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Advanced Gas Turbine Systems Research

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

January 1, 1999 – March 31, 1999

SUMMARY

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

Administrative

- AGTSR supported DOE in revising position paper for the next generation of gas turbine power systems
- AGTSR updated performing member points-of-contact list for the Gas Turbine Association (GTA)
- AGTSR continued telephone debriefings for the non-winning PI's from the 98RFP
- AGTSR coordinated with Clemson's office of sponsored programs on contractual wording changes for the upcoming RFP
- AGTSR coordinated the review and revision of a DOE-FETC combustion simulation white paper with its academic and industry contacts
- AGTSR reviewed and cleared with the IRB research papers from UT-Austin (heat transfer), Cornell (combustion), Northwestern (thermal barrier coatings) and Clemson (heat transfer) for conference presentation and publication
- AGTSR selected The Windsor Group to conduct an economic impact analysis on the future use of land-based gas turbines for power generation systems through 2010

- AGTSR provided summary input to GTA for congressional testimony on research successes in combustion, aero-heat transfer, and materials
- AGTSR submitted research success stories to DOE-FETC on MIT computational aerodynamics study and UC-Santa Barbara thermal barrier coatings study
- AGTSR updated points-of-contact list for industry research subarea experts for DOE-FETC
- AGTSR updated DOE-FETC poster to include six new university research pictures/ results
- AGTSR helped DOE-FETC coordinate the review of SBIR Phase I proposals in the combustion area
- AGTSR held an IRB teleconference call to finalize the selection of 99RFP research topics

Research

- AGTSR submitted final technical report from Central Florida (on steam cooling/ blade degradation) to the IRB for review and evaluation
- IRB approved an 11-month add-on request from Clemson University to conduct an added research task for their mist/steam impingement cooling project
- Penn State/ Central Florida held a research kick-off meeting at UT-Austin for their new project on tip clearance de-sensitization anticipated to begin late spring
- UConn held a research kick-off meeting in San Diego, CA for their project on an NDI TBC technique which was initiated in February
- Through AlliedSignal, AGTSR submitted a draft research paper to OEM's and select utilities on a durability coatings R&D testing program for post-ATS

- AGTSR coordinated research position papers with industry-academia in thermal barrier coatings and aero-heat transfer technology areas
- AGTSR distributed FY96 research progress reports to DOE and the IRB
- AGTSR coordinated new research topics with the IRB for the seventh RFP announcement
- AGTSR presented research highlights on thermal barrier coatings at the TMS high temperature coatings session in San Diego, CA

Workshops/Education

- AGTSR co-organized a TBC Winter Workshop with UCSB, January 6-8, 1999, Santa Barbara, CA
- AGTSR coordinated with DOE-FETC and Energetics a strategic visioning workshop, February 9-10, 1999, Austin, TX
- AGTSR co-hosted an aero-heat transfer III workshop with UWisconsin and UT-Austin, February 10-12, 1999, Austin, TX
- AGTSR coordinated the combustion workshop VI agenda with DOE-FETC, Energetics, and Virginia Tech and released registration material for Combustion VI, April 18-21, 1999, Blacksburg, VA
- AGTSR had paper accepted for ASME-Turbo IGTI99 on catalytic combustion, Indianapolis, IN, June 7-10, 1999
- AGTSR invited to co-chair an experimental aero-heat transfer/ film-cooling session at IGTI99, Indianapolis, IN, June 7-10, 1999
- AGTSR selected four faculty fellows for 1999: one each from Utah, Oklahoma, Penn State, and North Dakota
- AGTSR received 17 applications for 1999 for the industrial internship program

- AGTSR distributed the project briefs for the 1998 industrial interns to the IRB and DOE

Membership

- Valparaiso University becomes a new AGTSR performing member
 - Woodward FST invited to become an associate member of AGTSR
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MEMBERSHIP

During this reporting period, Valparaiso University (VU) became a new performing member of AGTSR. The contact at VU is Dr. Michael Barrett who has interest and experience in experimental gas turbine heat transfer. AGTSR membership is currently at 97 schools, representing 37 states.

The AGTSR Industry Review Board (IRB) currently consists of 8 companies; 6 are voting members and 2 are associate non-voting members. During this reporting period, AGTSR invited Woodward FST in Greenville, SC to become an associate member of AGTSR. Woodward FST is a manufacturer of fuel injection systems for industrial gas turbines. The point-of-contact for Woodward FST is Geoffrey Myers of their Greenville, SC office. The engineering group for Woodward FST is located in Zeeland, MI.

