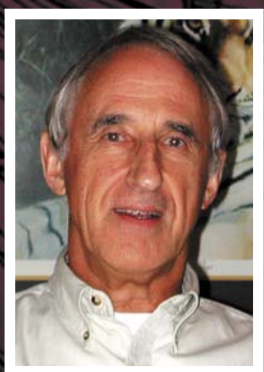
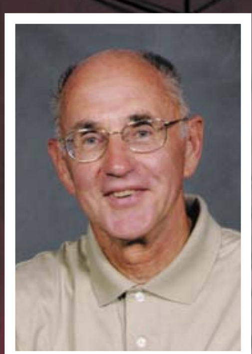
6.0.3

University Turbine Systems Research Program





6.0.3-1 Introduction

The University Turbine Systems research (UTSR) Program began in 1992, as part of the U.S. Department of Energy's major development program in gas turbines[1]. Between 1992 and 2001 the program was funded with about $400 million of DOE money and a similar amount of contractor money. Part of the program was a university research effort. Major emphasis areas were university research projects, internships, and technology transfer. The university program was coordinated by the South Carolina Institute for Energy Studies (SCIES), a part of Clemson University, under the overall direction of DOE's National Energy Technology Laboratory.

Total cost of the university research program from 1992 until 2001 was $35.5 million, of which $34.2 million came from DOE and $1.2 million came from industry. The UTSR activity, which began in 2002, is budgeted for $15 million in DOE funds and $750,000 from industry over 5 years. More details on the UTSR Program can be found in note 1[2].

The DOE Program has continued since 2002 and is now called the Turbine Program. The university activity is continuing as the University Turbine Systems Research (UTSR) Program. In 2003, the UTSR program shifted from an emphasis on natural gas fuel to research that supports a future power industry needing turbines fueled by syngas and hydrogen (SGH).

Under the university research program 108 universities in 40 states did/do research in the fields of aerodynamics and heat transfer, combustion, and materials. Besides the universities, the UTSR consortium includes leading gas turbine original equipment manufacturers (OEM's) and users, and gas turbine component manufacturers. These companies comprise the Industry Review Board (IRB), who recommend and track research projects that are funded, and are the host sites for graduating seniors and graduate students from UTSR universities placed for summer assignments (Fellows).

Current IRB Member Companies are BP, Capstone Turbine Corporation, Cinergy Energy Services, Clean Energy Systems, EPRI, ExxonMobil, General Electric Company, Ingersoll Rand Energy Systems, Parker Hannifin, Pratt & Whitney/UTRC, Precision Combustion Inc., RAMGEN, Rolls-Royce, Siemens Westinghouse Power Corporation, Solar Turbines, Inc., Southern Company Services and Woodward FST. Voting member companies are gas turbine manufacturers: GE, Pratt & Whitney, Rolls-Royce, Siemens Westinghouse and Solar Turbines. The others are Associate Member companies.

1. The overall program in 1992-2001 was called the Advanced Turbine Systems (ATS) Program, and the university research portion of ATS was called the Advanced Gas Turbine Systems Research (AGTSR) Program.

An Academic Advisory Board (AAB) was formed in 2004 to provide a mechanism for obtaining input from the academic community to the UTSR program and to develop short courses on gas turbine technologies. Their first product was a short course in August 2004 on the impact of synfuels on gas turbines. Current AAB members represent Virginia Tech, Georgia Tech, U. of California Irvine, U. of Central Florida, Penn State, U. of Connecticut, Brigham Young and U. of Wisconsin.

