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Technical Quarterly Progress Report

**Quarterly Report
January 1 - March 31, 1998**

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Technical Quarterly Progress Report
Advanced Gas Turbine Systems Research
Cooperative Agreement DE-FC21-92MC29061

January 1, 1998 - March 31, 1998

SUMMARY

Major Accomplishments by AGTSR during this reporting period highlighted below and amplified in later sections of this report:

ACQUISITION & ASSISTANCE
1998 APR 16 APR 8 51
USDOE-FETC

Administrative

- AGTSR conducted 10 new NEPA's for the 97-01 awards in conjunction with DOE-FETC
- AGTSR reviewed conference/journal papers with the IRB from Oklahoma (aerodynamics), Penn State, BYU, Georgia Tech, Cornell (combustion), Minnesota (heat transfer), and U-Conn (materials)
- AGTSR distributed progress reports and technical papers on Central Florida's hot corrosion/steam oxidation materials research to Allison Engine Company
- AGTSR distributed a list of updated performing member universities to DOE-FETC for Congressional briefing purposes
- AGTSR revised industry panel transcripts for DOE-FETC from the 1997 ATS Annual Review
- AGTSR submitted invoices to the IRB companies for their 1998 annual contributions
- AGTSR provided IRB heat transfer technical contact information for the Navy's advanced engine program

- AGTSR distributed its 'review and comment' publication policy to the new 97-01 principal investigators
- AGTSR continued telephone debriefings to the 97-01 RFP non-winners
- AGTSR reviewed progress report assessment comments from the IRB with respective principal investigators
- AGTSR distributed information on its research consortium to program managers at DOE-Germantown
- AGTSR renewed its 'network' collaboration with Concepts, ETI in White River Junction, VT
- AGTSR provided to DOE-FETC an FY95 through FY01 funding profile and milestone chart for out-year planning purposes
- AGTSR visited the Science & Technology representative at Cherry Point, NC to discuss the Navy/Marine's advanced materials R&D for turbine engine blade repair and diagnostics
- AGTSR distributed progress report format letters to the 10 new principal investigators from the 97-01 awards
- AGTSR updated its fact sheet to include new 97-01 awards, new IRB members, and new educational opportunities
- AGTSR provided by-law and consortium guidelines to West Virginia University who are establishing a new research consortium for the state
- GE announced that Ken Etkin of GE-Greenville will be the new focal point for AGTSR replacing Harold Miller of GE-Schenectady
- Information sent to Dave Little of Westinghouse-Orlando on Syracuse University's inverse aero-design code supported by AGTSR

Research

- AGTSR initiated 10 new research projects in February 1998 from the 97-01 RFP
- AGTSR released its sixth RFP (98-01) on March 31, 1998 covering eleven research topics in combustion, aero-heat transfer, and materials
- AGTSR distributed to the IRB for review an add-on research proposal from U-Conn outlining added tasks to their parent award related to failure mechanisms in thermal barrier coatings
- AGTSR submitted potential research issues in active combustion control to Wright-Patterson AFB and NASA-Lewis who are considering a new initiative in that area
- AGTSR distributed research results on endwall heat transfer from Carnegie Mellon and Minnesota to Gary Steuber of GEAE in Cincinnati, OH
- AGTSR distributed final report on turbine heat transfer from Carnegie Mellon to IRB and DOE-FETC
- AGTSR distributed white paper to GE and Westinghouse from Penn State on a new weldable alloy for turbine blade repair
- AGTSR distributed final report on intercooling aerodynamics from Oklahoma to IRB and DOE-FETC
- AGTSR distributed FY96 progress reports to IRB and DOE-FETC
- AGTSR distributed two combustion white papers from the University of Maryland to IRB for review – the IRB did not recommend the white paper add-on research for funding by AGTSR
- AGTSR conducted a telecon with the IRB on March 3, 1998 to discuss and finalize the research topics for the 98-01 RFP announcement

- AGTSR distributed final report on combustion modeling and experiments from BYU to IRB and DOE-FETC
- Solar Turbines expressed interest in collaborating closer with Northwestern and the University of Pittsburgh on AGTSR thermal barrier coatings research

