Advanced Turbine Systems Program Conceptual Design and Product Development

Quarterly Report

November 1, 1995 - January 31, 1996

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For
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QUARTERLY STATUS REPORT

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Reporting Period: November, 1995-January, 1996

CONTRACT TITLE AND NUMBER: Advanced Turbine Systems Program --
Conceptual Design and Product
Development DE-AC21-93MC30247

CONTRACTOR'S NAME: Westinghouse Electric Corporation
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CONTRACT PERIOD: August 5, 1993 to July 5, 1996

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

Task completed.

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

Task completed.

3.0 MARKET STUDY

The market study was completed. The study results were submitted in draft form as Topical Report Task 5.0 on January 30, 1996. Final release will be submitted March 11, 1996.

4.0 SYSTEM DEFINITION AND ANALYSIS

This task was completed. Study results will be submitted in draft form on February 13, 1996.

5.0 DESIGN AND TEST OF CRITICAL COMPONENTS

Last Row Turbine Blade Development

In prior developments the BVM was tested using a two probe approach. Subsequent developments resulted in a 16 probe system suitable for monitoring vibration during various engine operating conditions. Initial stage 4 vibration tests showed low amplitude responses. Additional testing was completed last quarter with no significant levels of vibration being reported. A summary report of the testing has been released. A final report is scheduled for completion before April 15, 1996. Casting trials for Row 4 blades has continued.

Single Crystal Blade Casting Development

This task was completed last quarter.

Ceramic Materials Development

The new ring segment design has been modeled using finite element analysis. Radiographic and Thermal Wave Imaging testing has been completed with test coupons. Plans to pursue mechanical tests at ORNL have been developed. A risk assessment and mitigation analysis has been expanded to include the entire ring segment development program in addition to the engine retrofit program. Sources of risks have been identified and the mitigation plan is scheduled for completion by February 29, 1996.

Combustion Cylinder Flow Mapping

This task is near completion. Based on both the CFD and experimental results, it was concluded that using a longer top hat provided better flow mixing than using the "combustor shield" originally proposed. The modified top hats have been fabricated and installed. Testing with the modified top hats is in progress. Data analysis and reporting shall proceed into the next quarter.

Shroud Film Cooling

Since resolving the software problems last quarter, benchmark testing of models has begun. Reynolds number sensitivity testing of the row one stator is in progress.

Directionally Solidified Blade Development

Generation of material design property data has continued. Specifically, long-term creep rupture testing of 247 type alloys has proceeded. Specimens have been tested for the evaluation of coatings on HCF strength. Two CM247 DS blades have been fabricated and cut up for evaluation of tensile strength, LCF and creep. Similar tests for CM247 CC blades is near completion. Test slabs of M002 DS material are undergoing mechanical tests. These slabs were cast with a 6" per hour withdrawal rate (versus the baseline 12" per hour) to understand the effects of withdrawal rate on mechanical properties. Fatigue and creep specimens of M002 DS have been coated with a bond coat and TBC for investigating the effects of coatings on M002 properties.

Shrouded Blade Cooling

Task completed.

Closed-Loop Steam Cooling

Row 1 vane and blade cooling designs were completed and modified to improve manufacturability. Row 1 and 2 vane steam cooling manifold and piping sizes have been estimated. Pedestal cooling designs with spanwise flow are under investigation.

Active Tip Clearance Control

P&W Talon completed abrasability testing of samples with their coating applied. The tests determined wear characteristics of coatings and blade tips with simulated incursion rates and temperatures. Test results indicate that with the low incursion rates encountered in large industrial gas turbines, blade tip treatments would be beneficial in keeping blade tip wear within acceptable limits. Only a few blades in a given stage would need to be treated in order to minimize wear of all blade tips. Tip treatments would be unnecessary for designs where little rubbing would be expected.

Flow Visualization Tests

This task was completed.

Combustion Noise Investigation

Assembly of the sub-scale combustion stabilization test section was completed and installed in the STC high pressure, preheated-air test facility. Problems with igniter reliability during testing indicates the igniter assembly needs improvement. Active noise control concept verification has continued. Bench tests and analyses on the remote sensing of pressure oscillations within full size gas turbine engine combustors have been completed. It was found that minimizing

transducer cavity compliance and anechoic termination of the tubing were of primary importance.