The program is geographically broad – based, see figure 1.66

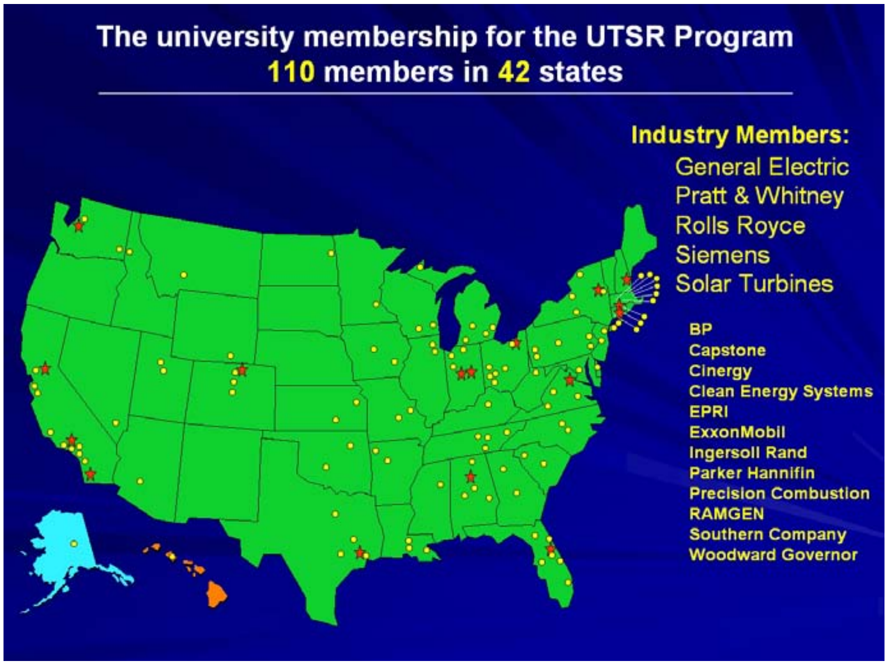


Fig. 1. The UTSR Process

The point of the research program is to address the goals of the DOE Turbine Program while producing results that are useful to the gas turbine industry. In order to achieve that outcome the program is designed with significant input from industry, through the IRB. The IRB and DOE decide which research topics are most relevant to their needs, in the areas of a) combustion, b) materials – focusing on thermal barrier coatings (TBC's) – and c) aerodynamics / heat transfer – focused on the turbine section of the gas turbine. These topics define the requested research in the Request for Proposals released yearly to the UTSR universities.

Then, after the proposals come in from the universities, the IRB ranks them within each of the three subject areas and recommends a short list to DOE for funding in the annual IRB meeting. The short list is created in rank order starting with the most important proposal and ending where the expected funding runs out, plus typically two backup proposals in case there is extra funding or enough cost savings can be achieved on the selected ones to fund more projects.

The typical project lasts for three years, averaging about $150K per year. So each year, the available funding needs to cover projects that were started one and two years ago in addition to the first year costs of new projects.

There is considerable communication between industry, the universities, DOE and SCIES, designed to keep the program relevant to the needs of industry, DOE's priorities, and the capabilities and ideas from the universities. The overall process of the UTSR Program is illustrated in figure 2.

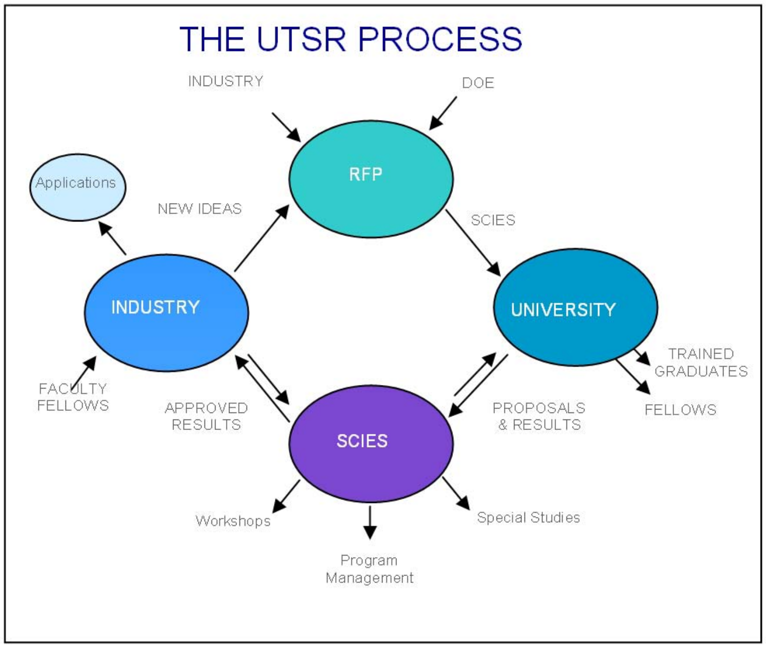


Fig. 2. Research Program

Since its inception in 1992, the UTSR research program has launched 103 projects, including 77 completed, 21 underway and 5 announced but not yet started. By visiting the website mentioned in note 1 the reader can select descriptions of each project and search by Principal Investigator or University[3].

