Utility Advanced Turbine System (ATS) Technology Readiness Testing and Pre-Commercial Demonstration Phase 3

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For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Power Generation System
General Electric Company
1 River Road
Schenectady, New York 12345

MASTER

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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 detailed 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.

This report summarizes work accomplished during the period 4Q95. The most significant accomplishments are listed below:

- The compressor rotor cooling analysis was completed.
- An updated gas turbine layout was issued.
- Two corporate executive level reviews were held.
- A utility advisory board meeting was held.
- An airfoil material model was defined and released.
- Turbine rotor ingot specifications were released and a purchase order issued.
- A turbine stator design review was held.
- Casting trials were performed on first-stage nozzle, second-stage nozzle and first-stage shroud.
- A compressor airfoil design review was held.
- A compressor rig design review was held.
- The exhaust frame and forward diffuser concept was frozen.
- The compressor discharge casing design concept was frozen.
- An exhaust frame preliminary layout was released.
- A detailed exhaust frame analysis and mock-up were started.
- A compressor rotor design review was held.
- A compressor structures design review was held.
- Compressor rotor forging specifications were released.
- The ATS Phase 3 NEPA Topical Report was submitted to DOE for review.

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.

Technical Progress

Work on the Phase 3 topical NEPA report was initiated. 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 in place or in the process of being obtained to support the Phase 3 activities.

Activity was initiated on the Phase 4 topical NEPA report. This report will take the form of a "generic" Environmental Information Volume (EIV). ERM, Inc., has again been contracted to provide support. The GE Power Systems' engineering power plant projects environmental organization, working with ERM, prepared an outline for the planned report. The technical basis for the report will be the 7H Base Reference Plant. This work will continue into 1Q96.

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

Technical Progress

Completion of the fourth-stage design of the turbine airfoils has allowed the aerodynamic model of the turbine gas path to be completed. This model now contains a complete aerodynamic description of the turbine including the turbine blading, cooling, and most geometric parameters.

The aerodynamic description of the airfoils has been converted into plane geometric parameters and transferred to both heat transfer and mechanical design engineers.

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

Section 2.2.2.1 (GTFFCP) Compressor Design

Objective

Mechanical design of the 7H and 9H compressor rotor and stator structure will be performed with the goal of achieving lower cost and greater durability by applying proven GE Power Generation heavy-duty design practices. The designs will be based on the GEAE CF6-80 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 tests of the first unit.

Technical Progress

Drawings for several compressor components were prepared and released for manufacturing. All rotor forging drawings are complete, and some blade and vane definitions are complete. The large structures casting drawings are nearly complete, and preliminary part definition was given to Manufacturing. This definition of castings and forgings will continue in 1Q96 and will be followed by detailed machining drawings.

Preliminary design reviews were successfully completed for all major compressor components. The compressor is expected to meet or exceed all performance and life requirements. Final design reviews are planned for mid-1996.

The compressor flow path, including the inlet and diffuser, is defined. Axial gaps between airfoil rows have been sized to ensure that no contact occurs between airfoils at all conditions.

Compressor bleed has been established aft of the 12th stage to supply turbine cooling and facilitate machine startup.

The sub-scale compressor rig has been defined and manufacturing of components has begun. This rig is expected to test in 4Q96 and will verify compressor performance,

operability, and aeromechanically acceptable operation. The rotor cooling system will also be validated by this test.

Section 2.2.2.2 (GTFFCB) Combustor Design

Objective

A combustor will be designed 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.

Technical Progress

Preliminary spatial definition of compressor discharge case and turbine shell penetrations, nominal combustion system length and cant angle, compressor diffuser, transition piece forward and aft mount locations, and control of clearances between the transition piece/impingement sleeve and the steam piping has been completed.

Preliminary transition piece design continued with detailed analysis of the impact of small shape changes on life and performance. These shape changes were made to accommodate steam piping and assembly clearances. A transition piece body shape for cold flow-testing was defined and fabrication begun. A detailed study of various sealing concepts between the transition piece and first-stage nozzle was conducted. Preliminary seal definition permits release of the casting drawing for the first-stage nozzle.

Specification and design of the pressure vessel for the combustion test stand were completed.

Development testing of the short liner concept is reported under Phase 2.

Section 2.2.2.3 (GTFFTR) Turbine Rotor Design

Objective

The turbine rotor components (wheels, spacers, aft shaft, transition discs, coolant systems, and fastening devices) will be designed. 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.

Technical Progress

Rotor wheels are designed to withstand overspeed while continuing to operate without maintenance. Elastic/plastic analysis of the wheels and spacers and correlations with data from oversped wheels have helped in determining overspeed design requirements for solid rotor wheels.

Extensive parametric analysis of the highly stressed, limited-space 3-4 Spacer has been performed on several bore diameter configurations to balance the design requirements of overspeed strength and rabbit loads with the adjacent wheels.

Section 2.2.2.4 (GTFFTB) Turbine Bucket Design

Objective

Buckets for the four rotating stages will be designed. 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 be applied throughout. Drawings and specifications will be developed in preparation for manufacturing.

Technical Progress

No progress was made on the 7H turbine buckets in 4Q95.

