If you are interested in more information or pricing for any of the products listed below, please contact inquiries@spsinc.com and reference the product number you are interested in.

GE94-02: Repair Flow Testing and Calibration Procedures for General Electric Frame 7E and 7EA Combustion System Fuel Nozzles for the Multi-Nozzle Quiet Combustor. February 1997.

This report describes the procedures developed and verified to inspect, repair and flow test fuel nozzle assemblies for the G.E. Frame 7E/EA Multi Nozzle Quiet Combustor (MNQC) system. The flow test facility developed to accomplish this work is also described. The absolute quality of the instrumentation used for flow testing and measurements is given. Two new fuel nozzle assemblies were initially flow tested, disassembled, dimensionally inspected and reassembled for final flow testing to establish the recommended procedures. These procedures establish the basis to inspect, repair and flow test field service-run fuel nozzle assemblies. All of the data developed for the two new fuel nozzle assemblies and one set of ten-field service fuel nozzle assemblies are presented. Analysis of the flow data, over a wide range of test conditions, show highly accurate, consistent and reproducible results. The final confirming check for the quality of repaired and restored field service-run fuel nozzle assemblies would be based on performance data from a turbine into which the fuel nozzle assemblies had been installed. This was not possible within the time constraints of this project. It is expected, because the ten field service-run fuel nozzle assemblies are closely matched that the field performance results would have been excellent.

GE94-06CX: Repair Specification for General Electric MS7001 Combustion Liners Manufactured from Hastelloy X Alloy. July 1995.

This specification covers the minimum requirements for the weld repair and heat treatment of General Electric MS7001 combustion liners manufactured from Hastelloy X (49Ni 22Cr 18Fe 9Mo 1.5Co 0.5W) alloy. Both the slot cooled (in single and multiple fuel nozzle configurations) and louver cooled designs are covered. Liners repaired to these requirements should provide service life approaching that of new components.

GE94-06TBC. Repair Specification for the Deposition of Thermal Barrier Coatings by Low Pressure Plasma Spray. July 1995.

This specification covers the minimum requirements for the thermal barrier coating of General Electric MS7001 combustor transitions manufactured from Nimonic 263 (51.5Ni 20Cr 20Co 5.9Mo2.2Ti 0.45Al) alloy as well as combustion liners and transitions manufactured from Hastelloy X (49Ni 22Cr 18Fe 9Mo 1.5Co 0.5W) alloy using the low pressure plasma spray process.

GE94-06TPN. Repair Specification for General Electric MS7001 Combustor Transitions Manufactured from Nimonic 263 Alloy. July 1995.

This specification covers the minimum requirements for the weld repair and heat treatment of General Electric MS7001 combustor transitions manufactured from Nimonic 263 (51.5Ni 20Cr 20Co 5.9Mo2.2Ti 0.45Al) alloy. Transition pieces having fixed aft brackets or moveable brackets are covered. Transitions repaired to these requirements should provide service life approaching that of new components.

GE94-06TPX. Repair Specification for General Electric MS7001 Combustor Transitions Manufactured from Hastelloy X Alloy. July 1995.

This specification covers the minimum requirements for the weld repair and heat treatment of General Electric MS7001 combustor transitions manufactured from Hastelloy X (49Ni 22Cr 18Fe 9Mo 1.5Co 0.5W) alloy. Both the thin wall and heavy wall (Block III) designs are covered. Transition pieces repaired to these requirements should provide service life approaching that of new components.

GE94-15-06: Corrosion Resistance Testing of Coatings Employed for Gas Turbine Discs. July 1995.

