjets applied to dump combustors can increase three-dimensionality and promote heat release.

In my previous work, the turbulent flow that occurs within the modified dump combustor has been simulated using a commercial code and NASA's National Combustion Code (NCC). Currently, an in-house multi-domain, spectral method code is being developed for turbulence simulation. This code will be extended to include the Partially Resolved Numerical Simulation (PRNS) method which was developed at NASA. PRNS is a hybrid model that solves for the structures of turbulence by allowing a Reynolds-averaged Navier-Stokes (RANS) solution to evolve to a Very-large-eddy Simulation (VLES) on a coarse grid. Previous visits to the NASA Glenn Research Center (GRC) allowed me to learn the practical uses and commands of NCC, and how to implement the PRNS equations into a computer code.

A multi-domain, spectral method code is currently being developed by my research group. This code uses a staggered mesh for compressible flow solutions utilizing the Navier-Stokes equations. In this method, the computational domain is divided into multiple subdomains, simplifying the computation of solutions in complex grids. The high-order polynomials used in each subdomain lead to more efficient and accurate calculations, and reduce time step restrictions. Initially, simple wall-bounded flows will be simulated with the in-house code after the implementation of PRNS. Results will be compared with NCC data and validated with experimental results. The code will then be extended to solve for the modified dump combustor and complex geometries.

Project Relevance to NASA

Computational modeling is used to solve for the turbulent flow that occurs within the modified dump combustor. Cold flow and reacting results have been obtained using the commercial code, FLUENT. Simulations are conducted within a RANS framework utilizing the two-equation realizable k-epsilon model. The RANS model is adopted because it is computationally less

expensive compared to Direct Numerical Simulation (DNS) and Large-eddy Simulation (LES) methods. The preliminary results will be used to determine an optimum combustor design to perform LES of the flow and for experimental demonstration.

From previous visits to NASA GRC, cold flow and reacting simulations of the dump combustor with a sloped step extension were conducted using NCC. A visit to NASA GRC is also planned for this summer (July 2008) where the focus will be on using PRNS. The PRNS method has the benefits of evolving RANS to VLES within one code, thus reducing computational time as compared to LES. This method solves for the unresolved scales of turbulence approximated by the eddy viscosity models used in RANS. The equations are independent of mesh size and are simple to employ into a code, which makes this a desirable method for implementation in the in-house spectral code.

Project Benefits to Society

Efficient flame stabilization is essential for the performance of liquid-fuel propulsion systems of the future. Bluff-body geometries, such as the backward-facing step dump combustor, are traditionally used as flame holders in propulsion systems. Improving the performance of these systems must occur without increasing thrust penalty. In bluff-body geometries, the physical-chemical processes responsible for combustion occur within the turbulent shear layer. The novel control strategies explored in this research are used to alter the characteristics of the turbulent near-field as a means to reduce ignition delay time. This research focuses on developing engineering techniques that will produce efficient flame holding required for compact combustion.

Project Goals

Summer 2008

- Modeling ramjets for flame stabilization using FLUENT
- Visit NASA GRC for 1 month in July 2008 to obtain data for research
- Compare in-house code results with NCC, validate with experiments or DNS
- Continue to work on the in-house code

2008-2009 Academic Year

- PhD Preliminary Exam
- Work on in-house code with PRNS for final modified combustor design
- Validate code with experimental results
- Start dissertation
- Visit NASA GRC for 1 month in July 2009 to obtain data for research and give final research presentation for GSRP

Project/Student Accomplishments

Summer 2006

- Visited NASA GRC for 9 weeks to learn about PRNS and how to use NCC
- Completed 2D cold flow and reacting simulations of the modified dump combustor using NCC

2006-2007 Academic Year

- Completed 2D unsteady cold flow simulations of the traditional dump combustor using NCC and FLUENT
- Completed 2D reacting simulations of the modified dump combustor using FLUENT
- Designed 3D mesh of the traditional dump combustor (done at NASA GRC in March 2007)
- Completed 3D cold flow simulations of the modified dump combustor using FLUENT
- Designed 3D mesh of the 39 vertical microjets combustor

Fall 2007

- Designed 3D mesh of the single horizontal microjet combustor (multiple designs)
- Completed 3D cold flow simulations of the single horizontal microjet combustor (mass and momentum studies) using FLUENT
- Gained background information on the in-house multi-domain, spectral method code

GSRP– Graduate Student Research Project

Administered via Cooperative Agreement between NASA and NASA Research and Education Support Services (NRESS)

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PROGRAM DESCRIPTION

The NASA Graduate Student Researchers Program (GSRP) awards fellowships for graduate study leading to masters or doctoral degrees in the fields of science, mathematics, and engineering related to NASA research and development. This twelve month award includes a required ten-week internship at the NASA center affiliated with the NASA sponsored research.