Detail design proceeded on all four stages of buckets for the 9H turbine. Gas-side boundary conditions were determined for the buckets. The airfoil and cooling designs were frozen for the first-stage bucket, and a thermal analysis was performed. The second-stage bucket airfoil design was frozen. Cooling circuit design work was performed for the second-stage bucket. The third-stage bucket airfoil design was frozen. A cooling circuit

evaluation was performed and a cooling configuration was selected for the third-stage bucket. Thermomechanical analysis was performed for the third-stage bucket. The fourth-stage bucket airfoil design was frozen, and the creep life of the fourth-stage bucket was evaluated.

Section 2.2.2.5 (GTFFTS) Turbine Stator Design

Objective

The inner and outer turbine shells will be designed, including a turbine stator cooling system to provide rotor/stator clearance control. A closed circuit coolant delivery and return system for the turbine flow path stator components will be designed. Component, sub-assembly, and assembly flow tests will be incorporated concurrently. Implications for handling equipment (crane and manipulators) will be included in design considerations.

Steam-cooled turbine nozzles will be designed. Thermomechanical transient and steady-state analyses will be performed to determine parts lives. Material, manufacturing, and heat transfer database expansion is planned and will be integrated concurrently.

Shrouds will be designed. Sealing systems will be selected for minimum leakage. Thermal and structural analysis of equiaxed or anisotropic materials will be applied as appropriate.

Calculations will be made of all flow in the cooling systems, including leakage flows, to support performance, thrust balance, and component temperature calculations.

Design of hot-gas-path seals will be based on laboratory tests. Seals developed for transition-piece-to-nozzle segment and intersegment interfaces will be evaluated in cascade tests. Both sealing and wear performance will be assessed. Manufacturing drawings and specifications will be produced.

Technical Progress

Exploration of several alternative methods of manufacturing the turbine shells has begun with a view to developing the highest quality parts at minimum cost. This activity will be completed in 2Q96.

The coolant delivery system design for the first-stage nozzles is nearing completion, and a laminate object model of a design iteration close to the final version has been procured to address potential manufacture, assembly, and maintenance issues by visualization. Second-stage design is well underway, building from the lessons learned during the first-stage work, and is on track for design completion by the end of 2Q96.

Several reviews of cooling concepts on the flow-path components (nozzles and shrouds) were held with experts from GEPG, GEAE, and CRD. These reviews yielded cooling concepts that will help achieve the cost, durability, efficiency, and emissions goals for the ATS machine.

Section 2.2.2.6 (GTFFST) Structures Design

Objective

The exhaust frame, steam box, and aft bearing housing will be designed. Instrumentation and test plans for component model, factory, and field testing will be prepared.

Technical Progress

An engineering concept review was held at the Greenville manufacturing facility with key individuals representing areas of the design including piping, instrumentation/conduit, gas turbine base design, manufacturing engineering, and the possible manufacturing vendor. In this meeting, new concept options for simplifying the design were reviewed. The potential effects of these concepts for diffuser flowpath performance, structural integrity, and part producibility are being addressed. A mock-up of the exhaust inner barrel area to help ease assembly of and access to the aft wheelspace and bearing housing/steam box base is in the planning stage. Concept freeze of the exhaust frame is complete, and detailed cooling circuit and structural analyses are in progress. An interfacing schedule has been put in place to lay out a plan to advance the steam gland and bearing housing design schedule while the turbine rotor design concept is not yet frozen. Steam gland design is progressing with seal design and steam scroll input initiated. Bearing housing, steam gland, and turbine rotor 1D heat transfer analysis is completed for preliminary sealing concerns; a 2D heat transfer analysis of this area is progressing.

Section 2.2.2.7 (GTFFMS) Mechanical System Design

Objective

System level studies will be performed 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.

Technical Progress

System level studies continue to be performed to optimize cost, performance, weight, size, maintainability, reliability, and manufacturability. System level and integration issues, such as performance, cost, and weight, are being monitored and tracked. The systems review team, which includes personnel responsible for engineering, manufacturing, sourcing, and maintainability, continues to meet to review the merit of system issues and to determine whether or not design incorporation is feasible.

A maintainability, reliability, and serviceability team has been established and is working to ensure that all of the "lessons learned" for field operation are being incorporated into the Advanced Machine design. This team is also in the process of procuring full-scale mock-ups of critical sections of this machine to ensure that the assembly and maintainability

issues are resolved prior to manufacturing hardware. These mock-ups will also be used to design and fabricate assembly and maintainability tooling.

The mechanical interface drawing, which includes the internal and external mechanical interfaces, has been updated and reissued.

All of the requirements known to date to be necessary for accessory and control development and fabrication have been issued and incorporated into the Design Manual.

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

Objective

Piping will be designed for fuel, air, steam, and oil transfer.

Technical Progress

Development of conceptual designs for piping systems continued. Key areas addressed were in interface control and system requirements. Work was begun on the initial conceptual design.

Section 2.2.2.9 (GTFFIT) Instrumentation and Test

Objective

Test plans will be formulated and instrumentation will be specified. Compressor and turbine rotor telemetry systems will be developed and acquired.

