**Utility Advanced Turbine Systems (ATS) Technology
Readiness Testing and Pre-Commercialization
Demonstration**

**Quarterly Report
October 1 - December 31, 1996**

Work Performed Under Contract No.: DE-FC21-95MC31176

For
U.S. Department of Energy
Office of Fossil Energy
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Section 1 Executive Summary

The overall objective of the Advanced Turbine System (ATS) Phase 3 Cooperative Agreement between GE and the U.S. Department of Energy (DOE) is the development of the GE 7H and 9H combined cycle power systems. The major effort will be expended on detail design. Validation of critical components and technologies will be performed including: hot gas path component testing, sub-scale compressor testing, steam purity test trials, and rotational heat transfer confirmation testing. Processes will be developed to support the manufacture of the first system, which will be sited and operated in Phase 4. Technology enhancements that are not required for the first machine design but will be critical for future ATS advances in performance, reliability, and costs will be initiated. Long-term tests of materials to confirm design life predictions will continue. A schematic of the GE H machine is shown in Figure 1-1.

This report summarizes work accomplished in 4Q96. The most significant accomplishments are listed below:

9H related

- Hot flowpath machining drawings released
- Suppliers selected for casing and turbomachinery components
- Engineering detail drawings for casing material procurement completed
- Design review for released components as required by the NPI tollgate process completed
- Gas turbine bill of materials updated
- Exhaust frame and midsection mockup utilized for tooling and assembly trials
- Preliminary test plan for fully instrumented tests (FSNL and FSFL) established

7H related

- Detail design of gas turbine components continued
- Aerodynamics for better part-load performance refined
- Design reviews completed for released components as required by the NPI tollgate process

Figure 1-1. Schematic of H machine cross section

Section 2 Technical Progress Reports

Section 2.1 (NE) NEPA

Objective

A draft topical report will be prepared which provides the environmental information associated with Phase 3, Technology Readiness Testing, as specified in the National Environmental Policy Act (NEPA). DOE will use this information to prepare the NEPA documentation for Phase 3. DOE will review the report and advise the participant of the acceptability of the report or the need for additional information. A final report will then be submitted.

A second draft topical report will be prepared which provides the environmental information associated with Phase 4, Pre-Commercial Demonstration, as specified in NEPA. DOE will use this information to prepare the NEPA documentation for Phase 4. DOE will review the report and advise the participant of the acceptability of the report or the need for additional information. A final report will then be submitted.

Progress

The Phase 3 topical NEPA report was completed. An outside consulting firm, ERM, Inc., specializing in the area of environmental compliance, was contracted to support information-gathering, assessment, and report preparation. Information was gathered on planned program test activities at the Schenectady main plant and the GE Corporate Research and Development (CRD) facility in Schenectady, NY, and the GE Aircraft Engines (GEAE) test facilities in Evendale, OH, and Lynn, MA. The NEPA topical report was prepared, reviewed, and submitted. All sites were found to have the necessary permits to support the Phase 3 activities either in place or in the process of being obtained.

At DOE's request a supplemental table was submitted for the ATS Phase 3 NEPA Topical Report. This table summarizes process feedstocks used and environmental releases from ATS Phase 3 Program test activities for all sites. Quantitative information necessary for DOE to issue the Phase 3 NEPA Comprehensive Exclusion was provided.

The Phase 4 topical NEPA report was also completed. This report took the form of a "generic" Environmental Information Volume (EIV). ERM, Inc., again was contracted to provide support. The GE Power Systems' engineering power plant projects environmental organization, working with ERM, prepared the report. The technical basis for the report was the 7H Base Reference Plant. After review by DOE, the report was resubmitted after proprietary data were removed.

Section 2.2 (GT) Gas Turbine Design

Section 2.2.1 (GTAD) Aerodynamic Design

Objective

To achieve ATS performance goals, a four-stage turbine will be designed. Advanced aerodynamic technology (sometimes called 3D aerodynamics) pioneered at GE Aircraft Engines will be applied to each stage to maximize performance and meet mechanical design requirements required by steam cooling technology.

The 7H (60 Hz) and 9H (50 Hz) turbines have similar flowpaths and a common rotor but require different aerodynamic designs. Performance requirements for the 7H and 9H turbine aerodynamics are the same.

Progress for this Quarter

The final 7H turbine aerodynamic flowpath was completed, formally reviewed, and documented. All mechanical issues related to flowpath aerodynamics were resolved.

Plans for Next Quarter

This task has been completed.

Technology Application

Advanced aerodynamic technology (sometimes called 3D aerodynamics) pioneered at GE Aircraft Engines has been applied to each stage to maximize performance and meet mechanical design objectives required by steam cooling technology.

Section 2.2.2 (GTFF) Gas Turbine Flange-to-Flange Design

Section 2.2.2.1 (GTFFCP) Compressor Design

Objective

The objective of this task is to design 7H and 9H compressor rotor and stator structures with the goal of achieving lower cost and greater durability by applying proven GE Power Generation (GEPG) heavy-duty design practices. The designs will be based on the GEAE CF6-80C2 compressor. Transient and steady-state thermomechanical stress analysis will be performed to ensure compliance with GEPG life standards. Drawings will be prepared for forgings, castings, machining, and instrumentation for full speed, no load (FSNL) tests of the first unit.

Progress for this Quarter

Except for a few remaining parts, the 9H compressor including casings, frames, airfoils, and rotor has completed drawing definition. A major task completed during 4Q96 was the definition of the variable guide vane (VGV) system and drawings of many components. Rotor bolting drawings were finished, completing all major components of the rotor. Manufacture of the compressor hardware has been initiated and considerable progress has been made on several components. The 9H compressor components are on schedule to support the 9H program.

The 9H sub-scale compressor rig instrumented assembly continues. The compressor rotor is fully assembled and ready for final balance. The aft stator assembly is complete, the mid and forward stators are in final assembly steps, and the inlet frame assembly is started. Rotor and stator assembly is expected to start in late January. This rig is a CF6-80C2 aircraft-engine-sized compressor (approximately one-third scale) that will be used to verify the product compressor performance, operability, airfoil aeromechanics, diffuser performance, and power turn-down operation. This test vehicle will begin testing in a Lynn, MA Aircraft Engine facility in April. Testing is planned to be complete during May.

Engineering of the 7H compressor has started. The 7H is similar to the 9H with the following exceptions:

1. The scale factor is 0.847 of the 9H.
2. Three new aft stages (15, 16, and 17) and three new front stages (0, 1, and 2) are designed to meet power output requirements.
3. A simplified rotor bolting arrangement is being evaluated that uses one set of bolts. The 9H used two sets of bolts because of capacity limitations on size in the manufacturing shops.

Current 7H compressor aerodynamic design of the airfoils is complete, and mechanical sizing of the flowpath that locates airfoils relative to each other to allow operation at all conditions without contact is nearing completion. Conceptual design of each component has been started, thereby defining a preliminary 7H cross section.

Plans for Next Quarter

The 9H compressor efforts will focus on completing assembly and instrumentation drawings. Manufacturing support will be provided as needed. A final design review of the 9H compressor is planned.

The 9H compressor rig assembly is planned for completion and will be sent to Lynn, MA, for installation in the test facility.

The 7H compressor will continue its early design definition with completion of the flowpath definition. The airfoils for the 7H sub-scale rig program will complete drawing definition.

Technology Applications

The compressor design (aerodynamic and mechanical) and rig test results establish the basis for the 7H and 9H production hardware.

Section 2.2.2.2 (GTFFCB) Combustor Design

Objective

The objective of this task is to design a combustor based on the commercial DLN2 combustion system, with modifications made for improved use of available air, reduced cooling, and greater load turndown capability. This design will be similar for both the 7H and 9H machines. It will be configured to ensure the ability to use preheated fuel. Rig testing of full-scale and scaled components will be conducted at 7H and 9H cycle conditions. The final configuration will be validated in single-combustor, full-scale tests under full operating conditions.

The premixer-burner design will be optimized to use minimum pressure drop, achieve required fuel/air mixing, maintain stable flame, and resist flashback. The basic design will be developed and evaluated in full-scale single burner tests and then implemented in full-scale combustors. The ability to meet high cycle fatigue (HCF) life goals depends on understanding the effects and interrelationships of all combustion parameters. Existing dynamics models used in parallel with laboratory-scale and full-scale testing will be used to predict combustor dynamic behavior.

Chamber arrangement, casings, cap and liner assemblies, flame detectors, and spark plugs will be designed and analyzed to ensure adequate cooling, mechanical life, and aerodynamic performance. Fuel nozzles will be designed for operation on gas alone or on gas with distillate as a backup fuel. The transition piece will be designed and integrated with the design of the machine mid-section, transition duct cooling, and mounting.

A full-scale, single-combustor test stand will be designed and fabricated to verify performance of the combustion system. Facility modifications will be made to support the test. These include installation of the test stand, installation of high-temperature stainless steel air piping, an additional air heater, control systems, upgrades to the combustion video system, and tooling.

Progress for this Quarter

The design of the test stand hardware has been completed. The aft frame castings for test transition pieces were completed. Casting tooling for the transition piece bodies was started. Impingement sleeve body and first hole pattern definition was released to support test stand transition piece manufacturing. Purchase orders were placed for two test stand transition piece assemblies. Updated temperature and stress predictions for the 9H transition piece were completed and documented. Aft bracket stress analysis was completed and documented. The aft bracket was changed from casting to fabrication.

Plans for Next Quarter

Test stand hardware procurement and fabrication will be underway. The pressure vessel and nozzle box will be delivered late in 1Q97. Machining of aft frame castings will be completed. Producibility reviews of transition piece and aft frame will be completed. Transition piece body casting tooling will be completed and the first body (for the test stand transition piece) will be cast. Impingement sleeves for test transition pieces will be completed. Aft seals will be procured and aft seal testing at the CRD facility will begin. Radial diffuser testing in the 9FA test stand will be completed (postponed from 3Q96).

The first fuel nozzle "swizzle" casting definition will be released for quick prototype development. Fuel nozzle configuration will be released to a vendor for manufacturing of development hardware.

Technology Application

Design and development of the combustion system is required for the ATS gas turbine to meet the low emissions targets at the high cycle conditions of inlet temperature, pressure, air flow, and outlet temperature, all of which are greater than those of any of our developed products.

Section 2.2.2.3 (GTFFTR) Turbine Rotor Design

Objective

The objective of this task is the design of turbine rotor components (wheels, spacers, aft shaft, transition discs, coolant systems, and fastening devices). Transient and steady-state stress analyses will be used to calculate parts lives. Rotor and system vibratory characteristics will be evaluated. The coolant flow circuit for routing the cooling steam to and from buckets will be designed and performance calculated. Test results will be incorporated concurrently. Drawings and specifications will be developed in preparation for manufacturing.

Progress for this Quarter

The preliminary turbine rotor structural system model (transient thermal/mechanical) is currently being exercised to complete the 9H secondary flow system. Several startup-to-steady-state analyses were completed, as was a shutdown analysis. Multiple variations on secondary flow parameters have also been analyzed.

The critical dimension drawing is in the manufacturing review cycle.

Plans for Next Quarter

The 9H secondary flow system will be completed, and construction of the final turbine rotor structural system model will begin.

Critical dimension drawings are planned for release in order to begin tooling development.

Technology Application

The turbine rotor analysis and design effort have defined the basis for the 7H and 9H production hardware.

Section 2.2.2.3.1 (GTFFTR) Mechanical Analysis - Turbine Rotor**Objective**

The objective of this task is to identify the best possible locations and sizes for the cooling hole and bolt hole in the embossment of the ATS turbine rotor so that the final configuration will satisfy design criteria for maximum stress, ligament stress, and maximum residual growth at the rabbet and at the live rim.

Progress for this Quarter

Nonlinear 3D stress analyses of the spoolie for the steam delivery system are being performed. These analyses have included the contact interference to the wheel hole and the effects of thermal transients and initial interferences as well as plasticity and creep. Analyses have focused on stresses caused by angulation due to differential heating of the wheels. For this load case the spoolie must rotate against friction at the spherical contact surfaces. An analysis has shown that angulation of the spoolie from wheel radial thermal expansion will cause leakage and high stress for the larger diameter spoolie in the axial steam tubes. Several design changes that reduce the stress were analyzed. The smaller diameter spoolie for the bucket was analyzed and it was found that angulation did not result in leakage. Several other design changes offering potential solutions have been analyzed.

A 3D model of the latest forward manifold design was constructed. Several stress analyses, incorporating both centrifugal and pressure loadings, were performed on the forward manifold. Parametric analyses were completed that investigate the effect of thickness of the wall and outer rim on the resultant stress distribution. Ways of strengthening the manifold wall using a central plate were investigated, including shortening the plate, changing the thickness of the plate, and splitting the plate. Studies were also made of the effect of a support plate at the symmetry plane of the manifold.

Plane stress analyses were performed on various cross sections of the 2-3 spacer to determine hoop stress levels near the steam holes and feed holes. A parametric study was completed assessing the effect of steam hole size and location for one of the cross sections. A minimum required ligament

length between the steam hole and outer radius was determined. Steam hole radius was determined to be less important than the radial location of the steam hole. Using these results, two other cross sections of interest were examined under centrifugal loading conditions. Both cross sections produced acceptable hoop stress levels. Plane stress analyses were also performed on the 2-3 spacer under combined centrifugal and thermal loading conditions simulating transient and steady-state thermal conditions. Three cross sections were examined for each case. For all the 2D cases examined thus far, stress levels are acceptable.

Stress analyses were performed to determine the influence of steady-state thermal distributions as well as the bolt clamp load on the embossment flange opening/closing of the second-stage rotor. It was found that flange closing is not significantly affected by the size of the bolt clamp load. A load almost triple the normal bolt clamp load is required to close the gaps under steady-state thermal conditions. During steady-state thermal conditions, the flanges remain closed when no heat transfer takes place in the cooling holes. Although the flange does open when heat transfer occurs, the amount of opening is acceptable at this stage.

A 3D finite element analysis of the 7H third-stage bucket dovetail was performed to assess the preliminary design and to determine acceptable dovetail skew angle. The model includes fine meshes of the wheel and bucket dovetail regions and coarse representations of the bucket shank and wheel. Skew angle can be varied parametrically. A coarse airfoil is currently being added.

The bore tube carries supply and return steam through two holes that are close to one another. Because the thermal gradient between the supply and return steam holes is significant, it is important to study the stresses in the structure caused by thermal as well as mechanical loadings. Three-dimensional structural analyses consisting of thermal, centrifugal, and internal/external pressure loads on the bore tube joint have been performed. The thermal loads are the most significant. Overall maximum stress levels are well below the design criterion. Hence, the current design is considered to be structurally acceptable at this stage.

Preliminary thermal and structural analyses were completed for the endcap of the bore tube. The objective is to determine the stresses in the endcap of the bore tube when supply and return steam paths are split into two separate components.

Plans for Next Quarter

We will continue to provide design and analytical support for rotor components as needed.

Technology Application

The results obtained have been used to select the aft shaft design for the ATS gas turbine.

Section 2.2.2.3.2 (GTFFR) Wheel Forging Residual Stress Analysis

Objective

The objective of this task is to determine the influence of residual stresses on overspeed design limits for turbine forgings since residual stresses will influence the deformations of the wheel during overspeed.

Progress for this Quarter

The thermal analysis of the quenching process for the ATS turbine second-stage wheel was performed. The analysis simulated the heating up to the solution temperature, the 8 hours soak, and the subsequent oil quenching. The temperatures from this analysis will later be used as input for the stress analysis that will determine the residual stresses after quenching. The temperature rates will also be used to determine the thermal conditions under which the material stress-strain curves must to be obtained.

The 7FA first-stage wheel "on-cooling" stress-strain data to be used for the quenching process analysis were received. The data contain stress-strain curves for three different physical locations through the disk thickness. The stress analysis simulating the 7FA first-stage wheel quenching process was also performed. This analysis used temperatures obtained from the earlier thermal analysis to predict the residual stresses in the wheel as a result of the quenching process. The residual plastic strains from the stress analysis were mapped from the heat treatment geometry onto the final machined shape of the wheel and the remaining residual stresses left after machining were determined. The stresses will be reduced some from the aging process which has not been taken into account yet, but even then, these stresses could severely limit the over-speed capability of the wheel.

Plans for Next Quarter

This task has been completed.