Workshops/Education

- AGTSR chaired and organized a gas turbine university research session for the ASME Energy Technology Conference in Houston, TX, February 2-4, 1998
- AGTSR hosted the Combustion V Workshop with UC Berkeley on March 25-27, 1998, Berkeley, CA
- AGTSR distributed registration material in February 1998 for the Metallic Coatings Specialty Workshop at Stevens Institute, Hoboken, NJ
- AGTSR gave an invited talk at the Western States Combustion Institute Spring Meeting on March 24, 1998
- AGTSR received 16 applications for 1998 summer industrial internship program
- AGTSR announced the new faculty fellowship program to its performing members in January 1998
- AGTSR assembled and distributed a project briefs booklet on the 1997 summer internship to the IRB and DOE-FETC

Membership

- One new university became an AGTSR performing member: University of Florida, Gainesville, FL
- Southern Company Services and AlliedSignal Engine Company became active industrial members of AGTSR in January 1998

MEMBERSHIP

During this reporting period, the University of Florida became an AGTSR Performing Member. The point of contact at the University of Florida is Dr. Gerald Fuchs. AGTSR membership is currently at 94 schools, representing 37 states.

Southern Company Services (SCS) in Birmingham, AL became a non-voting, associate member of AGTSR from January 1, 1998 through December 31, 1998 for a fee of \$7K. The point-of-contact there is Charles Boohaker of the Power Technology Division.

AlliedSignal Engine Company became a voting, full industrial member of AGTSR for 1998 at a fee of \$25K. The points-of-contact are Vinod Nangia of Advanced Technology and Len Meyer of Marine and Industrial Engines. The main focal point for voting purposes will be Len Meyer.

During the last reporting period, Williams International in Walled Lake, MI was invited to become an associate member of AGTSR. Our contact at Williams was Carl Schiller, who indicated to AGTSR that they would probably become a member if DOE starts up a microturbine technology program in the 25 to 75kw range, as they are mainly interested in the advanced small engine development.

In 1993 through 1997, AGTSR received cost-sharing contributions of \$25,000 from each of the IRB voting members. The IRB now consists of eight U.S. turbine engine/component manufacturers with EPRI and GRI continuing to act as utility and industrial gas turbine advisors for AGTSR. Invoices for the IRB 1998 contribution to AGTSR were released in January 1998 to be paid by March 31, 1998. As of this date, Westinghouse, AlliedSignal Engine Company, Southern Company Services, and United Technologies have paid their annual contribution fee for 1998. Parker Hannifin is still an associate member of AGTSR and have paid their non-voting dues in advance until 1999. Payment for 1998 is still due from GE, Allison Engine Company, and Solar Turbines.

1993-through-1997 SUBCONTRACT PROGRESS

All the FY93 final reports have been received by AGTSR. BYU's FY93 final report (4-year project) was received in March 1998 and is out for review by the IRB. Out of the thirteen FY94 AGTSR research projects, four are still active. The four active FY94 projects are: Purdue (aero-heat transfer), Maryland and UC Irvine (combustion), and Georgia Tech (materials). These four projects will have their final reports due in June-July 1998. In December 1997, AGTSR received their final report from Carnegie Mellon University (FY94 heat transfer - Chyu). This report is also being

reviewed by the IRB. The final report from Clemson University (heat transfer - Leylek) is still delinquent. AGTSR has notified Professor Leylek several times about his final report obligation, but it has been to no avail. Clemson University Sponsored Programs Office are now discussing this issue with Professor Leylek directly. The Oklahoma (aerodynamics - Agrawal) final report was received in February 1998 and was distributed to the IRB for review.

The FY96 Semi-Annual Progress Reports have all been received by AGTSR and were distributed to both the IRB and DOE. These were the first set of progress reports for the FY96 awards and all were accompanied by assessment forms for our industry contacts to complete. The FY95 Semi-Annual Progress Reports are due by the end of April 1998. The FY97 Progress Reports are due on August 31, 1998. Since AGTSR secured FY98 funding from DOE-FETC in December 1997, all the FY97 projects were supported with a start-date of February 1, 1998, with the exception of UC-Irvine and Central Florida who requested a January 1, 1998 start-date. Any new awards from the 98RFP are expected to get started in February 1999.