Corrosion of turbine disks results from condensation of moisture in the air when the units are out-of-service. This is especially serious in peaking gas turbines where the units are frequently started and stopped. The cyclic heating and cooling of turbine disks combined with condensation aggravates the situation. In the newer units under full load conditions the wheel space temperature can be as high as 1100F. As a result, many gas turbine rotors, wheels and disks exhibit pitting corrosion at their surface. Vendors have begun applying corrosion resistant coatings to these components in an effort to combat the pitting corrosion. This report documents the durability of three commercially available corrosion resistant coatings for turbine disk materials. The three coatings include a General Electric CC-1 and three Sermatech, Inc. coatings: 2F-1, M-1 (a thicker version of the 2F1 coating), and 5380DP. To get a good statistical average, four test coupons per coating type were used in the tests. Both the ASTM B117 Salt Spray Test and ASME B368 CASS Test were utilized to evaluate the various coatings. The results of the Salt Spray Tests indicated that GECC-1 coating surface failed (indicated by greater than one percent surface area of the specimen was corroded during testing) after 330 hours, 2F-1 coating failed after 376 hours, M1 coating after 440 hours and 5380 DP coating after 400 hours. However, further testing to evaluate the coating for subsurface corrosion indicated that the GECC1 had relatively far less subsurface corrosion compared to the other three coatings even after 1100 hrs of testing. Based on these observations GECC-1 was determined to be the best performer when compared to the other three coatings in the salt spray and subsequent thermal cycle tests. Under the CASS test all the coatings had almost identical exposure times prior to failure. Typical coating life under CASS testing was 160 hr. at 120^0F and 72 hours at 300^0F with a linear variation in between.

WE94-03: History of Mature Frame Westinghouse Compressor Disk Problems. July 1995.

This report reviews and analyzes the mature frame Westinghouse gas turbine compressor disc problems including disc ovalization, migration and cracking. Included is a history of the compressor disc problems compiled from a survey of Westinghouse gas turbines owners. The pertinent Westinghouse Service Bulletins and Technical Publications were reviewed. Also, “indicators” or “signatures” for detection of disc problems were investigated, and Westinghouse recommended operational procedures for mitigation of disc migration and ovalization were reviewed.

Aero 95-01: Good Maintenance Practices Guide Book for Pratt & Whitney Ft4-A8 and A9 Power Packs. December 1996.

There are number of utilities that operate Pratt & Whitney FT4 A-8 and A-9 aero-derivative gas turbines in peaking duty. Most of these turbines have been in operation since the mid-1960’s. The current day economic and regulatory climate is causing many utilities to look closely at extending the useful service life of this aging fleet of turbines as an alternative to investment in new facilities. Their objective is to maintain this capacity as long as possible at a minimum cost. Two factors are critical in order to achieve this objective. They are: 1) implementing good operation and maintenance practices and, 2) keeping track of the availability of critical components. In order to address these issues, members of the Combustion Turbine and Combined Cycle (CTC^2) Users' organization initiated two projects. Project #AERO 95-01 addresses the operation and maintenance practices, and project #AERO 95-02 addresses the availability of critical components. This report contains the results of work carried out under the first project: AERO 95-01 -- *Good Maintenance Practices Guide Book for Pratt & Whitney FT4-A8 and -A9 Power Packs.*

Aero 95-02: A Survey of Pratt & Whitney FT4-A8 and A9 Aero-Derivative Gas Turbine Parts Availability. December 1996.

There a number of utilities who operate Pratt & Whitney (P&W) FT4 A-8 and A-9 aero-derivative gas turbines in peaking duty. Most of these turbines have been in operation since the mid-1960's. The current day economic and regulatory climate is causing many utilities to look closely at extending the useful service life of this aging fleet of turbines as an alternative to investment in new facilities. Their objective is to maintain this capacity as long as possible at a minimum cost. Two factors are critical in order to achieve this objective. They are: 1) implementing good operation and maintenance practices and, 2) keeping track of the availability of critical components. In order to address these issues members of the Combustion Turbine and Combined Cycle User's Organization (CTC^2) initiated two projects. Project number AERO 95-01 addresses the operation and maintenance practices, and project number AERO 95-02 addresses the availability of critical components. This report contains the results of work carried out under AERO 95-02 — *Identify Suitable Replacements for Obsolete/Inadequate OEM Equipment for Pratt & Whitney FT4 Engines.*

GE96-06: Thermal Barrier Coating (TBC) Repair Specifications for GE MS7001 Combustor Liners and Transition Pieces. December 1996.

