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Advanced Gas Turbine Systems Research

**Quarterly Report
April - June 1994**

July 1994

Work Performed Under Cooperative Agreement No.: DE-FC21-92MC29061

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Clemson University
Clemson, South Carolina

MASTER

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P.O. Box 880
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By
Clemson University
South Carolina Energy Research and Development Center
Clemson, South Carolina

July 1993

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

April 1, 1994 - June 30, 1994

SUMMARY

The first AGTSR program manager retired on March 30, 1994; therefore a search for an AGTSR program manager was initiated. Of 53 applicants, five were interviewed on site and a recommendation made to METC. METC approval is pending.

Allison Engine Company has not submitted its IRB membership fee. A July 15, 1994, deadline has been established. If the Allison membership fee is not received by that date, they will be deleted from the AGTSR panel.

Three new universities have indicated an interest in joining the AGTSR.

Reports issued by AGTSR this reporting period include:

- Performing Member Capabilities Notebook,
- AGTSR Quarterly Reports No. 1 and 2 for RFP 93-01,
- Combustion Instability white paper,
- AGTSR summary paper for the ASME IGTI Conference.

The IRB has agreed to cost share at 10% the curriculum stem development proposed by the University of Oklahoma on power generation. The AGTSR commitment will only apply if the NSF award is received by the University of Oklahoma. The IRB is also considering sponsoring an undergraduate honors research project at Clemson University on a one year trial basis to assess its value.

MEMBERSHIP

During this reporting period, three universities have expressed interest in the AGTSR program and requested information on becoming Performing Members. The universities now considering joining AGTSR are as follows: the University of Connecticut, the University of Illinois at Chicago, and the University of Massachusetts at Lowell. Assuming these universities complete the membership application, the total university base will be 66 representing 34 states.

ADMINISTRATION

The sitting AGTSR program manager retired on March 30, 1994; therefore, a search for an AGTSR program manager was initiated and completed during this reporting period. The position vacancy was advertised at the Nashville Combustion Workshop, internally through the IRB and Performing Members, the Greenville News and the ASME Magazine. These announcements resulted in 53 applications for review by the Search Committee assembled at SCERDC. The Search Committee consisted of the following:

- Director, South Carolina Energy Research and Development Center
- Senior Vice Provost, Clemson University
- Assistant to the President, Clemson University and
- Associate Vice President for Academic Administration, Clemson University.

A short list of 5 candidates were interviewed on site with a candidate recommendation forwarded to DOE METC for review. After discussions with METC are completed, an offer to the selected candidate will be extended.

Program cost sharing fees have been received from General Electric, Westinghouse, Solar and TurboPower. Allison Engine Company is again considering membership renewal. A deadline of July 15, 1994, has been established for Allison. EPRI and GRI continue to be non-voting, no fee IRB members.

The AGTSR Cooperative Agreement was extended for a nine month period through December 31, 1994. The approved extension was for

\$3,993,120. Based on the extension, the 13 new research contracts were negotiated and signed so that all could begin by July 1, 1994. The AGTSR now has 23 research contracts in place.

On April 18, 1994, a Performing Members Notebook was released. This notebook contains descriptive information of our Performing Member institutions. The Notebook was released to encourage ease of establishing communications between Performing Members and with the IRB. As needed, the Notebook will be updated.

1993 SUBCONTRACT PROGRESS

Progress reports from the ten universities receiving 1993 research awards have been received at AGTSR. No delinquent universities have been observed. Quarterly reports numbers 1 and 2 have been assembled into report notebooks and distributed to all IRB members and METC. AGTSR has requested our subcontractors to begin providing two page project summaries with complete progress reports. Beginning with Quarterly Report 3, only the two page summaries will be distributed unless AGTSR receives specific requests.

COMBUSTION WORKSHOP

A significant conclusion from the Combustion Workshop held in Nashville was the identification of combustion instability as a major industry problem and a potential area of university research participation. Based on the significance of this issue, a brief paper summarizing the needs was prepared by AGTSR, reviewed by the IRB and submitted to METC for consideration. A copy of the Combustion Instability paper is attached.

