Advanced Turbine Systems Program Conceptual Design and Product Development

**Quarterly Report
November 1994 - January 1995**

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U.S. Department of Energy
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QUARTERLY STATUS REPORT

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CONTRACT TITLE AND NUMBER: Advanced Turbine Systems Program --
Conceptual Design and Product
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CONTRACTOR'S NAME: Westinghouse Electric Corporation
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CONTRACT PERIOD: August 5, 1993 to January 6, 1996

1.0 MANAGEMENT PLAN

The project management plan was updated for 1995.

2.0 NATIONAL ENERGY POLICY ACT (NEPA)

Westinghouse supplied NEPA information for Phase 2 is complete.

3.0 SELECTION OF NATURAL GAS-FIRED ADVANCED TURBINE SYSTEMS (GFATS)

The final Topical Report on "Selection of Natural Gas-Fired Advanced Turbine System" was issued in December, 1994.

4.0 SELECTION OF COAL-FIRED ADVANCED TURBINE SYSTEMS (CFATS)

Task completed.

5.0 MARKET STUDY

Market study was started in December.

6.0 SYSTEM DEFINITION AND ANALYSIS

The ATS gas turbine flange-to-flange conceptual design is proceeding.

8.0 DESIGN AND TEST OF CRITICAL COMPONENTS

Effects of Blade Cooling Alternatives

An automated performance calculation system is being developed by Carnegie Mellon University (CMU) to assess the effects of different cooling media and cooling schemes on gas turbine cycle performance. NASA reports on an advanced blade cooling system were obtained and reviewed. These reports were helpful in providing information on the performance benefits of internal impingement cooling compared to film cooling. A report on coolant pressure profile computations was prepared. The latest version of ASPEN PLUS code was obtained for use in calculations of overall gas turbine systems performance.

Last Row Turbine Blade Development

To achieve minimum exhaust losses, the annulus area of the last row turbine blade must be as large as possible. This results in a long highly stressed blade. To avoid excessive vibratory stresses, this blade incorporates an integral interlocked tip shroud. In this type of a blade design, there is a possibility that two blade natural frequencies may occur between adjacent harmonics. These two frequencies can become coupled and result in high vibratory stresses. The objective of this program is to develop an optimized last row turbine blade design which will result in acceptable mechanical reliability and enhanced performance. The available test data and the established design rules for interlocked blades have been reviewed. An improved analysis method has been proposed. High cycle fatigue calculations on existing blades to calibrate the proposed method against operating experience have been performed. Conceptual designs for freestanding and interlocked blades were carried out. Evaluated alternatives with regard to performance, reliability and manufacturability.

Casting trials to determine feasibility of mid-span snubber are underway. The results of this program will be used as the basis for the increased annulus area ATS stage 4 blade design, which will result in about 0.1 percentage point increase in plant efficiency.

Single Crystal Blade Development

The last mold of three Row 3 blades was constructed with platinum pins in order to correct core movement encountered in previous castings. This mold was cast and the blades were inspected. The platinum pins solved the core movement problem. However, some grain defects were detected. The causes for these defects are being investigated.

Ceramic Materials Development

Work continued on the parametric finite element model for 501D5 engine ring segment design. This model was used to analyze steady-state operation thermal loads for both the current X45 material design and with minor modifications for one of the proposed Continuous Fibre Ceramic Composite (CFCC) design alternatives. Effort continued on developing alternate conceptual designs for CFCC ring segments. The ceramic ring segment designs will be used on the first two stages of the ATS engine to reduce or eliminate cooling requirements and enhance plant efficiency by about 0.2 percentage points.

Diffuser Air Extraction Study

The objectives of this program are as follows:

1. To improve engine efficiency by reducing compressor exit diffuser and combustion cylinder pressure loss.
2. To optimize air extraction for the IGCC system.
3. To enhance flow uniformity around combustor baskets to help in reducing NOx emissions.