The purpose of this project was to produce a purchasing specification for the application of Thermal Barrier Coatings (TBC's) to extend the life of service exposed MS7001 combustion hardware. The specification produced covers the minimum technical, processing and quality requirements for coating of components used in the B, E, EA, F and FA versions of the engine.

This report describes some of the important features of the specification and provides some guidance for its use.

As part of the preparation of the specification, analyses were conducted on combustion components from an MS7001FA turbine and on samples provided by several after-market coating vendors. The results of those analyses are also presented in this report.

GE96-10B1. Specification for Repair of MS7001 EA, F, FA First Stage Buckets. July 1998.

This specification identifies the requirements for repair of MS7001EA F and FA first stage buckets, which are made from GTD 111 nickel-base alloy in equiaxed and directionally solidified forms. It includes provisions for repair by re-coating and optionally weld repair and/or HIP rejuvenation, as specified in the purchase order. The life extension achieved by repair will depend on the condition of the buckets as removed from service and the extent of repairs performed.

GE96-10B2. Specification for Repair of MS7001 EA, F, FA Second Stage Buckets. July 1998.

This specification identifies the requirements for repair of MS7001EA, F and FA second stage buckets that are made from IN 738 or GTD111 nickel-base alloy with optional provisions for the removal and re-application of protective coatings. The repaired bucket life should approach service life of the new buckets.

GE96-10B3. Specification for Repair of MS7001 EA, F, FA Third Stage Buckets. July 1998.

This specification identifies the requirements for repair of MS7001EA, F and FA third stage buckets that are made from Udimet 500 or equiaxed GTD111 nickel-base alloy with optional provisions for the removal and re-application of protective coatings. The repaired bucket life should approach service life of the new buckets.

GE96-10N1. Specification for Repair of MS7001 EA, F, FA First Stage Nozzles. July 1998.

This specification identifies the requirements for repair of MS7001EA first stage nozzles, which are made from FSX 414 cobalt-base alloy. The repaired nozzles life should safely achieve regularly scheduled overhaul intervals.

GE96-10N2. Specification for Repair of MS7001 EA, F. FA Second Stage Nozzles. July 1998.

This specification identifies the requirements for repair of MS7001EA, F and FA second stage nozzles, which are made from FSX 414 cobalt-base alloy or GTD222 nickel-based alloy. The repaired nozzles life should safely achieve regularly scheduled overhaul intervals.

GE96-10N3. Specification for Repair of MS7001 EA, F, FA Third Stage Nozzles. July 1998.

This specification identifies the requirements for repair of MS7001EA, F and FA third stage nozzles, which are made from FSX 414 cobalt-base alloy or GTD 222 nickel-based alloy. The repaired nozzles life should safely achieve regularly scheduled overhaul intervals.

GE96-11C. Specification for Repair of MS7001 F and FA Combustor Liners. July 1998.

This specification identifies the requirements for repair of MS7001 F and FA combustion liners manufactured from Hastelloy X, Haynes 188, Inconel X750 and Nimonic 263 alloys with a thermal barrier coating.

GE96-11T. Specification for Repair of MS7001 F and FA Transition Pieces. July 1998.

This specification identifies the requirements for repair of MS7001 F and FA transition pieces manufactured from Hastelloy X and Nimonic 263 with a thermal barrier coating.

GE96-20M. Eddy Current Measurement of Thickness and Degradation in Advanced Gas Turbine Coating Systems. November 1996.

An eddy current method was developed for estimating the relative degradation of the General Electric proprietary GT-29PLUS coating system on directionally solidified GTD-111 first stage turbine buckets. The method consisted of recording the magnitude (vector length) of the impedance during a sweep of frequencies from 500 KHz to 6.0 MHz. We then employed the variations of magnitude with frequencies as parameters for the correlation with coating structure and composition.