IGTI CONFERENCE PAPER PREPARED AND PRESENTED

The former AGTSR program manager, Roy P. Allen, and the METC program manager, Paul L. Micheli, prepared a summary paper of AGTSR activities for presentation at the IGTI Conference held in The Hague. A copy of the paper is attached.

MISCELLANEOUS ACTIVITY

The AGTSR has agreed to cost share (10% level) a proposal in preparation by the University of Oklahoma for submission to NSF titled *Combined Research - Curriculum Development Program in Advanced Power Generation*. A series of courses leading to a curriculum in Advanced Power Generation will be developed by the University of Oklahoma if the NSF award is received. The AGTSR will maintain close ties with the university to assure industrial relevance of the courses. NSF will reach a funding decision in the fall of '94.

A request to support an undergraduate honors research program was received from Clemson University. Based on the lack of design problems submitted by the IRB, supporting undergraduate research may be a mechanism to reach undergraduates with the AGTSR program. This concept is now being considered by the IRB.

COMBUSTION INSTABILITY - NO_x FORMATION

ATS/AGTSR OPPORTUNITY NOTICE

ISSUE

The ATS goal of achieving low NO_x levels (below 25 vppm at 15% O₂) without post combustion cleanup has led the gas turbine industry into combustor designs utilizing lean premixed flames. With natural gas (methane) as the present fuel of choice, manufacturers have devoted significant time and dollars developing proprietary systems that will meet the ATS goal. The limiting factor in virtually every case has been identified as a combustion limitation or combustion instability.

GENERAL NO_x DISCUSSION

Lean combustion occurs at equivalence ratios less than one. By definition, equivalence ratio is defined as the ratio of the actual fuel-air ratio to the theoretical fuel-air ratio or

$$\Phi = \frac{(F/A)_{\text{act.}}}{(F/A)_{\text{theo.}}}$$

For a system operating at 100%, theoretical air $\Phi=1$. When the equivalence ratio is less than 1, the mixture is called lean; when greater than 1, the mixture is rich.

Under stable flame conditions, as the equivalence ratio is reduced, the flame temperature is reduced and a reduction in NO_x should be observed. Total NO_x is generally considered to be:

$$\text{Total NO}_x = \Sigma (\text{thermal NO}_x + \text{fuel NO}_x + \text{prompt NO}_x).$$

During stable combustion thermal NO_x forms rather slowly and at temperatures above 1300-1400C. The key parameters in thermal NO_x formation being

- increased O₂ concentration
- increased combustion temperature, and
- increased residence time at flame temperature

Fuel NO_x, on the other hand, occurs rapidly and at lower flame temperatures, is insensitive to the form of fuel nitrogen and combustion temperature when the flame is above approximately 800°C. Increases in fuel nitrogen and increased oxygen concentration during release of bound nitrogen favor fuel NO_x formation. The third contributor to total NO_x formation is prompt NO_x. Generally, prompt NO_x is considered a minor contributor to total NO_x; however, as total NO_x is reduced, prompt NO_x can be as significant as thermal or fuel NO_x. Prompt NO_x is formed by fuel rich conditions and is formed from nitrogen in air and hydrocarbons in the fuel by formation of intermediate species which are oxidized to NO; for example

where HCN and CN are oxidized to NO.

Under unstable combustion conditions, the criteria for total NO_x formation--the local flame temperature, species concentrations and residence time--can vary so widely that the necessary conditions to evaluate and control total NO_x cannot be predicted at this time. Combining the criteria for NO_x formation with the unknown of unstable combustion makes this a doubly difficult problem.

ATS ROLE

The Advanced Turbine Systems program is addressing this combustion problem on two fronts. The contractors via their facilities operating at lean combustion conditions will be battling with instability as they push combustion to higher turbine inlet temperatures while at the same time attempting to reduce NO_x. The universities participating in the

ATS industry/university consortium (AGTSR) are investigating the fundamentals of lean premixed flames. This combination offers the opportunity for collaboration to solve this barrier technology issue.

TECHNOLOGY PLAN

The combustion instability issue is both universal and design sensitive. Understandably, it is not an area the manufacturers wish to air in detail in the media. The companies will concede, however, that if the problem is not solved the ATS NOx goal cannot be achieved. Therefore, it seems that a two-pronged approach is in order.