Considerable results of use to industry have been achieved from these projects. A sampling of some of the most significant are listed below in the three technical areas of concentration.

MATERIALS (THERMAL BARRIER COATINGS):

• Laser fluorescence (LF) was determined to be the most promising technique for non-destructive evaluation (NDE) of TBCs and a UTSR projected started the commercial development of a new low cost and portable NDE instrument.

• Processing approaches have been identified that can increase TBC lifetimes by a factor of four and more.

• A new Small Particle Plasma Spray (SPPS) process was shown to produce a factor of two lower internal oxidation rate of the bond coat and TBC coatings that experience lower fatigue damage.

• Two superior alloys and one coating were identified for operation at surface temperatures above 700 C (1290 F which did not experience significant degradation associated with water vapor effects, significant to operation with syngas fuel.

COMBUSTION:

• Active control approach to overcome instabilities in low emission turbine combustors. A factor of four reduction in combustor pressure oscillations was demonstrated, and several gas turbine companies have started projects to evaluate application of the approach to their combustors.

• Method to determine the stability margin of combustors before experiencing problems in the field.

• Computer code for NOx and CO emissions prediction design of low emission turbine combustors. The code has shown a factor of forty reduction in computation times.

• Devices using infrared light for measuring fuel-air mixedness in combustors. Less than one-third of the cost of laser devices for measuring mixedness and are more compact and rugged.

AERODYNAMICS / HEAT TRANSFER:

• Experiments showing a scientific foundation for use of a fine water mist in steam for cooling high temperature turbine components. The addition of 1% water mist can enhance cooling by 50 to 100%, and in best cases, as much as 700%.

• Internal surface features within channels improve turbine blade cooling. Dimples on the interior of cooling channels can improve cooling effectiveness by as much as a factor of two, significant for operation with syngas fuels.

• LES (Large Eddy Simulation) computational approaches improve predictions of heat transfer and design of turbine blade cooling. This enables less coolant air to improve turbine performance.

Illustrations of a few of the completed projects are shown in figures 3 – 5.