Technology Application

These residual stresses will influence the deformations of the wheel during over-speed. If they are found to be significant, they will have to be included in the design calculations for the ATS turbine wheels.

Section 2.2.2.3.3 (GTFFTR03) Turbine Rotor YFT Flow Analysis**Objective**

The objective of this task is to determine the design operating conditions of the steam delivery circuit used to cool the buckets of the advanced machine. The study will employ YFT, a one-dimensional, compressible flow network analyzer.

Progress for this Quarter

Effort was focused primarily on the development and exercise of a detailed YFT model that includes multiple buckets. The model will be employed in determining the effects of parameter variations from bucket to bucket.

Plans for Next Quarter

This task has been completed.

Technology Application

This study has had a direct impact on the design and selection of the ATS gas turbine steam delivery and distribution system. Hydraulic performance of the baseline concept (pressure drop and leakage, primarily) affects the overall cycle efficiency and this link to the combined cycle has been carefully

considered in, and has been a key output of, this analysis. This study has also pointed out the critical elements in the steam delivery circuit that should be tested.

Section 2.2.2.3.4 (GTFFTR) Turbine Rotor Shaft Temperature Analysis - Number 2 Bearing

Objective

The objective of this task is to investigate design options that would result in a minimum temperature of the shaft surface in contact with oil and/or air oil mist, and a maximum thermal gradient in the area of the oil seals in the Number 2 bearing.

Allowable temperatures in the seal forward of the 9H machine Number 2 bearing are limited due to accelerated decomposition of lubricating oil at high temperatures. Thermal gradients are also limited in that uneven thermal expansion of the shaft will adversely affect seal clearances and performance.

Progress for this Quarter

This task has been completed.

Technology Application

All the design options evaluated in this study are being considered for ATS turbine rotor design in a detailed follow-up study using a Fluid Element Analysis approach to better simulate the heat transfer boundary conditions in the current modeling effort.

Section 2.2.2.4 (GTFFTB) Turbine Bucket Design

Objective

The objective of this task is the design of buckets for the four rotating stages. The heat transfer and material databases for steam-cooled first- and second-stage buckets continue to expand and will be integrated concurrently with the design. Cooling passages will be sized consistently with manufacturing practicalities and the bucket life requirements. Flow variation and consistency will affect life calculations and will be considered. Current practices for thermomechanical steady-state and transient analyses, dynamics and vibration analysis (which can deal with anisotropy), and corrosion/oxidation analysis will apply throughout. Drawings and specifications will be developed in preparation for manufacturing.

Progress for this Quarter

A formal design review was held to approve the frozen aerodynamic design on the 7H turbine buckets. Significant progress was also made in the mechanical design of all four stages. Detailed 3D finite element modal analyses were completed on all four stages. TBC effects were included on the first two stages. Preliminary cooling flow and thermal analyses were completed on all cooled stages. 3D finite element analyses were continued on the second- and third-stage dovetails including thermal gradients. A technical review of all four stages was completed in mid-December.

9H turbine bucket detailed design proceeded on all four stages. Post-cast operations were defined and machining trials continued. Tooling for the first-stage bucket castings was completed. Construction of the tooling for second-stage bucket castings continued. Casting trials were completed on the third-

and fourth-stage buckets and on prototype first- and second-stage castings. Worked began on a core-enhancement design-of-experiments to optimize core processing for minimal casting variability.

Plans for Next Quarter

Tooling for the 9H second-stage bucket will be completed. Castings trials on first- and second-stage 9H buckets will begin. Casting trials on third- and fourth-stage 9H buckets will continue. Preliminary robust design activities will be completed on 9H buckets. Post-cast processing trials will continue on 9H buckets. Transient analysis on 9H buckets will continue.

LCF and creep analyses for the 7H buckets, cooling design of the 7H first-, second-, and third-stage buckets, and casting trials on proposed 7H buckets will all continue.

Technology Application

The design and development of turbine buckets are required for the ATS turbine to ensure that the buckets deliver power to the turbine shaft and to ensure that the buckets meet the stated part life requirements.

Section 2.2.2.4.1 (GTFFTB) S4 7H Wheel Dovetail Analysis

Objective

The objective of this task is to perform 3D thermomechanical analyses of ATS gas turbine rotor dovetails, bolt holes, and steam cooling holes. The dovetails are highly stressed and, in addition, there are severe thermal gradients in the dovetail region. Detailed 3D stress analyses are required to ensure that the dovetails and the wheels meet design guidelines.

Progress for this Quarter

The Unigraphics files of the ATS gas turbine second-stage stage wheel and bucket were received. A detailed 3D finite element model of the wheel was finished. The model contains approximately 28,000 brick elements. A preliminary finite element model of the bucket was also finished. This model consists of tetrahedron elements, and the bucket is modeled without the internal cooling channels. This preliminary model was built so that the mechanical analysis of the wheel/bucket assembly could get started. Initial analyses of the bucket/wheel assembly have been performed with mechanical loads only. The final model, which includes the internal cooling channels and consists of all hex elements, is almost complete.

Plans for Next Quarter

We plan to finish the 3D thermal and stress analyses of the bucket/wheel assembly.

Technology Application

The dovetails are highly stressed and, in addition, there are severe thermal gradients in the dovetail region. Detailed 3D stress analyses are required to ensure that the dovetails and the wheels meet design guidelines for the ATS turbine rotor.

Section 2.2.2.4.2 (GTFFTB) S4 9H Design Optimization**Objective**

The objective of this task is to optimize stresses and creep deflections in the 9H fourth-stage bucket shroud. A detailed 3D creep analysis is needed to ensure that the stresses are within the required limits for creep life.

Progress for this Quarter

This task has been completed.

Technology Application

The redesigned shroud will be used in the 9H fourth-stage bucket design. This analysis methodology will be repeated for the 7H fourth-stage bucket.

Section 2.2.2.4.3 (GTFFTB) Bucket Defect/Plug Life Sensitivity Analysis**Objective**

The objective of this task is to show the effect on natural frequency of the variations in grain size and orientation of 9H fourth-stage buckets. If the variations in natural frequency can be shown to be non-critical, bucket yield can be improved.

Progress for this Quarter

This task has been completed.

Technology Application

The results of this study will be used on the ATS gas turbine design primarily as a means of improving bucket yield.

Section 2.2.2.4.3.1 (GTFFTB) S1B 9H Robust Design and Life Assessment**Objective**

The objective of this task is to develop design methods for buckets to minimize influence of design and manufacturing variables. Statistical design methodology will be used to relax presently used worst case conditions (worst material, worst temperature, etc.) and develop capabilities to quickly assess bucket life.

Progress for this Quarter

Based on the wall thickness measurements, a series of analyses were conducted in order to determine the effect of wall thickness variation on the low cycle fatigue (LCF) life of the buckets. The analyses involved expressing the variations as 3D cubic spline functions that modify the pressure side and suction side profiles of the bucket. Results showed that the current processing parameters will yield buckets with satisfactory lives.

The Robust Design and Life Assessment of the buckets is underway. The Design of Experiments factors have been identified: capabilities of varying wall thickness in the leading and trailing edges and

in the pressure and suction sides; TBC thickness in the airfoil, root fillet, leading edge, and tip radius have been added to the FE model. The analyses are currently being conducted. The results will initially be used to quickly assess bucket life and other critical-to-quality (CTQ) criteria.

Plans for Next Quarter

Work will continue on the Robust Design/Life Assessment of the first-stage bucket and will begin on the second-stage buckets.

Technology Application

The results of this study will be used on the ATS gas turbine in order to assess bucket performance and obtain optimized factor settings and statistical distributions of the CTQs given the distributions of the factors. The results of this study will be used on the ATS gas turbine design primarily as a means of improving bucket yield.

Section 2.2.2.4.4 (GTETIH04) Bucket Squealer Tip Characterization

Objective

The objective of this task is to determine the specific heat transfer characteristics associated with the ATS turbine first-stage blade tip region. Blade tip geometry will be optimized to the extent possible when other design constraints are taken into account so as to have a positive impact on blade design and turbine performance.

External heat transfer coefficient distributions will be determined on the blade tip and on the airfoil surface near the blade tip using transient liquid crystal techniques in a blade tip cascade. The Blade Tip Heat Transfer Cascade is located in the Turbomachinery Laboratory of Texas A&M University. The blade tip region has been the recipient of mostly trial-and-error design by industry. With the elimination of blade tip film cooling and tip dust holes in the ATS turbine design, the tip region external heat transfer becomes a much more important issue. Integration of the heat transfer load with geometry alterations to reduce clearance leakage and provide rub resistance is critical to the success of this design. This task will address these issues by measuring detailed heat transfer distributions for various design geometries.

Progress for this Quarter

Under the direction of CRD, Texas A&M University is performing an experimental study of blade tip heat transfer using a blade tip flow field representative of that of the ATS turbine first-stage blade to measure the local heat transfer distributions for candidate tip geometries.

Just prior to this quarter, Texas A&M had performed heat transfer tests on plain and enhanced blade tip models with low freestream turbulence intensity, as well as the plain blade tip model with a bar grid installed upstream of the blade leading edge to generate higher turbulence. They reported a reduction of approximately 40% in tip heat load with the enhanced geometry. They also reported an increase of approximately 20 to 30% in plain tip heat load when higher turbulence was introduced, which was consistent with expectations.

As heat transfer tests for the near-tip pressure and suction surfaces (source and sink regions) were being run, the upstream acrylic splitter plate shattered. Apparently, small cracks in the threaded bolt

regions of the plate gradually extended over accumulated test runs until the plate broke apart. The impact stresses associated with sudden transient blowdown tests probably contributed to the cracking problem. No significant damage occurred to the test airfoil. An additional problem was observed in that a large portion of the molded Renshape blade tip material was delaminated from the heated aluminum core, apparently as a result of overheating. Texas A&M remolded the blade tip and replaced the acrylic splitter plate with a metal plate. Additional problems were encountered with the color display of the liquid crystals on the blade tip insulator material (Renshape) that were thought to be due to the level of heating required. Texas A&M switched to a different liquid crystal using a broader band green signal for surface temperature detection in order to alleviate this problem. The new color band signal provided a clear display, prompting a check of the original liquid crystal viability. Texas A&M subsequently ordered a new batch of the original crystals for viewing the narrow band red color with the result that color display was very good. Thus it appears that the previous batch of liquid crystals had somehow been corrupted, either through contamination or lack of proper refrigeration. This problem is solved now. Texas A&M then ran both the plain blade tip and the enhanced tip geometry cases with the new crystals and verified the approximately 40% reduction in blade tip heat load with the improved rub-strip geometry.

A second cascade shroud plate was fabricated with an array of static pressure holes over the blade tip region.

Plans for Next Quarter

During 1Q97, Texas A&M will concentrate on completion of the required test scope, including tip heat transfer for the two geometries with high and low freestream turbulence intensity, near-tip surface heat transfer, shroud pressure measurements, and freestream turbulence intensity measurements. They will then initiate work on the continuation tasks dealing with variations in enhanced tip geometry to achieve better performance or to meet manufacturing constraints or a combination of both.

Technology Application

The improved blade tip geometry resulting from this task will be used directly in the design of the ATS turbine first-stage blade and, most likely, incorporated into the design of the second-stage blade as well. Measurements of the heat load will allow for accurate assessments of the tip stresses and life, while pressure measurements will allow estimation of the turbine performance benefit. All data will be used for improved CFD analyses.

Section 2.2.2.5 (GTFFTS) Turbine Stator Design

Section 2.2.2.5.1 (GTFFTS) Bucket Nozzle Air/Steam Coolant Transition Analysis

Objective

The objective of this task is to determine the time required for switching from air cooling to steam cooling for the 9H first-stage bucket to keep thermal stresses within acceptable levels.

When the cooling medium is switched from air to steam during startup, the steam comes in at a lower temperature than the air. The switch results in a thermal shock that will increase the stress level in the

bucket. The LCF life due to these thermal shocks will be calculated. If the LCF life is too short, the sequence of the air-to-steam transition might have to be changed.

Progress for this Quarter

The automation process for steady-state thermomechanical analyses, using ANSYS/LFE, of the ATS gas turbine first-stage bucket is complete and has been validated at full speed, full load (FSFL) conditions. Comparisons of temperature predictions between ANSYS/LFE and previous YFT and ANSYS iterative calculations show good agreement. A computer program has also been developed to scale the bucket external heat transfer boundary conditions (h and T). The boundary condition scaling is based on the FSFL heat transfer predictions as well as the firing temperature, core flowrate, and air properties at the desired operating condition. This procedure will also be used to generate boundary conditions for the ATS gas turbine first-stage bucket robust design activities.

The analysis process has been used to evaluate the steady-state bucket performance at 10% load, where the air-to-steam transition occurs. The gas path thermal boundary conditions are obtained by scaling the FSFL convective film coefficients and temperatures, while the internal boundary conditions are evaluated using ANSYS/LFE. The peak metal temperatures are found to be approximately 400°F lower for the air cooling condition and 500°F lower for the steam cooling condition than under the FSFL conditions.

The details of the air-to-steam transition process have been defined using the transient cycle predictions for a cold start and the current transient rotor performance. The transient rotor predictions of temperature at the bucket inlet and pressure drop across the bucket during the air-to-steam transition are used in the transient analyses. A preliminary transient thermal analysis of the air-to-steam transition is complete. The bucket inlet temperatures and flowrates are obtained from the current rotor model and step-changed from the steady-state air values to the steady-state steam values. The transport properties of the internal coolant are also step-changed from air-to-steam at the transition time. The computed temperature distributions will be used as thermal loading for structural analyses to determine the time, location, and magnitude of the peak component stress from which life estimates can be made. Bucket exit conditions will be provided as refined boundary conditions for future rotor design iterations.

Plans for Next Quarter

An airfoil platform will be included in the ANSYS/LFE model and steady-state and transient structural analyses of air-to-steam transition will be performed. The transient analysis of air-to-steam transition will be completed.

Technology Application

The air-to-steam transition requirements during startup will have to be controlled so that the LCF life of the buckets will meet design guidelines. If the LCF life is too short with the present control plan, the air-to-steam transition rate might have to be changed to put the LCF life at an acceptable level.

Section 2.2.2.5.2 (GTFFTS) S1N Assembly - Product Vision Software Support**Objective**

The objective of this task was to evaluate the maintainability and assemblability of first-stage nozzle inserts. It was proposed to utilize Product Vision (PV) to assist in verification of assembly of models while saving both time and money. PV is a powerful analysis and visualization tool used for determining assemblability and maintainability of mechanical systems electronically, without the use of mockups or SLA models.

Some of the airfoils for the ATS turbine contain inserts to facilitate airflow. The inserts are designed to fit inside the airfoil cavities, but the geometries involved are so complex and the tolerances so small that it is difficult to predict whether or not an insert will actually slide into the cavity it was designed for. The traditional verification methods are expensive and time-consuming.

Progress for this Quarter

Product Vision (PV) has been enhanced to include progress paths and workspaces. Progress paths allow a user to monitor path generation on-the-fly. Workspaces encapsulate studies making them easy to reload. The new PV has been installed on a workstation in Schenectady. The upgrade of the production system is being scheduled. The rotors design team is beginning to use PV. Limited training has taken place. PV has been used to verify the design of several airfoils and two manifolds, resulting in cost and time savings and verifying a design difficulty.

Plans for Next Quarter

We plan to issue a new version of Product Vision and to continue to support its use within airfoils and rotor groups.

Technology Application

Product Vision is being used to evaluate assemblability and maintainability issues for the ATS Gas Turbine.

Section 2.2.2.6 (GTFFST) Structures Design**Objective**

The objective of this task is to design the exhaust frame/diffusers, steam gland, and aft bearing housing. Instrumentation and test plans for component model, factory, and field testing will be prepared.

Progress for this Quarter**Exhaust Frame and Diffuser**

The exhaust frame and diffuser supplier (Patterson Pump, USA) has completed a material layout and has begun purchasing material to produce the first exhaust frame and diffusers. Detailed fabrication drawings of the radiation shields based on input from the vendor and the GE manufacturing engineer have been completed. The machining drawing release of the exhaust frame is in the review process. A failure modes and effects analysis (FMEA) has been undertaken for the cooling circuit of the exhaust

frame and adjacent cavities for a detailed evaluation to identify methods to lower risk to the system. A cooling circuit analysis with various operating conditions and sensitivities to off-design conditions has been examined and has identified methods to adjust the flow circuit based on actual frame flow test results. The 3D finite element analysis (FEA) of the exhaust frame and forward diffuser has been completed for all mechanical and steady-state thermal effects as well as for transient thermal loads and stresses for final lifing estimates. A preliminary instrumentation plan for design verification on first unit test has been completed, including an evaluation to remove/support the telemetry system for rotating instrumentation lead-out.