To begin with, there must be an understanding of what is occurring in the flame zone when instability is approached. This is where universities can make the largest contribution. Sophisticated combustion models and extensive laser based diagnostics of flames will develop a basic understanding of instability issues that can be related to manufacture designs.

The second phase will be the adaptation of these fundamentals to actual manufacturer ATS design conditions. This will be the responsibility of the manufacturers, and will likely be carried out on a proprietary basis. University assistance could be arranged directly between the two parties.

RECOMMENDED ACTION

At this time, this is perhaps the barrier issue for ATS. In addition, the first step is primarily theoretical and university oriented. SCERDC therefore recommends that a special emphasis be placed on resolving the theoretical issues. A workshop dedicated to this subject should be scheduled by METC within the next six months, with all available U.S. talent invited to participate. Shortly thereafter, an RFP should be issued by SCERDC that solicits potential solutions to develop a basic understanding of the fundamental causes of combustion instability and its relationship to NOx formation.

Verification of the theories developed will require expensive high pressure/high temperature testing with extensive diagnostic instrumentation. Locations where such tests can be run are very limited, and it is likely that there will be considerable equipment and facility costs.

Therefore, DOE should earmark additional ATS funds to AGTSR to cover these test expenses. Otherwise, the overall technology development plan that has been established by industry and which the universities are now implementing may be severely diluted.

It is suggested that DOE should consider an increase of \$1 to \$2 million per year for AGTSR to support this activity for a period of two to three years. This is the suggested minimum level that realistically will be required. This would be supplemented by approximately \$2 million in related research that AGTSR has currently obligated and would allocate to this area in future awards.

SUMMARY

The Nashville combustion workshop and industry input has identified combustion instability as a major issue requiring a theoretical understanding cross tied to manufacture facility designs. To assure that the ATS goals can be achieved, a special program focus should be developed. The first phase, that of achieving an understanding of the theoretical mechanism involved through university investigations, would be administered by SCERDC through the AGTSR program, and would begin immediately. DOE should consider allocating additional ATS funds for AGTSR in FY95-97 to assure that relevant combustion test costs are adequately supported.

THE ADVANCED GAS TURBINE SYSTEMS RESEARCH PROGRAM: A MODEL FOR INDUSTRY, UNIVERSITY AND GOVERNMENT COOPERATION

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ABSTRACT

An integral part of the U. S. Department of Energy's Advanced Turbine Systems Program is the Industry/University consortium, formed to strengthen the gas turbine technology base among American universities. The Advanced Gas Turbine Systems Research program is sponsored by DOE, directed by industry leaders, and the universities conduct the research. This close alliance assures that the research is accomplished in a timely fashion, in areas critical to industry needs.

In the past year and a half the consortium has been organized, members solicited, Requests For Proposals issued, and contracts awarded. Some 60 universities in the U. S. are participating. This paper will discuss how the program was initiated, how it functions, and will review some of the interesting research that is under way in support of the overall ATS goals.

INTRODUCTION

Through recent legislation, the U. S. Congress has authorized a cooperative development of gas turbine technology for the Nation. As discussed in DOE's Report to Congress (July 1993), the impetus for this effort comes from the prediction that at least 50% of the new electrical power generating capacity in the USA will be produced by gas turbines. The new program relies on bringing together the Nation's relevant expertise--gas turbine manufacturers, electric utility and industrial power users, the university community, and government and private sector R&D

sponsors and laboratories. The structure of the university program addresses the issues of integrating these resources in an effective manner, competing where that is desirable and working cooperatively where that is best. It may well be an indicator of the way future national research will be funded.

President Clinton (1993) has stated in his proposals for "A Vision of Change for America" that his administration will "...launch initiatives to develop new, clean, renewable energy sources that cost less and preserve the environment. We will also encourage energy efficiency and conservation..." As a consequence, the Department of Energy's goals include increasing energy efficiency, securing future energy supplies, respecting the environment, and building a technical knowledge base that will enhance U. S. competitiveness in the global market. Implementation of the Advanced Turbine Systems (ATS) Program supports these goals; technologies developed will be advanced ultra-high efficiency, environmentally superior energy producing systems that will have definite cost advantages over systems they replace.