In 1993 through 1998, AGTSR received cost-sharing contributions of \$25,000 from each of the IRB voting members. The eight IRB companies are complemented by EPRI and GRI who continue to act as utility and industrial gas turbine advisors for AGTSR. Invoices for the 1999 IRB membership fee were released in January 1999. As of this date, Pratt & Whitney, Siemens-Westinghouse, Solar Turbines, and Southern Company have paid their annual membership fee for 1999. Parker Hannifin is an associate member of AGTSR and have paid their non-voting dues in advance through 1999.

1993-through-1998 SUBCONTRACT PROGRESS

All ten of the FY93 projects have been completed and final reports have been received and processed by AGTSR.

Twelve of the thirteen FY94 AGTSR research projects have finished and completed their final report commitment. The remaining FY94 project is from UC Irvine (combustion). The PI is Professor Samuelsen. The UC Irvine final report is expected to be submitted to AGTSR by the end of April 1999.

All the FY96 Semi-Annual Progress Reports have been received by AGTSR and were distributed to both the IRB and DOE. These progress reports were all accompanied by assessment forms for our industry contacts to complete. The FY97 progress reports are due by the end of April 1999.

Per the 98-01 RFP, the IRB short-listed ten proposals (5 in combustion, 3 in aero-heat transfer, and 2 in materials). In February-March, AGTSR initiated five new awards: Connecticut (TBCs), Georgia Tech (combustion), Mississippi State (aero-heat transfer), Pittsburgh (materials), and Penn State (combustion). Three additional awards are anticipated this spring: Berkeley (combustion), Penn

State (aero-heat transfer) and Central Florida (aero-heat transfer). The decision to fund the latter three proposals should be finalized by the end of the next reporting period.

Two new \$50K add-on research projects were supported by AGTSR during this period: one to Penn State/ Lakshminarayana on unsteady flow compressor modeling and the other to Clemson/ Wang on impingement mist cooling. Both add-ons are for an approximate one-year period continuing through the end of 1999.

The final report from Professor Desai of Central Florida (hot corrosion/ steam effects) is currently being reviewed by the IRB.

AGTSR'S SEVENTH RFP

The research topics for the 99-01 RFP have been finalized by the IRB during a teleconference call on March 30, 1999. Minutes were immediately distributed to the IRB after the conference call. Eighteen R&D experts and seven IRB members participated in the telecon. There will be three topics in combustion, six in aero-heat transfer, and two in materials. The 99RFP will be released to the performing members by the end of April 1999 with proposals due in early July. Proposals for the 99RFP will be limited to a maximum two-year period of performance. The research topics (only) are listed on the web: see www.clemson.edu/scies/RFP.htm.

AGTSR's COMBUSTION WORKSHOP VI

AGTSR Combustion Workshop VI will be co-hosted with VPI in Blacksburg, VA. The meeting date is set for April 18-21, 1999, and the co-hosts are Professors Uri Vandsburger and Will Saunders who have an ongoing AGTSR project in the area of active combustion control. DOE-FETC, Energetics, AGTSR and VPI have detailed an agenda for the Workshop which includes a strategic planning session on Sunday afternoon, a facilitated combustion R&D roadmapping session on Monday, and a strategic simulation initiative session on Wednesday morning. The DOE-FETC contacts for the combustion workshop are Abbie Layne, Geo Richards, and Tom O'Brien. Jim Carey is the contact at Energetics. The registration material for the workshop was released in January 1999. To-date, there are 90 registrants. The second mailing for the workshop will be released to all the registrants in early April and will include updated draft position papers from DOE-FETC on the next generation gas turbine power system and strategic combustion simulation needs. For additional information, please contact AGTSR at 864-656-2267.