The instrumentation system incorporated an SE Systems, Inc. SmartEDDY 3.0 digital eddy current module, with software modified to conduct a frequency sweep, into a standard Structural Integrity Associates TestPro data acquisition and analysis system. An SE Systems 3 mm. diameter probe in a 5 mm. diameter housing was positioned in a holder that controlled lift-off and normality. The procedure included balancing (nulling) the instrument at 2.0 MHz at each test location.

A Frame 7FA bucket, removed for refurbishment after 18,700 hrs. of operation on natural gas, was sectioned to allow metallographic evaluation of the coating at 50 percent span. The thickness of the interdiffusion layer between plasma sprayed GT-29 and the substrate alloy and the equivalent thickness of beta cobalt aluminide in the outer layer of the coating were measured at several locations and compared against various eddy current signal parameters involving the magnitude versus frequency response. One parameter — the rms slope of both the high frequency and low frequency portions of the sweep — was ultimately selected.

Reproducible correlations between coating layer thickness and rms slope were obtained for the particular blade tested. The interdiffusion layer thickness, estimated by the low frequency eddy current parameter, was shown to provide an acceptable indication of relative surface temperature, and the approximate remaining beta aluminide layer thickness could be estimated from the high frequency parameter. The calibration curves for different batches of coated blades were found to be different, requiring reference measurement of each batch at a location of low operating temperature. The procedure developed can be used to compare these batches and insure the selection of representative blade samples for field tests.

Sections of a Frame 6B bucket that had operated for about 10,000 hr. were also evaluated by metallography and tested by the eddy current procedure. While only minimal in-service degradation was found from the metallographic data, the eddy current test results were different and, in turn, appeared to represent differences in the initial coating process.

Acceleration of the degradation of other coated samples was accomplished by furnace exposure. These experiments produced samples that were moderately degraded and differed in their eddy current responses. The main results were that the as-processed GT-29 (without over aluminizing) was differentiated from GT-29PLUS and GTD-111 by lift-off tests, while the exposed GT-29 coating produced a similar eddy current response to the GT-29PLUS coating.

With normalization of the test for different batches of blades, the eddy current method can be employed in its present state of development to estimate the relative degradation of the GT-29IN-PLUS coating. However, with further development, the method should be capable of predicting the remaining life of the coating system. Additional testing of the effects on eddy current response of processing variations in the beta aluminide concentration and thickness of the plasma sprayed layer and of cyclic operation versus base load is required in order to achieve additional confidence and accuracy in the microstructural correlations.

GE96-20-2: Eddy Current Method for Measuring Combustion Turbine Blade Coating Deterioration. September 1999.

GEN96-07: Evaluation of Turbine Blade Coating Stripping Processes. March 1999.

Commercial stripping methods for the removal of MCrAlY overlay coatings (where M indicates Ni, Co, or their combinations) were evaluated using service-exposed combustion turbine blades. The stripping methods included conventional hydrochloric, nitric/phosphoric and sulfuric/hydrochloric acid immersion techniques, as well as a diffusion aluminize and mechanical strip procedure. The coatings included in the vendor evaluation were an over aluminized CoCrAlY (GT-29 In-Plus), a stand-alone CoNiCrAlYSi (Sicoat 2231) and an over aluminized NiCoCrAlYHfSi (PWT-286). Dye-penetrant examination, contour measurements and optical metallography were used to evaluate the stripping processes. The acid stripping solutions were capable of removing residual coating and interdiffusion layers containing a certain amount of the aluminum-rich, β- (Ni,Co)Al phase. They are not effective at removing remnant coating layers completely depleted of β phase or internally-oxidized and γ'-depleted nickel-base superalloy alloy substrates. In contrast, the diffusion aluminize and mechanical strip process was less selective and removed areas of residual coating in addition to internally oxidized and depleted base alloy. However, the thickness of the aluminized layer varied due to geometry effects, and some manual blending was still required after heat tinting. The results of this study and prior experience were used to develop a Stripping Guideline for the removal of these MCrAlY coatings without damage to the turbine blades.