TBC Field Testing

Field tests of twelve 501D5 first stage coated turbine blades has continued. The first inspection is due next quarter.

Eight 501F row 1 blades have been cast and are being machined. These blades will be installed for testing in an engine with a higher firing temperature of 2300°F. Thermal barrier coatings by physical vapor disposition and air plasma sprayed have been applied.

Catalytic Combustion Development

Flow visualization tests on the EGR combustor at the Casselberry test facility has continued. The test data will provide CFD model validation.

Optical Diagnostics Probe Development

Tests were conducted with the fiber-optic equivalence ratio probe in the 1 atm, high temperature facility in Casselberry. Measurements were made in the primary zone, both with and without combustion, at conditions of 750°F inlet temperature and air-to-fuel ratio equal to 30. The probe was inserted through the center post into the primary zone and traversed along the centerline of the combustor, with measurements being made at 1 inch intervals. One of the main objectives of the tests was to evaluate the durability of the probe, particularly with combustion. The probe was run for a period of several hours with combustion and showed no evidence of wear or mechanical failure. In fact, with the probe fully inserted into the primary zone, the maximum temperature at the tip of the probe with combustion was only 66°C. The measurements which were made under non-combusting conditions showed that the mean equivalence ratio gradually decreased by about 10% from the upstream to the downstream end of the primary zone. It was also found that the rms fluctuation of the local equivalence ratio was about 30% at all measurement locations. In the case of the measurements with combustion, only intermittent evidence of fuel was found along the primary zone centerline, which is consistent with the notion that combustion is occurring near to the walls of the combustor. In addition to the above results, numerous improvements to the probe and to the test procedure were identified during the Casselberry tests. These improvements will be implemented in the near future.

It is proposed that additional tests be conducted at Casselberry before attempting to use the probe at AEDC. In these tests, however, measurements will be made closer to the combustor wall. This will be accomplished by either modifying the probe or by providing radial access to the combustor facility.

Serpentine Channel Cooling Tests

All thermal testing was completed. Pressure loss testing on the tracking edge model was completed. Data analysis is in progress.

Brush Seal Development

The fabrication of two subscale test seals were finished. Test rig assembly and instrumentation installation was completed. A second test rotor was instrumented, balanced and installed in the EG&G test rig. The first subscale brush seal was reinstalled. This seal has a generic design for the turbine interstage location and can be fabricated by several manufacturers. Testing has proceeded using maximum interference representative of an industrial engine start up cycle.

High Efficiency Compressor Design

Design work on the high efficiency design has continued. Compressor airfoil shape definition has been completed for most stages. Axial spacing calculations were completed and some stators were moved axially in the flow path to achieve the required inner shroud disc clearances. Blade dovetail/disc stress evaluations has continued. Analysis of two operating points and startup characteristics were initiated.

Advanced Air Sealing Development

The turbine rim seal feasibility investigation is in progress. The subcontractor, EG&G, has continued design, material selection and test plan development for the compressor diaphragm and turbine rim seal locations.

Advanced Coating Development

Bond coat development has continued. An order was placed with DuPont Lanxide, Inc. for CMC cylinders which will be tested in the Hot Gas Test Facility at STC. Radiographic and thermal imaging of test coupons has been completed. Data analysis is underway.

Single Crystal Blade Development

The program logic controller to handle the complex heat treatment cycle has been installed. Metallographic evaluation has been completed for all five solution heat treatments. Results indicate that the microstructure of the large 501F Row 1 and Row 3 blades were coarser (larger dendrite arm spacing and larger γ/γ' eutectic particles) than had been observed in typical small aeroderivative engine cast components. All of the five candidate cycles were able to reduce the level of eutectic phase to less than 1% and significantly homogenize the chemical segregation across the dendrite structure. One optimum cycle was selected and recommended by STC, because it was particularly effective, achieving 99.9%+ solution of eutectic phase and greatly

reducing the chemical segregation, and it can be easily implemented in commercial production environment.