TBC WINTER WORKSHOP

The theme of the TBC Workshop hosted by UC-Santa Barbara was mechanism-based life prediction for thermal barrier coatings (TBCs). Some of the outstanding research issues centered on developing prime reliant coatings, which would enable TBCs to be explicitly included in the design process. By having the coatings become a design feature, new designs that reduce the cooling air and improve NO_x emissions could be successfully implemented. Other critical areas included the need for examination of TBCs that have failed in engine service, potentially different requirements for oxidation resistant and bond coats that yield extended TBC lives, and the need to understand the role of impurities and spinel formation in TBC failure. It was pointed out that laser piezospectroscopy has demonstrated the ability to measure the thermally grown oxide (TGO) stress state with or without a TBC present, and that this method has the potential for being utilized as a TBC non-destructive evaluation (NDE) technique. At the conclusion of the workshop, several participants were integrated into teams, which will prepare position papers describing critical R&D needs and benefits of TBCs in future gas turbine systems. The critical topic areas were designated as follows: reduced thermal conductivity TBCs with higher temperature capability and improved hot corrosion resistance, long-term thermal cycle testing in a thermal gradient, lifetime prediction modeling, non-destructive inspection technique development, coatings on ceramics, process modeling/ validation, and modeling of long-term TBC system stability. The Workshop had approximately 70 participants from 40 different organizations. The proceedings for this Workshop should be distributed by the end of April 1999. For additional information, please contact AGTSR at 864-656-2267 or Professor Levi at UCSB, 805-893-2381/ levic@engineering.ucsb.edu.

AGTSR's AERO-HEAT TRANSFER III WORKSHOP

The third AGTSR Aero-Heat Transfer Workshop was co-hosted with UT-Austin (UTA) and Virginia Tech (VT) at the Barton Creek Conference Resort in Austin, TX, February 10-12, 1999. The contact persons were Professor Bogard of UTA and Professor Thole of VT (who recently transferred from the University of Wisconsin-Madison). The workshop included a review of both aerodynamic and heat transfer R&D with AGTSR/ATS university and industrial partners. On February 10, a strategic planning session was held to discuss future aero-heat transfer R&D as influenced by evolving DOE gas turbine initiatives for the post-

ATS era. On February 11-12, three industry panels were held on turbine cooling, aerodynamics, and endwall flows to discuss the critical generic R&D needs pertaining to particular company initiatives and/or DOE future gas turbine initiatives as described in the DOE-FETC position paper. At the conclusion of the workshop, several participants were integrated into teams, which will prepare position papers describing critical R&D needs and benefits of aero-heat transfer research in future gas turbine systems. The critical topic areas were designated as follows: Multidisciplinary design integration, 3-D unsteady flows, CFD and advanced modeling, innovative cooling, aero-heat transfer-structures-materials, external flows, and gas path (non-gas path) aerodynamics. Summaries of the three industry panel sessions will be included in the proceedings. The proceedings for this Workshop should be released by the end of April 1999. Over 60 people participated in the Workshop. For additional information, please contact AGTSR at 864-656-2267.

DOE's VISIONING WORKSHOP

On February 9-10, 1999, a workshop on Strategic Vision for Next Generation Gas Turbine Power Systems was hosted by DOE-FETC. The workshop convened over 45 representatives from stakeholder groups, with almost half representing end-users. The purpose of the workshop was to collaboratively address what are the drivers that will shape the market and technology-selection decisions, the system goals to meet the challenge, and the barriers to achieving these goals. DOE-FETC has already analyzed the results of the workshop and have incorporated them into the draft paper titled "Developing the Next Generation of Gas Turbine Power Systems – a National Partnership." For further information, please call Ms. Abbie Layne of DOE-FETC (304-285-4603) or SCIES at 864-656-2267.

AGTSR ATTENDS IGTI SEMINAR

On March 16, 1999, AGTSR attended the IGTI seminar on Combustion Turbines: Managing Risk for Increased Profit, Atlanta, GA. The seminar included two interesting presentations: one on gas turbine buying guidelines by Rodger Anderson of the Hartford Steam Boiler Inspection and Insurance, and the other by Sal Della Villa of Strategic Power Systems on gas turbine reliability and information technology. The seminar was moderated by Professor Lee Langston of the University of Connecticut. For additional information on the seminar, please contact Ms. Ann McClure of IGTI at 404-847-0072.

AGTSR SELECTS TWO ADD-ON RESEARCH PROJECTS

During the last quarter, Professor Lakshminarayana of Penn State submitted an add-on proposal to AGTSR requesting an additional \$50K to enhance his current research on multistage compressor modeling and experiments. The added task related directly to the parent program and focused on resolving in detail the unsteady flow in the endwall region. The majority of the IRB recommended it for support and AGTSR funded the add-on for a 12-month period in early 1999. In this quarter, Professor Wang of Clemson submitted an 11-month/ \$50K add-on request to extend his mist cooling research project to include impingement cooling on flat and curved surfaces. This add-on request was also endorsed by the IRB and the project was initiated last month. If interested in obtaining more information on the results of these two research projects, please contact AGTSR at 864-656-2267.

