Establishing the Scientific Foundation for the 21st Century Gas Turbine

AGTSR

by

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ABSTRACT

The Advanced Gas Turbine Systems Research program (AGTSR) was established in 1992 at the beginning of the U.S. DOE Advanced Turbine Systems (ATS) program. Since inception AGTSR has matured, but age and growth has not created inflexibility nor stagnation – the AGTSR is now a vibrant virtual laboratory that through its nationwide membership can quickly respond to technology needs of the industry. The initial major goals of AGTSR were to develop high quality base research to support the industry. That still is the prime mission, but as AGTSR has matured, various other activities have naturally grown into the portfolio to make AGTSR a comprehensive virtual national laboratory. In 1992 the AGTSR was completely unknown and lacked even name recognition. Now through DOE and industry guidance, and quality research by the U.S. academic community, AGTSR has developed into a research laboratory that SCIES believes is respected worldwide. The research mission is still the focus, but workshops for technology transfer, education activities for undergraduate and graduate students with opportunity for faculty study, short courses and specialty studies being added.

HOW IS AGTSR ORGANIZED?

The South Carolina Institute for Energy Studies provides the central administration for the Advanced Gas Turbine Systems Research (AGTSR) program. AGTSR effectively builds units that cut across university boundaries to create teams of excellence. Key features of the AGTSR are that

- researchers are spread out geographically
- researchers can move temporarily to major test sites
- electronic communications are exploited
- periodic specialty meetings are held for peer review and
- one annual program review meeting fits the research into the big picture.

The distribution of researchers throughout the U.S. provides for maximum contact of the researchers to each other and with major research sites. With DOE oversight and industry guidance the program is managed by SCIES with a focus on quality, relevance, and timeliness of the research. The quality of the research is assured by university peer review at workshops and through the publication process. Relevance of the research is assured by the definition of the research needs provided by industry – followed by the selection of the research to be accomplished and subsequent critique of results by industry. Finally, timeliness is assured by industry and DOE interest and continued contact with Performing Member institutions throughout the life of a project. The universities realize that for success, competition to win research awards is necessary and so is cooperation after awards are made.

The AGTSR presently has a membership base of 97 performing member universities located in 37 states, distributed as shown in Figure 1. The Industry Review Board (IRB) consists of nine major U.S. firms that are either OEM's, users, or component manufacturers (see Figure 2). The university members determine how and where to conduct the research recommended by the industry. The IRB provides corporate leaders to define the thrust of the research program and technical experts to evaluate the university research proposals. It is SCIES' responsibility to be the linkage between all three groups: universities, government and industry. The research program is broadly segmented into three discipline areas – combustion, aero/heat transfer, and materials. To date 62 research contracts have been awarded with 32 completed and 30 research projects now on-going. The awards based on RFP 1999 have not as yet been selected. The prime thrust of the research has been to improve efficiency, reduce emissions and improve engine and system performance. The general focus of each research area is shown on Table 1.

WHAT HAS AGTSR ACCOMPLISHED?

In 1992 the AGTSR focused solely on research. As the program has matured research has continued to be the key element of the program, however, workshops, internships, fellows, and special studies have been added (see Figure 3). AGTSR accomplishments can be grouped into 3 areas:

philosophical – personnel – technical

From the philosophical point of view AGTSR has changed the way gas turbine research and maybe university research in general is accomplished. Prior to AGTSR it would not be uncommon for a university researcher to work with a funding agency on a one-on-one basis. With AGTSR programs this is not the typical way research is accomplished – cooperation is the key. As reported to SCIES, the universities believe that they have had over 230 key interactions (56 universities reporting) or approximately a four-fold increase in university-to-university-to industry-to-government interaction. The reported number of interactions is shown in Figure 4. Meaningful relationships beyond these should continue outside the AGTSR/ATS as university-industry-government research personnel become more and more familiar with each other's capabilities.

From the perspective of personnel SCIES is a resource for training competent professional staff. The accomplishments to date include

- every available Summer Intern joined an OEM as an employee except one
- one intern is now a professor
- nine Faculty Fellowships provided in-depth training for university professors
- approximately 300 graduate and undergraduate students have been involved in the research program
- approximately 120 university faculty have been involved in the program, and
- approximately 110 area experts from industry have assisted in the program.