Training grants are awarded for one year in the amount of \$30,000. This amount includes a \$21,000 student stipend, a student travel allowance of \$4,000, up to \$1,000 for health insurance, and a \$4,000 university allowance, which typically goes to the Research Adviser, who becomes the Principal Investigator for the Training Grant. Awards are renewable up to three years based on satisfactory academic advancement, research progress, and available funding

Following is the stated GSRP goal:

Cultivate research ties to the academic community, to help to meet the continuing needs of the Nation's aeronautics and space requirements by increasing the number of highly trained scientists and engineers in aeronautics and space-related disciplines, and to broaden the base of students pursuing advanced degrees in science, mathematics, and engineering. Research opportunities described on the GSRP website are assessed and updated annually to complement the mission requirements of NASA. Research areas are in disciplines that lead to aeronautics and space careers.

PROGRAM RELEVANCE TO NASA

GSRP directly addresses outcome 1 and supports outcome 2 of the NASA educational strategic plan. These outcomes commit the education office to fund programs which (1) contribute to the development of the STEM workforce and (2) attract and retain students in STEM disciplines needed to achieve NASA strategic goals. Put simply, GSRP is an important contributor in developing NASA's future workforce as well as increasing the size and quality of the overall future aerospace workforce to which NASA contractors depend. Research shows that incorporating experiential opportunities into higher education programs provides several benefits over traditional "lecture and lab" curricula - including improved retention through graduation and into degree-related employment at NASA and its contractor partners.

In addition to the workforce development benefits of GSRP fellowships, NASA also benefits through the immediate productivity gained by hosting hundreds of the nations top engineering and science students and putting them to work on current research, analysis, operations, and planning activities crucial to the agencies mission.

PROGRAM BENEFITS TO SOCIETY

The need for increased STEM graduates in the U.S. is well documented. This need is dramatically magnified in the aerospace field. Documentation from the National Aerospace Initiative (2004) shows the average age of the US aerospace workforce at 49. As many reports and studies affirm, the health of the aerospace workforce is directly connected to America's long-term security interests - both economic and defense.

Research shows that one of the best methods of maximizing retention within a field of study is to incorporate experiential opportunities into the traditional course of study. Benefits in terms of retention to graduation, GPA at graduation, increased capability at graduation, pursuit of advanced degrees, and retention within the career field are well documented.

PROGRAM GOALS

GSRP goals for 2007 are to provide fellowship/internship experiences to:

- a. Provide \$30,000 fellowships for a minimum of 181 STEM graduate students
- b. Select a geographically and institutionally diverse group of GSRP fellows from a wide array of backgrounds, who are fully representative of U. S. graduate students enrolled in STEM majors
- c. Generate a large and appropriately diverse pool of candidates

PROGRAM ACCOMPLISHMENTS

For 2007, 181 graduate students were selected for fellowship/internship positions representing 43 separate institutions, 97 congressional districts, and 38 states plus Puerto Rico. In 2007 GSRP fellows were hosted at all NASA centers including the Jet Propulsion Laboratory.

GRC

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Environmentally Assisted Crack Growth in Ni-base Superalloys at Elevated Temperature

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PROGRAM DESCRIPTION

This research project will evaluate the oxygen embrittlement of Ni-base superalloys at elevated temperature. At elevated temperature, these materials can suffer damage from surface oxidation, creep deformation, oxidation induced grain boundary embrittlement, and microstructural evolution. These four damage processes can operate in a synergistic fashion and cause catastrophic failure. The interaction of oxidation and creep crack growth is not fully understood. The research project proposed will evaluate the oxidation-assisted damage mechanisms that operate in the presence of creep deformation in the crack tip region by performing controlled environment creep-fatigue experiments.

One goal of this research project is to develop a creep-fatigue crack growth model that incorporates the environmental contribution. In order to accomplish this oxidation experiments are being conducted to more fully evaluate the oxide that forms at elevated temperature on ME3. Along with oxidation/diffusion experiments, creep-fatigue experiments using air, vacuum and controlled partial pressure of oxygen are being performed at the University of Arkansas and at the Air Force Research Lab (AFRL) at Wright Patterson Air Force Base in Dayton. Subsequent analytical techniques will be employed to evaluate grain boundary diffusion, fracture surfaces, and embrittlement mechanisms.