At the request of the IRB, AGTSR has devised an assessment form to evaluate the research progress reports. Starting with the previous reporting period, all the progress reports (semi-annual and final) were distributed to the IRB with the assessment form attached - to be completed by the appropriate subarea R&D expert. For the semi-annual progress reports, AGTSR coordinates IRB comments directly with the PI when deemed appropriate. Assessment of final reports, when completed, will be consolidated by AGTSR and distributed to DOE-FETC for their review. Final reports currently being reviewed by the IRB include BYU (combustion), Oklahoma (aerodynamics), and Carnegie Mellon (heat transfer).

COMBUSTION V WORKSHOP CO-HOSTED WITH UC-BERKELEY

AGTSR's Combustion Workshop V was the largest workshop to date hosted by AGTSR. There were 117 participants. The workshop was co-hosted with Dr. Robert Dibble of UC Berkeley on March 25-27, 1998 in the Berkeley Marina Radisson, Berkeley, California. In addition to the industry and university talks, special talks were given by Abbie Layne of DOE-FETC on the ATS program and future initiatives, by David Hatfield of CEC on their new R&D solicitations, and by Bill Day of P&W/GTA who discussed the flexible midsize gas turbine program. An impressive tour of the LBNL was also given on the afternoon of March 25, 1998 to view fundamental combustion research and 3-D visualization graphics/ supercomputer

capability that could benefit both industry and universities. At the workshop, DOE-FETC distributed a survey/ position paper on Future Trends and Research Needs for Gas Turbine Combustion. As a follow-up, AGTSR resent copies of the survey to the workshop participants requesting they be completed and returned to AGTSR by April 30, 1998. The proceedings for Combustion Workshop V should also be available by the end of June 1998. If interested in obtaining a copy of the survey and/or proceedings, please contact Ms. Donna Kelly at 864-656-2267/ donnak@clemson.edu.

METALLIC COATINGS SPECIALTY WORKSHOP

This specialty workshop will be co-hosted with Professor Lee of Stevens Institute of Technology and is scheduled for April 16-17, 1998 at Stevens in Hoboken, New Jersey. Other organizers are from Oak-Ridge National Laboratory, NASA-Lewis, and AGTSR. The Workshop will focus on the development, processing, and science issues pertaining to aluminide and platinum aluminide coatings for gas turbine components used in the aircraft propulsion and power generation industries. These coatings are used as both bond coats for TBC systems and as overlayers for oxidation resistance. Three main sessions are planned: OEM usage and experience, coating manufacturer and repair/overhaul issues, and research issues presented by select university, NASA, and ORNL investigators. During the evening of April 16, 1998, a special dinner presentation will be given by the Dean of Engineering at Stevens Institute on "Re-Engineering Engineering Education." Registration material for this specialty workshop was distributed in early February 1998. To date, 68 people have registered for the Workshop. Due to the fairly high attendance (approximately 50 people were expected), the workshop is now closed and no more registrations will be accepted. Per request from the U.S. OEM's, foreign companies/attendees were not permitted to register, although several were interested in attending. For further information, please contact Angie Justice or Dan Fant at 864-656-2267.

AGTSR CHAIRS ASME GAS TURBINE SESSION

At the request of DOE-FETC, AGTSR held a gas turbine session for the ASME Energy Sources Technology Conference, February 2-4, 1998, Houston, TX. The session was entitled "Land-Based Gas Turbine Research." The session included four university research presentations which were representative of the core technologies being pursued by the AGTSR

program. The AGTSR papers presented were: (1) Performance of Industrial Gas Turbine Materials at High Temperatures by Dr. Vimal Desai, University of Central Florida, (2) Progress with 3D Inverse Method for Turbomachine Blade Design by Dr. Thong Dang and Sachin Damle, Syracuse University, (3) Flow and Heat Transfer Measurements in Gas Turbine Film-Cooling by Dr. Terrence Simon and Rohit Oke, University of Minnesota, and (4) Fiber Optic Probe for Primary Zone Fuel Distribution Measurements in Actual Gas Turbine Combustors by Dr. Jong Guen Lee and Dr. Dom Santavicca, Penn State University. The Proceedings for this ASME meeting is available on a single CD. ASME also informed AGTSR that they are considering other specialized gas turbine sessions for their 1999 meeting next winter.