Approximately 600 individuals, a majority of which are university personnel, have been involved in AGTSR. Some individuals have suggested that the training of competent professional staff in the university environment is the most important facet of AGTSR. The reason being that these individuals are the future for the industry.

From the research perspective AGTSR has had numerous contributions to gas turbine power technology with several being reported as success stories. The two presentations following this talk from the University of Connecticut and Clemson University highlight two AGTSR research projects. The poster session that follows this session shows much of the on-going work with an opportunity for all to have one-on-one discussion with the researchers. Here I will briefly mention some additional activities being conducted at performing member universities by showing you information they have provided SCIES. For complete details it is best to talk directly with the university professor or graduate student.

In early AGTSR research Professor Santora and Yang at Penn State have developed a fiber optic equivalence ratio probe for making fuel distribution measurements in combustors. The performance of the probe has been successfully demonstrated at Westinghouse and FETC. Also with probe development Professor Dibble at the University of California at Berkeley has developed a fiber optic probe for measuring fuel-air mixedness. This probe has also been tested at several sites with relation to NO_x reduction (see Figure 5).

Professor Lakshminarayana, also at Penn State, is acquiring flow data in a multistage environment for the design of next generation multistage compressors. Allison Engine Company has used the Penn State data to predict the performance of a three stage industrial gas turbine booster compressor. The results show that the performance prediction of the booster compressor has improved dramatically. Also of significance is that the Penn State flow data is being used by Stanford University in their program aimed at predicting the flow field in an entire jet engine. This activity is also DOE sponsored (see Figure 6).

Recently Professor Zinn at Georgia Tech has demonstrated the control of combustion instabilities on a 3MW combustor at Siemens Westinghouse. The active control system automatically detected the combustion instabilities, identified its characteristics and "instantaneously" attenuated the unstable mode by up to 15dB. This is shown on a video produced by Georgia Tech. At the University of California, Irvine Professor McDonnell has been working on extending stability limits by the introduction of a pilot gas into the flow stream. Maps of performance and the associated fuel distribution have been developed.

TECHNOLOGY TRANSFER

The research work is freely discussed at AGTSR workshops – a list of which is shown in Table II. The Workshops provide a vehicle for researchers from industry, government and the university to interact and discuss research results and progress in a low-key environment. The first half of 1999 was particularly busy with 4 workshops being held. Of particular note is the Strategic Visioning Workshop hosted by the University of Texas with Energetics which started the planning for the Next Generation Gas Turbine Program. All Workshop reports are available from SCIES. In addition to the Workshops SCIES has also released a University Facilities Survey and Research Position Papers as part of the Next Generation Road Mapping activity. An Economic Impact study will be released shortly.

The University Facilities Survey has confirmed that the U.S. universities have the necessary laboratory equipment for conducting gas turbine power systems research, however, the universities lack capabilities for conducting systems integration studies. The Economic Impact study, now in draft form and in review, shows that the energy savings attributable to DOE's ATS program in the year 1999-2010 amounts to $1,914 million based on a 32% reduction in fuel firing. Environmental benefits are now being evaluated. The Position Papers report was developed by 50 federal, university, and industry workers that accepted this assignment at the combustion, aero/heat transfer and TBC Workshops held in 1999. In summary, the research needs outlined in the position papers report are:

Combustion

The basic goal of the combustion recommendations is to minimize environmental issues and to ensure increased power plant efficiency. The researchers realize that the present day fuel of choice is natural gas, however, "non-standard fuels" such as occurring in chemical plants, landfills and biomass systems need consideration. The need for improved understanding of the effect of fluctuations in heating value, fuel/air ratio on flame stability and flame blowout is required. Ultra lean premixed combustion must be fully investigated. The SSI initiative can be used to improve combustion chemistry calculation, improve benchmarking data and improve engineering simulations. Improved sensors and diagnostic tools are required for identification of parameters in fuels that are key indicators of emissions and stability.