GEN96-08: Evaluation of Directionally Solidified Turbine Blade Repair Processes. February 1999.

The objective of this program was to conduct a preliminary evaluation of repair techniques for the dimensional restoration of service-exposed, directionally solidified (DS) industrial gas turbine blades. The components provided for the vendor repair demonstrations were General Electric MS7001F first stage buckets, manufactured from DS GTD-111 alloy with the GT-29 In-Plus coating system. These buckets exhibited (1) severely oxidized (burned) airfoil tips; (2) radial thermo mechanical fatigue cracks in the squealer tip walls and (3) worn angel wing seals. The welding procedures evaluated included manual TIG/wire, automated CO_2 laser/powder feed, and micro plasma/powder feed methods. The recrystallization behavior of the DS GTD-111 alloy was also investigated to determine the thermal exposure limits of this alloy. It was found that DS GTD 111 alloy could be successfully welded by the elevated temperature TIG and CO_2 laser methods using René 80 and René 142 filler alloys, respectively. The micro plasma powder feed method also produced acceptable welds using IN-625 filler alloy. In contrast, micro plasma powder feed welds with IN-738 filler alloy exhibited cracking in both the weld deposits and the DS substrate alloy. The DS GTD-111 alloy exhibited unacceptable surface recrystallization (to depths of 0.004 inches or more) after 8-hour thermal exposures at 2100, 2150 and 2200^{o}F. At 2050^{o}F, recrystallization beneath the machined root faces and simulated foreign object damage (FOD) indents was limited to depths of approximately 0.001 inches after 8-hours exposure. The implications of these results have been discussed in addition to the issues requiring further substantiation before the repairs are attempted on serviceable DS blades.

GE98-01A: Specification for Thermal Barrier Coating of FSX-414® Combustion Turbine Nozzles. March 2000.

This specification establishes the minimum technical requirements for applying a two-layer (metallic and ceramic) thermal barrier coating (TBC) on FSX-414, cobalt –base alloy substrates.

GE98-01B: Specification for Thermal Barrier Coating of GTD-111® Combustion Turbine Buckets. March 2000.

This specification establishes the minimum technical requirements for applying a two-layer (metallic and ceramic) thermal barrier coating (TBC) on GTD-111, nickel –base alloy substrates.

GE98-02: The Life Cycle Value of TBC Coatings on MS7001E/EA First Stage Nozzles and Buckets. February 2000.

The purpose of this project was to investigate the life cycle value of TBC coatings on GE MS7001E/EA 1st stage turbine nozzles and buckets. The life cycle cost/benefit analysis indicated that the combined, net present worth of older style 1st stage nozzles and buckets could be increased by between $225,000 and $4,200,000 over a 12-year analysis period for a single unit plant. The net present worth was maximized using strategies that involved increasing the firing temperature from 2020°F from 2035°F. The economic benefits were greatest for MS7001E/EA units in continuous vs. peaking duty.

GE98-06: MS7001E/EA 1st Stage Parts Life Extension vs. Expedited Depletion. July 1999.

The purpose of this project was to perform an analysis of expedited GE MS7001E/EA 1St stage nozzle and bucket life depletion under uprated (2035?F) operating conditions.

The life cycle cost/benefit analysis indicated that the combined net present worth of older style 1st stage nozzles and buckets could be increased by between $450,000 and $1,190,000 over a 12-year analysis period for a single unit plant. These gains were realized through O&M strategies that included (1) expedited life depletion, (2) repair and re-use (including the application of TBC coatings) and (3) the replacement of older style components with conventionally cast, 1st stage buckets with TBCs vs. upgrading to current design DS GTD-111 buckets.

GE98-06-2. Determination of Cumulative Effects of Over and Under Firing Temperatures on MS7001EA Component Life. September 2000.