Steam Gland

The casting release review of the steam gland was completed, and the vendor (Goodwin Steel, UK) has started the casting pattern for the first unit. A revised CAD 3D solid model of the steam gland has been completed incorporating casting pattern/producibility comments for final lifing predictions. Floating seal leakage design and mechanical analysis of the bolted flanges based on the new geometry have been completed. A 3D solid finite element model (FEM) of the steam gland current geometry to be used for deflection and detail stress (for LCF analysis) is complete. Minor geometry adjustments to the aft two seal designs, the "false flange" at top and bottom, etc., have been completed to ensure deflection and lifing concerns are met. A final computational fluid dynamics (CFD) analysis of the steam inlet scroll with the rotor feed cavity was completed by CRD to confirm pressure drop calculations for the steam supply entering the rotor cooling circuit. Detailed labyrinth seal drawings have been completed.

#2 Bearing Housing

The casting release design review was completed, and the vendor has started the casting pattern for first unit (Middelburg Foundry, NETH). A detailed 3D FEA has been completed to evaluate the structural integrity of the housing under dynamic loading (i.e., shipping and blade out) and incorporating new geometry to maximize the bearing drain cavities. Flow analysis of the oil and air seals is complete with the assumptions of holding rotor temperature and delta temperature across seals to within GE Power Generation experience levels. Mechanical design of supports and bolting is complete. Thermal and flow analysis work will continue on the heat rejection at the bearing due to steam supply through the rotor bore and acceptable deflections. Preliminary first unit test instrumentation has been identified.

Plans for Next Quarter

Exhaust Frame and Diffuser

Structural, thermal, and cooling flow analyses of the 9H exhaust frame and forward diffuser are almost complete with focus shifting to final drawing (machining, assembly, instrumentation, etc.) release. A unit assembly planning meeting will be held in Greenville to develop tooling, accessibility, and maintainability methods with assembly personnel. The mockup will be used for instrumentation routing definition and for discussion of a possible heat shield in the steam gland area. Concept and preliminary design work will begin on the 9H outer aft diffuser. Preliminary design work will begin on the 7H exhaust frame and diffuser with flowpath definition and a commonality study with 9H components.

Testing of the steam pipes in the diffuser flowpath will be completed at CRD for a 1/9 scale model to properly model the effects of pipe vortex shedding and its possible effect on performance. Testing of

the possible design configuration of the aft diffuser and its interfaces to the high pressure recovery aft duct will be started. Initial tests will focus on the surface effects of an internally-insulated duct and any performance impact.

Steam Gland

A final geometry CAD 3D solid model of the steam gland will be completed for final machining and assembly drawings. The adjustments to the 3D solid FEA of the steam gland final geometry for deflection and detail stress (LCF analysis) will be completed. The machining and assembly drawings will be issued and the vendor will have completed the casting pattern and possible cast pour. The steam gland design will be examined for possible cost reduction/design optimization using brush seals in place of the labyrinth seals.

#2 Bearing Housing

A final geometry CAD 3D solid model of the bearing housing will be completed and incorporated into the machining and assembly drawings. The bearing housing casting vendor will complete the casting pattern and the first pour will be completed. All interfacing conditions with the rotor, bearings, etc. will be established for normal conditions and off-design conditions. Bearing instrumentation placement and routing will be finalized using the mockup.

Technology Application

The analysis and design effort establish the basis for the 7H and 9H structure designs.

Section 2.2.2.6.1 (GTFFSTEFAT) Exhaust Diffuser Vortex Shedding/Acoustic Test

Objective

The overall objective of this project is to establish design guidelines to prevent the coupling of strut vortex shedding and acoustic modes in the ATS exhaust diffuser. In order to achieve this objective, tests will first be run in a baseline scale-model exhaust diffuser that reproduces the coupling between vortex shedding and acoustics measured in prior field and factory tests of exhaust diffusers with the baseline geometry. Following the reproduction of acoustic resonance in the laboratory setup, the mechanism by which acoustic resonance occurs will be established. Aerodynamic fixes will be tested in order to understand the mechanism through which diffuser dynamics can be reduced or prevented.

Progress for this Quarter

A baseline exhaust diffuser scale model designed for flow tests at Mach numbers representative of ATS gas turbine conditions was assembled. The baseline configuration was a scale model of a GE F-machine exhaust diffuser. This design was chosen because of the large quantity of field and factory data available. A comparison to that database would validate the aeroacoustic behavior of the scale model test stand.

Unsteady pressure instrumentation was installed on the outer wall of the model. Test data show that the aeroacoustic resonance of the scale model matches that found in gas turbines at high inlet swirl angles representative of full speed, no load conditions. The nondimensional frequency (Strouhal number) for the model was 0.48, nearly matching the value of 0.47 measured in field tests. Additional tests with tapered struts in the exhaust diffuser showed that the acoustic resonance was eliminated.

Again, this behavior is consistent with field data. The aeroacoustic response of our scale model facility has been validated.

Plans for Next Quarter

A scale model of the ATS gas turbine exhaust diffuser will be designed and constructed in preparation for aeroacoustic and pressure recovery testing.

Technology Application

The results of this exhaust diffuser test program will validate the design of the ATS gas turbine exhaust diffuser. Data will be used to ensure that an acoustic resonance is not present during operation. Pressure recovery (performance) levels will be verified.

Section 2.2.2.6.2 (GTFFST) Steam Box CFD Analysis

Objective

The objective of this task is the design of a steam delivery system as part of the 9H/7H steam cooling design. A steam gland is being designed to bring the cooling steam from a stationary inlet pipe onboard a rotating shaft. Steam will enter the steam gland through an axial inlet pipe. The pipe turns 90° so that the resulting flow is traveling tangent to the rotor shaft and into an inlet scroll. The inlet scroll cross-sectional area is sized to match the steam velocity to the rotor tangential velocity. As the steam travels around the scroll circumferentially, some of the steam is being extracted into rotor slots. A 3D CFD analysis is required to define the appropriate geometry of the steam gland inlet scroll that will result in a nearly uniform radial outflow from the scroll circumference.

Progress for this Quarter

To confirm the results obtained thus far with NOVAK3D and to assess the effect of the constant exit static pressure assumption required by NOVAK3D, Tfc, another CFD code, has been used to solve both the original and “continuous scroll outlet” concepts. Both Tfc and NOVAK predict a better performance for the modified design, as measured by the standard deviation of the velocity profiles about their mean. Although the comparison between the NOVAK and Tfc solutions is satisfactory, the root of the differences was investigated and found to be the differences in the flow predictions in the elbow region of the design. The NOVAK flow pattern indicates a stronger recirculation downstream of the elbow than predicted by Tfc. The effect of the exit static pressure on the solution was evaluated by running Tfc in the “uniform exit pressure” mode (similar to NOVAK's) and then again with the “non-uniform exit pressure” option. The results of this effort have been documented and presented in a design review of the steam gland design. No outstanding issues in this area were identified. The proposed “continuous scroll outlet” concept is the current baseline design.

Plans for Next Quarter

This task has been completed.

Technology Application

The results of this study have had an impact on the design of the scroll geometry and confirmed its proper performance in meeting the desired uniform flow distribution. The analysis of the entrance to

the rotor has served three purposes: it incorporates rotational effects and confirms the 1D analyses of the YFT study of the steam distribution system; it points to the relative insensitivity of the current design to variation in the inlet conditions of the flow; and, with the prediction of the relative swirl angle, obstacles in the annular passage will be designed to be aligned with the incoming steam.

Section 2.2.2.7 (GTFFMS) Mechanical System Design

Objective

The objective of this task is to perform system level studies to optimize cost and performance. Performance, cost, weight, and other system level integration issues will be monitored and tracked. A flange-to-flange cross-section drawing will be maintained, and all mechanical interfaces will be controlled. All gas turbine systems, as well as the technical requirements for accessories, will be defined and specified.

Progress for this Quarter

System level studies were performed to optimize cost, performance, weight, size, maintainability, reliability, and manufacturability. Performance, cost, weight, and other system level and integration issues were monitored and tracked. The systems review team, which includes engineering, manufacturing, sourcing, and maintainability personnel, continues to meet to review the merit of system issues and to determine whether incorporation of ideas meets system goals such as cost, schedule, and performance.

The maintainability, reliability, and serviceability team continued to work to ensure that all of the "lessons learned" for field operation are being incorporated into the 9H/7H design.

A full-scale mockup of the midsection including the compressor discharge casing (CDC), combustion transition piece, and steam piping was completed. It is being used for assembly and maintainability trials, with feedback to GEPG Engineering to ensure that assembly and maintainability issues are incorporated into designs prior to hardware procurement.

Cross-checking and updating of the 9H mechanical interface drawing continued. Integrated schedules were updated as improvements were found in the engineering and manufacturing cycles.

Performance estimations for both the 7H and 9H were updated, reflecting the current design configuration and assumptions.

Plans for Next Quarter

System studies to optimize cost and performance will continue. Progress in cost, risk, schedule, and performance of the gas turbine design and manufacturing effort will be monitored and tracked. The component integration effort to establish and document interfaces will continue. The 7H engineering milestone schedule will be integrated with the manufacturing schedule and released as a working document.

Section 2.2.2.7.1 (GTFFMS) Transient Gas Turbine Cycle Platform Evaluation

Objective

The objective of this task is to evaluate computer platform and software options to best support the integration of a transient gas turbine model into a combined cycle simulation.

This task was started in October 1996. The current state of transient modeling for the ATS gas turbine was reviewed with a number of people in GEPG Engineering. The GEAE approach was also investigated. From this brief study it was determined that a new transient model of the ATS machine was necessary in order to reflect more accurately its aero and thermal behavior. This work will assist GEPG Engineering in developing the new transient model with a steady-state accuracy goal of approximately $\pm 1\%$. The model will be designed to be included in overall power plant simulations.

Progress for this Quarter

The current state of transient modeling for the ATS gas turbine was reviewed with various people in GEPG Engineering. The steady-state performance calculations consist of four parts: Gas Turbine, Steam Turbine, HRSG, and Balance of Plant. Each part is owned and developed by a separate group within GEPG. This leads to a distributed system which requires that some gas turbine models must be run on several computers. For the ATS gas turbine, all of the software runs on the same workstation. A complex UNIX script has been developed to minimize the difficulty of running the four programs.

Transient simulations are run by two groups: controls and steam/gas process. Currently they both use the same very limited transient model of the gas turbine. The steam/gas process transient analysis is performed using PC-Trax. This simulation language has been obtained from an outside vendor and has a very good library of standard valves, pumps, heat exchangers, and other components. The controls group uses EASY5, a general purpose simulation package for real time simulation and verification of turbine controllers. The controls group has also developed a library of valves, pumps, heat exchangers.

The GEAE approach was also investigated. A Cycle Work Station has been developed for performance simulation. This system provides detailed aerothermal calculations. Because of the complexity of the model, it generally runs slower than real time. A simpler, component level model has been developed primarily for real time and controls design. Its accuracy is in the range of 1% while the accuracy of the cycle model is an order of magnitude better (0.1%).

Three recommendations resulted from this review.

1. Although cumbersome, the steady-state performance approach was workable. Longer term development should be toward a performance system based on the Cycle Work Station.
2. A component level model of the ATS gas turbine should be developed. An existing component level model of the LM2500 would be the starting point since the compressor on the LM2500 is similar to the compressor on the ATS turbine.
3. The feasibility of using Easy5 as the simulation language for both the control and process groups should be studied.

These recommendations were reviewed with the Vice President of Engineering, who approved proceeding with recommendations 2 and 3.

To meet the schedule time constraints, it was decided as a first step to extend an existing ATS cycle model so that it could operate over the entire operating region including startup. GEPC engineers have completed this model by extending the compressor and turbine maps. This new model has demonstrated cycle balance down to 10% speed. It shows good agreement at 50% speed. Further verification is being performed.

Plans for Next Quarter

The primary effort will be in integrating the new transient model into the EASY5 and PC-Trax simulation environments. Use of the GEAE "back-bone" compressor and turbine mapping techniques will be explored. The goal is to reduce the computation time allowing the model to run in real time and to improve the accuracy of the model.

Technology Application

This transient model will be used with detailed overall simulations of the plant gas and steam processes. This overall simulation will be used to verify the performance of the ATS system and to minimize the risk of any problems.

Section 2.2.2.8 (GTFFPP) On-Base and External Piping Design

Objective

The objective of this task is to design piping for fuel, air, steam, water, and oil transfer. A turbine base will also be designed for securing the machine to the foundation.

Progress for this Quarter

The conceptual design of turbine base interfaces has been completed. Development of conceptual designs for piping systems continued.

Plans for Next Quarter

A turbine base conceptual design review is planned for 1Q97. System requirements will continue to be addressed and reviewed. Work on conceptual piping designs will continue.

Technology Application

The turbine base and piping designs require the consideration of new ideas in this technology application. The turbine base must be capable of handling and transferring much larger loads than in previous gas turbine designs. This requirement is complicated by the limited space available to the turbine base because of the machine shipping envelope, the increased number of systems requiring piping for fluid transport, the piping size and quantity, and the foundation interface limits. In summary, the piping design challenge is driven by the increase in size and quantity of fluid systems support required by the machine and the limited space around that machine. These piping designs demand creative ideas in packaging and hardware selection.

Section 2.2.2.9 (GTFFIT) Instrumentation and Test**Objective**

The objective of this task is to instrument and conduct field tests that validate the ATS gas turbine design for mechanical integrity and operating performance of the unit and establish emissions performance. Test plans will be formulated and instrumentation will be specified. Compressor and turbine rotor telemetry systems will be developed and acquired.

Progress for this Quarter

The telemetry system approach has been selected as a front-end system for transmitting signals from all sensors mounted on the rotor including the compressor and turbine sections. The telemetry systems will be mounted in the load coupling. Work has started on the instrumentation drawings, including first- and second-stage buckets and first-, third-, and fourth-stage nozzles.

Plans for Next Quarter

Work on instrumentation drawings and telemetry system design will be continued.

Technology Application

These are test plans to establish the instrumentation requirements for 7H and 9H FSNL and FSFL tests.

Section 2.2.3 (GTET) Technology Validation

The overall objective of this task is to provide confirmation of critical component design and technology. The validations include hot gas path component testing, sub-scale compressor testing, steam purity test trials, and rotational heat transfer testing. Technology enhancements that are not required for the first machine design but will be critical for future ATS advances in performance, reliability, and costs will be conducted.

Section 2.2.3.1 (GTETNC) S1N Design**Section 2.2.3.1.1 (GTETNC) Nozzle Cascade CFD Analysis****Objective**

The objective of this task is to apply a fully viscous 3D computational fluid dynamics (CFD) analysis to predict the flow and aid in the generation of heat transfer boundary conditions for the first-stage Nozzle Cascade Test. Such a validated CFD tool then becomes the vehicle to apply the Nozzle Cascade Test data to the actual machine design problem.

Progress for this Quarter

This task has been completed.

Technology Application

The validation of NOVAK3D predictive capabilities provides a valuable tool to evaluate the impact of design modifications and off-design performance of ATS nozzles in particular. It also contributes to a

more realistic calculation of heat transfer coefficients and consequently enhances the heat transfer predictions in complex geometries.

Section 2.2.3.1.2 (GTETEH02) Combustion-Generated Flow Effects on Heat Transfer

Objective

The objective of this task is to evaluate the freestream turbulence intensity incident upon the ATS first-stage nozzle airfoil, and the effect of this turbulence level on the airfoil heat load. This turbulence intensity level and its character have a major and direct bearing on the heat load for the nozzle airfoil and endwall.

Progress for this Quarter

This task has been completed.

Technology Application

The ATS cascade test results have been incorporated directly into the ATS first-stage nozzle design. Comparison of results with both high-turbulence-generating perforated plates and a DLN combustor system cold-flow mockup have verified the applicability to design of heat transfer results from the former method.