Technical Progress

Preliminary instrumentation and test plans have been identified and defined. Factory test facility modifications have been identified.

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) First-Stage Nozzle Design

Objective

A full-scale sector of the first-stage nozzle will be operated at full engine conditions to demonstrate the validity of the design concept. Temperatures will be measured and any distress to the thermal barrier coating (TBC) will be quantified. The combustor exit conditions in the premix combustor mode will be characterized by testing. Internal cooling circuitry conditions and airfoil metal temperature distributions will be determined. Life-

prediction models will be validated and low cycle fatigue (LCF) failure mechanisms will be characterized with LCF tests.

Technical Progress

There was no test activity associated with this task under the ATS Phase 3 program during the current reporting period; test effort was supported by the ATS Phase 2 program and is reported in accordance with the provisions of that program.

Manufacturing effort on the heat transfer (metal temperature) and LCF nozzle cascades continued. Completion of the heat transfer cascade has been delayed about one month because of fit-up problems associated with seal gaps, which are currently being addressed in final assembly. A technique to assist in fit-up of the LCF nozzle using coordinate measurement machine (CMM) data to fit the impingement cooling boxes in the nozzle sidewalls has been employed. This technique will largely eliminate the need for hand fitting on the heat transfer cascade thus reducing manufacturing cost.

It is expected that the heat transfer nozzle cascade will be completed and shipped to the Evendale, OH, Component Test Facility in 1Q96 for assembly in the test stand, with the test to start in late 1Q96. The LCF nozzle cascade will be available in early 2Q96.

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.

Technical Progress

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

Section 2.2.3.3 (GTETSE) Rotor-Bucket Steam Transfer Spoolie

Objective

Rotating air test 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.

Technical Progress

Work was initiated on the latest phase of the rotating test program for verifying the leakage performance of spoolies. To provide information on the impact of thermal differential expansion of the components on leakage rate, a heated enclosure was designed and fabrication started.

Test activity to verify spoolie leakage characteristics associated with alignment and relative motion continued. Results of durability testing without side loads were acceptable for the coated spoolies; two different coatings were tested. Tests for one of the coatings have been completed with side loads, and the leakage rate results are acceptable.

Section 2.2.3.4 (GTETRH) Rotational Heat Transfer

Objective

Local heat transfer coefficients in a high aspect ratio rectangular duct will be measured in the Rotational Heat Transfer Test Rig. Turbulator geometries will be evaluated.

A limited database exists on the effect of rotation on heat transfer in turbine blade cooling passages. The objective of this task is to construct, install, and test a high aspect ratio cooling passage in a full-scale rotating test rig. A sub-scale test rig will be employed in parallel to evaluate alternate turbulator designs in order to identify the best configuration for subsequent evaluation in the full-scale test rig.

Technical Progress

The thermal performance of a mixing rib heat transfer turbulator design alternative in a duct of midrange rectangular geometry was determined by tests in the sub-scale rig. A second mixing rib alternative test followed. When the data from both tests are combined and compared, it is clear that the rib design can be tailored to meet pressure drop and heat transfer requirements. A castable mixing rib configuration for maximum heat transfer was built and tested; it yields the same pressure drop as the configuration that was not castable.

Section 2.2.3.5 (GTETIH03) Surface Enhanced Internal Heat Transfer

Objective

The objective of this task is to evaluate impingement heat transfer coefficient enhancements for validation and improvement of turbine airfoil design.

Tests of enhanced flat-plate surfaces with impingement at moderate pressure levels will be conducted for various impingement jet array parameters, providing both heat transfer performance and pressure loss data. Acrylic test models and liquid crystal techniques will be used to study those surface treatments that give the best performance.

Technical Progress

Design of two test sections with different aspect ratios was completed in 3Q95. The instrumentation and final assembly of the first (rectangular) test section has now been completed.

The rectangular test section is ready to begin testing with two turbulator configurations, over a range of Reynolds numbers. In 1Q96, heat transfer results will be analyzed and compared with existing correlations of channel flows in the same Reynolds number range. Assembly and instrumentation of the second channel will also be completed.

Section 2.2.3.6 (GTETE02/03) Surface Roughness and Combustor-Generated Flow Effects on Heat Transfer

Objective

The ATS Turbine Nozzle Cascade test facility will be used to validate design data of external heat transfer coefficients on airfoils with surface roughness. The cascade will incorporate instrumented airfoils with flow conditions representative of the ATS first-stage nozzle geometry. The appropriate nondimensional parameters for dynamic similarity will be made close to those of the engine first-stage nozzle. External heat transfer coefficient distributions will be 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 will be bonded onto the surface heaters. Data will include various roughness levels, distributions, and types in order to allow for 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 will also be used to assess the effects of transition piece wake shedding on airfoil heat transfer.

Technical Progress

Data defining the external heat transfer coefficient distribution obtained from these tests have been applied to the design of the ATS first-stage nozzle. A third set of pressure distribution data was taken to confirm past measurements and diminish uncertainties in the data. Preparations were begun for modeling TBC spallation effects on airfoil heat transfer. Trials were carried out to determine an appropriate method for coating the heat transfer airfoil with a rough surface that models the ATS nozzle TBC layer. Surface roughness measurements were made on the fully instrumented nozzle segments intended for testing in the Nozzle Cascade test rig.