AGTSR INTERNS: 1997 and 1998

During the summer of 1997, AGTSR placed 17 graduate-level interns at ATS company sites to gain hands-on, practical experience in an industrial setting.. To date, AGTSR has placed 37 interns at ATS industrial sites. Of the 17 interns placed this summer, 6 were in the combustion area, 7 in heat transfer, and 4 in CFD/ materials. AGTSR has assembled a booklet on project briefs for the 1997 industrial interns which was distributed to DOE and the IRB mentors. The majority of the interns had a very worthwhile experience. Some issues that emerged that are being addressed for this summer include: streamlining compensation to interns by utilizing a letter of appointment to each intern as opposed to requiring a subcontract through their university, streamline computer access with their industrial sponsor, and offering a 12-week option for the internship period.

For the summer of 1998, AGTSR received 16 applications. These applications were reviewed and ranked by the IRB during March 1998 and 13 interns have been selected for this summer. Most have opted for the 12-week internship period which should get started in May/June 1998. The selected interns have until April 30, 1998 to accept the AGTSR internship offer.

AGTSR REVIEWS U-CONN ADD-ON PROPOSAL

Professors Gell and Jordan of the University of Connecticut (U-Conn) submitted an add-on, 6-month/ \$60K, proposal to AGTSR to extend their current AGTSR subcontract which is scheduled to end on August 31, 1998. The IRB have been very interested in this research, as U-Conn has made substantial progress in using laser fluorescence as a possible NDI technique and have gained better understanding of failure mechanisms of TBC's using

both PtAl and MCrAlY bond coat systems. Their add-on research tasks support better modeling, TBC durability improvements, and NDI techniques for determining initial coating quality and residual life remaining. The add-on proposal was distributed to the IRB material R&D experts in March 1998 with comments due back to AGTSR by April 30. If the majority of the IRB recommend it technically and AGTSR has the necessary funds, it will be supported. To date, Pratt&Whitney, Parker Hannifin, and Allison have endorsed the add-on request from U-Conn.

AGTSR OFFERS FACULTY FELLOWSHIP PROGRAM

The Faculty Fellowship Program is a new program for university professors and offers a unique opportunity for university faculty members to gain valuable experience/ knowledge working with gas turbine manufacturers in research, engineering, and design. The program offers an opportunity for professors to take a mini-sabbatical with industry for a duration ranging from 1-2 months up to a year. Applications are due to AGTSR by April 30, 1998. Five professors have expressed interest in applying, and AGTSR will probably support only 2-3 fellows for the first year of the program. The five are: Jay Gore/ Purdue @ Allison – combustion, Fred Culick/ CalTech @ P&W - combustion, Abe Engeda/ Michigan State @ Allison – compressors, Ram Roy/ Arizona State @ Solar Turbines – disk cavity cooling, and Mingking Chyu/ Carnegie Mellon @ P&W or Solar Turbines – turbine heat transfer. Selected fellows for 1998 should be announced by the end of May/ early June. All applications must be endorsed by an ATS company to be considered by AGTSR.

AGTSR CONSIDERS NEW SHORT COURSES

AGTSR conducted their first short course on advanced film-cooling in August 1997. Since then, the IRB have endorsed the possibility of other short courses in the area of TBC's, combustion and aerodynamics. Some short course interests/suggestions have recently emerged: Don Boone of BWD will be giving a talk at the upcoming Metallic Coatings Workshop at Stevens Institute and has indicated to AGTSR that he may be interested in giving a course on superalloys; Fred Culick/ CalTech and Ben Zinn/ Georgia Tech are both interested in putting together a course on active combustion control; and Abe Engeda of Michigan State is conducting some compressor aerodynamics courses for industry and is looking to possibly expand his courses/seminars in

cooperation with AGTSR. If one of these courses comes to fruition, AGTSR plans to announce and offer it in fiscal year 1999.