Section 2.2.3.2 (GTETRS) Rotor Steam Transfer

Objective

For stable cooling of the turbine buckets, static flow tests will be conducted to validate the steam flows in the circuit to and from the buckets, through the rotor. These will establish flow losses for the unique components in the steam delivery circuit.

Progress for this Quarter

During tests of geometry simulating the main bore tube, where the steam enters the rotor from the stator, flow losses have been evaluated for two inlet geometries. These losses match analytical predictions and have enabled selection of the preferred design. Tests included investigation of various tangential flow components to determine the effects of off-design point conditions.

Plans for Next Reporting Period

The bore tube inlet work is continuing, investigating various design details around the steam inlet. A rig is under construction to flow-test the supply steam exit from the bore tube, and testing should begin in 1Q97. Further work will flow-test the spoolies that will be used to connect the components of the steam system.

Technology Application

Rotor steam transfer tests are used to evaluate the design optimum for 7H and 9H turbine bucket cooling.

Section 2.2.3.3 (GTETSE) Rotor-Bucket Steam Transfer Spoolie

Objective

Rotating air rig tests will be completed to validate the steam transfer spoolie design concept. (Spoolies are the hollow, spool-shaped ducts that bridge the gap between the steam delivery channels in the turbine rotor and cooling channels in the buckets.) A stationary steam test rig will be used for evaluation of durability and alignment effects on leakage.

Progress for this Quarter

With the rotating tests completed successfully, static component wear testing continued to investigate geometry and material parameters. These tests simulate misalignment and axial motion, with side loading to represent rotational forces. Tests to date have investigated tube thickness, bore coatings, two temperatures, and assembly interference. In addition, repeated assembly and disassembly trials were conducted. All tests to date have resulted in acceptable leakage rates.

Work is continuing to construct a new rig that can test in a steam environment and that can accommodate larger spoolie sizes. The rig design has been completed and construction is underway.

Plans for Next Reporting Period

The steam wear test rig will be completed. On completion, several tests will begin to investigate wear rates in a steam environment as well as the geometry effects of larger diameter spoolies.

Technology Application

These tests will validate the rotor bucket steam transfer spoolie design.

Section 2.2.3.4 (GTETRH) Rotational Heat Transfer

Section 2.2.3.4.1 (GTETRH01) Turbine Rotational Heat Transfer

Objective

A limited database exists on the effect of rotation on heat transfer in turbine blade cooling passages. At the conditions present in the ATS turbine, major extrapolation of the existing data is required. To extend the data to the range of Reynolds and Buoyancy numbers present in the ATS turbine, measurements of the local heat transfer coefficients under these conditions were obtained in a low aspect ratio rectangular blade cooling passage with and without turbulators. One objective of this task is to construct, install, and test a 6.6:1 aspect ratio cooling passage in the full-scale CRD rotating test rig over a range of Buoyancy numbers previously obtained in the low aspect ratio passage. In parallel, a sub-scale test rig will be employed to evaluate alternate turbulator designs in order to identify the best configuration for subsequent evaluation in the full-scale test rig.

Progress for this Quarter

The tests of the various castable configurations of turbulators and ribs for the 3.3:1 aspect ratio duct in the small-scale test rig, to determine the performance improvement over that measured with the original turbulator configuration, have been completed. Significant performance improvement was obtained over the full range of the Buoyancy numbers of interest with an easy-to-cast change in the

turbulator configuration. The final report covering this activity was completed and forwarded to GE Gas Turbine Engineering. This report included recommendations for the new turbulator configuration that needs to be tested in the full-scale test rig since the small-scale rig can accommodate only 70% of the duct length-to-diameter ratio and 15% of the Reynolds number present in the application. A patent docket has been filed that covers the new turbulator configuration.

Plans for Next Quarter

This task has been completed.

Technology Application

The data obtained in the full-scale test rig have been employed to design bucket cooling passages that avoid the low performance operating range. The data that are being obtained on the effect of alternate turbulator configurations in the small-scale test rig are being employed in design tradeoff analyses for the 7H bucket. The planned full-scale test of the best turbulator configuration, to be selected from the small-scale tests, will then provide the needed design data.

Section 2.2.3.4.2 (GTETRHTPD) Bucket Cooling Circuit Rotational Pressure Drop Test

Objective

The objective of this task is to determine the effect of rotation on the pressure drop in a radial bucket cooling passage. The computational fluid dynamics (CFD) computations of the effect of rotation on bucket cooling passage heat transfer and pressure drop indicate a significant effect of the Buoyancy number on pressure drop. Since the bucket pressure drop is a major fraction of the total system pressure drop involving the coolant, it was deemed necessary to measure this effect using the full-scale test rig.

The high aspect ratio turbulated duct assembly was instrumented to measure the pressure drop between the inlet and outlet manifolds. Appropriate heaters were employed on the pressure measurement lines to avoid condensation of the working fluid and to minimize the density corrections required due to temperature differences between the measurement lines and the test duct. This allowed the differential pressure transducer to be mounted near the rotational axis, where no transducer correction for centrifugal effects was required. The pressure drop for both outflow and radial inflow was measured.

Progress for this Quarter

This task has been completed.

Technology Application

The new pressure drop correlation, which includes the effect of the Buoyancy number, is now in use in the evaluation of alternate coolant passage designs and in the evaluation of the flow-pressure drop characteristic of the ATS turbine bucket cooling system.

Section 2.2.3.5 (GTETIH03) Surface Enhanced Internal Heat Transfer

Section 2.2.3.5.1 (GTETS2NHT) S2N Trailing Edge Flow Test

Objective

The objective of this task is to perform heat transfer tests in the trailing edge region of the second-stage nozzle using a Plexiglas™ model built in 1995. The purpose of the work is to generate a cooling scheme that will (1) even out the coolant side heat transfer coefficients along the channel and (2) yield results that are comparable to or better than the turbulent pipe flow correlation predictions.

The model keeps the important geometric variables of the passage close to the actual design. It has thin-foil heaters on both the suction and pressure sides, and liquid crystals to determine the temperature distributions. Tests were planned to investigate the triangular passage performance with several turbulator designs.

Progress for this Quarter

This task has been completed.

Technology Application

The test results for cooling passages in the second-stage nozzle trailing edge cooling circuit provided the necessary design information and turbulator configurations for the ATS second-stage nozzle. This allows the design to obtain the desired heat transfer enhancement for the passages, and to channel the cooling flow near the apex of the triangular flow passage near the trailing edge region effectively.

Section 2.2.3.5.2 (GTETTE) S2B Trailing Edge Testing

Objective

The objective of this task is to determine the optimum turbulator distribution in the trailing edge cavity, including the tip turn region, of the ATS gas turbine second-stage bucket. The flow will be modeled using FLUENT, a commercial computational fluid dynamics (CFD) code, to help determine whether the turbulators are effective in cooling the extremely low aspect ratio areas in the trailing edge cavity. These results will be used to optimize the turning vane(s) in the turn region. In a parallel subtask (described in Section 2.2.3.5.1), the thin-foil heater/liquid crystal technique is used to map heat transfer coefficient distributions experimentally in a non-rotating scale model of the trailing edge/tip turn region.

Progress for this Quarter

CFD

The CFD portion of this task has been completed.

Liquid Crystal Heat Transfer

The model tested in 3Q96 was built on an expedited basis. As a result, the thin-foil-heater/liquid-crystal surface used was not optimally designed. During 4Q96, the model was redesigned and rebuilt to improve the quality of the data generated. The test of the first design configuration was conducted with the improved model and better quality data were generated. The data were reduced to a useful

form and reported. The heat transfer coefficients were calculated using $T_{bulk\ local}$ as described in previous reports. These results were scaled to the actual ATS gas turbine conditions using the techniques and assumptions described in previous reports. The scaled predictions for heat transfer coefficients were reported to the GEPS design engineer.

The improved model was modified to represent a second design case and a similar test was conducted. The data for the second design case were reduced to a useful form and reported. The heat transfer coefficients were calculated using $T_{bulk\ local}$ as described in previous reports. The results for the second case were also scaled to the actual advanced gas turbine conditions using the techniques and assumptions in previous reports. These scaled predictions for heat transfer coefficients were reported to the GEPS design engineer.

Plans for Next Quarter

The model will be modified to represent at least one different configuration, with changes to the turning vane or cavity ribs or both. Heat transfer distributions will be measured for the modified geometry(ies) to determine whether trailing edge or tip heat transfer or both can be improved or a simplified design can be achieved without compromising heat transfer performance.

Technology Application

Results from these tests are being used directly to design the cooling circuit for the ATS second-stage turbine bucket trailing edge region.

Section 2.2.3.5.3 (GTETIH04) S1N Outer Band Liquid Crystal Heat Transfer Tests

Objective

The objective of this task is to perform heat transfer tests with a representative outer band impingement configuration and measure the heat transfer coefficient distributions underneath the impingement jets. The data will be compared with the design calculations and expectations. A test rig is used to simulate the design impingement jet plate geometry as closely as possible. The test section walls are instrumented with three etched thin-foil heaters and a liquid crystal layer to measure the local wall temperature distributions as a function of flowrate and heat flux. The temperature data are then converted into heat transfer coefficient values.

Progress for this Quarter

This task has been completed.

Technology Application

The test results obtained with the flow and heat transfer tests showed that the design calculations and models were able to successfully predict the flow directions and heat transfer coefficients for the complicated impingement pattern of the ATS first-stage nozzle outer band. The tests also showed that the heat transfer is dependent on the leading and trailing edge cavity discharge pressure levels. The data also showed that an impingement design without a separating rib is more effective than a design with a separating rib on the suction and pressure sides.

Section 2.2.3.5.4 (GTETIH04) S1N Convex Cavity Heat Transfer Tests

Objective

The objective of this task is to perform flow and heat transfer tests in a simple test rig representative of a first-stage nozzle convectively cooled passage geometry with two different turbulator designs to determine the effect of corner radius on the heat transfer enhancements obtained with the turbulators. Two simplified plastic models of the cooling channel were constructed with the important geometric variables kept as close as possible to the actual design. An additional test section was also constructed to model the exact geometry of the convectively cooled cavity, which incorporated the area changes along the radial distance. The inside surfaces of the test pieces were coated with liquid crystal paint or a liquid crystal sheet, and transient and steady-state tests were run to determine the friction factors and local heat transfer coefficient distributions. The results were also compared with the CRD database. An additional flow test was conducted with a metallic test section manufactured with exactly the same dimensions as the prototypical passage to verify the flow models of the design.

Progress for this Quarter

Three series of tests were planned to show the accuracy of the cooling concept and the predictive design tools. The first series involved measurement of the friction factors and heat transfer coefficient of the smooth cooling cavity with no flow partition. The second series was also conducted with a smooth wall but with a flow partition dividing the passage into two parallel flow cavities. The third series was run with the divided passage and the turbulators according to the design requirements.

The results of the first two series of tests with the smooth passages were included in the Annual Technical Progress Report. During 4Q96 the appropriate turbulators were installed in the acrylic passage with the separating rib, and tests were conducted to measure the friction factors and heat transfer coefficient distributions.

Heat transfer tests were also conducted with the turbulated passages as a function of flow Reynolds numbers. Tests with the liquid crystal video thermography (LCVT) system were used to obtain area-averaged heat transfer coefficients. The new test value for enhancement factor was used in the design calculations. The heat transfer test results show improved uniformity of heat transfer coefficient along the two passages.

Plans for Next Quarter

This task has been completed.

Technology Application

The results of these tests with rectangular and filleted turbulated tubes provided the designer with information on the differences between the two and showed that the database can be used to predict the friction and heat transfer. The results with various turbulator heights changed the design requirements to prevent large variations in the local heat transfer coefficients. The test data also showed that the heat transfer enhancements are not reduced at the high Reynolds numbers of interest for the present design.

Section 2.2.3.5.5 (GTETIH05) Bucket Tip Closed Circuit Cooling**Objective**

The objective of this task is to measure non-rotating heat transfer and pressure drop in the 180° tip turn region of a two-pass serpentine bucket tip, and to evaluate the ability of an enhanced surface in the tip region to enhance the tip cooling without a substantial pressure drop penalty.

Progress for this Quarter

This task has been completed.

Technology Application

These results were used by the designers of the advanced gas turbine buckets to design the tip turn regions of serpentine cooling circuits.

Section 2.2.3.5.6 (GTETLE) Bucket Leading Edge Heat Transfer Testing**Objective**

The objective of this task is to evaluate turbulator geometries for the first-stage bucket leading edge passage by performing non-rotating heat transfer and pressure drop tests at high Reynolds numbers on scaled models of the leading edge passage.

Progress for this Quarter

This task has been completed.

Technology Application

The heat transfer and pressure drop results from this task have been used in the design of the first-stage bucket in the ATS gas turbine.

Section 2.2.3.5.7 (GTETIH03) SIN Surface Enhanced Internal Heat Transfer**Objective**

The objective of this task is to investigate and determine the heat transfer coefficient enhancements that could be generated under impingement jet cooling modules by adding surface roughness elements without increasing the total system pressure drop. The effect of bumps missing in some regions due to manufacturing problems will also be investigated.

The test section used for impingement heat transfer tests is enclosed in a high pressure enclosure that can be operated at pressures up to 10.2 atm (150 psia) by means of a back-pressure control valve. The impingement air is fed to a supply chamber equipped with a square impingement jet plate that can accommodate several hole configurations. The impingement test surface is in intimate contact with a copper block that is heated by four cartridge heaters. The impingement test plates, positioned at a controlled distance from the impingement jet plates, are instrumented with four embedded thermocouples that measure the plate temperature. Tests are conducted at various jet Reynolds numbers and several jet plate geometries. To investigate the effect of bumps missing in some regions, the high pressure containment is modified so that a window can be attached at one end. A thin-foil

heater and a liquid crystal assembly are glued onto the impingement test plate and the color changes observed with the liquid crystal video thermography (LCVT) system.

Progress for this Quarter

Tests were conducted with the test plate prepared with a band of missing bumps. The tests were run with the band perpendicular to the cross flow, positioned near the first jets where the cross flow effects are small and near the last jets near the exit region where the cross flow effects are strong. Tests were also conducted with the band parallel to the cross flow.

Some tests were conducted with a new enhanced surface that was proposed and developed by GEAE to enhance the impingement heat transfer coefficients. The rough surface consists of a bond coat layer deposited on a smooth surface. The typical roughness of the surface was measured by GEAE and CRD and found to have a centerline average roughness of 20 micrometers. Two test specimens were manufactured at GEAE and tested at the CRD facilities. Preliminary tests conducted at GEAE at low jet Reynolds numbers and atmospheric discharge conditions showed that the new rough surfaces were providing enhancements comparable to the bumpy surfaces. By running tests under high pressure conditions, the present test facility is capable of running tests at high Reynolds numbers and low jet exit Mach numbers. This new rough surface can be an alternative impingement heat transfer enhancement technique that could be used in some specific locations of the nozzle design instead of the bumpy surfaces.

Plans for Next Quarter

This task has been completed.

Technology Application

The ANSYS analysis results provide the increases in wall temperature expected for various numbers of bumps missing. The acceptable temperature rise will determine the quality control criteria and the nondestructive testing technique for the missing bump number determination. The transient technique provides a nondestructive technique to check the non-uniformity of the cooling and the number of missing bumps.

Section 2.2.3.5.8 (GTETH03) S1N Trailing Edge Flow and Heat Transfer Tests

Objective

The first-stage nozzle trailing edge air-cooled cavity is a complicated cooling system involving turbulators, pin-fin-type pedestals, trailing edge film slots separated with ribs, and pressure and suction side film holes. The flow and heat transfer design calculations depend on empirical correlations and predictive tools that have to be verified.

The objective of this task is to perform flow and heat transfer tests in a representative passage geometry of the trailing edge region of the first-stage nozzle using a Plexiglas model and run flow tests with a cast prototypic model of the cooling circuit. The results are compared with the design calculations.

The Plexiglas model keeps the important geometric variables of the passage as close as possible to the actual design. It is equipped with thin-foil heaters on both the suction and pressure sides and has

liquid crystals to determine the temperature distributions. The prototypical metal model is machined according to the design drawing and represents the actual part geometries.

Progress for this Quarter

First, flow tests were performed with the metallic test piece while the pressure ratio across the inlet and exit of the passage was kept at 1.63 with an exit discharging to the ambient atmospheric pressure. The flowrate measured for this pressure ratio was 19.9 gm/sec. The cooling passage was also modeled with a flow circuit model without the film holes. For the experimental pressure ratio, the measured total flowrate was found to be within 10% of the flowrate calculated by the flow model of 18.1 gm/sec.