Section 2.2.3.7 (GTETCP) LCF Coupon Tests

Objective

LCF durability of TBCs for first-stage nozzles will be evaluated under simulated ATS conditions. Specimens will duplicate the alloy, coating, and principal mechanical features. Testing will be performed using the electron-beam High Thermal Gradient Test Facility. The facility will be modified for the use of steam as an alternative cooling medium for the coupons. The coupons will be geometrically representative of a section of the turbine first-stage nozzle airfoils. The test rig will be refitted for the new test piece geometry. Coupons will be instrumented for evaluation of the thermal conditions during testing. Tests will be performed to evaluate various TBC coatings as well as metal durability. Post-test evaluations of the TBC and metal will be performed.

Technical Progress

Emphasis on LCF testing has shifted from this task to the Phase 2 task of "LCF Life and Crack Propagation."

Section 2.2.3.8 (GTETSP) Steam Particulate Deposition**Objective**

Tests will be performed to verify the adequacy of the steam purity system. Long exposure at near-7H steam conditions will be used to evaluate performance of steam filters under various steady-state and transient conditions, verify power plant steam purity assumptions and deposition characteristics, and evaluate performance of steam delivery components. An additional objective of this task is to measure the rate and location of steam particulate deposition in bucket tip turns.

Technical Progress

A centrifugal deposition rig with two specimens at each end of a rotor arm that simulates the G-fields at the coolant entry tip of a steam-cooled ATS gas turbine second-stage bucket is being installed and separately reported on as part of the Phase 2 activities of this program. Since the installation of the rig is still in process on the Phase 2 task, there is no progress to report on exposures of the specimens.

Section 2.2.4 (GTMT) Materials Technologies**Section 2.2.4.1 (GTMTSE) Steam Effects on Mechanical Properties****Objective**

This task will be conducted to evaluate any effects on the operation in a steam environment of candidate turbine materials. 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.

Technical Progress

Compliance is being used to supplement the methods for measuring crack length in fatigue crack propagation (FCP) tests. Modifications have been made to the compliance gauge. FCP experiments have continued with simultaneous measure of crack length by mechanical compliance and by electrical potential drop. The FCP testing in steam of a full-size prototype turbine rotor component was initiated this reporting period at two temperatures.

Studies to evaluate the effect of surface condition on properties in steam continued this reporting period. Twelve low cycle fatigue (LCF) samples previously prepared to an unsatisfactory condition were re-machined and re-treated to a satisfactory surface

condition. Testing was initiated under load control, and two specimens were tested during this reporting period.

A new series of tests to evaluate the effect of loading rate and crack propagation characteristics on the LCF behavior of structural materials was begun. Six tests were completed at one temperature. Specimen machining from a full-size structural component was begun and partially completed.

Creep testing of gas path and structural materials continued. Testing using the newly installed stepping motors in the creep equipment has started. Creep tests in air and steam on the second-stage bucket and nozzle materials were initiated, and some long-running tests were completed or intentionally stopped. Specimen orientation was one of the variables in this testing. Interrupted testing of smooth and notched samples of structural materials was performed to aid in the mechanistic understanding of the creep fracture process. The two tests started in 3Q95, one notched specimen and one smooth specimen, with periodic unloads were completed. Another notched specimen test was started and completed, and three tests continue to run. All of these tests were performed in steam. They are intended, in conjunction with the shorter period steam sustained peak low cycle fatigue (SPLCF) testing, to yield information on the influence of local stress concentrations on the cyclic performance of materials in steam.

The original matrix of SPLCF testing on notched structural materials in steam was completed this reporting period. Testing of smooth specimens in steam continues. This series of tests is being run to adequately characterize the LCF behavior of the materials.

High resolution scanning electron microscopy (SEM) and Auger spectroscopy is being used to characterize the samples on the crack face of FCP samples during testing in air and in steam. Initial results have been obtained for structural materials this reporting period to augment previously obtained transmission electron microscopy (TEM) results. The results of these studies are being used to fully characterize the behavior of the materials in ATS turbine environments.

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.

Technical Progress

The test matrix developed in 3Q95 for the next series of testing was refined to identify in more detail the exact nature of the samples that will be included. The variables which will be examined include not only the material being tested, but also the surface conditions, microstructural variations, and parameters seen in processing. These variables were included in the test matrix, and sample layouts were made on existing material from which specimens will be obtained. Some material was supplied to machining vendors for machining into test specimens.

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

To evaluate the performance of ATS materials in potentially corrosive environments, 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.

Technical Progress

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

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 selected parts will be conducted for life verification purposes and establishment of final manufacturing parameters.

Technical Progress

Preliminary high cycle fatigue (HCF) testing of the material for the forward airfoils was completed. The testing comprised one heat of material tested in three different environments. Results showed that the proposed processing of this material will increase the HCF endurance limit above GE-accepted design criteria. Test specimens for the second and third heats of this material were machined for testing during the next reporting period.