Research funded by government agencies is often characterized by unduly long processing cycles and lack of relevant focus. When the ATS program was conceived, the Department of Energy (DOE) embarked on some new ways to achieve objectives. The industry/university consortium, assigned the responsibility of strengthening the gas turbine technology base, is a principal supporting function to the ATS's main turbine design, development, and demonstration programs. The operation of the consortium is one of the

"new" ideas. As a result of these innovations, the program was organized and functioning in record time, and the research is assured to be meaningful and applicable to industry's needs.

This cooperative approach could be a model for successful industry, academia, and government research. The necessary rules for fairness and accountability are present, as well as the incentives for achieving the goals of relevance and timeliness. Industry accepts the responsibility for providing the technical guidance, universities accept the fact that industry can best identify the relevant technologies to be pursued and that the transfer of this technology to industry is critical. The government has the responsibility to assure that the program is administered properly and coordinated with other ATS activities.

How this new concept was developed is described in this paper. To demonstrate its success, there is a description of some of the work already in progress, which was begun less than nine months after program initiation.

GAS TURBINE DEVELOPMENT HISTORY

Since manufacturers introduced gas turbines commercially about 40 years ago, they have steadily improved turbine efficiency and have reduced emissions. Over the same period, they have improved reliability, availability, and maintainability (RAM). Many of the advances for the commercial sector have resulted from technology developed through military R&D programs.

Gas turbine manufacturers have consistently made improvements resulting from incremental changes in existing designs, often as implementations of proven aeroderivative engine technology. The turbine manufacturers themselves have historically paid for the development costs of these near-term improvements. Today, turbine systems are operating at thermal efficiencies in the mid-50 percent range for large natural-gas-fired combined-cycle systems, with lower emissions than 5 years ago. Smaller gas turbines for the industrial market tend to be lower in efficiency, but the emphasis has been on cogeneration where lower gas turbine efficiency is not as critical.

Further improvements in gas turbine efficiency are both possible and desirable. To reach the ATS goals, however, materials science advances and integral thermodynamic cycle changes will likely be required, and a significant amount of technology base research and system/component development will be necessary. Due to the technical/economic risks involved, private industry is not expected to pursue this ultra-high efficiency goal without risk sharing in the form of a government/industry cost-sharing

partnership.

ATS PROGRAM CONCEPTION AND GOALS

Planning activities began with two workshops (1991, 1992), one of several mechanisms for input to the program from industry. In these and other forums (Bajura, et al., 1992; DOE/FE-0251P, 1992), strong industrial support was voiced for the program. At the conclusion of the second workshop, the goals of the program were defined. Overall, the objective of the ATS Program is to develop ultra-high efficiency, environmentally-superior, and cost-competitive gas turbine systems for base-load application in utility, independent power producer, and industrial markets. Specific performance targets were set using natural gas as the primary fuel:

- System efficiency that will exceed 60 percent [lower heating value basis (LHV)] on natural gas for large-scale utility turbine system; for industrial applications, systems that will result in a 15 percent improvement in heat rate compared to those currently available gas turbine systems.
- An environmentally superior system that will not require use of post-combustion emissions controls under normal operating conditions.
- Busbar energy costs that are 10 percent less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are also capable of being adapted to operate on coal, coal-derived, or biomass fuels.
- Reliability-Availability-Maintainability (RAM) levels that are equivalent to those established by current turbine systems.
- Water consumption levels that are minimized consistent with cost and efficiency goals.
- Commercial systems that will enter the market in the year 2000.

Although the target fuel is natural gas, advanced turbine systems will be adaptable to coal and biomass firing. Other DOE sponsored research will address applying the ATS Program results to coal- and biomass-fired systems. This work may be performed as additions to either the ATS major systems projects or by other DOE projects.

FIGURE 1. ADVANCED TURBINE SYSTEMS PROGRAM STRUCTURE

ATS PROGRAM PLAN

As shown in Figure 1, the ATS Program has three major elements: utility system development and demonstration, industrial system development and demonstration, and Technology Base Development to support the overall program. The university/industry consortium will provide cross-cutting technology support, all with eventual technology transfer to coal and biomass applications.