Then the static pressure taps along the main turbulated passage and in each trailing edge passage of the machined metallic test section were EDM-drilled to record the pressure drop distributions. Flow tests were performed and detailed static pressure distributions were measured along the cooling passages and compared with the 1D flow model. The results showed that the static pressure distribution in the main turbulated passage is quite uniform. The pressure distributions at every trailing edge discharge cavity showed that the pressure drop across the pin fin portion is much lower than the design assumption. On the other hand, the pressure drop across the turbulated portions of the trailing edge cavities near the discharge region is much higher than the design assumptions. The effect of one pressure drop appears to balance the other so that the prediction for the overall cooling flow was accurate for the given pressure ratio. Although the model is predicting the total flow accurately, the pressure drop coefficients do not seem to be correct for each individual portion. The flow model was modified to reflect these observations.

The design of an acrylic model that is representative of the cooling passage has been initiated. This model will be used to measure the heat transfer coefficient distributions along the cooling passages.

Plans for Next Quarter

The design of the Plexiglas model will be finished and the test section will be instrumented, then tested.

Technology Application

The flow and heat transfer results obtained will check the design tool predictions and ensure that the predictions are correct and that there are no regions that have friction and heat transfer coefficient values different from the design assumptions.

Section 2.2.3.5.9 (GTETBKHT) High Reynolds Number Turbulator Static Heat Transfer Test

Objective

The objective of this task is to investigate and determine the heat transfer coefficient enhancements possible in the first-stage nozzle. Internal cooling will be supplied by two different types of convection: one using impingement heat transfer within the internal airfoil cavities, the other using high Reynolds number turbulated heat transfer within the aftmost convective channel of the airfoil. This task will concentrate on the latter type of heat transfer. Experimental work reported in the open literature on turbulator heat transfer enhancement and friction factors is limited to passage Reynolds

numbers below 80,000. This task will supply data and correlations to be used for advanced machine design conditions. Heat transfer and pressure drop data are required at far higher Reynolds numbers than previously tested with common turbulator geometries and passage aspect ratios.

Progress for this Quarter

This task has been completed.

Technology Application

The results from this task are applicable to any non-rotating components in the advanced gas turbine that use turbulated passages for cooling. As long as rotational effects are accounted for, these results are also applicable to turbulated passage cooling of rotating components.

Section 2.2.3.5.10 (7SGTET) S1N Insert Flow Tests**Objective**

Flow and static pressure tests conducted in Phase 2 (1995) with the first impingement inserts had shown that the supply pressure of some impingement jets in the insert was lower than expected resulting in lower impingement cooling flows, thus reducing the local impingement heat transfer coefficients. The design procedure was improved to reduce or eliminate this effect. The purpose of the present tests and activity was to verify that the new design procedure had fulfilled the expected objectives.

Progress for this Quarter

The Stereo Lithographic model of the insert and the cavity were manufactured by GEPG. The model is a 2X-scale representation of the original design. The impingement jets along the insert on the faces opposite the suction and pressure sides of the airfoil were marked according to the design requirements and drilled to the appropriate diameters. The drilled impingement holes were then pin checked and the actual values of the jet diameters recorded for each jet.

The first flow test was conducted with the impingement insert directly discharging to the atmosphere. The pressure ratio between the supply chamber and the atmosphere was set to 1.07, and the static pressures feeding each impingement jet were measured one at a time by using a calibrated pressure transducer and a pressure probe consisting of a metallic tube with a rubber end. The test total flowrate was also measured for the given pressure ratio. Since there are more than 400 impingement jets, the plugging of one jet during the static pressure measurement did not change the measured flowrate significantly. The static pressure distributions feeding each impingement jet were found to be uniform, and the results did not show any regions where the flow was reduced as a result of lower feed static pressures. Static pressure taps were then drilled along the ribs of the cavity along which the coolant is channeled after impingement at the pressure and suction surfaces. The static pressure distributions were measured along the return ribs for the insert centered in the cavity. The pressure distribution was found to be uniform, with the pressure drop across the impingement holes being the dominant value. Parametric variations of the insert position were also investigated. The insert was moved into non-concentric locations with respect to the cavity close to the ribs or close to the suction and pressure sides, and the pressure distributions and mass flowrates were measured for the same supply-to-discharge pressure ratio. These variations, which may be caused by the non-concentric

placement of the insert or variations of the wall dimensions, are important factors to investigate since the design assumes a baseline configuration with given impingement jet-to-wall distances.

Plans for Next Quarter

If this task is continued in 1997, the objective will be to determine the critical jet-to-wall distance that affects the coolant flowrate for a given supply-to-discharge pressure ratio.

Technology Application

The test results obtained with the impingement insert showed that the present design methodology has eliminated the regions where the impingement jets were being starved. The pressure drop along the ribs where the post impingement coolant is channeled also appears to be uniform. The dependence of the impingement coolant flow as a function of the jet-to-impingement surface appeared to be a parameter of interest that affects the manufacturability and positioning tolerance of the insert inside the cavity.

Section 2.2.3.6 (GTETEH02/03) Surface Roughness and Combustor-Generated Flow Effects on Heat Transfer

Section 2.2.3.6.1 (GTETEH04) S1N Heat Transfer for Production Aero with TBC Spall Effects

Objective

The objective of this task is the quantification of the external heat transfer coefficient distribution for the production aerodynamic design definition of the ATS turbine inlet nozzle airfoil.

A previous task begun in Phase 2 and completed under Phase 3 quantified the external heat transfer distributions for the original aerodynamic design, including effects due to roughness and turbulence intensity. The production aerodynamic design is sufficiently different in crucial regions to warrant a new series of tests, again including roughness and turbulence intensity effects. The new aerodynamic definition for the nozzle is specifically designed to lower the heat load on the airfoil. Results from the previous cascade tests are being used on the new airfoil design, but with the assumed validity of local Reynolds number scaling of heat transfer coefficients. Since such scaling of results has no experimental basis for airfoils that deal with complex flows, it is necessary to verify the new design. Results from the original series of tests will be used to reduce the present task efforts to a minimum. Most of the original apparatus hardware from the ATS Turbine Inlet Nozzle Cascade will be reused for this task.

Progress for this Quarter

There was no activity on this task in 4Q96.

Plans for the Next Quarter

Plans are uncertain, awaiting establishment of program priorities.

Technology Application

When completed, the results from this series of tests will yield external heat transfer load validation on the production first-stage nozzle design.

Section 2.2.3.6.2 (GTETE03) Surface Roughness Effects on Heat Transfer**Objective**

The external heat loading for the ATS first-stage nozzle airfoil is heavily dependent upon the nonlinear effects of surface roughness, especially as the nozzle design cannot rely upon film cooling. Given the current state of turbine cooling technology, the only viable method for determining the nozzle heat load with roughness effects is experimental validation of the heat transfer distribution under non-dimensional engine-representative conditions.

The ATS Turbine Inlet Nozzle Cascade has been used to provide data on external heat transfer coefficients on airfoils with surface roughness. The cascade incorporates instrumented airfoils with flow conditions representative of the ATS inlet nozzle geometry. The appropriate non-dimensional parameters for dynamic similarity are close to those of the engine inlet nozzle. External heat transfer coefficient distributions are measured through the use of embedded thermocouples, with a constant surface heat flux condition supplied by thin-foil heaters. Surface roughness elements of the appropriate size and distribution have been bonded onto the surface heaters. Data include various roughness levels, distributions, and types to allow the calibration of predictive methods. Characterization of surface roughness effects includes the interactive nature of roughness with fluid dynamic conditions such as acceleration. The cascade has also been used to assess the effects of transition piece wake shedding on airfoil heat transfer, the effect of extreme surface roughness representative of as-sprayed thermal barrier coatings, and the effect of modeled coating spallation on heat transfer enhancements.

Progress for this Quarter

This task is complete for the current cascade airfoil configuration.

Plans for Next Quarter

There are no plans for further work at this time.

Technology Application

The test results have been used directly in the design of the ATS first-stage nozzle airfoil. Thus the cascade conditions for an appropriate rough surface condition, with elevated freestream turbulence intensity from a DLN combustor mockup, were used as the convective heat load definition for the nozzle airfoil. Since modeled spallation heat transfer enhancements were equal to or below the assumed enhancement levels for the nozzle design, the conservative nature of this portion of the design was verified. Cascade testing verified the requirement to polish the thermal barrier coating on the Full Scale Nozzle Cascade instrumented airfoils, thereby avoiding potential test problems in that task. The optimal relative location for the transition piece endwall segments, as determined through cascade testing, has been incorporated into the turbine design.

Section 2.2.3.7 (GTETCP) LCF Coupon Tests

Section 2.2.3.7.1 (GTETCP) LCF Nozzle Coupon Life Validation Tests

Objective

The primary objective of this task is the determination/verification of the ATS turbine first-stage nozzle low cycle fatigue (LCF) life. Tests are required to verify LCF life under conditions representative of the ATS turbine.

The E-beam high thermal gradient test facility will be used to test several nickel-based superalloy (N5) coupons for LCF durability. The coupons will be geometrically representative of a section of the turbine inlet nozzle airfoil containing hot and cold sides. Coupons will be instrumented for the evaluation of the thermal conditions during testing. Tests will be performed to evaluate metal durability under conditions of temperature, thermal gradient, and stress representative of the ATS turbine inlet nozzle. Testing will be cyclic, developing cycles of exposure on the test coupons considered to be representative of engine cycles. Post-test evaluations of the TBC and metal conditions will be performed. Data will provide a basis for LCF life evaluations.

Progress for this Quarter

The E-beam high thermal gradient test rig was brought back on-line after a lengthy down period resulting from power problems within the transformer array of the rig. An additional problem was encountered in the high voltage supply cable connecting the rig transformers to the E-beam gun. A replacement cable was installed after a short downtime.

LCF Testing

Testing of LCF tophat specimens was resumed during this period with the first two of a set of specimens to be processed without single-point turning or other machining; i.e., the tophats are cast-to-dimensions and the TBC applied as in the turbine design process. These specimens are LCF #5 and #6. The conditions for LCF testing in this facility exceed the ATS turbine inlet nozzle design conditions for substrate/bond-coat interface stress but fall short of causing the quick plastic deformation seen in early specimens.

LCF #5 completed 5000 cycles of exposure with no apparent damage to the metal or TBC.

LCF #6 specimen is a duplicate of LCF #5 specimen. At the time of this report, LCF #6 has completed 3000 cycles of E-beam exposure. No visual damage is apparent in either the TBC or the substrate. Testing was halted due to the year-end holidays and other priority tests.

LCF Metallographic Evaluations

Evaluation of LCF specimen #4 was completed. This specimen had been mistakenly cut in the wrong direction for proper fatigue opening. The specimen was sectioned and polished to observe any cracks. Cracks in the N5 substrate were about 25 microns (1000 micro-inches) deep. This specimen had completed approximately 1850 cycles under conditions similar to those of LCF #5 above. The cross-section was studied with laser-induced fluorescence to detect the formation of ruby (aluminide plus chromium) at the bond-coat/TBC interface. A strong spike of ruby was seen here, indicating thermally grown alumina combined with chromium. This is evidence of one proposed mechanism for the loss of TBC.

Plans for Next Quarter

LCF testing will continue in 1997. Specimen LCF #6 will continue to be cycled to 5000 cycles and then fatigued open for evaluation. Specimens LCF #5 and 6 will both be metallographically evaluated for striation counts to determine the cycles to failure and estimated LCF life.

Investigation of crack propagation behavior/severity for substrates exposed to superheated steam at pressure and temperature will have high priority in 1997. The test procedure to be used for determining the severity of substrate crack propagation in a superheated steam environment will be assessed. Testing will begin with hollow cylindrical Instron specimens in both air and steam environments with controllable crack initiation and growth capabilities.

Technology Application

The results obtained have been of value in two ways. (1) The LCF testing, both for bond-coat/substrate systems and for TBC/bond-coat/substrate systems, indicates a minimum required life for the materials under high thermal gradient and stress conditions. These life indications provide a direct confirmation of the ATS turbine design. (2) Testing is revealing many processing and preparation steps that must be controlled in order to maintain component quality. Determining the extent to which such processing steps are crucial and determining the effects of deviating from these procedures are equally valuable and necessary to design.

Section 2.2.3.8 (GTETSP) - Steam Particulate Deposition**Section 2.2.3.8.1 (GTETSP) Steam Particulate Rotational Deposition**

The objective of this task is to measure the rate and location of steam particulate deposition in bucket tip turns and in two heat transfer structures to be employed within the ATS gas turbine nozzles and buckets.

ATS Phase 2 studies have determined that the particulates come from the superheater of the examined power plant, and a filter system was specified and tested to assure that damaging particulates would be captured. The purpose of this task is to validate sedimentation predictions in a steam centrifuge deposition rig and assure that no deleterious deposition occurs on critical cooling structures in static specimens simulating ATS cooling passages.

The approach employed is to use gas turbine combined cycle (GTCC) steam flowing in series through a special filter specified for the ATS gas turbine system, then through the tip turns in a specially constructed centrifuge deposition rig, and finally through two static specimens consisting of turbulated and impingement-cooled specimens. Deposit amounts and locations in these specimens will be used to verify the predicted results from ATS Phase 2 studies that indicated that the desired time between outages will be reached.

Progress for this Quarter**Static Specimen Exposure**

The static specimens, impingement and turbulated, installed in August have been on-line for 17 and 24 weeks, respectively, with few outages. The specimens were taken off-line and examined with a

borescope for foreign particle deposition. They had no visible deposit, testifying to the cleanliness of the original steam and the effectiveness of the 2-micron full flow steam filter.

Steam Filter

The steam filter went back on-line in early August, and has been on-line upstream of the specimens since then with occasional outages. No increases in pressure drop across the filter have been observed. Steam samples were taken and analyzed for steam purity.

Centrifugal Deposition Rig

At the conclusion of ATS Phase 2, the centrifugal deposition rig was assembled and tested, but the steam leak rate from the rotary shaft seals was well above expectations from design calculations. In September, the vendor redesigned the seal gap array for the estimated cooler shaft temperatures, and an order was placed for a new set of seals. This new, third seal set was installed in December. A two-day steam seal trial was conducted that showed a dramatic reduction in steam leakage, but the carbon seal rings now are apparently grabbing the shaft, instead of having a cold clearance. After reviewing results with the vendor, it has been decided to try to find a lower steam pressure at which the centrifugal deposition rig would run and wear in the carbon seal rings.

GT Cooling Steam Specification

The steam particulate specifications generated earlier are being integrated with chemical specifications for an overall steam purity specification for the ATS gas turbine. Recommendations for conducting simplified, custom steam particulate measurements as part of the prototype operation are being generated by this staff for the GEPS specification.

Steam Filter System

CRD staff have been working with ATS filter system designers and filter system vendors to develop a design that provides filter performance and status monitoring as well as ease of access to the filters.

ATS Steam Cooling Risk Reduction

Disclosures on steam leakage detection schemes to enhance system reliability have been issued. Other sources of steam contamination in the cooling system have been identified and controls are being specified and developed.

Plans for Next Quarter

A condition will be found at which to operate the centrifugal deposition rig in order to wear in the new seals and put the rig on-line. In the meantime, the static specimen trials will be continued until the rig comes on-line.

Brush Seal Development

The use of the centrifuge facility to test new seal designs is now being planned for an April 1997 seal installation. Steam task staff have worked with the seal staff to help specify equipment for the seal test. Brush seals will leak more than the current carbon seals on the centrifuge, but the test is required to validate predicted leakage rates.

The target of 1000 hours of validation exposure on the centrifugal deposition rig specimens has been put off to 1997 (instead of 1996 as planned). However, the centrifugal deposition rig will be made available for seal testing in April 1997, independent of the level of success with the current seal set.

Technology Application

Throughout this task, a close relationship has been maintained between CRD and GEPS staff. During ATS Phase 3, not only have the static specimens being exposed been provided as actual proposed cooling components, but the experience developed while conducting the current studies has also been used by design engineers focusing on the overall steam cooling system. Regular meetings have been held with GEPS staff as well as consultations on steam purity issues for full-size heat transfer testing, chemical contamination issues for steam system specification, and steam leak detection as a way to enhance ATS availability.