Three heats of material for a lower-cost compressor back-end material had LCF, creep, and notched and smooth HCF specimens machined for subsequent testing. Tensile specimens were machined and tested at elevated temperatures, and a preliminary curve was issued.

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 support 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.

Technical Progress

Discussions were held with vendors about their candidate materials and processing options for a number of bushing materials for the variable guide vane system. These discussions covered materials currently used, as well as some that may offer better wear characteristics at various temperatures. Orders were placed for small batches of the materials for wear testing.

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.

Technical Progress

Mechanical testing of compressor rotor materials to assist in the design process was conducted. HCF testing of the material for use in the forward stages continued. This testing is being performed at the design temperature of interest and at four mean stresses to develop a Goodman-type diagram for design use. Testing on one heat of material has been completed and the data analyzed. Notched HCF test bars were machined from one heat of the compressor rotor material for the latter stages. Analyses of HCF/LCF interactions and hold-time effects on the mechanical properties of these materials were conducted. LCF testing of this same material was completed for one cyclic frequency at two A-ratios (i.e., conditions used to evaluate the effect of mean strain) and three temperatures spread over the strain ranges to cover design conditions. This testing was also aimed at checking on any possible effects of specimen location (rim vs. bore), specimen orientation (circumferential vs. radial), and hold times in tension. Preliminary test data were analyzed and the results reported to Design Engineering.

The layouts of the inlet, compressor, and compressor discharge casings were reviewed to assure producibility and to specify all of the pertinent material and process requirements. Meetings were held with suppliers to discuss future qualification requirements as related to these components.

LCF testing of one of the casing materials was completed for two heats of material. Test conditions included three temperatures and two A-ratios spread out over the strain range to cover design conditions. Tensile testing was performed on one heat of material to confirm the existing design curves. All data were analyzed and preliminary design data curves were created.

A list of candidate materials for the compressor diffuser was compiled along with a tabulation of the critical properties for each one. Discussions were then held with the vendor to discuss producibility of each one and any necessary development.

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 properties in parts made by the chosen manufacturing process.

Technical Progress

Post-processing testing of a full-scale prototype trial forging in an ATS rotor size and configuration continued. This testing is destructive and is aimed at optimizing and qualifying the processes to be used during commercial production of the ATS turbine rotor forgings. The testing done on the prototype during this reporting period included microstructural evaluations at twenty-five locations, tensile testing at five different temperatures, impact toughness testing, creep rupture testing, low cycle fatigue testing at two temperatures, fracture toughness testing, and crack growth testing at two temperatures. These tests were used to quantify and evaluate the processing of this part. Machining of specimens from this forging to be used to supplement the existing design data curves was initiated and completed. Physical property testing of the prototype part was completed. Tests on the sub-scale forgings made prior to the full-size prototype forging continued. Three static crack growth rate threshold tests were performed at the maximum expected service temperature. Additionally, smooth bar strain-controlled LCF testing was completed at one test frequency for various temperatures of interest. This testing was conducted with and without hold times, and the results will be analyzed and compared to previously obtained results from notched bars.

Based on initial results of the prototype part and results obtained at the forging supplier during production of the full-size prototype, process optimization studies continued during this reporting period. These optimizations include changes in some of the processing parameters based on analytical and experimental results.

Following the ultrasonic testing of the prototype forging, discussions with suppliers were initiated which will lead to the fabrication of the ultrasonic equipment necessary to inspect the incoming ATS turbine rotor forgings. This system will incorporate currently used GE

ultrasonic testing techniques but allows for inspection of a wider range of forging geometries.

Section 2.2.4.8 (GTMTSR) 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.

Technical Progress

Spoolie materials and coatings continued to be the focus of this activity during 4Q95. After a review of available GE data to identify the most critical parameters, a test matrix including materials, coatings, surface conditions, and material processing options was developed to evaluate the components at the expected service operating conditions. These tests will begin in 1Q96.

Section 2.2.4.9 (GTMTSB) Structural Bolting

Objective

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

Technical Progress

Creep testing on high temperature bolting material at three temperatures continued. Time continues to accumulate on the samples in test to refine and update curves for use in the design. Stress-relaxation tests on the same bolt material at four test temperatures within the service operating temperature range and at three pre-strains of design interest also continued.

Relaxation tests on a lower temperature bolt material continued. These test are being conducted at three temperatures and four pre-strains within the expected service operation range.

Section 2.2.4.10 (GTMTTA) Turbine Airfoils Materials and Processes

Objective

Microstructure and mechanical properties will be evaluated for full-size 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 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.