AGTSR RELEASES NEW RFP

On March 31, 1998, AGTSR released their sixth RFP to the performing member universities. Copies of the RFP were also distributed to DOE and the AGTSR Industry Review Board (IRB). Proposals are due to AGTSR on June 5, 1998. AGTSR received over 20 research topics from the IRB and due to projected funding availability in FY99, a telecon was held with the IRB on March 3 to prioritize and reduce the number of topics actually listed in the 98 RFP. As a result of the telecon, the research issues were finalized and reduced to 11 topics: 4 in combustion, 4 in aero-heat transfer, and 3 in materials. The topics are as follows: *combustion* – sensors and diagnostics, thermal radiation in premixed flames, lean stability limit augmentation, and dual fuel and liquid issues; *aero-heat transfer* – gas temperature radial profile prediction, real surface effects on turbine heat transfer, non-intrusive gas temperature measurements, and tip clearance desensitization in high pressure turbines; *materials* – interaction of steam/air mixtures with turbine airfoil materials and/or coatings, long-term thermal stability of TBC, and TBC lifing issues. Proposals will be reviewed by the IRB experts during the summer and the IRB voting meeting should take place at SCERDC in the early fall. Any new awards are projected to begin in February 1999.

AGTSR GIVES INVITED TALK ON COMBUSTION

AGTSR was asked to give an invited talk at the Western States Combustion Institute Spring Meeting on March 23-24, 1998 at UC Berkeley, CA. There were a total of five invited talks at this meeting: Professor Candel from France on Dynamics of Interacting Flames; Robert Carling from Sandia National Laboratories on Engine Combustion Research; Professor Harley from UC Berkeley on Reformulated Gasoline on Vehicle Emissions; Professor Chen from UC Berkeley on Reduced Chemistry Modeling; and Daniel Fant from SCERDC on the AGTSR Program and Combustion Research Highlights. AGTSR's talk was in four parts: consortium overview, new combustion topics in the 98RFP, highlights on current combustion research activity, and new gas turbine initiatives being advocated by the Gas Turbine Association (GTA). The Western States Meeting included sessions on modeling and theory, diagnostics and control, air pollution, and both

fundamental and applied combustion research. If interested in obtaining a copy of the AGTSR talk, please call SCERDC at 864-656-2267.

SOLAR TURBINES VISITS ARIZONA STATE

Dr. Mike Fox of Solar Turbines in San Diego visited Arizona State University (ASU) on March 10, 1998. The purpose of the visit was to review the Disk Cavity Experimental Facility project supported by AGTSR. The principal investigator for this project is Professor Ram Roy. ASU is already teaming with AlliedSignal on this program, but are considering future collaborative work with Solar Turbines. While at ASU, Dr. Fox reviewed the facility and measurement instrumentation and was briefed on the experimental results on the flowfield and heat transfer in the disk cavity. He also reviewed their Particle Image Velocimetry (PIV) system and some preliminary results on the use of PIV to specifically study main flow ingress into the disk cavity. CFD results using Fluent and comparisons to experiment were discussed. Dr. Fox completed his visit by sharing some of the on-going disk cavity work at Solar Turbines, and discussing some needed follow-on research that would be useful to industry. As a result, Professor Roy is planning a short sabbatical this summer at Solar to learn more about their disk cavity research and current design needs. Afterwards, he plans to submit a one-year add-on research request to AGTSR to conduct some of these follow-on tasks as coordinated with both Solar Turbines and AlliedSignal Engine Company. For further information on this project, please contact Professor Roy at roy@asu.edu.