Section 2.2.4 (GTMT) Materials Technologies

Section 2.2.4.1 (GTMTSE) Steam Effects on Mechanical Properties

Objective

The objective of this task is to evaluate the candidate turbine materials for any effects due to operation in a steam environment. Tests of materials that are exposed to steam will be performed to measure fatigue crack propagation, low cycle fatigue, and creep. Additional tests deemed necessary to meet design criteria will be performed. Comparisons will be made to data collected in air. Where necessary, the program will evaluate the roles of alternate heat treatments and/or surface treatments.

Progress for this Quarter

Low cycle fatigue (LCF) testing of turbine wheel material continued to be collected. Creep tests on the first piece qualification (FPQ) forging were continued. Fatigue crack growth rate (FCGR) testing of the turbine wheel material continued at two different temperatures and two different environments. Optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and auger analysis were used to examine the fracture surfaces of the various types of test specimens. A revised FCGR matrix for 1997 testing was completed. LCF testing of the first piece qualification (FPQ) material was completed in the environments and temperatures of interest. Static and dynamic crack growth testing was initiated at one temperature. Baseline testing of the FPQ material in air continued.

Work was initiated on the effect of environmental conditions on the welded and brazed joints that will be used with the hot gas path materials. An initial array of joined specimens was prepared and evaluated with compact tension tests.

Plans for Next Quarter

Work will continue to determine the effects of processing (such as forging flow direction and temperature distribution) on time-dependent crack growth behavior. Low cycle fatigue (LCF) testing and creep testing will continue. Static and dynamic crack growth testing will continue. Additional welded hot gas path material joint specimens will be pre-cracked and tested.

Technology Application

This task will evaluate the behavior of turbine materials in a steam environment in order to account for the introduction of steam cooling.

Section 2.2.4.2 (GTMTSO) Oxidation Due to Steam**Objective**

Testing of ATS materials in steam will be performed to evaluate the long-term oxidation responses to this environment. Specimens will be subjected to steam exposure in an autoclave and removed at specified intervals for examination of oxidation characteristics.

Progress for this Quarter

Specimen machining was completed and four point bend specimens were loaded in fixtures for exposure. Initial testing of the new steam generation system and two new exposure retorts indicated that they met acceptable check limits. Air exposure bulk aging blanks were machined and are now in exposure.

Plans for Next Quarter

Four point bend specimens will be submitted for air exposure in January 1997.

Technology Application

This task will evaluate the static behavior of turbine materials in a steam environment in order to account for the introduction of steam cooling.

Section 2.2.4.3 (GTMTCE) Corrosion Rate Evaluations of Airfoil Overlay Coatings**Objective**

The objective of this task is to evaluate the performance of ATS materials in potentially corrosive environments with various overlay coatings and substrate materials. Initial evaluations will be performed in small burner rigs with known contaminants. This will allow ranking of the corrosion rates of materials and coatings. Subsequent testing will be performed in facilities that better simulate gas turbine service conditions, including high gradients, for confirmation of burner rig results.

Progress for this Quarter

Approximately 2000 additional hours of exposure time have accumulated on those coated samples still running in the high temperature oxidation burner rigs. The first set of strain-to-crack tests was initiated.

Plans for Next Quarter

Additional time will accumulate on the samples in test. At set intervals, samples will be removed for evaluation of corrosion characteristics. Analysis of these samples will continue.

Technology Application

This task will evaluate potential airfoil coatings in environments that reflect planned turbine operating conditions.

Section 2.2.4.4 (GTMTBV) Compressor Blades and Vanes Materials and Processes**Objective**

Although material selections have been completed, this task will examine potentially less expensive materials for use in blades and vanes in the latter stages of the ATS compressor. These evaluations of alternate materials will be based on results of tests of mechanical properties, with emphasis on high cycle fatigue properties. For materials that have been selected, tests of critical properties will be conducted under ATS-specific conditions. Component tests of select parts will be conducted for life verification purposes and establishment of final manufacturing parameters.

Progress for this Quarter

Two creep tests continued to accumulate hours at stress and temperature.

Plans for Next Quarter

The creep tests will be suspended and the data analyzed. This will be the conclusion of this project.

Technology Application

This task will characterize the mechanical behavior of existing and new blade/vane materials in more aggressive environments than past compressor operation.

Section 2.2.4.5 (GTMTVG) Compressor Variable Guide Vane System Design Support and Process Development**Objective**

Information to support selection of materials for the variable guide vane bushings and thrust washers will be gathered to ensure a robust and reliable design. Testing will be conducted to confirm materials selections, cover any parameters outside of existing data, and gather data for new materials.

Progress for this Quarter

The candidate bushing and washer materials have been subjected to impact tests and oscillating wear tests. The ninth set of oscillating wear tests was completed. The third set of impact tests was initiated.

Plans for Next Quarter

The oscillating wear tests will continue at increasing test temperatures. The impact tests will be completed on the full array of candidate bushing materials.

Technology Application

This task will provide operational test data on ancillary materials used in the variable guide vane system. Potential bushing and sleeve materials will be screened.

Section 2.2.4.6 (GTMTCS) Compressor Structural Materials and Processes**Objective**

Mechanical and physical property tests will be performed on ATS compressor structural materials to provide an expanded mechanical and physical property database for design validation and enhancement. Material processing parameters for prototype manufacturing of the components will be selected based on design requirements and discussions with vendors. When necessary, material and processing specifications will be modified or new ones written.

Progress for this Quarter

Tensile and high cycle fatigue (HCF) testing of one of the compressor rotor wheel materials was completed. Test specimens were machined for the remaining compressor rotor wheel material, and requests for a quote for testing were distributed. All of the HCF testing of the diffuser material was completed. GE continued technical support of the supplier as prototype diffuser castings were made.

Plans for Next Quarter

The tensile and HCF data for both wheel materials will be analyzed and the results reported to Design Engineering. The tensile and HCF diffuser material test data will also be analyzed, with these results reported to Design Engineering, too. GE personnel will assist in the refinement of heat treat cycles at the supplier for the diffuser.

Technology Application

This task will continue characterization of compressor structural materials in test conditions that reflect service environments.

Section 2.2.4.7 (GTMTRF) Turbine Rotor Forging Materials and Processes**Objective**

Processing parameters of forged large turbine rotor components will be optimized to achieve the desired forging attributes. These parameters include chemistry and processing temperatures as well as post-processing surface treatments. Sub-size and full-size forgings will be produced to verify and evaluate the processing approaches, and forging supplier process plans will be developed for all components. Forging acoustic properties will be determined by ultrasonic testing on test block and prototype parts. The attenuation, anisotropy, frequency bypass, and signal-to-noise ratio will be measured and used in fracture mechanics analyses to support rotor design. Optimized inspection methods, any necessary software, and scan plans will be developed based on the work with prototype parts. Property evaluations will be conducted to ensure that material behavior models used for design accurately reflect those achieved in parts made by the manufacturing process selected.

Progress for this Quarter

The second modified chemical composition ingot was processed to billet successfully. The new automated ultrasonic inspection system was qualified for production testing. Three operators were trained to use the system.

Plans for Next Quarter

The second modified chemical composition billet will be cut for evaluation of microstructure and metallurgical anomalies. The rotor forgings made of the nominal chemical composition material will be finish-forged. Software will be programmed to automate the evaluation of data collected along a tapered surface and/or with the sound beam directed at angles other than normal to the surface will continue. Phased array and angled longitudinal wave probes and calibration methods will be investigated to develop and implement a flow line test capability in 1997.

Technology Application

This task will enhance process capabilities for manufacture of turbine rotor forgings.

Section 2.2.4.8 (GTMTS) Turbine Rotor Spoolies and Transfer Devices Materials and Processes**Objective**

Although material selections for the cooling system delivery systems have been completed, this task will perform testing to verify properties and identify potentially better materials. Any applicable or needed coatings or joint materials will also be identified. Procedures for joining delivery components together and inspecting them will be evaluated.

Progress for this Quarter

Sample steam delivery tubing material in the form of strips and welded tubes, and spoolies has been received from vendors and machined into test specimens. Some of the samples were evaluated by microstructure examination and mechanical property testing. Discussions were held with spoolie and tube suppliers on the manufacturing processes used to fabricate these components. A test rig was constructed to permit the evaluation of coatings, in air and steam, to quantify the sliding and fretting response of the spoolie/tubing interface conditions. Potential coatings were applied to some of the test specimens.

Plans for Next Quarter

Metallurgical evaluation of spoolies with various wall thicknesses will continue. Testing of sheet material used for the spoolies, steam tubes, and manifolds will continue. Welds used in the fabrication of the steam cooling circuitry will be evaluated.

Initial baseline tests will be conducted in air in the wear test rig. Subsequently, steam testing will be initiated to monitor the spoolie/tubing coating interface behavior in service condition environments. The primary coating candidates will be identified for subsequent evaluation under fretting conditions.

Technology Application

This task will develop processes and mechanical property data to optimize steam delivery hardware manufacture and subsequent operation.

Section 2.2.4.9 (GTMTSB) Structural Bolting**Objective**

Mechanical and physical property tests on two high strength bolting materials will be conducted at ATS turbine conditions. If required, manufacturing trials will be conducted to optimize forming processes.

Progress for this Quarter

The stress relaxation specimens continue to accumulate time in test.

Plans for Next Quarter

Future work will continue to be devoted to developing long-term relaxation data on the two prime bolting alloys.

Technology Application

This task will increase the database for flange/flange and wheel/wheel bolting applications.

Section 2.2.4.10 (GTMTTA) Turbine Airfoils Materials and Processes**Objective**

Microstructure and mechanical properties will be evaluated for full-sized castings processed in this program. A comprehensive program will yield final specifications with appropriate heat treatments and will quantify the effects of ATS airfoil geometry and structure/property variability. Casting processes will be developed for all airfoils by utilizing developmental casting trials. Critical nozzle and bucket long-term material properties will be measured at elevated temperatures. Metallic coating systems will be developed for internal and external oxidation protection of the airfoils. Samples will be coated using various techniques for optimization studies and process verification.

Progress for this Quarter

Four-thousand-hour air furnace exposure experiments were carried out on turbine bucket and nozzle alloys at one selected temperature to determine the effect, if any, of thermal exposure on microstructure and low cycle fatigue (LCF) life. Test data were analyzed and compared to existing design curves. LCF specimens were machined from slabs of turbine bucket and nozzle material intentionally produced with casting anomalies. Long-term creep tests were conducted on various bucket and nozzle alloys. The total accumulated test hours range from 24,000-28,000 hours. Additional preliminary creep design curves were issued for several of the turbine bucket and nozzle materials.

Plans for Next Quarter

LCF tests on the specimens with casting anomalies will be initiated during 1Q97. Long-term creep tests for the turbine bucket and nozzle alloys will continue through 1997.

Technology Application

This task will enhance the database of mechanical properties at service conditions for bucket, nozzle, and shroud materials.

Section 2.2.4.11 (GTMTCB) Combustion Materials and Processes**Objective**

Properties of materials for combustion components will be evaluated at ATS conditions.

Progress for this Quarter

There was no activity on this task in 4Q96.

Plans for Next Quarter

Metallurgical and manufacturing evaluation of castings previously produced will continue.

Technology Application

This task will enhance processes and mechanical property data to optimize combustion hardware manufacture and subsequent operation.

Section 2.2.4.12 (GTMTST) Turbine Structures Materials and Processes**Objective**

Producibility evaluations for the turbine structures will include selection of materials processing parameters and chemistry, and preparation of material and process specifications. Processing trials will be used to confirm producibility and verify capabilities of suppliers. Testing will be conducted where necessary to evaluate the materials under ATS conditions.

Progress for this Quarter

The steam gland and bearing housing drawings were reviewed with Design Engineering. Various specifications were revised to incorporate ATS component acceptance criteria. Representative material cast with the steam gland was received from the supplier. Mechanical property test bars were machined, and testing was initiated.

Plans for Next Quarter

Support of the suppliers' metallurgical activities will continue as the various components are cast, fabricated, and/or machined. Testing of the steam gland material will be completed, the data analyzed, and the results reported to Design Engineering.

Technology Application

This task will continue characterization of turbine structure materials in test conditions that reflect service environment.

Section 2.2.4.13 (GTMTSH) Turbine Shells**Objective**

Materials and processes will be identified for production of the turbine shells. Specifications will be defined after material property testing and process verification/optimization trials are conducted to achieve the best quality part to meet all design criteria.

Progress for this Quarter

Meetings were held with the supplier of the inner turbine shell to review issues associated with welding and non-destructive examination of the component. A comprehensive review of the potential nondestructive examination (NDE) techniques that could be used to evaluate the outer shell was conducted with Design Engineering. Agreement was achieved on the suitability of radiographic inspection. Mechanical property testing of the inner turbine shell material was postponed due to a lack of material from the supplier. Testing of the friction and wear properties of the inner and outer turbine shell materials was also postponed due to material availability issues.

Plans for Next Quarter

Final weld and inspection plans from the supplier will be reviewed and a determination made as to whether any additional development work is required. Effort will be expended to ensure that process qualification requirements are met by the supplier. Machining of specimens for the inner shell material will be started and, if possible, mechanical testing of these specimens will begin. Materials will be obtained and testing of the friction/wear characteristics of the inner and outer turbine shells will be initiated. Candidate coating materials to address any wear issues that may be identified in testing will be developed.

Technology Application

This task will enhance characterization of turbine shell materials in test conditions that reflect service environments.

Section 2.2.4.14 (GTMTSR) Seal Technology**Objective**

Improved gas path seals will be developed for the ATS turbine utilizing seal technology developed for aircraft engine components, where applicable. The technology will be evaluated utilizing developmental hardware and samples.

Progress for this Quarter

Acceptance criteria for joint integrity evaluations were established with Design Engineering. Results were incorporated in process specifications.

Plans for Next Quarter

This task has been completed.

Technology Application

This task will optimize seal attachment processes focused on airflow leakage restrictions to enhance performance.

Section 2.2.4.14.1 (GTFFTSSESV) Vib/Static Seals for Combustor-Turbine Hot Gas Path**Objective**

Advanced low leakage seals will be developed to meet the requirements for the advanced machine system. The seals will be analyzed using finite element analysis (FEA), and their performance will be evaluated through laboratory component testing. Detailed testing will be conducted using the High Temperature seal test rig developed under the ATS Phase 2 program. These advanced seals have numerous applications throughout the ATS turbine.

Progress for this Quarter

Standard length samples of single-shim, crimped cloth seal have been tested for use as hot gas path seals. They offer a low equivalent gap at 1000°F and are therefore strongly recommended for the H-machine. Wear testing of the cloth against several first-stage nozzle materials has been completed, and the results are being documented. Preliminary results from nine wear tests conducted on compound structural blocks indicate that there are no wear problems.

For transition piece seal development, FEA of the outer seal has been completed. There is a large relative motion between the outer transition piece and the first-stage nozzle. The cloth seal being designed appears not to undergo any plastic deformation under these conditions. Elastic recovery in the seal is essential in order for this junction to be well sealed. The analysis of the inner seal is in progress.

Plans for Next Quarter

System level tests on seals for outer shrouds and nozzles are planned, and good data on seals for this application are available.

Test data on standard length samples of seals for the inner shroud will be obtained and the inner shroud sealing system tested in early 1997.

GE's seal vendor has been supplying good quality seals, but they are custom made. In order to reduce the cost of producing seals, it will be necessary to investigate ways of making large quantities of cloth seals.

Transition piece seal development will include analysis, leakage-testing, LCF life testing, high-temperature creep testing, and detailed design.

Technology Application

Cloth seal design concepts developed thus far are being designed as specific components for the ATS gas turbine. More tests are underway to determine design attributes that influence their actual application in practice: seal assembly, tolerances, and sensitivity to slot geometry.

Section 2.2.4.14.2 (GTETBS) Brush Seals Development for Steam Box**Objective**

Brush seals will be developed to minimize steam leakage in the steam gland; reducing this leakage will increase the efficiency of the ATS Gas Turbine. The successful implementation of brush seals in the steam gland will allow for a shorter steam gland, thereby reducing manufacturing cost for the steam gland.