With the determination of the solution cycle, the second part of the study, precipitation (aging) heat treatment, will follow. A test matrix of time and temperature parameters, which encompasses potential blade coating thermal cycles, have been selected. The aging study will start next month. In addition, an experiment of incipient melting by thermal gravimetric analysis (TGA) will be performed on R1 blade specimens to supplement the knowledge base.

CMSX-4 SC cast slabs of 5/8" and 1 1/4" thicknesses are being procured from the Howmet Whitehall plant. These slabs will be cast with controlled parameters to simulate the large blade microstructure.

Ni-Based Disc Forging Development

A purchase order for a second qualification disc was released to Wyman Gordon. They will produce a trial 1N706 forging from an existing ingot. A test plan for the first qualification disc, manufactured by Alcoa, has been developed.

Steam Cooling Effects on Materials

Proposals from ORNL and SWRI for specimen testing in steam at elevated temperatures and pressures have been evaluated, and SWRI was selected. Specimen geometry has been defined. Test plans have been drafted. Materials for the test rig have been ordered.

PLANS FOR THE NEXT REPORTING PERIOD

Task

- 5.0 Issue final topical report, ATS Marketing Study.
- 6.0 Issue final topical report, ATS engine and plant conceptual designs.
- 8.3/8.13/8.26 Complete last row blade casting trials and first article inspection. Issue a report on BVM field test results.
- 8.7 Develop design concepts for the proposed CFCC ring segment and select optimum design.
- 8.8 Complete air extraction tests and report results.
- 8.10 Complete model tests at Dynalysis.

- 8.11 Generate required DS material design data.
- 8.14/8.31 Continue conceptual closed loop cooling design.
- 8.17/8.35 Continue active noise control concept verification testing.
- 8.18 Monitor performance of TBC blades already installed on 501D5. Install TBC blades on 501F for 2300°F testing.
- 8.19 Continue conceptual exploration on catalytic combustion technology.
- 8.20 Continue probe evaluation test at atmospheric pressure and high temperature.
- 8.22 Continue data analysis of mid circuit model tests.
- 8.23/8.24 Continue seal rig tests.
- 8.25/8.27 Complete high efficiency compressor design.
- 8.29 Continue rim and compressor diaphragm seal development.
- 8.30 Continue development of advanced bond coat/TBC system.
- 8.32 Continue development of ceramic ring segment.
- 8.33 Continue generation of SC materials data for ATS blade design.
- 8.37 Continue data analysis of first disc material, receive and test second disc.
- 8.38 Receive test rig materials and finalize test plans.

L. R. Southall
Program Manager

Attachments:
List of Acronyms and Abbreviations

LIST OF ACRONYMS AND ABBREVIATIONS

APS	air plasma spray
ASME	American Society of Mechanical Engineering
ATCC	advanced technology catalytic combustor
ATS	Advanced Turbine Systems
BVM	blade vibration monitor
CC	conventionally cast
CDA	controlled diffusion airfoils
CFATS	Coal-Fired Advanced Turbine Systems
CFCC	continuous fiber ceramic composites
CFD	computational fluid dynamics
CM247	Ni-based blade alloy
CMC	ceramic matrix composite
CMSX-4	single crystal alloy (by Cannon-Muskegon)
CT	combustion turbine
DS	directionally solidified
EB-PVD	electron-beam physical vapor deposition
EGR	exhaust gas recirculation
GFATS	Gas-Fired Advanced Turbine Systems
HCF	high cycle fatigue
ICP	integrated catalytic pilot
LC	low carbon
LCF	low cycle fatigue
MARM002	Ni-based blade alloy
MCSSB	multiple catalytic swirl stabilized burner
Nd:YAG	neodymium, yttrium, aluminum, garnet
NDE	non-destructive examination
Ni	nickel
NIST	National Institute of Standards and Technology
NO _x	nitrous oxides
ORNL	Oakridge National Laboratory
PC	personal computer
PVD	physical vapor deposition
RT 122 +Pt	diffusion coating with platinum overlay
SC	single crystal
SEM	scanning electron microscope
SRI	Southwest Research Institute
STC	Science and Technology Center
TBC	thermal barrier coatings
ZrO ₂	zirconium oxide

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