Transition piece fabrication was completed, access holes for probes and pressure taps were drilled. Sensor calibration and testing was completed and sensor installation was started. The test model assembly was completed and made ready for transportation to the test facility (Figure 1 shows test model in assembly stage). The test data acquisition program was streamlined for the pre-dump diffuser.

The scaled down dry low NOx combustor model was delivered to Clemson University in November. W. Ryan visited Clemson University in January to review progress on the combustion cylinder model construction and to discuss results of discharge coefficient measurements on the model combustor.

He proposed that the discharge coefficient tests be carried out with fuel injectors installed in the model combustor and that additional probe holes be drilled at the top hat entrance.

CFD simulation of the different combustion cylinder domains continued (see Figure 2). A 1/16th computational domain was employed to calculate the flow field for regions without cooling air pipes and 1/4th computational domain for regions with cooling air pipes. A convergent solution was obtained for the 1/16th pre-dump diffuser domain. The CFD results were used to install additional pressure taps near the predicted stagnation points. Work continued on Griffith diffuser design.

Shroud Film Cooling

To optimize turbine stator shroud cooling design series of model tests were planned. The model consists of two complete airfoils and a full channel between the two airfoils. Different cooling jet configurations will be tested, each at different flow rates. The heat flux distribution will be measured using thermochromic liquid crystal technology. The test rig assembly was completed and shakedown tests commenced at Dynalysis of Princeton.

Directionally Solidified Blade Development

A decision was made to redirect this program to generating material property data for DS CM247 and another similar alloy, DS M002. Two reasons prompted this change. The first is that an internally funded program, which was started in mid-1994 to develop DS M002 cast blades, is making significant progress. The second is that DS blade design data are needed in order to facilitate the implementation of DS casting technology. A new program plan is being prepared to start the data program next month.

Shrouded Blade Cooling

The Row 3 turbine blade will incorporate an integral interlocked tip shroud for performance and mechanical integrity reasons. Temperature and stress considerations necessitate tip shroud cooling, which is complicated by excessive cooling air heat-up as it passes from the blade root to the tip shroud. Different cooling concepts are being evaluated, including a blade design with a large central hole to provide cooling air at a reasonable temperature for shroud cooling.

Flow Visualization Tests

The full-scale plastic model of the multi-swirl combustor was tested in the cold flow atmospheric test facility to verify the design air splits. The results indicated that the current design provides satisfactory air splits for low emissions.

Combustion Noise Investigation

Very lean premix combustion will have to be employed to achieve ultra-low NOx emissions in the ATS engine. This may result in flame instability, combustion generated noise and high vibratory stresses in the combustion system components as well as the downstream turbine airfoils. The objective of this program is to extend the stability range for lower emissions. To achieve this objective an active noise control system is being developed in collaboration with Dr. Ben Zinn of Georgia Tech.

Design of the reduced-scale combustion stability test section is in progress. This test section will be used as an evaluation platform for combustion stabilization systems.

TBC Field Testing

The application of uniform and durable TBC on the turbine airfoil and end wall surfaces is critical to the design of closed-loop cooling systems without the protection provided by the cooling air film in the current cooling designs, the thermal barrier provided by TBC will be very important in maintaining low surface metal temperatures in the ATS engine without requiring high internal heat transfer coefficients. The results of the TBC field test program will provide information on the longevity and effectiveness of the different coating systems.

Field testing of thermal barrier coated blades will be carried out to determine comparative coating longevity and effectiveness of air plasma spray (APS) and physical vapor deposition (PVD) thermal barrier coatings (TBC) under typical operating conditions. Four 501D5 Row 1 blades were coated with APS TBC. Four additional blades are being coated with PVD TBC. Prior to installation, TBC thickness will be measured for comparison with thickness distribution after service in a gas turbine.