AGTSR PRESENTS PAPER AT 1999 TMS ANNUAL MEETING

AGTSR presented an invited paper at the TMS Meeting in San Diego, CA, February 28 – March 4, 1999. The paper was titled TBC Research Highlights in the AGTSR Consortium. The paper was presented in the high temperature coatings III – thermal barrier coatings II session. The talk focused on highlighting the active research projects being supported by AGTSR in the area of thermal barrier coatings. The issues discussed included TBC bond strength and stress measurements, chemical and mechanical instabilities at TBC interfaces, advanced coating techniques, NDI for TBC's, and life prediction. In addition, a summary of the TBC Winter Workshop at UCSB in January 1999 was provided. The co-organizer for the TMS Meeting and co-chair for this particular session was Professor Hampikian of Georgia Tech. For additional information on the meeting, please contact Dr. Hampikian at 404-894-2845 or AGTSR at 864-656-2267.

UConn HOLDS KICK-OFF MEETING AT SOLAR TURBINES

In conjunction with the TMS Annual Meeting in San Diego, CA, UConn held a kick-off meeting at Solar Turbines on March 2, 1999 for their newly awarded program on "Development of Laser Fluorescence as a Non-Destructive Inspection Technique for Thermal Barrier Coatings." The objectives of the meeting were to: obtain industry commitments to provide TBC specimens, participate with the instrument manufacturer in demonstration of a prototype portable laser fluorescence instrument, and define a preliminary industry

specification for the portable laser fluorescence instrument. Eighteen participants were in attendance at this meeting representing seven companies, ORNL, and UConn. For additional information on this new research program, please contact AGTSR at 864-656-2267.

AGTSR COORDINATES MARKETING STUDY FOR DOE

DOE-FETC requested that AGTSR coordinate an economic impact analysis (EIA) on the gas turbine power generation outlook through 2010. The emphasis is on pre-competitive R&D needed in industry, monies spent on gas turbine R&D within government and industry, and the future market and R&D forecast of gas turbines and its impact on the U.S. domestic economy. Per the recommendation of IGTI and Gas Turbine World, AGTSR sought out two candidates to conduct the EIA study. They were Forecast International in Newtown, CT and The Windsor Group in Boston, MA. AGTSR reviewed both qualifications packages and in February selected The Windsor Group. The project was let on March 10, 1999 for a 5-month period of performance. The cost of the project was \$126K and the main contact at The Windsor Group is Craig Lentz. Note that the Strom Thurmond Institute at Clemson and the Clemson University Business School were also contacted about the EIA study but could not meet the necessary time constraints. For additional information on this EIA study, please contact AGTSR at 864-656-2267.

AGTSR'S EDUCATIONAL PROGRAMS

For 1998, AGTSR placed 11 interns at ATS company sites. The final summary reports for these interns were distributed to DOE and the IRB during this quarter. For 1999, AGTSR received 17 applications and after review with the IRB expects to place 15 interns during the summer/fall of 1999. Also, for 1999, the interns pay will be pro-rated at \$450, \$550, and \$650 per week for graduating seniors, MS, and PhD students, respectively. In 1998, AGTSR selected five-faculty fellows. Of the five fellows, two have already completed their programs (Professor Roy/ASU at Solar, and Professor Gore/Purdue at Allison). The other three will be continuing throughout part of 1999. In addition, AGTSR received 4 faculty fellowship applications for 1999 and has selected all 4 for support – the fellows are from Utah, North Dakota, Penn State, and Oklahoma.

Miscellaneous Activities

AGTSR plans to release its tenth newsletter in May 1999 in which the results of several new workshops and research-educational projects will be highlighted.

AGTSR co-organized a special forum for the XIV International Society for Air Breathing Engines (ISABE) Symposium in Florence, Italy, September 5-10, 1999. The focus of the forum is on the use of Aero-Derivative Land-Based Gas Turbines for future power generation. The forum will include presentations from eight organizations: GE, P&W, MHI, Solar Turbines, Rolls Royce, NASA-Lewis, DOD-Air Force, and ENEL-Italy.

AGTSR will also be participating in the ASME-Turbo Expo IGTI99 in Indianapolis, IN this summer, June 7-10. AGTSR will have a university research poster display at the DOE ATS exhibit, will be presenting a research paper on catalytic combustion and co-chairing a technical session on aerodynamics-film cooling flows.