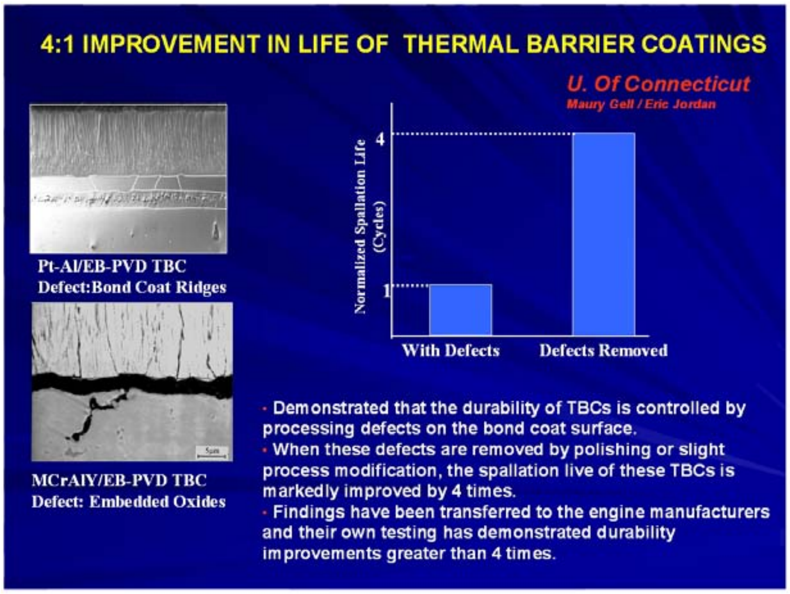


Fig. 3. Improvement in Life of Thermal Barrier Coatings

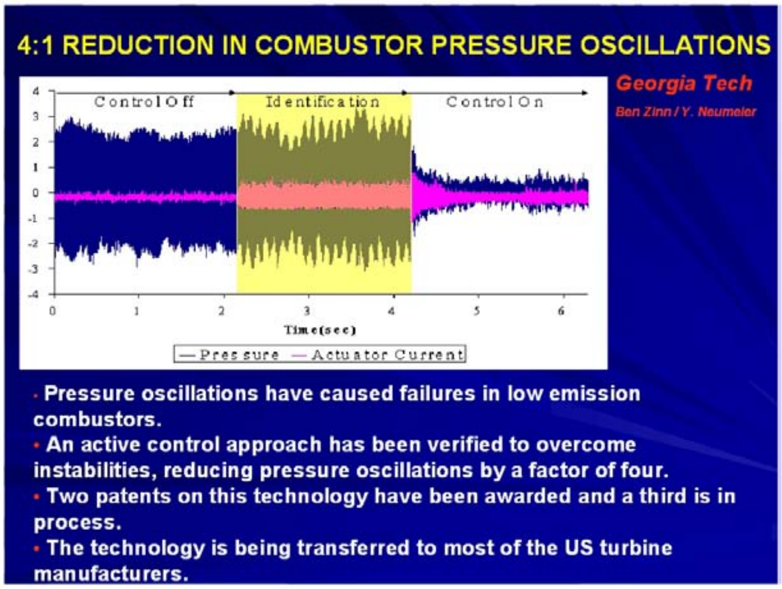


Fig. 4. Reduction in Combustor Pressure Oscillations

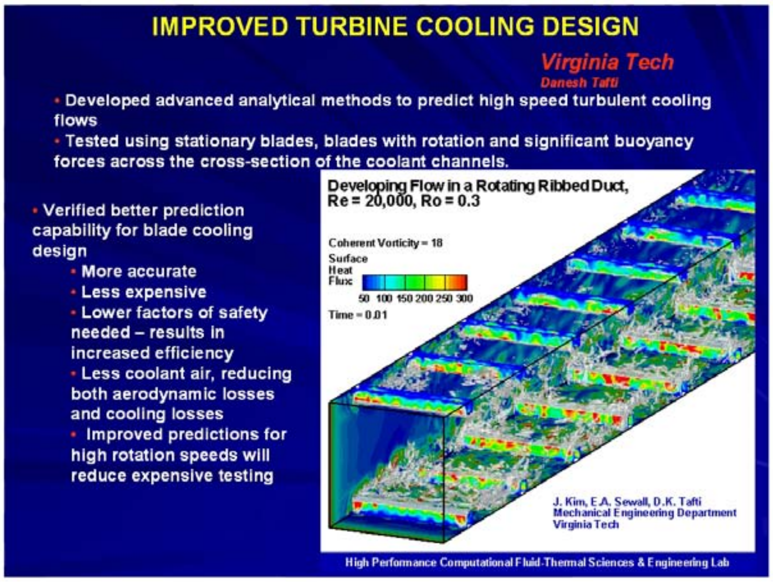


Fig. 5. Improved Turbine Cooling Design

6.0.3-2 The Challenge of Synfuels

The use of coal-derived synfuels poses particular issues to the designers of the hot parts of the gas turbine. Table 1 summarizes the major turbine research challenges and suggested means to overcome them.

Table 1

Issue Syn-H2 Gas Introduces	Description	Challenge/Resolution
Heating Value Variability	Syngas to natural gas variability is as much as 20:1.	Current combustors cannot manage this variability and research is needed to aid design of combustors that will.
Gas Constituent Variability	Constituent proportions vary significantly; for example H2 can vary 8.6% to 44%. Amount of H2O in the combustion process will be significantly greater than for conventional fuels.	Flash back is an issue for H2 bearing fuels and research on flashback will also aid design of natural gas turbines. Increased mass flow has required down rating of current designs. Design to prevent combustion instabilities is complicated by fuel variability
Blade coatings	Mixed gases (H2O, salt, etc.) attack current airfoil base materials.	Research for more robust barrier blade coatings is justified in order to increase operating temperature and life.
Heat Transfer	Increased heat transfer to components results for syngas-hydrogen fuels.	Research to gain improved understanding of heat transfer mechanisms for syngas is justified.
Deposits	Syngas deposits will cause special problems not now fully understood.	Research needed to gain improved understandings of consequences such as blade wakes, reduced flow passageways, and clogging of film cooling holes.
Erosion-Corrosion	Erosion-corrosion issues not fully understood.	Research is needed to understand rates and consequence of blade passage wear, especially in blade tip region. TBC degradation and spalling need to be understand in order to allow operation at higher more optimal temperatures. Contribution of syngas contaminants need improved understanding.
Combustion	Flashback is an issue and increased residence time is needed for CO burn-up.	Flashback due to H2 in the fuel, leanness limits to support low NOx and residence time needs for CO burnout, must be researched separately and in an integrated sense.
Prediction of Problems	Syngas-hydrogen fuels are likely to challenge predictive understanding of turbine robustness.	Research is very important to aid prediction of slow failures that would result in environmental issues, accelerated blade degradation, hindrance of engine cycling.