The purpose of this project was to evaluate the life-cycle effects of including significant periods of over-firing and/or under-firing in the operating profile of MS7001E/EA units. Within the limits of the O&M models and the component life assumptions utilized, the economic evaluations demonstrated that power plant operators could significantly enhance overall profitability by selectively over or under firing at opportune times. The greatest economic benefits were associated with balancing over firing with under firing, such that parts lives remain essentially constant. Balancing over firing with shortened HGPI intervals is a simpler strategy to implement and produced economic benefits approaching those associated with under-for-over firing.

GEN98-01. Standardized Life Assessment Guidelines for First Stage Turbine Vanes and Blades. January 2000.

The primary purpose of these guidelines was to identify methodology to determine the remaining useful life of first stage combustion turbine components, and to develop generic evaluation procedures and acceptance criteria for replacement or refurbished blades and vanes. This standardized life assessment guideline addresses several needs identified by operators of large frame combustion turbines with respect to the maintenance of first stage components.

GEN98-15. Third Party Replacement Blade Specification for IN-738 Low Carbon Blades. March 2000.

This specification provides the minimum material specification technical requirements necessary for the purchase of IN-738 Low Carbon (LC) blades for the hot section of gas turbines from third party, non-OEM vendors.

AERO99-26: FT4/GG4 1st Stage Turbine Nozzle Assembly Reverse Engineering and Product. February 2001.

GE99-03. Evaluation of Wear Packages for GE Gas Turbine Combustion System Components. April 2000.

This report summarizes the results of a program to gather information on and evaluate industry experience with wear packages for the major combustion system components in heavy frame General Electric gas turbines. These wear packages represent various techniques being used to minimize wear and erosion of the components. Wear, erosion and other damage to combustion components typically dictate the maximum allowable service intervals between mandatory shutdowns for inspection. Hardsurfacing, the application of wear or erosion resistant materials at critical areas on combustion components, can lengthen inspection intervals and decrease the level of repairs required following service.

Formal industry surveys were used to gather program information: survey questionnaires were sent to both gas turbine operators and to the independent (non-OEM) repair shops that typically refurbish these parts. The combustion components specifically included in the report are transition pieces, combustion liners, crossfire tubes/retainers and fuel nozzles.

GEN99-01. Predictive Maintenance Testing of Air-Cooled Generators Driven by Combustion Turbines. August 2000.

The alternating current electric generator has proven to be one of the most reliable components of a gas turbine generating power station. Generator reliability depends upon three factors: proper application, proper operation and regular maintenance. Over the past several years there has been a move from preventative maintenance practices to predictive maintenance. The move is due to improved diagnostic techniques and a more active approach to generator maintenance. This report addresses predictive maintenance and the monitoring techniques that have been developed to detect potential failures. No single test can detect a potential failure. It is a combination of tests over time that can detect deterioration of the generator systems. The CTC^2 organization initiated this project to provide air-cooled gas turbine generator maintenance personnel with a comprehensive review of the testing that would be most useful and cost effective on their generators. Experienced engineers can use the combination of tests covered in this guideline along with visual inspections, the generator history files and maintenance records to analyze the condition of the generator and determine corrective action.

GEN99-13. A Survey of Nondestructive Evaluation Methods for Thermal Barrier Coating. July 2001.

Thermal barrier coatings (TBCs) are used to reduce the operating temperature of the metal components they cover. TBC is now being applied in land-based combustion turbines (CTs) to extend the design life rather than as a system to allow increases in the unit operating temperature. This is expected to change as new CT models actually incorporate the characteristics of TBC into their basic design approach.

Because the use of TBC in land-based CTs is growing rapidly, it will be useful to have nondestructive evaluation (NDE) approaches available to determine their condition. The ideal NDE method would be able to determine where the TBC is in the degradation cycle leading to failure so that examinations would allow the estimation of the remaining life. Also, to be ideal, the NDE method would be able to be applied *in-situ* to the area of interest without any more disassembly of the CT than would normally occur at that point in the planned maintenance and inspection program. This project surveyed the state of development of visual, thermography, laser fluorescence, laser ultrasonic and eddy current NDE methods for TBC. The present strengths and weaknesses of each method as well as its future potential were evaluated and are described.