Technical Progress

Microstructural analyses of bucket castings to optimize and evaluate prototype parts continued during 4Q95. Dendrite arm spacing (DAS) measurements were made on a previously produced first stage bucket and compared to measurements on slabs and cast-to-size bars. Based on these comparisons, findings from earlier DAS measurements, and Laue diffraction results of the orientations in prototype parts, creep tests were initiated on the bucket alloys from samples machined from castings as well as slabs. These tests are being done to correlate properties in actual component castings. Beyond standard specimen designs, samples are also being used to assess geometry factors. Forty-three creep tests, covering four temperatures and a minimum of three stress levels, have been completed on this program. Extensive microstructural investigations of twelve of the tested samples (six slab, six bucket) were conducted to better understand the mechanism of creep voiding. Stereomicroscopic evaluations were performed on the fracture surfaces of these samples. Additional work on latter-stage bucket materials continued. Scanning electron microscopy (SEM), long-term aging previously initiated, evaluation of the morphology of the material, and deformation studies are all being used to better quantify the behavior of the material. Microstructural evaluation of samples to determine the recrystallization temperature and finalize the heat treatment limits for the large ATS buckets was completed. An experiment was begun to identify the process defect map for this material. This experiment will yield a plot of gradient vs. withdrawal rate and identify the optimum process window. Examinations of chemistry variations within specification limits for latter-stage bucket materials continued using a casting that was made during 3Q95. Differential thermal analysis (DTA), heat treatment studies, and microstructural analysis have been initiated, as well as creep tests from samples with various heat treatments. Work on developmental heat treatments of the second-stage bucket material continued with the goal of improving the solution heat treatment to enhance properties above current ATS-required values. Twelve creep tests were initiated, with the remainder to be loaded in 1Q96. Metallographic evaluations of tested creep samples were conducted to determine the extent of creep voiding. SEM evaluations of several heat treatment microstructures were evaluated to determine and highlight any differences in microstructure morphology compared to the standard heat treatment.

Casting trials on the first- and second-stage nozzle and first-stage shroud configurations continued at casting suppliers to optimize the processing. Non-destructive tests (NDT) were conducted on successful trials. Dimensional and metallurgical evaluations continue to be made on the trial parts at the casting suppliers to assess and optimize the casting processes. Preliminary acceptance limits for the airfoil components were established, and the information was relayed to and discussed with the suppliers. A program is in progress with a casting supplier and a core supplier to better understand and improve core processing for bucket applications. An evaluation of a variety of cores has been initiated.

A number of candidate coating systems and application processes are being examined to assess the viability and processes required to apply the best integrity internal and external (non-TBC) coatings on ATS-sized and configured airfoils. Buckets were prepared with various metallic coatings to obtain information on their application processes and subsequently to obtain performance information on full-size parts. Scale-up trials were completed. Thirty-seven full-size buckets were coated in 4Q95. In addition to the bucket tests, laboratory information was generated in small burner rigs to continue to evaluate the oxidation life and integrity of the coatings. In order to provide a relatively quick and inexpensive means of ranking coating susceptibility to cracking, initial laboratory trials were performed to measure the strain-to-cracking behavior of coatings as a function of temperature.

Critical mechanical tests on bucket and nozzle materials continued. Creep tests were conducted on standard bars as well as specimens to assess geometry effects. Specimens were examined, both visually and metallographically, after testing. Low cycle fatigue (LCF) tests initiated in 3Q95 using notched bars designed to simulate the conditions in a bucket dovetail were completed. It was observed that the fatigue notch sensitivity was typical of high-strength airfoil alloys. Long-term creep tests continued on latter-stage bucket materials, including tests to assess orientation and geometry effects. Creep rupture testing was performed on samples of first- and second-stage nozzle materials thermally pre-exposed earlier. Pressurized and non-pressurized LCF tests were performed on tubular samples of the first-stage nozzle material. The test bars were previously cast to size and were deliberately cast with defects in the gauge section. Some solid, defect-free specimens were also cast and tested for comparison purposes. As testing of samples is completed, the fracture surfaces undergo stereomicroscopic evaluation.

A program was initiated to select the best post-cast processes. Samples of bucket materials were prepared. LCF data on the effect of post-casting processes on the first- and second-stage bucket materials were obtained, and metallography was performed on these samples to evaluate the general microstructure. Metallographic analysis of shaped cooling holes produced by a candidate manufacturing procedure was completed.

Section 2.2.4.11 (GTMTCB) Combustion Materials and Processes

Objective

Properties of materials for combustion components will be evaluated at ATS conditions. Where necessary, trial components will be made in order to acquire material of the appropriate size using full-scale manufacturing processes.

Technical Progress

Spray metal tooling previously produced using an existing design was used to provide wax patterns. The process necessary to achieve patterns with high integrity was developed, and waxes were obtained. Initial trials with a thermally controlled solidification processing technique resulted in a complete casting for evaluating this method of fabrication. Initial non-destructive testing was completed with good results. One piece will be fully processed for parameter selection. Additional liners will be sectioned for metallographic evaluation.

and mechanical testing to be performed in subsequent reporting periods. Slabs of material were processed that will be used to supplement the mechanical testing from the cast parts for purposes of obtaining additional property data to aid in final material selection.

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.

Technical Progress

Discussions were held with a potential supplier to review the producibility of the steam box in its current configuration. An exhaust structures design review was held.

Section 2.2.4.13 (GTMTSH) Turbine Shells

Objective

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

Technical Progress

Mechanical properties testing of materials for casing applications was performed. Coefficient of friction/wear testing on five different material combinations (including base materials, wear pads, and coatings) was initiated. All samples were machined successfully and, where appropriate, specimens were coated. Testing was initiated on two of the combinations, and some test results were received. The results were analyzed, and it was determined that changes to the test parameters will be required for future tests to obtain more reliable results.