Progress for this Quarter

There are two seal locations to be considered: aft of the steam scroll is a leakage flow with a relatively small pressure drop; forward of the scroll is a leakage flow with a very high pressure drop. A single-stage brush seal design was developed for the first location, and a two-stage brush seal for the second. Static leakage tests were used to determine the leakage performance of the seals under operating conditions. CFD modeling was used to design the interstage geometry of the two-stage seal. As wear is assumed to occur mostly during transients, wear life is being determined via wear testing under conditions based on the most severe portion of the ATS gas turbine transients. The design will be validated by a sub-scale test under operating conditions.

The objective of the interstage geometry design for the two-stage seals is to ensure that the flows coming out of the first stage do not damage the second-stage seal: the jet velocity must be attenuated, and the flow along the upstream bristles of the second-stage must be radially inward rather than outward.

The CFD modeling work has shown the desired spacing between the last labyrinth tooth and the second-stage brush to ensure favorable flows into the second-stage brush. As the flow patterns seem insensitive to the number of labyrinth teeth, similar flow patterns can be expected in the first ATS gas turbine and in the steam deposition rig.

The seal holders for the steam deposition rig tests have been completed. Two of the four shaft seal sets will be replaced with brush seals. One brush seal set will consist of unsegmented seals, the other will consist of segmented seals with the segment end design intended for the ATS gas turbine. Both sets will have four labyrinth teeth between the brush stages.

Based on the predicted ATS gas turbine transients, wear test conditions were identified, with testing conducted at EG&G Sealol. As these conditions exceed the pressure capability of the rig, tests are being conducted at 0.93 MPa (135 psi) with an interference to provide the same contact pressure. The testing is underway.

Plans for Next Quarter

The rotating wear tests at EG&G Sealol will be completed by the middle of January. The seal holders will be fabricated. Seals and instrumentation will be purchased. A detailed test plan will be developed for an April 1997 test.

Technology Application

The brush seals are expected to be used as the primary seal design for the steam gland used on the ATS gas turbine to help control leakage and reduce product cost.

Section 2.2.4.15 (GTMTAR) Airfoil Repair**Objective**

Existing techniques will be evaluated and adapted for the material/geometry combinations unique to the ATS turbine airfoils to extend component life.

Progress for this Quarter

Efforts continue to examine the repair of single crystal alloys.

Plans for Next Reporting Period

Studies will continue to evaluate repair methods for single crystal alloys.

Section 2.2.5 (GTTT) Thermal Barrier Coating Technology**Section 2.2.5.1 (GTTTSD) Coating System Development****Objective**

Plasma spray TBC coating processes will be developed for specific ATS combustion and turbine components. Both axisymmetric and non-axisymmetric plasma gun and part motions will be developed. The approach will be to conduct iterative spray trials using specimens, coupons attached to the part, and trials on the part. Coating evaluations will consist of metallography, property measurements, and thermal cycling exposure. Thick thermal barrier coatings will also be evaluated in rig tests and full-scale combustor tests. Improved process monitoring will be developed to increase process repeatability and control.

The TBC manufacturing technologies portion of the task will focus on integration and compatibility between TBC processing and other component manufacturing steps. Techniques to prepare components for spraying will be defined. Fixturing and masking will be developed. Surface finishing techniques will be developed for the first-stage bucket and first- and second-stage nozzles.

The TBC process and diagnostics portion of the task will focus on achieving a better fundamental understanding of the TBC application process. Specific robot control algorithms and process conditions critical to the thickness and properties of the TBC system will be evaluated. Continuing work will focus on improving robot path planning accuracy and identifying key control characteristics (KCCs) for the ceramic top coat and metallic bond coat. The KCCs will be those directly controllable aspects of the coating process that most strongly influence process variability and TBC quality.

The TBC nondestructive evaluation (NDE) portion of the task will develop NDE techniques to measure attributes and properties of TBCs on turbine hardware that are relevant to manufacturing. The primary focus will be on development of methods to measure coating thickness.

Progress for this Quarter

Optimization of the new robotic equipment was conducted. A motion synchronization problem was solved and verification testing completed. In addition, an error attributed to tooling inaccuracies was corrected. The result of these incremental improvements is that robot/workpiece motion control is now within the process requirement.

The laser velocity measurement techniques were enhanced. A set of experiments was completed to test the effect of the laser beam offset distance, angle, and orientation to the part. A series of motion tests utilizing a variety of angles and orientations was conducted, and it was determined that these variations have minimal effect on the measured velocity and offset distance.

Significant progress was made in the development of software for programming complex coating paths. Testing of the final set of modules necessary to realize full functionality of the software was initiated. These modules were used to program refined motions for development components. Data collected during coating trials on nozzles and buckets included cycle time, temperatures, as-sprayed roughness, coating thickness, microstructure, and coating coverage.

The initial phase of the study to develop techniques for producing good quality coatings in areas of tight radii was completed. The results were used as the baseline for testing in the second phase, which was initiated. Development of techniques for measuring and optimizing part temperature during coating continued. Experiments were conducted to determine bond coat emissivity as a function of powder chemistry, surface roughness, and viewing angle.

Testing of bond coats with improved oxidation characteristics progressed with additional analyses of samples removed from burner rigs after 2000 and 4000 hours of testing. Both metallography and microprobe analyses were utilized to evaluate coating environmental resistance. Furnace cycle testing for evaluation of ceramic adherence and bond coat oxidation was initiated on 156 samples. These tests will be run at temperatures closer to the actual operating conditions of the ATS components than earlier tests, which were conducted at accelerated conditions to gather first information and down-select processes and materials.

Work was resumed to develop a process for production of a thick, durable TBC for transition pieces. Baseline process data were obtained and critical process parameters were identified. An experimental test matrix was conducted to test the effects of selected process variables on particle behavior and coating properties. The information will be used to generate production process specifications by the end of 1997.

TBC Manufacturing Technologies

Development of a robust surface finishing process focused on computer numerical control (CNC) grinding techniques using hard and conformable abrasive media. Sample plates were prepared and supplied to manufacturing for preliminary trials. Experiments to study the effects of TBC surface finish on airfoil heat transfer were completed. The data will be used to correct the TBC surface roughness measured using a cone stylus profilometer to the hydraulic TBC surface roughness.

TBC Process and Diagnostics

Statistical analysis of over ninety designed experiments conducted between 1994 and 1996 was completed. All coatings were applied to flat plates. Ten process variables were included in the analysis. TBC properties considered were tensile strength, modulus, and thickness per pass. Process models were developed at a confidence level of 95% to predict 77.7% of tensile strength variation, 88.6% of modulus variation, and 99.5% of thickness variation.

Experiments to increase the aluminum content of the APS bond coat near the substrate in order to improve oxidation resistance were performed. Aluminum enrichment was accomplished without formation of a continuous brittle beta-phase interlayer. The bond coats were examined in the as-

processed condition and after vacuum heat treatment. Specimens were metallographically polished and examined optically and the aluminum composition profile was determined using an SEM microprobe. The technique was successful in enriching the aluminum content of the bond coat in the vicinity of the bond-coat/substrate interface. It is expected that the aluminum enrichment will enhance the environmental protection to the substrate while maintaining the excellent TBC durability exhibited by the APS bond coats.

TBC Nondestructive Evaluation

A series of compound curvature specimens was designed. Additional flat specimens were fabricated in order to evaluate the influence of bond coat roughness on measurement accuracy. An HP impedance analyzer was set up for eddy current bond coat thickness measurement.

A flexible eddy current probe was built and tested. This probe is required to accurately measure coating thickness on small radii of curvature. A gauge repeatability and reproducibility study was conducted with this probe. Small fixtures to stabilize the eddy current measurements were built and tested for the study. The reproducibility and repeatability of the flexible probe well exceeded ATS requirements.

Plans for Next Reporting Period

Refinement of motion control techniques for nozzles and buckets will continue. Spray trials will be conducted on development components to validate programming approaches. Vendor and GE software for optimizing motions will be tested and refined.

Evaluations of improved bond coats will continue. Development of coating processes for transition pieces will continue using flat plates. First spray trials will be conducted on development components in April. Surface finishing trials will be conducted on development airfoils.

A hybrid coating thickness inspection technique involving eddy current and coordinate measurement machine (CMM) data will be developed.

Technology Application

The process for applying air plasma spray TBC to ATS combustion and turbine components will be defined. This process will define the baseline upon which coating durability will be evaluated and evolutionary improvements will be made.

Section 2.2.5.2 (GTTTRR) TBC Risk Reduction

Objective

TBC durability will be evaluated under conditions very similar to the surface temperature, thermal gradient, and stress state of TBC in ATS applications. An electron-beam rig capable of inducing high thermal gradients will be used to assess the relative durability of various TBCs, and the controlling mechanisms of TBC failure will be characterized. TBCs with a spectrum of microstructures will be tested to determine the role of TBC thickness on stress development and failure mode in high thermal gradient conditions, the failure modes of various TBCs of different microstructures and deposition techniques, the role of number of cycles and hold times at high temperature on TBC failure mode, and the role of bond coat composition and roughness in TBC life and failure mode. The effects of environmental contaminants on TBC performance in high thermal gradient conditions will be

investigated. Numerical modeling will be used to determine the stress, strain, and thermal gradient conditions in the various TBCs during the tests.

Progress for this Quarter

Three TBC-coated samples were tested under full ATS conditions for 100 hours and 2500 cycles. One sample was pre-aged for 450 hours/600 cycles at 2000°F, which is equivalent to approximately 50% of furnace cycle test (FCT) life. No systematic changes in ceramic strength, strain tolerance, or microstructure were observed for either the un-aged or pre-aged samples within the resolution of the evaluation methods.

A TBC surface temperature measurement facility was set up using a HgCdTe detector. TBC optical properties were measured as a function of wavelength in order to refine techniques for pyrometric measurements of TBC surface temperature and provide thermophysical data for radiation heat transfer calculations. Reflectivity data was obtained from porous and DV μ C TBCs over 25-1300°C. The data were used to calculate TBC transmittance and emittance as functions of wavelength and temperature.

Plans for Next Reporting Period

Testing of fillet tophats will begin. The first tests will be at low power "validation" conditions to compare the experimental results with the numerical predictions.

TBC top surface temperature measurements and bond coat temperature measurements will be performed.

Technology Application

Durability of the baseline TBC in an environment simulating that of the ATS baseline will be evaluated. These results will establish confidence that the TBC will provide acceptable minimum durability for safe and reliable operation of the ATS turbine within the time frame of the first inspection interval.

Section 2.2.5.3 (GTTTDD) TBC Design Data and Life Analyses

Objective

Thermomechanical failure modes in advanced TBCs will be identified, classified, and defined using empirical methods. Experiments will be performed to find key relationships among plasma spray processing variables, coating microstructure, coating physical and mechanical properties, and coating performance under simulated ATS conditions.

Numerical analyses will be performed to determine TBC stress states expected in ATS turbine components and in laboratory thermal cycling tests. The influence of the TBC stresses on TBC failure modes will be examined. Specially developed finite elements will be used for modeling the behavior of the interface cracks and free-edge stress singularities. The effects of bond coat roughness on TBC stress state, crack driving forces, and delamination failure will be examined. Parametric studies to determine the effects of bond coat and top coat properties on the TBC stress states will be performed.

A new subtask to evaluate the spatial and run-to-run variability of TBC thermal conductivity was initiated. Improved understanding of this variability is essential because the variation in TBC thermal

conductivity can be several times greater than that seen in metals due to variations in TBC microstructure, leading to design inaccuracy. Various methods of measuring thermal diffusivity and conductivity on flat and curved samples will be evaluated. The gas pressure dependence of thermal conductivity as a function of temperature will be measured. The results will be used to estimate the thermal conductivity of TBC at ATS conditions.

Information from this task will be used as input to other tasks. Appropriate data and modeling results from parallel GE programs will be incorporated. Design guidelines will be developed for TBCs on ATS components. Ultimately, a TBC life analysis methodology and a life predictive model will be developed that will include effects of long-term exposure on top coat and bond coat physical and mechanical properties.

Progress for this Quarter

Furnace Cycle Test

TBC evaluations using the furnace cycle test (FCT) continued. The FCT furnaces were calibrated using an improved procedure in order to reduce the site-to-site and furnace-to-furnace variability on measured TBC lives. Variability in specimen temperature profiles during exposure was greatly improved.

Oxide and precipitate-free-zone (PFZ) thicknesses were measured for a series of specimens that were previously exposed at 1149°C (2100°F), at dwell times ranging from 0.1 to 20 hours per cycle. The oxide and PFZ thicknesses were measured in order to evaluate the contribution of bond coat and substrate oxidation to the TBC failure. Specimens that were furnace cycle tested as part of the bond optimization effort were examined in both the as-polished and etched conditions in order to relate the microstructural observations to the FCT data.

Thermal Conductivity

(A) Planar samples

Reproducibility of measurements was evaluated after storing specimens for a 2-month period. Acceptable reproducibility was obtained.

Measurements were made in nitrogen and in vacuum up to the highest temperatures of interest for the ATS design. Good agreement of the data with the gas pressure effect model was obtained. It was confirmed that the radiation contribution to TBC thermal conductivity is small up to the highest temperatures of interest.

(B) Parts

Measurements on curved and flat tape cast samples were made to test the laser flash method for various radii of curvature. The results for all samples were identical (within experimental error), verifying this technique as useful for most regions on parts.

Sections from production first-stage buckets were evaluated. Eight samples were prepared from each of two sections, each section corresponding to a different APS run. In each section, two parts were taken with small radius of curvature and two with large radius of curvature from both concave and convex locations. Changes in radius of curvature were noted after sample removal, in some cases by a significant amount. The final radii of curvature were used for density determinations by weight and volume. There was no trend in density corresponding to subclassification (e.g., run-to-run, convex vs.

concave, large vs. small radius of curvature). Sample thickness was measured using a micrometer and corrected for the effect of roughness.

There was higher scatter in the thermal conductivity compared to planar samples, consistent with a larger error in thickness and density compared to planar samples. Within the measurement uncertainty, there was no trend in thermal conductivity corresponding to subclassification (e.g., run-to-run, convex vs. concave, large vs. small radius of curvature). However, the absolute value of thermal conductivity was slightly lower than the values measured previously on corresponding planar samples.

Plans for Next Reporting Period

FCT cycling at 1093°C (2000°F), using dwell times of 0.1, 0.75, and 10 hours/cycle will continue. Cycling at 20 hours/cycle will begin. Measurements of oxide and precipitate-free-zone thicknesses in specimens exposed at 1149°C (2100°F) will be completed.

Thermal conductivity of TBC samples from additional development and production parts will be measured. For regions of radius of curvature too small for thermal conductivity measurements (e.g., in fillets), samples will be produced of a similar thickness and microstructure on planar substrates to evaluate variability of thermal conductivity. Thermal conductivity vs. temperature of aged TBC samples will be measured.

Technology Application

A database will be established that will link TBC properties and durability in laboratory tests to TBC durability in the ATS turbine. This database will be used ultimately to predict TBC life as a function of temperature and strain at specific locations on ATS turbine components. The database will also be used to identify process improvements to the baseline TBC which result in improved properties and durability.

Section 2.2.5.3.1 (GTFFTB01) Bucket TBC Roughness and Spall Characterization

Objective

This task will quantify the external airfoil heat transfer coefficients associated with the roughness characteristic of TBCs. This task places specific attention on the roughness associated with TBC structure, which can be very different from that of metallic surfaces or coatings.

Typical average roughness measurements made on surfaces cannot fully distinguish between metal finishes, artificial rough surfaces, and applied or polished TBC surfaces. While the measured average roughness values of such surfaces may be the same, the effect on external heat transfer may be quite different due to the specific character of the roughness. This task will use CRD's Transient Heat Transfer Cascade to test an airfoil coated with TBC that has been polished to various levels, and assess the effect of TBC-type roughness.

Progress for this Quarter

Four series of tests were conducted on the APS TBC-coated airfoil to determine external heat transfer coefficient distributions. Each series had a different average surface roughness. In addition,

the fourth series incorporated two spalled regions to determine the effects of local TBC loss. All roughness values were determined with a conical stylus profilometry unit.

Two main conclusions can be drawn from the results of these tests: (1) APS TBC must be polished from its as-sprayed condition to avoid large increases in airfoil heat loads and (2) heat transfer enhancements due to local spalls are not as severe as assumed in the design of airfoils, tending to be much reduced by other effects associated with surface roughness and high freestream turbulence intensity.