6.0.3 Gas Turbine Industrial Fellowship

As part of the UTSR Program, the Gas Turbine Industrial Fellowship Program offers students valuable work experience and the opportunity to practice the "art" of engineering in an industrial setting. Discipline areas, as applied to land-based gas turbine power generation systems, include mechanical design and manufacturing, heat transfer, aerodynamics, combustion, thermodynamic analyses, materials and coatings, and testing and evaluation.

Emphasis is placed on gas turbine component design and manufacturing techniques, using state-of-the-art experimental and computational facilities. UTSR professors and industry engineering staff serve as mentors and advisors for the fellows. Students are exposed to gas turbine design techniques, analysis and system optimization methods, design limitations and practical problems encountered in the industry.

Fellows participate in a 10-12 week work experience at turbine industry sites (manufacturers and end users). In order to participate in the program, students must be in good standing in an appropriate degree program at an accredited U.S. college or university that is a UTSR Performing Member. The program targets B.S. (graduating seniors), M.S. and Ph.D. graduate students. Applicants must be U.S. citizens or permanent resident aliens. The applicant's selection is based on academic record, aptitude and gas turbine engineering interest, as well as the recommendation of the applicant's advisor and engineering instructors.

Fellows are paid a stipend of $700, $800, or $900 per week, depending on academic status of BS, MS or Ph.D. respectively, plus a one-time payment of $1200 to help cover travel and relocation expenses. Further details and background can be found in note 4[4].

Process of the Fellowship Program

Selection of Fellows: Annually, an announcement of the program is released, and applications are received and reviewed by industry. The applicants rank the companies they most want to work for, and the IRB companies rank the applicants they are most interested in, typically their top 4 or 5 since they get only 1 or 2 Fellows; one per Associate Member and two per Voting Member. The applicants respond, accepting or rejecting the offers. Typically the student acceptance rate is about 90%. For those cases where the applicant rejects the offer, SCIES, after conferring with the IRB company where that student was offered placement, makes offers to backup candidates as needed until all the available slots are filled.

Reports and Presentations: At the conclusion of their projects, the Fellows are required to make a report on their projects, including objectives, procedure and results. Also they develop a PowerPoint description of the projects. One Fellow from each IRB company participates in a poster session at the annual Peer Review Workshop. The PowerPoint presentations are posted on the UTSR website. The presentations are cleared with the IRB companies for placement in the public domain.