Coefficient of thermal expansion testing was completed on two candidate shell materials to aid in the final down-selection of the prime material.

Applicable material and process specifications for producing turbine shells were identified. As a result of working with suppliers, a preferred method of fabricating turbine shells was chosen. Details regarding the processing and inspection methods to be used were discussed with one of the potential suppliers.

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

Improved gas path seals will be developed for the ATS turbine using seal technology from aircraft engine components where applicable. The technology will be evaluated using developmental hardware and samples. These advanced seals will provide evolutionary advances in machine performance.

Technical Progress

Alternate joining methods for attaching seals and/or hardfacing materials were reviewed. Producibility issues were identified.

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.

Technical Progress

Existing aircraft engine repair processes were reviewed, and the development necessary to scale up to the large airfoils was identified.

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 process conditions critical to the properties of the TBC system will be evaluated. The initial work will focus

on three major areas: 1) deposition temperature effects, 2) off-angle deposition, and 3) plasma gun velocity effects. The primary objective will be to identify critical process parameters as they apply to the coating of ATS components.

The TBC Non-destructive 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.

Technical Progress

The spray motions developed for the first-stage nozzle were used to coat two components. Three additional iterations of the spray motion were conducted to further improve the uniformity of the coating thickness. These components will be used for a rig evaluation. Surface finishing of the components was completed by hand polishing.

Spray motion development was completed for the Transition Piece (TP) and one component was coated for rig evaluation. The TP was heat treated after coating. A second component was coated with attached samples for characterization of the TBC applied to the TP.

Spray motions were developed for a first-stage bucket. A series of parts were coated for evaluation.

Spray booth equivalency studies were conducted at several GE development and manufacturing sites. These studies identified potential improvements to the thermal spray system.

Coating of test samples for the determination of the vendor process window has been completed, and these samples are being evaluated.

TBC Manufacturing Technologies:

Improvements to the software used for off-line development of spray motions were made to enhance the ability to upload and download spray motion programs to the robot controller.

A series of first-stage buckets were coated with TBC for initial surface finishing trials. Two vibratory finishing methods were selected for evaluation. The surface finish and material removal achieved in the various trials are being evaluated.

TBC Process and Diagnostics:

Work to evaluate the effect of deposition temperature on coating properties continued. All sample testing for this series of experiments is complete except the furnace cycle tests (FCT) of the samples removed from the plates. Statistical analyses were performed for deposition temperature, tensile cohesion strength, and modulus of elasticity.

Techniques for measuring the plasma gun velocities and standoff distances over a complex geometry were developed. This information is necessary for identifying the limitations of various robotic systems and for controlling the thickness and properties of coatings on

airfoils. Modifications and upgrading of the equipment and analysis technique for the measurements are continuing.

Experiments were performed at a range of velocities and gun standoff distances to identify the optimal combination for coating airfoils. Preliminary evaluations of the data were completed.

Experiments to evaluate the effect of spatial non-uniformities in the bond coat on TBC spallation life were initiated. FCT testing was used to evaluate coating life. Metallographic and SEM evaluations were performed to assess compositional variability. It was hypothesized that localized regions of severe oxidation, related to spatial non-uniformities in the bond coat, occur during high temperature exposure. Future work will quantify the effects of the spatial non-uniformities and examine the influence of bond coat/substrate interaction.

TBC Non-destructive Evaluation:

The coating of vendor TBCs with a range of bond coat and top coat thicknesses was performed.

An enclosure is being constructed for the infrared (IR) radiometric system for thermal imaging of coated components.

An eddy current procedure for measuring the thickness of the ceramic portion of the TBC was developed for flat surfaces. A literature survey is being conducted to provide guidance on eddy current probe selection.

A portable capacitance gauge was received. A capacitance probe is being designed for use in trials on the specimens being built for the eddy current thickness method.

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 TBCs 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 differing 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 on 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.

Technical Progress

Two TBC-coated samples were tested for LCF endurance for 1200 and 1500 cycles at greater than ATS conditions. (See Section 2.2.3.7.) Two different TBC microstructures were used for these tests. Loss of TBC occurred in both tests. It is believed that the TBC loss was preceded by cracking of the substrate metal.

One TBC-coated samples with pre-deposited environmental contaminant was tested. The sample was tested for 30 cycles at reduced conditions. TBC spallation occurred during the test due to interaction between the environmental contaminant and the TBC. A second sample will be tested.

One TBC-coated tophat was installed in the electron-beam test facility for endurance testing. This sample will be tested under full ATS conditions.

Section 2.2.5.3 (GTTDD) 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.

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. This will include effects of long-term exposure on top coat and bond coat physical and mechanical properties.

Technical Progress

Analytical Predictions of TBC Stress/Strain Response and Life:

Finite element analyses of the FCT results continued. During thermal cycling, stresses are generated in the FCT specimens primarily because of the mismatch in coefficients of thermal expansion (CTE) of the bond coat and TBC. The TBC elastic through-thickness (or delamination) stress is primarily zero except in the vicinity of a free edge. In this location there is a stress singularity that causes high stresses and high stress gradients. Upon elastic cool-down, the entire FCT specimen returns to its initial state. However, when bond coat creep is modeled, the stress states in the bond coat and TBC do not return to their initial states upon cool-down. The conclusions from these analyses are that

the through-thickness stress resulting from bond coat creep contributes to the TBC stress state during thermal cycling.