The Department of Energy's Offices of Fossil Energy (FE) and Energy Efficiency and Renewable Energy (EE), formerly the Office of Conservation and Renewable Energy, are jointly responsible for the ATS Program. Management of the program is coordinated with the Environmental Protection Agency, the Electric Power Research Institute, the Gas Research Institute, gas turbine manufacturers, and the Department of Defense.

UNIVERSITY PARTICIPATION

The goals of the Advanced Gas Turbine Systems Research (AGTSR) program are presented in Figure 2. Strengthening the university base and transferring technology to industry should facilitate accomplishing the last two objectives, since the additional research and exposure to industry can enhance the curricula and the qualifications of the graduates.

To administer the university/industry consortium, DOE

signed a cooperative agreement with the South Carolina Energy Research and Development Center. DOE's Morgantown Energy Technology Center (METC) is responsible for this portion of the ATS program. METC monitors all aspects of the project and grants/denies approvals required under the Cooperative Agreement. SCERDC administers the interface between the industrial members and the universities. It issues competitive solicitations for proposals from the university participants that reflect the research technology guidelines established by industry representatives.

- Strengthen Gas Turbine Technology Base in American Universities
- Transfer Technology to Industrial Members
- Enhance Turbomachinery Curricula
- Develop Experienced Graduates for Industry Employment

FIGURE 2. AGTSR PROGRAM GOALS

FIGURE 3. LOCATIONS OF PERFORMING MEMBERS

Work by the university participants will be performed in existing facilities, so program funding will be spent on R&D. The work will generally be non-proprietary, with intellectual rights retained by the performing universities.

Participation in the program is open to accredited engineering schools in the United States. Membership requires that the university have some experience and capability in the gas turbine and/or power generation areas, and that the university administration indicates support for their faculty's involvement with the program. There are no membership fees.

As of December 1993, sixty universities have been granted Performing Member status. They represent 32 states, and include 18 private and 42 public institutions. Figure 3 shows the locations of the members.

FIRST YEAR ACTIVITIES

Any new function needs to be properly launched in order to

assure its future success. One of the first orders of business is to put together the organizational ground rules, or bylaws. For the AGTSR, these were developed early in the program, as shown by the milestones in Figure 4. The bylaws, although not excessively detailed, provide the framework for membership requirements for university and board members, funding, board responsibilities, staffing, and general business practices.

Since the purpose of the program is to sponsor university research, the next task was to issue a Request for Proposals (RFP). The key ingredient here is defining the critical research areas for advancing gas turbine technology. (This area is discussed at some length in a later section of this paper.) The RFP called for a consistent format to facilitate evaluation, and defined the criteria that would be used for evaluation. It also outlined the terms and conditions that would have to be agreed upon. The first RFP was issued about four months after the program was formally begun, as Figure 4 indicates.

FIGURE 4. FIRST YEAR MILESTONES FOR AGTSR

THE INDUSTRIAL REVIEW BOARD

This concept implements the overall desire to have the AGTSR program industry driven. The IRB establishes the technical objectives for each of the proposals, conducts the reviews, and recommends the awards. It also provides guidance for administering the program, and approves the bylaws. The Director of the AGTSR acts as Chairman of the IRB, and, along with an administrative assistant, is one of only two full time employees of AGTSR.

The 1993 makeup of the IRB is shown in Figure 5. One non-manufacturer membership is presently open. EPRI and GRI provide the important customer focus for the work, and they are also represented in an advisory capacity on the main ATS program.