Aero-Heat Transfer

An accepted method of achieving higher turbine efficiency is to raise turbine inlet temperature. This in itself creates the need for improved understanding of aero-heat transfer effects in turbine airfoils. A program consisting of improved CFD models, unconventional cooling systems and improved understanding of turbulence and turbulence effects on airfoil heat transfer is proposed that would include, but not be limited to:

- establish improved CFD models to study strongly unsteady three dimensional flows with identifiable embedded vertical structure
- research unconventional cooling methods that do not directly use gas path cooling air drawn from the compressor
- develop CFD codes with improved grid generation techniques, improved mass flow and energy conservation and improved large eddy simulation (LES) and direct numerical simulation (DNS)
- develop technology aimed at providing improved aerodynamic performance with reduction in stage count with performance benefit
- develop advanced design concepts which integrate aero-thermal-mechanical considerations with new materials for structures and coatings
- develop an improved understanding of turbulence and effect of turbulence on turbine airfoil heat transfer.

Materials Issues

The position paper establishes a rationale for coatings as arguably the most critical materials issue in enabling revolutionary advances in gas turbine technology. The discussion extends beyond the original focus on TBCs to include Environmental Barrier Coatings (EBCs) for ceramics and CFCCs. While the need for materials with improved capabilities is recognized, the study concludes that the impact of such improvements can only be fully realized if the uncertainties in coating life can be minimized, thus enabling their utilization in prime-reliant design.

The study identifies the need for a coherent set of science-based methodologies for the design, manufacturing and life prediction of coating systems, and proposes a conceptual infrastructure of engineering tools as a long-term goal to guide the development of such capabilities. The core of the idea is the ability to generate computationally a profile of the coating characteristics and their variability over the surface of a complex component, and to simulate its response to the profile (spatial and temporal) of operating conditions anticipated for the component in the engine. The goal is certainly ambitious, but the challenge is not unlike that undertaken by the casting industry in the recent past, wherein conceptually similar tools were developed to assist in the design and manufacturing of complex castings for gas turbines.

While the long-term vision is articulated in terms of modeling tools, it is recognized that the bulk of the challenge resides in developing the science-based mechanistic understanding of the materials, processes and evolutionary phenomena that dictate coating performance and life. As such, the strategy must include substantial experimental components to elucidate the physics of the various elements of the problem and validate the emerging models. Essential components of the strategy are efforts focused on improving materials, processes and NDE tools that would enable the full utilization of the anticipated advances in capabilities for coating design. The recommended strategy is expected to bear a multiplicity of shorter-term benefits while pursuing the long-term goal. The latter, in turn, would represent a "quantum-leap" in coating engineering, with benefits extending well beyond the realm of TBCs and EBCs for gas turbines.

WHAT'S NEXT FOR AGTSR?