Establishment of Experimental Matrix and Sample Preparation:

A test matrix was established to emphasize materials and processes critical to durability of TBCs for ATS components. Initial testing is being performed at greater than ATS conditions. Two different thermal exposure cycles are being used. The FCT is a one-hour cycle and the furnace exposure test (FET) is a ten-hour cycle. Sample groups extracted prior to failure are being evaluated using metallography and SEM. Mechanical properties of the coatings at various stages of thermal cycling are determined. Arrhenius plots are constructed from the failure time data and used as a guide in defining failure mechanisms.

The data collected to date indicate that the life of the primary TBC system will exceed ATS requirements. The FCT matrix is being expanded to examine the relationship between cycles-to-failure and furnace dwell time in greater detail. This is important in order to accurately extrapolate the test results to ATS conditions.

Section 2.3 (CC) Combined Cycle Integration

Section 2.3.1 (CCSD) Combined Cycle Systems Design

Objective

Optimization analyses 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 specify control system design. Operability will be assessed.

Technical Progress

The gas turbine performance prediction program (i.e., cycle deck) has been updated to reflect current design status and estimated final performance characteristics. The steam system model has been revised based on this updated cycle deck. Models of the fuel heating and cooling-air cooling systems, generator, major mechanical auxiliaries, and unit control continue to be updated and incorporated into the steady-state performance model (SSPM). Information from this SSPM will be used to release steam turbine and heat recovery steam generator (HRSG) requirements for detailed design.

Control constants are being tuned to complete the control model portion of the dynamic model. An initial run of load change from base load to full speed no load (FSNL) has been made and is being used to further refine the dynamic model.

The cooling-air cooling system has been optimized by including an evaporative heat exchanger.

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.

Technical Progress

Several options continue to be developed for the cooling-air cooling system; initial options involved a combined circuit with the fuel heating system operating at a lower pressure. Newer options have been developed that are not combined with the fuel heating system and where the water circuit operates at a much higher pressure than earlier options. In order to narrow the options, a performance study and a cost analysis were conducted. Several new suppliers for heat exchangers and pumps were pursued in order to develop a budgetary cost estimate based on preliminary specifications. To date, based on the results of the performance study and the cost analysis, the list of seven options for the cooling-air cooling system has been narrowed down to two options which proved to be the best in both performance and cost. Further analysis is underway to make the final selection between the two remaining options.

Preliminary analysis of a more efficient exhaust diffuser has resulted in establishing goals for increased pressure recovery. The structural limits of the diffuser design and the physical limitations of the diffuser (e.g., how much space the diffuser will occupy vs. amount of space the average customer will have available) are being defined. The result is a new diffuser configuration that still meets the pressure recovery goal but at a shorter physical length than the previous configuration in order to satisfy space requirements. CFD analysis, rather than costly model testing, will be used to develop various diffuser configurations.

Section 2.3.3 (CCCL) Controls

Objectives

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 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.

Technical Progress

The definitions of the HRSG and steam turbine continuous loop algorithms and the unit startup and shutdown sequence logic are nearing completion. The definition of the control

algorithms and logic has been implemented using control engineering tools. These tools allow functional block diagram definition of each control algorithm and logic sequence and provide a mechanism to generate software code automatically from the diagrams. The generated code is currently being tested in two simulation environments. The first concentrates on the thermodynamic response and the other on the control dynamics of the advance machine process model.

Definition of the gas turbine continuous loop algorithms is progressing. Strategies for control of the steam cooling system are being closely coordinated with the unit startup and shutdown sequence logic. Initial release of the gas turbine control definition is being tested within a simulation environment.

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.

Technical Progress

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

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 procurement schedules and cost will be defined.

Technical Progress

Development of the forging process continued, and estimates of the forging die material requirements were received in preparation for placing a tooling order.

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.

Technical Progress

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

Section 2.6 (DE) Pre-Commercial Demonstration

Objective

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

Technical Progress

GE continued to support the potential host utilities' technical and commercial evaluations. Economic evaluations consisting of capital price (both turnkey and equipment only), variable/fixed fuel cost assumptions, and variable/fixed operation and maintenance estimates were reviewed with potential "hosts" for different sites.

The second Utility Advisory Board (UAB) meeting was held to update UAB members on the status of Advanced Machine performance, operability, maintainability, reliability, availability, plant arrangements, and installed cost. The UAB feedback is critical as GE focuses on the importance of operability, reliability, and availability.

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.

Planned 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.

Technical Progress

The Phase 3 NEPA Topical Report was submitted. Financial tracking routines were implemented. Necessary software was obtained and accounts were set up to permit electronic funding request and collection. The first three Federal Assistance baseline forms (F4600.3, F4600.4, and F4600.5) were prepared and submitted. Subcontract passdown clauses were identified and are being implemented for compliance with ATS program requirements. GE's petition for an advance waiver of patent rights was submitted to and approved by DOE.