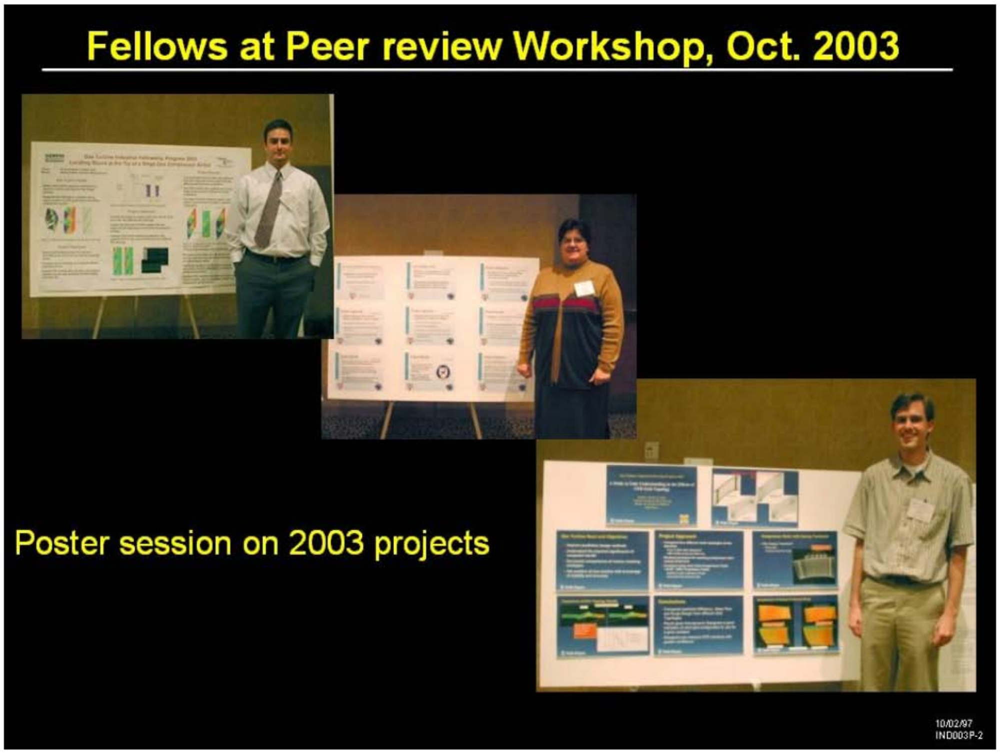


Fig. 6 Sample project description from the 2004 Fellowship Assignments

Title: CFD Modeling of Rotor-Stator Cavity Purge Flow
Author: Jonathan McGlumphy Virginia Polytechnic Institute & State University
Industrial Mentor: Dr. Philip Andrew, Mgr., Turbine Aero Engineering
Industrial Site: General Electric Power Systems, Greenville, SC facility
Objective: Apply GE in-house CFD solver to simple rotor-stator cavity geometries to lay foundation for future work

Achievements:

- Reviewed literature to find simple cavity geometry with available experimental data
- Performed initial computations using GE in-house code
- Developed technique to allow density-based code to solve incompressible flow field
- Results compared favorably with published data and accompanying computations
- Confirmed that code can capture fundamental physics without modification to the code

Future Work

- Code will be used to model flow fields of more complex geometries.
- Method could be used in the future to guide experimental set-ups

2005 Fellows

The placement of the Fellows for 2005 is shown in Figure 4; a total of 20 applicants from 12 universities were placed in 13 companies.

Fellow	University	Company Placement
Benjamin Asefa	University of Michigan	Parker Hannifin
Christopher Bolszo	University of California, Irvine	General Electric Company
Nicholas Cardwell	Virginia Polytechnic Institute	Pratt & Whitney/UTRC
Jeffrey Carullo	Virginia Polytechnic Institute	Solar Turbines, Inc
Jared Crosby	Brigham Young University	Pratt & Whitney/UTRC
Jason Habeger	Michigan State University	Siemens Westinghouse
Michael Hind	University of Wyoming	Ingersoll Rand Energy Systems
Jerrod Isaak	University of Wyoming	Clean Energy Systems
Richard Klop	Michigan State University	Rolls-Royce Corporation
Jonathan McGlumphy	Virginia Polytechnic Institute	Rolls-Royce Corporation
Adam Norberg	Virginia Polytechnic Institute	Ramgen
Clark Paterson	Colorado State University	Woodward FST
Travis Patterson	University of Central Florida	Siemens Westinghouse
Emmanuel Perez	University of Central Florida	General Electric Company
Stanton Peterson	University of Wyoming	BP
Patrick Sheppard	Vanderbilt University	Solar Turbines, Inc
Andrew Skoglund	University of Minnesota	Siemens Westinghouse
Ruwan Somawardhana	University of Texas, Austin	Precision Combustion
Paul Teini	University of Wyoming	Pratt & Whitney/UTRC
Scott Thawley	Virginia Polytechnic Institute	Capstone Turbine Corporation

In 2004 we contacted former Fellows concerning their permanent positions and heard back from 63 of them:

To the gas turbine industry:	29
To industry, non-gas turbine:	8
To academia:	3
Subtotal who have started full-time employment:	40
Still in graduate school at last report:	23

So, of those who have started full-time employment, 73% went to the gas turbine industry, and an additional 7% went to academia. If we include those in academia, 80% of them are benefiting the gas turbine industry.