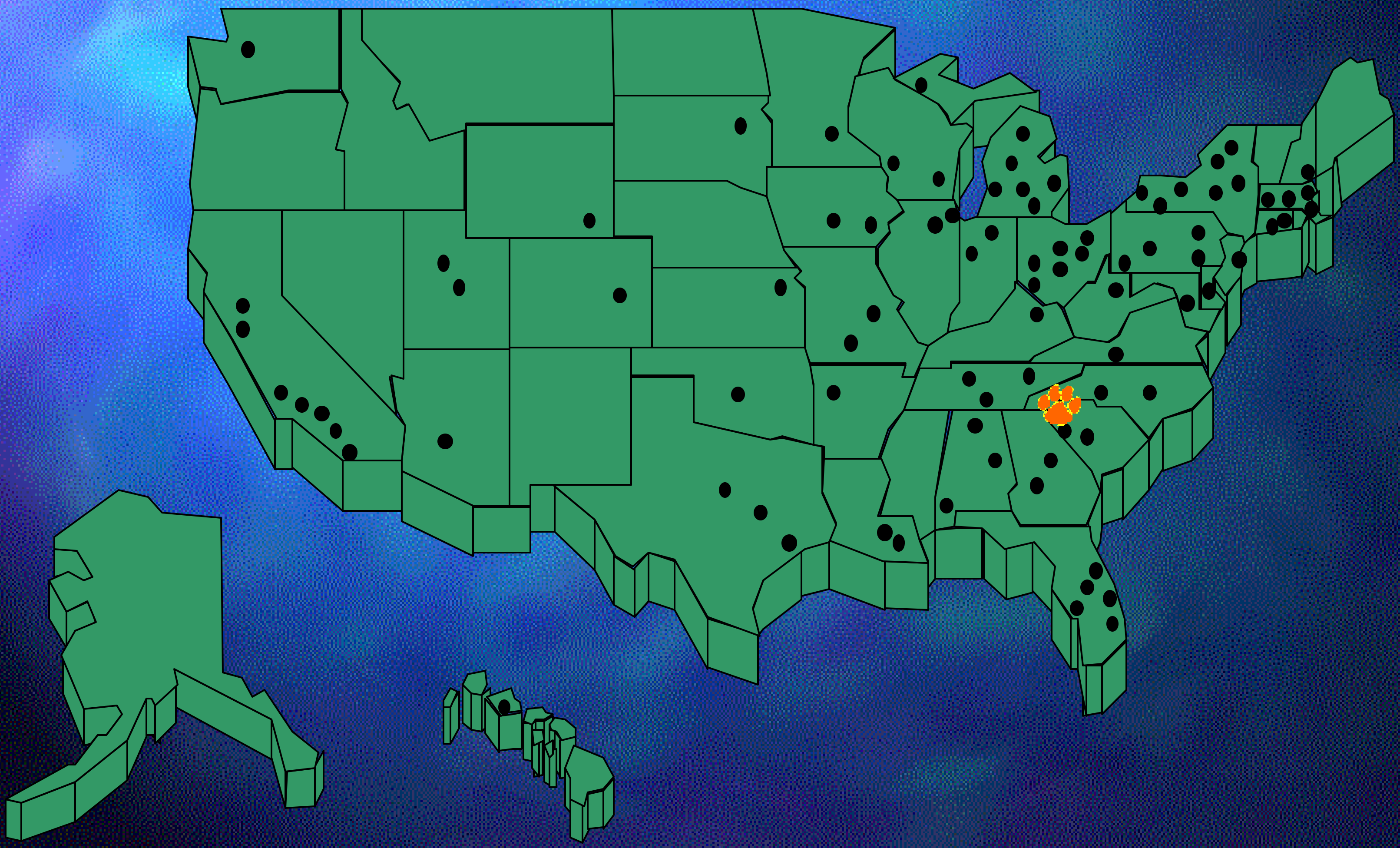
In 1992 when AGTSR began, the program obviously suffered from name recognition. AGTSR was untried, unknown and unproven. Now that is definitely not the case. When one mentions Mickey Mantle the natural thought is of baseball – AGTSR and it's association with gas turbine research may not be that natural, but we are getting there. Consider that for the AGTSR program manager position SCIES received applications from individuals in Sweden, South Africa, Saudi Arabia, and Israel. In addition SCIES recently organized a session on aero-derivative engines for the ISOABE meeting held in Florence, Italy; have been requested by the Japanese Society of Chemical Engineers to discuss U.S. gas turbine research on an expense paid trip to Japan, and been requested to participate in the Distributed Power Conference to be held in France in February 2000. On a more local level SCIES recently presented AGTSR at the EPRI Distributed Resources Conference held in Phoenix, Arizona. In addition SCIES has had one-on-one discussion with individuals in Egypt, India, and the U.K. concerning AGTSR program organization and management protocol. AGTSR has arrived.

Within the business, what has changed since 1992? First and foremost, the AGTSR program, through the universities have produced meaningful results under the guidance of industry and DOE FETC. The program results are available, of high quality, and relevant. The power needs in the U.S. and worldwide continue to increase but, at least in the U.S., the need may have shifted to intermediate load generation in the 30-150

MW range. The predictions by other groups show that worldwide the generating capacity needed in 2020 is approximately 6000GW, up from the nominal 3000GW now available, while in the U.S. an additional 360GW may be needed in the same timeframe. Finally, deregulation of the utility industry, distributed power, environmental concerns, the Kyoto Protocol, the PCCAST, and company mergers continue to support the need for AGTSR.