Catalytic Combustion Development

Commenced exploratory work on advanced ultra-low NOx combustor technology. The initial investigation is focusing on the relationship between catalyst effect and recirculation, and on turndown and durability. Catalyst light-off temperature for lean-premixed methane mixtures is typically greater than the compressor discharge temperature. Therefore, the combustor design must incorporate a method to raise the inlet gas temperature (such as exhaust gas recirculation [EGR]), raise the monolith surface temperature, decrease the catalyst light-off temperature (by enhancing fuel reactivity), or use an integrated combination of these approaches. Based on the ATS combustor conditions and geometry, the feasibility of several different integrated combustor designs was considered. A combustor design using EGR was determined feasible by recirculating about 20% exhaust gas from 50% to 100% of base load. Several concepts were considered to extend the catalytic combustor operating range below 50% load. These included multiple pilots, variable EGR, heating the catalyst substrate and enhancing the fuel quality.

One promising approach is to prereact part of the fuel in a fuel-rich catalytic reactor to produce a highly reactive warmer effluent gas similar to syntheses gas production from methane.

Optical Diagnostics Probe Development

Started the development of non-intrusive optical diagnostics probe for measurement of pertinent parameters, such as combustion products composition and concentration. Fuel seed evaluation and selection was completed. Lower purity acetone has been evaluated and shown to be adequate for the probe tests. A prototype probe was designed, fabricated and tested at atmospheric pressure and low temperature conditions. Preparations continued for fiber optic probe tests at Westinghouse Science and Technology Center. Probe evaluation at elevated pressure and temperature conditions at Westinghouse Casselberry Labs was initiated.

Serpentine Channel Cooling Tests

Test plan was prepared for heat transfer tests to be carried out at NASA-Lewis. Trailing edge plastic model fabrication was completed and the model was delivered to NASA in January. The triple-pass mid circuit model construction continued.

Brush Seal Development

The development of optimized brush seal systems for the compressor diaphragm seals, turbine interstage seals, and turbine gas path platform seals is very important to the ATS engine performance and mechanical integrity.

The brush seal development effort consists of: a preliminary investigation to look at the benefits, potential locations, and validation required in applying brush seals to industrial gas turbine engines, and a focused development effort for one selected engine location, the turbine interstage. EG&G Sealol, Warwick, RI, is the seal vendor selected to support the latter development work. The vendor effort includes: a conceptual study, tribology testing rig hardware fabrication and rig testing of candidate brush seals.

Initial meeting was held at EG&G Sealol to finalize planning for the vendor brush seal development work. A purchase order to EG&G Sealol was issued in January and work commenced on an eight-month development effort.

PLANS FOR THE NEXT REPORTING PERIOD

Task

- 5.0 Complete marketing survey on ATS.
- 6.0 Complete the conceptual design of the ATS combustion turbine.
- 8.1 Continue automated performance calculation system development to assess the effects of different cooling media and cooling schemes.
- 8.3/8.13 Continue last row turbine blade development.
- 8.5 Cast additional Row 3 mold and evaluate the resulting castings.
- 8.7 Develop design concepts for the proposed CFCC ring segment design and select the optimum design.
- 8.8 Complete the basic air model test at Clemson University and initiate additional testing.
- 8.10 Complete model tests at Dynalysis.
- 8.11 Prepare modified plan and generate material property data for CM247 and M002 DS materials.
- 8.12 Continue shroud cooling concept evaluation.
- 8.17 Start active noise control concept verification testing.
- 8.18 Complete PVD coating and install all coated blades in host engine for field testing.
- 8.19 Continue conceptual exploration on catalytic combustion technology.
- 8.20 Continue optical diagnostics probe development.
- 8.22 Complete plastic mid circuit model manufacturing and initiate test at NASA Lewis.
- 8.23/8.24 Continue preliminary investigation on brush seals.

R. L. Bannister
Program Manager

Attachments:

Figure 1 & Figure 2

Request for Patent Clearance for Release of Contracted Research Documents (Form METC F 1332)

U. S. DOE, METC Contract Report Transmittal Checklist

FIGURE 1
Combustion Cylinder Model Assembly

FIGURE 2
Preliminary CFD Results