6.0.3-4 Notes

1. SCIES website: http://www.clemson.edu/scies/; click on "University Turbine Systems Research" for information on the UTSR Program.
2. Ibid.
3. Ibid.
4. SCIES website: http://www.clemson.edu/scies/ then click on "Gas Turbine Fellowship"; W. Day, "University Turbine Systems Research Program: An Innovative Approach to Graduate Education" *ASME Paper number MECE2005*-82534 (to be presented at the ASME International Mechanical Engineering Congress & Exposition, Orlando, FL, November 2005).

BIOGRAPHY

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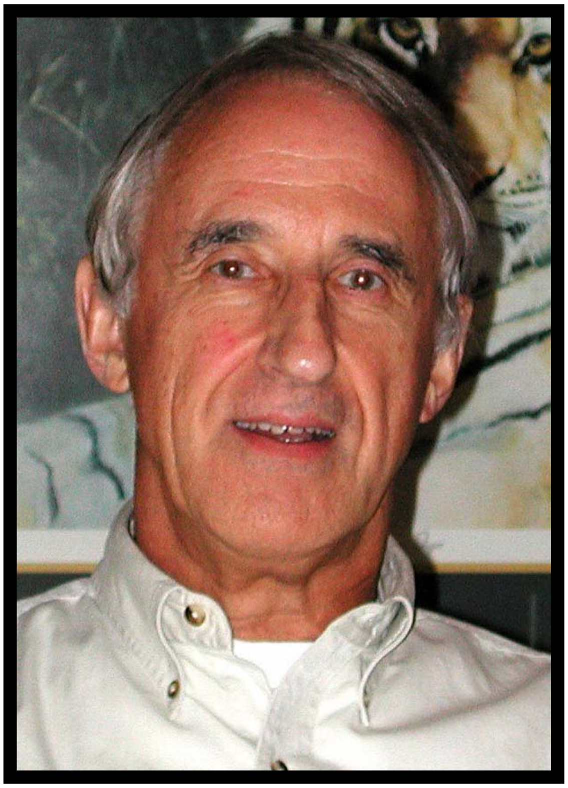
Dr. Day is a graduate of Cornell University BME 1960, Polytechnic University MSME 1966, and Polytechnic University Ph.D. ME 1970. Dr. Day started as an engineer with General Electric in 1960. During his career with GE's Gas Turbine Division he was responsible for establishing and managing the High Temperature Turbine Technology Program, and managed the business with EPRI and the US Department of Energy. In 1979 Dr. Day joined the United Technologies Corporation, where he managed a joint gas turbine design study between Pratt & Whitney and Siemens. He was also responsible for negotiating the contract with the People's Republic of China that launched the FT8 gas turbine and for directing the development of the FT8. He was responsible for negotiating the contract with Siemens that led to development of the V84.3A gas turbine and was in charge of that development effort at UTC. From 1995 until his retirement from United Technologies in 2002, Dr. Day was Manager of Advanced Engine Programs for Pratt & Whitney's industrial gas turbine business. In 1995, Dr. Day led the founding of the Gas Turbine Association, the trade association for the gas turbine industry. He served as Chairman of the Board of GTA from its founding in 1995 until his retirement from United Technologies in 2002. In 2001 Dr. Day was named a Fellow of Pratt & Whitney in recognition for his expertise in industrial gas turbines. In 2002, Dr. Day joined the South Carolina Institute for Energy Studies (SCIES) as Outreach Manager. SCIES coordinates the university research programs for the U.S. Department of Energy's University Turbine Systems Research (UTSR) Program. Responsibilities and accomplishments include a substantial expansion of the Gas Turbine Industrial Fellowship Program and of the Industry Review Board, publication of numerous articles in gas turbine trade journals and ASME papers on the UTSR Program, while working closely with the Department of Energy. Dr. Day has four patents and has published over 60 technical papers.