(Figure 1)

PARTICIPATING UNIVERSITIES

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Southern Co. Services
Woodward FST

(Figure 2)

(Figure 3)

AGTSR GROWTH

1992
Research

1993
Research

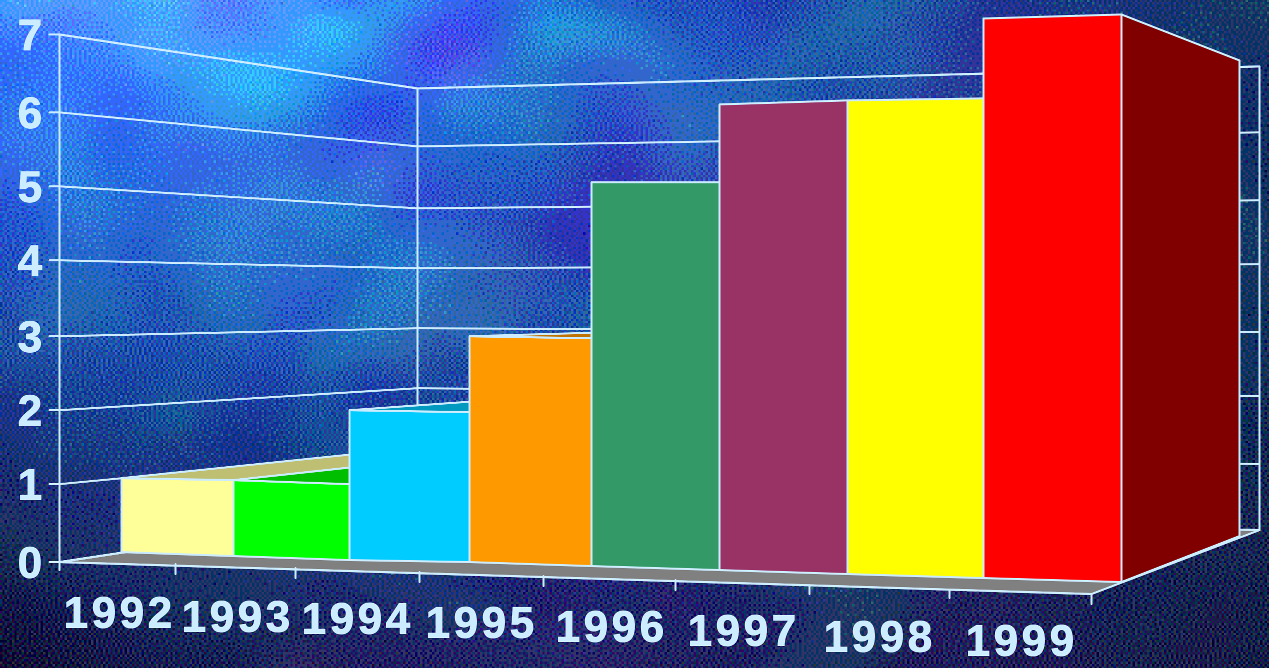
1994
Research
Workshops

1995
Research
Workshops
Internships

1996
Research
Workshops
Internships
Undergraduates
Faculty Fellows

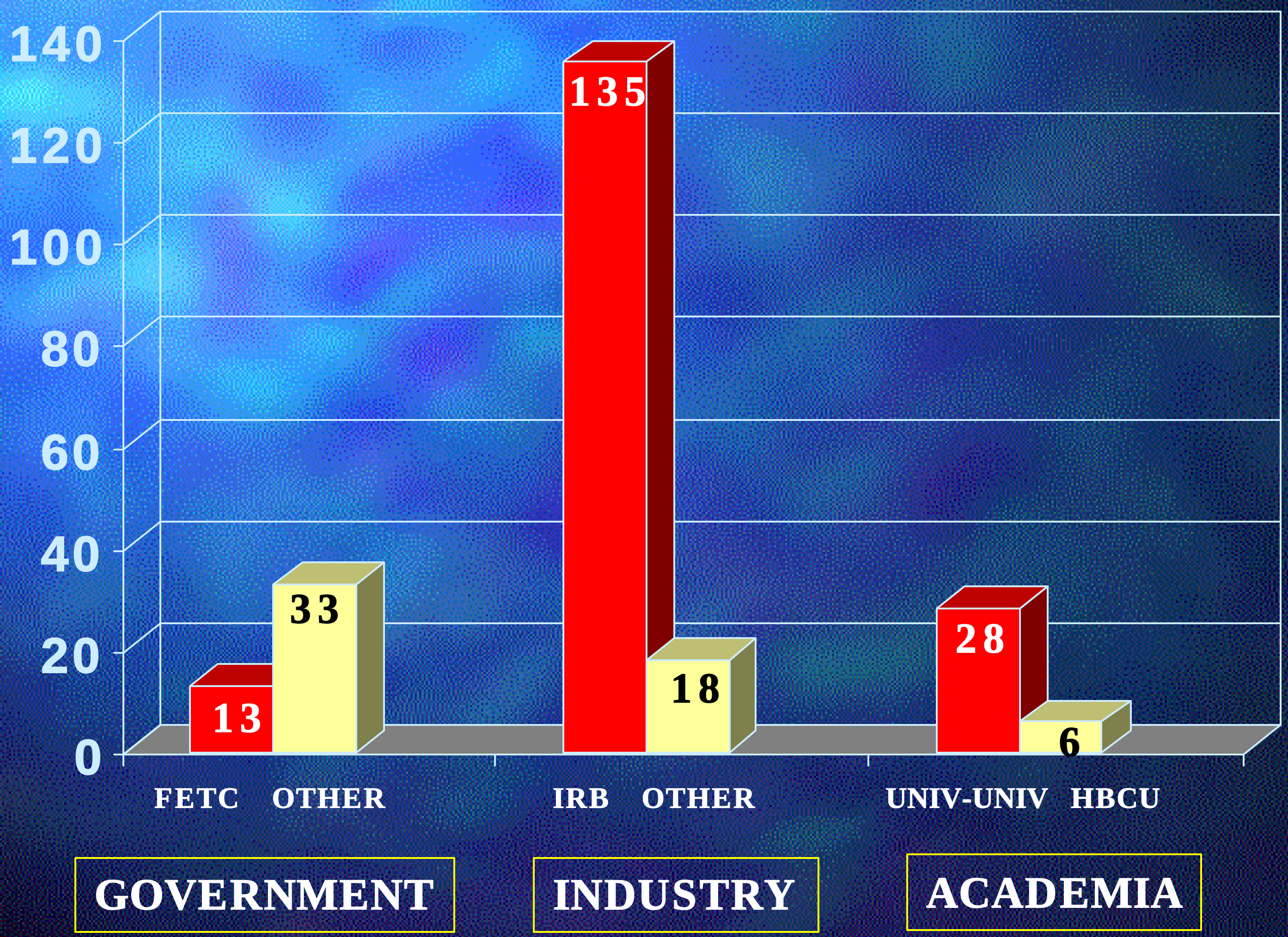
1997-98
Research
Workshops
Internships
Undergraduates
Faculty Fellows
Short Course

1999
Research
Workshops
Internships
Undergraduates
Faculty Fellows
Short Course
Specialty Studies



(Figure 4)

RESEARCH PROGRAM INTERACTIONS



(Table I)

GENERAL FOCUS OF AGTSR RESEARCH AREAS

COMBUSTION RESEARCH	**MATERIALS RESEARCH**	**AERO-HEAT TRANSFER RESEARCH**
Permit higher turbine inlet temperatures achieving cycle efficiency benefits while lowering NOx, CO, UHC and improving flame stabilizations	Improve performance and durability of thermal barrier coating-substrate materials	Enhance performance and efficiency while improving durability
Four Sub-Areas of Work: - lean premixed/instability experiments - advanced modeling - sensors and controls - catalytic combustion	Three Sub-Areas of Work: - TBC modeling and durability experiments - New coating techniques - Life prediction and non-destructive evaluations	Four Sub-Areas of Work: - internal cooling enhancement - external cooling flows - aero optimization - new design methods

(Table II)

WORKSHOPS

Feb 94	Combustion	Vanderbilt
Mar 95	Heat Transfer	Clemson
Mar 95	Combustion II	Purdue/Allison
Feb 96	Materials	DOE/HQ
Mar 96	Combustion III	UC Irvine
Apr 96	Sensors & Controls	Oak Ridge
Feb 97	Heat Transfer II	Clemson
Mar 97	Combustion IV	GA Tech
Jun 97	IGTI Expo	Orlando
Aug 97	Film-Cooling SC	CU
Mar 98	Combustion V	UC Berkeley
Apr 98	Metallics	Stevens
Jan 99	TBC	UC Santa Barb
Mar 99	Strategic Visioning	Energetics
Mar 99	Heat Transfer III	Univ Texas-Austin
Apr 99	Combustion VI	Virginia Tech