MANUFACTURERS

Allison Engine Company
General Electric
Solar Turbines
TurboPower & Marine/United Technologies
Westinghouse Electric

ENGINEERING/CONSTRUCTION

Fluor Daniel

CUSTOMER REPRESENTATIVES (non-voting)

Electric Power Research Institute
Gas Research Institute

FIGURE 5. INDUSTRIAL REVIEW BOARD MEMBERS (1993)

Materials - metals, ceramics, coatings
 Advanced cooling and heat transfer
 Combustion modeling
 Vibration and noise control
 Performance improvements
 MV Controls
 System performance and economics
 Coal and alternate fuels
 Concurrent Engineering

FIGURE 6. ATS TECHNOLOGY OBJECTIVES

TECHNICAL OBJECTIVES

The Workshops produced a consensus on the major challenges facing the design engineers that would be striving to meet the ATS goals. The list of items, listed generically in Figure 6, should not surprise anyone familiar with gas turbine technology. However, this was the first time that all the major participants had convened to confirm that these areas are those demanding increased attention, and to request government assistance to achieve them.

For the initial AGTSR solicitation, it was decided to leave the technology requirements in the general vein per Figure 6. This would allow most of the Performing Members an opportunity to propose work in line with their strengths, and hence provide a good understanding of their collective capabilities. As will be seen shortly, the distribution of technologies from the 1993 RFP's matched the specified priorities very closely.

For the second and subsequent solicitations, the technical requirements are and will be more specific. As more subcontracts are awarded, the priority areas will receive increased attention, allowing the Board to address the rest of the items on their need list. This will serve to accomplish one of the program objectives--broadening and strengthening the university gas turbine technology base--as well as emphasizing the areas of highest priority to industry. Each RFP, then, can be expected to have a different set of technical objectives.

EVALUATION PROCESS

There were two main objectives that AGTSR wished to accomplish during the review process: first, to conduct the proposal reviews with ultimate fairness, and second, to minimize time lost in initiating the research. The proposal evaluation criteria are contained in the RFP, so everyone

TECHNICAL significance	50%
Support of ATS goals	
Ease of technology transfer	
VALUE	20%
Scope, results vs. cost	
Educational value	
Effective use of facilities	
TIMELINESS of results	10%
Availability of useful data	
QUALIFICATIONS and experience	20%
Relevant gas turbine work	
Strength of team	

FIGURE 7. PROPOSAL EVALUATION CRITERIA

knows what the scoring system would be. These criteria are shown in Figure 7 for the 1994 RFP.

To accomplish the first objective, the proposals were kept at the SCERDC office after receipt. Only the Director reviewed them, summarizing the technical areas addressed and assigning them to the reviewers. The IRB came to SCERDC and reviewed the proposals on-site over a three day period, culminating in a ranking session and award recommendations on the final day.

This review session was conducted two weeks after the proposals were received. The following week the recommendations were reviewed with METC and approved. Winners and unsuccessful bidders were notified within the next few days. Total time from proposal submittal date to announcement of results: 25 days.

This prompt treatment of the proposals assures the participants that this is indeed a high priority program. The quick turnaround also assists the universities as they plan for their graduate student employment.

CONTRACTING

This phase of any program can easily take more time than the whole proposal review process. To avoid that in the AGTSR program, a model subcontract was developed during the period of the proposal preparation. This model contained all the necessary Federal regulation clauses and specific items related to the work. Very few modifications to this document were necessary as the negotiation process

progressed. As a result, signed contracts were obtained within two months after notification of award.

The entire evaluation and contracting process was completed in time for all the schools to begin work at the start of their fall term.

SITE VISITS

The commitment by the AGTSR Director to visit each of the Performing Members is viewed with considerable importance. These visits provide an opportunity to know the faculty, see the university's facilities, and understand their capabilities and interests. It also gives the schools a better feel for the program and its objectives. Since teamwork is strongly encouraged, information from the visits generates a data base for fostering complimentary research or facility utilization among the participants.

Follow up visits will also be made to each of the universities that have subcontracts, to assess progress, discuss problems, and review deliverables.

RESULTS FROM 1993 RFP

An analysis of the 51 proposals received in response to the first RFP shows a good match between university capabilities and ATS needs. Figure 8 shows a breakdown of the technical areas covered by the proposals. The areas related to elevating the turbine inlet temperature--the first three on the list--made up 60% of the submittals. The other 40% represent talent available to cover the rest of the desired technologies, which will be done through future RFP's.

From the 1993 proposals, ten were selected for subcontract awards. Their technology distribution is also shown in Figure 8 and again depicts the attention to the high priority items: combustion and emission reduction, cooling and heat transfer, and improved materials.