Plans for Next Quarter

Further efforts relating to the effects of APS TBC surface roughness on heat transfer will be reported in a new task to be performed in 1997. This new task will provide a detailed study of the effects of TBC surface roughness through the testing of instrumented and coated flat plates. Flat plate wind tunnel testing eliminates any complicating factors associated with airfoils, such as pressure gradient and curvature, and allows detailed surface maps to be made of both the roughness characteristics and the resulting heat transfer. During 1Q97, the wind tunnel test section will be designed and fabricated, along with several test plates, both with and without TBC.

Technology Application

The results from this task will be analyzed for consistency among the various roughness levels tested. The results will also be compared to other similar tests run in the same facility that used metallic rough surfaces. If the complete available data show a consistent and clear effect of TBC surface roughness on external heat transfer, these data will be used to determine an equivalent TBC roughness for use in the design heat load predictions on the ATS turbine airfoils.

Section 2.3 (CC) Combined Cycle Integration

Section 2.3.1 (CCSD) Combined Cycle Systems Design

Objective

Analysis will be performed and the combined cycle system will be configured to optimize cost/performance characteristics of the total plant. Steady-state modeling will be used to calculate the detailed plant performance. Dynamic modeling of load change sequences (e.g., startup and load rejection) will be used to develop and validate control system design, and assess component design. Operability will be assessed.

Progress for this Quarter

The steady-state performance model (SSPM) for the STAG 107H was updated for improved maintainability and platform portability. The 7H gas turbine cycle deck was updated and incorporated with an updated steam bottoming cycle model into the first major update of the 107H reference plant SSPM. Extension of both the STAG 109H and 107H SSPMs to include automation of design point calculations was started. The clearance control conceptual design for interaction with the steam cycle was revised. Vendor evaluation for compliance of STAG 109H HRSG functional specifications has been initiated. The STAG 109H thermal dynamic model (TDM) was successfully extended to simulate unit trip and flying restart transients that were released for general design purposes.

Plans for Next Quarter

The SSPM for the STAG 109H will be updated to include optimized design of the cooling-air cooling system and fuel heating system. An updated 9H gas turbine Cycle Deck with an updated steam bottoming cycle will be incorporated into the SSPM. Work will continue on extending both the STAG 109H and 107H SSPMs to include automation of design point calculations. Optimization of clearance control interaction with the steam cycle will continue. Final definition of all machine operating limits for use in final system design and implementation into the control system will be completed. Hot Restart and Load Change transients will be evaluated using the Thermal Dynamic Model. The TDM will be upgraded by incorporation of a higher fidelity gas turbine model.

Technology Application

Operability evaluation of the STAG 109H configuration will be directly applicable to the STAG 107H ATS plant. Also, cooling-air cooling and fuel heating system conceptual designs will be very similar for the STAG 107H ATS plant.

Section 2.3.2 (CCUA) Unit Accessories**Objective**

Four new accessory systems will be designed: the gas fuel heating system, the cooling-air cooling system, the clearance control system, and the gas turbine steam cooling system. Design of the heat exchanger and piping for the hot fuel will take into consideration the need to avoid coking. Deposit formation will be investigated. The effectiveness of coke barrier coatings, which have been under development for liquid-fueled systems, will be evaluated in long-term tests. Designs of remaining accessories will be conventional.

Progress for this Quarter**Fuel Heating System**

The final Process & Instrumentation Diagram (P&ID) was completed for the gas fuel heating system, which includes mechanical and electrical schematics and temperature/flow information. In addition, all device nomenclature was applied to the fuel heating system devices and submitted to the gas turbine device summary. The functional specification that defines the hardware required for the gas fuel heating system was started and is expected to be issued early in 1Q97. The engineering design team also began to pursue potential suppliers for the gas fuel heating system equipment and to establish the system cost.

Stanford University presented their completed static analysis for the gas fuel heating system failure modes and effects analysis (FMEA), which will be developed into a measure of reliability for the gas fuel heating system.

Cooling-Air Cooling System

The results of the feasibility study for the current configuration of the cooling-air cooling system (CAC) were presented in a design review. The results showed that the current system configuration yielded a highly efficient system at unacceptably high cost. Because of disagreement over the engineering assumptions and the selection of the suppliers that provided the quotes, the CAC system

components will be requested using different suppliers, working to design requirements made under different engineering assumptions. The results of these latest quotes will be reviewed in 1Q97.

Stanford University presented their completed static analysis for the CAC system FMEA, which will be developed into a measure of reliability for the CAC system. The FMEA was based on the current configuration of the CAC system, and will have to be revised if the system configuration changes after the pending design reviews are held in 1Q97.

Steam Cooling System

Based on scope changes made during 3Q96, the preliminary P&ID was revised and completed. The system components (valves and the steam filter vessel) were reviewed with suppliers. This review resulted in a change in the configuration of the steam filter vessel that should result in a more compact, lower cost component.

Stanford University presented their completed static analysis for the steam cooling system FMEA, which will be developed into a measure of reliability for the steam cooling system.

Clearance Control System

During 3Q96, the clearance control system (CCS) was lacking several design requirements (since the gas turbine compressor was added to the scope in 2Q96) and several issues regarding system operation had not been resolved. Therefore during 4Q96, a design review was held with the objective of reestablishing the purpose for the CCS in order to determine which design requirements were not yet defined and to document all issues of concern related to the system. The results of the design review required that the engineering design team summarize the results of the review into a formal document defining the CCS requirements which will be released to the Advanced Gas Turbine Design Memo book during 1Q97. This document will be the basis for the CCS engineering design team to design the clearance control system.

Stanford University presented their completed static analysis for the CCS FMEA, which will be developed into a measure of reliability for the CCS. The FMEA was based on the current configuration of the CCS. Once the Design Memo document is released in 1Q97, the FMEA will have to be revised if the clearance control system design is changed on the basis of the document specifications.

Exhaust Diffuser

During 4Q96, preliminary design of the exhaust diffuser was laid out based on the new design being developed for the F machine. The final design for the F machine diffuser was developed with suppliers. The exhaust diffuser for the ATS gas turbine will benefit directly from the F machine design work.

Plans for Next Quarter

Fuel Heating System

The functional specification for the gas fuel heating system will be completed. Suppliers will then be chosen to begin detailed design work on the system components. The engineering design team will hold regular design reviews with the component suppliers to ensure proper development of the gas fuel heating system.

Cooling-Air Cooling System

The second phase of the feasibility study will be completed for the current system configuration in which it will be determined whether a new system configuration is necessary or the current configuration can move into the next stage of development. The criteria for approval will be meeting cost and performance goals, as well as satisfying general functionality requirements. If the configuration is approved, the engineering design team will develop the preliminary P&ID for the system and hold a preliminary review of the system design. If the configuration is disapproved, 1Q97 will be spent developing a new configuration that satisfies the cost, performance, and functional requirements of this system.

Steam Cooling System

The final P&ID for the steam cooling system will be developed, reviewed, and, barring any complications with the system design, approved by the end of 1Q97. In addition, the engineering design team will complete the functional specification defining the components for the steam cooling system and begin working with suppliers to develop the detailed design of these components.

Clearance Control System

The engineering team will issue an updated design memo for the clearance control system (CCS) based on the design review held in 4Q96. Design of the CCS will be based on this design memo. The system P&ID will be completed as well as the system functional specification. Completion of these documents will enable work to begin with suppliers to develop the system components in the following quarters of 1997.

Exhaust Diffuser

Based on the final design of the new F machine exhaust diffuser, which will be completed early in 1Q97, the functional specification and design drawings for the advanced gas turbine exhaust diffuser will be started and brought to near completion by the end of the quarter. Based on this design, model testing may be necessary later in 1997 to verify the required pressure recovery for the diffuser before suppliers start the detailed design of the exhaust diffuser.

Technology Application

Development of the four new unit accessories is critical to the development of the ATS gas turbine in order that the gas turbine meet its performance goals and function properly. The ATS gas turbine uses a dry DLN 2.6 combustion system that requires the gas fuel to be heated in order to achieve the overall ATS efficiency goal. The cooling-air cooling system is required to maintain temperature within sections of the gas turbine within acceptable limits. The steam cooling system is required to cool the turbine hot gas path parts while meeting performance goals for the gas turbine. The clearance control system also enables the turbine to operate at a higher efficiency than would be possible without the system. The exhaust diffuser will be designed so that maximum possible pressure recovery will be realized thus increasing the performance of the ATS gas turbine.

Section 2.3.3 (CCCL) Controls

Objective

An integrated plant control system will be developed and designed that will be suitable for the advanced gas turbine combined cycle power plant. Specifications of control equipment requirements will be prepared. Control and protection strategies will be developed for gas turbine steam cooling and integration with the steam turbine and heat recovery steam generator (HRSG). Control system dynamic behaviors will be studied by dynamic simulations. Specifications of control algorithms will be prepared for implementation in the control system program.

Progress for this Quarter

The study of control loop dynamics continued. The control sequences for startup and shutdown were studied, including efforts to optimize the starting power requirements to achieve desired startup times. Control algorithms for startup and shutdown of the gas turbine were developed. Work continues on development of a standard graphics philosophy for the control system that will apply uniformly to all equipment in the combined-cycle power plant. The conceptual design of an integrated control system has been completed, and manufacturing processes have been initiated.

Plans for Next Reporting Period

The study of control loop dynamics will continue. The majority of the software algorithm will be defined for gas turbine, steam turbine, and HRSG controls. Software algorithms and sequence logic will be defined for auxiliary systems. Graphics philosophy concepts will be established. The design of the integrated control system will be completed.

Technology Application

The integrated plant control system conceptual design for the STAG 109H configuration will be very similar to that of the STAG 107H ATS plant.

Section 2.3.4 (CCRA) Reliability, Availability, and Maintainability (RAM) Analysis

Objective

An evaluation of the reliability, availability, and maintainability (RAM) of the 7H equipment will be performed. The basis for the work will be the EPRI High Reliability Controls and Accessories Study. The RAM analysis will include: the flange-to-flange gas turbine, heat recovery steam generator, steam turbine, controls and accessories, electrical generator, and balance of plant equipment. A failure modes and effects analysis (FMEA) will be included.

Progress for this Quarter

Activity during this reporting period has been restricted to FMEAs

Gas Turbine Flange to Flange - Turbine and Compressor:

FMEA development will be continued on all unconventional aspects of the turbine and compressor. The steam gland, third-stage bucket cooling delivery, and bore tube systems have been completed.

New Systems:

FMEA preliminary results for the gas turbine cooling-air cooling, gas turbine startup steam cooling, and gas turbine normal steam cooling systems have been released to the engineering community for further analysis.

Plans for Next Quarter**Gas Turbine Flange-to-Flange - Turbine and Compressor:**

FMEA development will be continued on the blower system, first- and second-stage buckets and nozzles, turbine rotor, compressor rotor/cooling, and variable guide vane (VGV) system.

New Systems:

Focus will shift to develop the FMEAs for the three new systems to include transient behavior under normal power plant transient events such as startup.

Technology Application

The FMEA results will be applied to the design of the 9H and 7H hardware, with special emphasis on the components involved with the steam cooling aspects of the design.

Section 2.4 (MF) Manufacturing Equipment and Tooling**Objective**

The materials, equipment, tooling, and processes required to produce the 7H and 9H turbines will be identified. Manufacturing schedules will be established to support ATS pre-commercial demonstration goals. Manufacturing schedules and cost will be defined.

Progress for this Quarter

Forging dies were completed, the first ingots were billetized, and several billets were processed through the first upset process. One smaller billet was successfully forged and two experienced some buckling. A sub-scale test program and process and tooling changes were defined to resolve this problem. The upgraded TBC coating equipment in Greenville was qualified for process development work, the mid-section mockup was completed and shipped to the training center, and meetings were held to plan and schedule the FSNL test stand modifications required to accommodate ATS gas turbines.

Plans for Next Quarter

The forgings will be processed for delivery to the ultrasonic inspection techniques (UT) and machining supplier. TBC process qualification will continue for airfoil components. The FSNL test stand design concept will be completed and work begun on procuring equipment to support FSNL testing.

Technology Application

Development of the turbine wheel forging dies and the ultrasonic inspection techniques (UT) are the first application in forgings of this size and will be used to provide high strength, high temperature material which is compatible with the steam cooling environment in the ATS turbine rotor. The

mockups are being used to assure fit-up of all components in very restrictive areas of the turbine. An electronic simulation of these areas of the machine is being done in parallel to develop simulation technology for future applications. The TBC robot controllers will provide the thickness control for the TBC coating that is required for proper heat transfer properties in the steam-cooled turbine airfoil components.

Section 2.5 (IG) Integrated Gasification and Biomass Fuel

Objective

An assessment of the ATS will be performed as part of an efficient and environmentally compatible integrated gasification combined cycle (IGCC) power generation system. Modifications to the gas turbine to accommodate the high mass flow resulting from the low heating value fuel gas and nitrogen injection for low NO_x emissions will be identified. Analyses will be performed to optimize the integration of the steam cycle with one oxygen-blown entrained flow gasifier and gas cleanup system and integration of the gas turbine with the air separation unit. IGCC system performance will be analyzed for one coal composition at ISO ambient air conditions.

Progress for this Quarter

There was no activity associated with this task under the ATS Phase 3 Cooperative Agreement during the current reporting period.

Plans for Next Quarter

There is no activity planned for this period.

Section 2.6 (DE) Pre-Commercial Demonstration

Objective

A commercial proposal will be prepared and submitted to the host utility.

Progress for this Quarter

Commercial activity remains high. Excess of generating capacity in the domestic market continues to delay project approvals; however, commercial discussions (equity shares, price, shipment requirements, insurance premiums, performance levels, construction financing, and service agreements) with potential host utilities and power marketers continue to intensify.

The third Utility Advisory Board (UAB) Controls "Sub-Group" meeting and the fourth UAB meeting were held on September 10 and September 24, 1996, respectively.

Plans for Next Quarter

GE will continue to support the potential host utilities' technical and commercial evaluations.

The fifth UAB meeting is being scheduled for March 1997. In addition to updating UAB members on the status of ATS gas turbine performance, operability, maintainability, reliability, availability, plant arrangements, and installed costs, a review of the critical-to-quality (CTQ) criteria for this design will be held.

Section 2.7 (PM) Program Management

Objective

Within GEPG Engineering, an ATS Program Office will be established and a Program Manager and a Contract Administrator will be assigned. The Program Manager will direct the overall activities of the Program Office, and will have responsibility for reporting to DOE and ensuring that the program goals are achieved. The Program Office is responsible for communicating contract requirements, authorizing applied labor and expenses for material and services, scheduling, monitoring, and reporting cost and technical performance. Additional responsibilities include coordinating ATS activities with CRD and GEAE. The assigned Contract Administrator will support the Program Manager in all administrative matters. All materials and equipment acquisitions will be closely monitored by the Program Office with support from the Finance and Sourcing organizations.

Actual scope, schedule, and budget will be tracked against plan. An integrated program plan will be maintained, including a detailed Work Breakdown Structure, that accurately describes the planned work, reflecting all changes in work scope or schedule. The integrated program plan includes the implementation and coordination of all program support procedures and initiatives such as Target Costing, Key Quality, and Design for Manufacturing.

Reports will be prepared to serve both DOE and GE needs for oversight and monitoring, including quarterly reports, annual reports, and topical reports. A final report will be prepared at the completion of the cooperative agreement. Reports specified in the Cooperative Agreements Financial Assistance Reporting Requirements Checklist will be supplied. Technical papers will be submitted for presentation to professional society meetings. Open communications will be maintained with DOE and the Industry Advisory Board.

Based on work in Phase 3, a Continuation Application will be prepared and submitted to DOE incorporating the details for the proposed Pre-commercial Demonstration including the host utility site selection, permitting, environmental factors, fuel characteristics, utilization plans, and plant arrangement constraints.

Progress for this Quarter

GE Power Generation participated in the DOE-sponsored Advanced Turbine Systems Annual Program Review held on November 7 and 8, 1996 in suburban Washington, D.C. The presentation reviewed the status of GE's ATS program and provided a comprehensive overview of the component design and technology efforts being applied to the H machine design.

As requested by DOE/METC, a preliminary BUDGETARY estimate of costs for a program replan for Phase 4 was prepared and submitted.

Plans for Next Quarter

A brief presentation of GE's ATS Program status is planned for DOE/FETC management on January 31, 1997, in Morgantown, WV.