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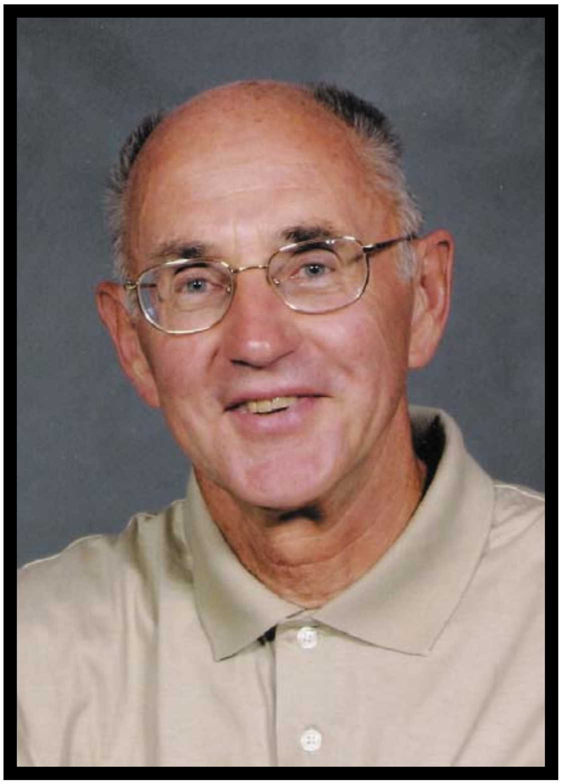
Richard Wenglarz received B.S. and M.S degrees from the University of Illinois, and Ph.D. degree from Stanford University, all in Engineering Mechanics. He has held positions at the University of Newcastle Upon Tyne, Bellcomm, Bell Laboratories, Westinghouse R&D Center, Rolls Royce/Allison Division of General Motors, and South Carolina Institute for Energy Studies (SCIES) at Clemson University.

His early experience involved dynamics and control for gyroscopic systems and manned space stations. Later experience concerned developing and applying analytical and experimental methods to evaluate deposition, erosion, and corrosion (DEC) in advanced energy systems (e.g., gas turbines and fuel cells) operating with alternate fuels. Currently, Dr. Wenglarz is Manager of Research at SCIES for the DOE sponsored University Turbine Systems Research (UTSR) program supporting university gas turbine research nationwide.

Dr. Wenglarz has over 80 publications and presentations including invited presentations at the Von Karman Institute for Fluid Dynamics, Yale University, UK Central Electricity Research Laboratories, Cambridge University, and the Kentucky Energy Cabinet Laboratories.



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Lawrence P. Golan is presently Special Assistant to the Vice President for Research at Clemson University (2003 – present). In addition, Dr. Golan is Director of the South Carolina Institute of Energy Studies - SCIES. (1986-2003) He established the Energy Systems Laboratory, a unit blending energy facilities, academics and research. Dr. Golan maintains a working relationship with the Gas Turbine Association, the Alliance to Save Energy and the Southeast Energy Efficiency Alliance. He received his Ph.D. from Lehigh University and his B.S. and M.S. from West Virginia University.

Dr. Golan's professional activities include: Chairman 1996 National Heat Transfer Conference hosted by AIChE, ASME, AIAA and ANS; 1990, 1994 and 1999 Chair of the AIChE Heat Transfer Division; 1992 National Heat Transfer Conference Best Paper co-Chair; 1992, 1994 and 1996 Chair Kern and Jakob Award Committee; member National Heat Transfer Conference Coordination Committee; AICHE Chair 2004 Summer Heat Transfer and Fluids Engineering Conference, advisor to the State of Illinois Coal Combustion Program; and member of the Academic Advisory Committee West Virginia University Mechanical Engineering Department. Dr. Golan has authored 34 articles, offered 13 short courses and organized numerous energy conferences and workshops. Prior to his present position at Clemson University, Dr. Golan was employed by Exxon Research and Engineering Company (presently ExxonMobil) for nineteen years. Since 1992 Dr. Golan has directed a nationwide activity of 110 universities and 10 U.S. corporations for the U.S. DOE that is providing technology necessary for developing the next generation of advanced land-based power generation systems.