SUBCONTRACT TOPICS

To provide an indication of the type of work that is in progress, a brief synopsis of the ten awards from the first solicitation is presented. All are multi-year efforts, averaging three years. Some 70 faculty and student participants will be involved, again accomplishing one of the AGTSR program objectives. Presented alphabetically, here are the 1993 subcontractors and their research plans:

Brigham Young University: Enhance an existing 3D combustion code to include natural gas fuel, while retaining the capability to address future conversion to coal

	PERCENT SUBMITTED	PERCENT AWARDED
Heat Transfer	22	20
Combustion	19	50
Materials	19	20
Aerodynamics	15	10
Vibration, acoustics	12	
Cycles and evaluation	5	
Coal applications	5	
Multivariable controls	3	
Concurrent engineering	-	
TOTAL	100	100

FIGURE 8. TECHNOLOGY DISTRIBUTION AMONG RFP 93-01 PROPOSALS AND AWARDS

or biomass. Submodels will be developed for CO and NOx, and for improved CFD. Industry technology transfer is a key element of their program.

California/Berkeley: Improve understanding of lean premixed combustion. Ultra low emissions are the objective, with attention to the instabilities associated with very lean mixtures. Assistance from catalytic and noncatalytic inserts will be investigated.

Clarkson: Reduce pressure losses in turbine stages through the iceformation design technique. The iceformation method uses a controlled phase change boundary that interacts with the flow to evolve novel shapes and help with flow visualization.

Lehigh: Develop a functionally gradient metal/ceramic interface between the base hot gas path metal surface and the gas stream. The challenges here are both in the determination of the material properties and in the application process.

LSU: Increase the heat transfer within blade cooling passages through the use of vortex generators. The rotational effect will be investigated, and computational tools will be available for designer's use.

Penn State: Examine the critical effect of thermal-mechanical fatigue on superalloys. Life prediction is the ultimate goal, and both macromechanical and microstructural investigations will be performed.

Purdue: Produce a NOx submodel that reflects the cycle parameters for tomorrow's gas turbines. This submodel will include the chemistry-turbulence interactions, and be ready for incorporation into all combustor design codes.

Texas A&M: Develop aerodynamic improvements

to enhance cycle efficiency. Three areas in the turbine will be investigated for their impact on losses and heat transfer: internal cooling flows, TBC spallation, and boundary layer transition.

Vanderbilt: Develop NO_x and CO submodels specifically for lean premixed flames. Emphasis will be on models for characteristic time, chemical reactors, and chemistry-turbulence.

Virginia Polytechnic Institute and State University: Investigate an innovative combustion stabilization scheme. An active control scheme is proposed, and is accompanied by the necessary high temperature materials research.

All of these subcontracts include experimental verification of theoretical work. This is mandatory, as the turbine designers cannot risk committing to a new design technique that is unsupported by adequate test data.

The deliverables, then, will include the theoretical analyses that have been performed, the computer models that have been developed, and the test data that has been taken. The emphasis on technology transfer makes these deliverables the key to success of the AGTSR program.

FUTURE PLANS

The AGTSR program is scheduled to continue through the year 2000. The planned funding profile will permit issuance of yearly RFP's; over the course of the program, they will address all of the technology areas that have been identified.

The DOE requires that subcontractors present the results of their research annually at a Contractors Review Meeting. To further the technology transfer among the universities and strengthen the relationships with the industry partners, DOE has provided additional funding for seminars where more detailed interchanges can take place. Another broadening function that is included is sponsorship of engineering project courses, where industrial members challenge the class to solve a problem of interest, and then attend and critique reporting sessions on the students' findings. These activities will reinforce the objectives of making the research relevant and providing increased student exposure to gas turbine technology.

SUMMARY

The university research portion of the ATS program has been successfully initiated. The cooperative relationships among the gas turbine industry, some 60 universities, and the Department of Energy should assure the

timeliness and the relevance of the work awarded to the Performing Members. Organizational innovations have contributed to the fast implementation of the AGTSR program, and industry leadership will keep the focus on the technologies needed to make the challenging ATS goals achievable.

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Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

**DATE
FILMED**

11/25/94

END