AGTSR VISITS NAVAL AVIATION DEPOT

On February 17, 1998, AGTSR visited the Naval Aviation Depot (NADEP) in Cherry Point, NC. The contact there was Mr. Gray Simpson who's the Science and Technology Coordinator for the NADEP engine repair facility. Mr. Simpson's main interest were in advanced materials to repair the leading and trailing edges of turbine blades and for advanced erosion coatings for compressor blades. AGTSR received a tour of their engine repair facility which is mostly for Marine helicopter engines in the 5 to 20 MW class range. NADEP's goal was to double the life of the blades from about 2500 hours to 5000 hours, as opposed to the ATS goal of 25,000 hours. Mr. Simpson discussed three programs: (1) a ceramic leading edge turbine airfoil program with Dupont/ NASA-Lewis, (2) a Russian compressor erosion resistant coating being tested at the University of Cincinnati, and (3) a turbine blade

study with Penn State University supported by the Navy using a unique diffusion layer over the alloy in conjunction with the Russia Air Transport Department. Mr. Simpson was interested in some of the AGTSR materials research and indicated that he or a colleague would likely attend the Metallic Coatings Specialty Workshop at Stevens Institute in April 1998.

AGTSR REVIEWS TWO WHITE PAPERS FROM MARYLAND

In January 1998, AGTSR received two combustion white papers from Professor Gupta of the University of Maryland. These white papers requested add-on funding to his existing AGTSR project to conduct additional combustion research. The first white paper proposed added research to investigate the effects of fuel composition on combustion stability; and the second dealt with using boron to visualize regions of high NO formation rates in combustion systems. Both white papers requested \$120K for an additional year of support. These add-on proposals were reviewed by the IRB during February and the majority did not recommend the research for AGTSR support. The IRB felt that AGTSR's investment in the UC Irvine fuel composition study was adequate at this time. They also felt that the boron chemiluminescence study should be continued as a SBIR extension instead of being funded by AGTSR. In addition, the IRB recommended that future add-on requests to AGTSR should be limited to approximately \$50K for up to a one year period, and that larger, more expensive, tasks should be re-competed in the annual RFP solicitation.

Miscellaneous Activities

AGTSR plans to attend the Emerging Horizons Turbomachinery Technology conference from May 11-15, 1998 offered by Concepts ETI in Wilder, VT. As part of our gas turbine information exchange with Concepts ETI, AGTSR has offered to host one of the luncheons at the meeting. The conference will focus on Advanced Small Gas Turbines, Emerging Design Frontiers, and Advanced Industrial Turbomachinery. AGTSR is especially interested in the Small Gas Turbine session to help us learn more about microturbines and some of the emerging technology issues. Elliot Energy Systems, Inc. will have on display at Concepts ETI their 45kw turboalternator demonstration. Other topics for this conference include: future computer power, directions for CFD, agile engineering, design code validation, rapid prototyping, and mini-consortium technology activities organized by Concepts.

Another meeting of interest to AGTSR is a DOD workshop on "Combustion-Driven Dynamic Instabilities in Gas Turbine Combustors." This workshop is planned for 14-17 September 1998 at the Dayton, Ohio Convention Center as part of the DOD IHPTET review. The purpose of the workshop is to identify the present state-of-the-art technical challenges associated with designing dynamic instability-free combustors for IHPTET engines. The organizer is Balu Sekar of the Turbine Engine Division at Wright-Patterson AFB. For further information on the workshop, please contact him at sekarb@wl.wpafb.af.mil.

Perhaps of interest to some AGTSR colleagues is an International Symposium on Industrial and Environmental Monitors and Biosensors, 1-6 November 1998, Hynes Convention Center, Boston, MA. This conference focuses on leveraging advances in lasers and optoelectronics to improve combustion diagnostics and emission monitoring. It's also intended to point the way in the development of novel instrumentation to meet -widely perceived industrial needs. Some of the session topics include: gas turbine diagnostics and monitoring, advances in continuous emission monitoring, characterizing air emissions, pollution control monitoring, and fire prevention and monitoring. More information can be found on the website at <http://www.spie.org>, or contact Ms. Linda Blevins of NIST at 301-975-3904/ linda.blevins@nist.gov.

AGTSR will also assist in evaluating any gas turbine related proposals as part of the Clemson University RFP State Project for renovating their central energy facility. Proposals for this project are due to Clemson University by June 19, 1998.