PROGRAM RELEVANCE TO NASA

Ni-base superalloys are used in some of the most demanding NASA applications, such as gas turbines for aircraft. A more complete understanding of the crack growth behavior of these materials when subjected to extreme temperature and aggressive oxidizing environments is essential to life prediction of mission critical components. NASA's contribution to the aerospace industry and to future manned space flight can be enhanced by an increased knowledge of the behavior of Ni-base superalloys at elevated temperature.

PROGRAM BENEFITS TO SOCIETY

The potential positive impact of this research is substantial. This research aims to provide a comprehensive predictive model of Ni-base superalloys in high temperature applications, such as aircraft jet engines, and it can also be applied to power generation turbines. Better predictive models could reduce the life cycle cost of gas turbine aircraft engines reducing military and commercial aircraft maintenance costs. Aircraft safety concerns are also addressed with this project. Increased life prediction capability of aircraft engine components provides the manufacturer and operator with enhanced reliability and safety. When products are safer, society always benefits immeasurably.

Currently the world's energy production is in short supply given the increasing demand. The world's power providers could realize a savings of approximately \$50 billion if life

prediction models were developed to incorporate all types of damage mechanisms. The demand for higher thermal efficiency is also driving the need for higher temperature capabilities. This requires a better understanding and more complete models to predict the life of Ni-base superalloys at high temperature. For all of these reasons the benefits to society are obvious.

PROGRAM GOALS

This proposal seeks to develop a life prediction model for Ni-base superalloys at high temperature that incorporates the synergistic effects of both oxygen and creep deformation. This is emerging as one of the most important needs for predicting life in a turbine disk. The goal of this project is to evaluate the relative contribution of oxygen, creep, and fatigue to the embrittlement of Ni-base superalloys. The key research objectives of this project are:

- Conduct Design-of-Experiment (DOE) based experimental assessment of Ni-base superalloys at high temperature in a controlled environment;
- Evaluate the surface oxides and their effects on crack growth;
- Determine the extent of oxygen diffusion along grain boundaries at the crack tip;
- Develop a model for the crack growth rate with time that incorporates the creep deformation, time at temperature, fatigue, and partial pressure of oxygen.

The significance of this research project will be several-fold. It will: (a) increase the predictive capabilities for Ni-base superalloys in general for aircraft engines and power generation turbines; (b) increase public safety; (c) provide scientists and engineers working on high-temperature materials a better model for use in designs; and (d) provide an incubator for the next generation of materials scientists to develop skills and capabilities to analyze materials at high temperature. This newly found information will be broadly disseminated into the hands of materials scientists and engineers to make the biggest impact possible. The results are expected to reduce life-cycle and maintenance costs substantially. More reliable and predictable gas turbines, whether for aircraft engines or land-based power generation systems, will substantially increase public safety and well-being.

PROGRAM ACCOMPLISHMENTS

The key research accomplishments over the last two years include:

- Literature review and summary paper written
- Completion of creep-fatigue testing in air at two hold times
- Fatigue crack growth rate model developed for the Ni-base superalloy ME3
- Microstructural characterization of ME3 after two different heat treating processes
- Performed fatigue crack growth rate tests in vacuum to evaluate environmental contribution on the crack growth rate
- Kinetic chart developed for analyzing the various time-dependent processes operating at elevated temperature
- Time rate of crack growth model developed to predict life during creep-fatigue conditions

STUDENT ACCOMPLISHMENTS

The education accomplishments of this project for the student researcher include:

- All coursework requirements for the Ph.D. degree have been completed.
- The written and oral components of the Ph.D. qualifying exam were completed successfully in the Spring 2007. The research proposal presentation, which constitutes the candidacy exam was passed in the Fall of 2007.
- This research project has generated a number of presentations and publications. A preliminary literature review for this project was presented at the Materials Science & Technology 2005 conference. A paper was also published in the proceedings for the symposium on Creep Deformation and Fracture, Design and Life Extension.
- The background and preliminary results for this project were also presented in poster sessions at the Spring 2007 and Spring 2008 Arkansas Academy of Mechanical Engineers Graduate Student Research Symposium.
- In June 2007 the analytical model for the crack growth rate of ME3 was presented at the AeroMat 2007 conference in Baltimore, MD. The results of that study are currently being prepared for submission as a journal publication.
- A paper was presented at the Materials Science & Technology 2007 conference