GEN99-16.. The Use of Optical Pyrometry on Combustion Turbine First Stage Blades with Thermal Barrier Coating. April 2001.

Optical pyrometry is presently used to monitor the surface temperature of selected areas of MCrAlY coated first stage blades in combustion turbines on a few operating units in the United States and overseas. The system in most common use, built by Land Infrared, evaluates radiation from the blades in a short wavelength bandwidth. Since MCrAlY coatings are opaque at this wavelength the system operates with minimum error. The thermal barrier coating (TBC) now being applied on blades is not opaque and this may introduce significant error in the indicated temperature obtained from a short wavelength system. An alternate optical pyrometry system is now under development, which collects and analyzes coating radiation of a much longer wavelength where the TBC properties are close to ideal.

The strengths and weakness of each system were evaluated in terms of the errors in indicated temperature that could result. This evaluation included the analysis of the optic properties of pieces of TBC that had been in service for widely different amounts of time. The provision of guidance to users considering the acquisition of an optical pyrometry system for monitoring the surface temperature of first stage blades with TBC is also included.

GEN99-22. Analysis of Compressor Water Washing. May 2000.

This report provides set guidelines about the utilization of compressor water washing for industrial gas turbines. A thorough investigation of the benefits and adverse effects of both off-line and on-line water washing are analyzed with specific recommendations provided to operators of gas turbines. Extensive surveys were performed to gather the relevant industry data from gas turbine operators, vendors and OEMs. An economic analysis of the value of compressor water washing is also included as a guideline to operators when making economic decisions regarding water washing.

GEN99-24. Status of Repair Technology Available for IN-738 Gas Turbine Blade (Bucket) Repair. March 2000.

The current worldwide population of heavy frame gas turbines used for electric power generation utilizes the superalloy IN 738LC more than any other material for the critical rotating blades in the hottest turbine stages. Significant damage that is routinely incurred during service has historically resulted in blade replacement rather than repair because the material is extremely difficult to weld without cracking. Traditional arc welding processes have been developed, but they can only be implemented when weld filler alloys much weaker than the blade alloy are employed. Thus, repairs have been limited to the outermost extremities of the blades where the applied stress is very low. Replacement costs, which have always been high, have increased dramatically in recent years and this has spawned development programs at many of the companies engaged in commercial blade repair. Little, however, is known about the actual progress made.

The CTC^2 organization initiated this project to determine the maximum blade repair limits that are currently being implemented in the industry and to gauge the status of development work. The ultimate goal was to find if current repair limits could be increased. A formal survey was distributed to a worldwide list of repair companies. The results of that survey form the basis of this report.

GEN99-25. In Situ Compressor Coatings Evaluation. April 2000.

This report provides performance comparisons on the effects of coating the compressor airfoils of a Westinghouse 501F gas turbine. The performance data is plotted as a function of time for the megawatt output, heat rate, adiabatic compressor efficiency and airflow of the coated unit and compared to the performance data for a sister unit that was left uncoated. FP&L reported that the coated unit experienced a four-megawatt increase in output after the compressor coating outage. However, the data available to this investigation started 3 months after the outage and the performance retention characteristics of the coated and uncoated units are similar. This indicates that the coated airfoils are not deteriorating any faster than the uncoated units for the 12 months of data that were reviewed. Analysis of a longer time period following coating may provide more meaningful separation of the trend curves.

AERO99-26-2. FT4/GG4 3rd Stage Turbine Nozzle Reverse Engineering and Product Definition. February 2001.

GE20-29. Low Pressure Plasma Spray Build-up of IN738 Buckets. April 2002.

This report provides a detailed metallurgical analysis of a first stage GE Frame 7C bucket set following repair and build-up using a low pressure plasma spray (LPPS) coating process. The bucket set was service run for 18,000 hours and 832 starts before the analysis.

GEN20-05. Cost Benefit Analysis of Compressor Blade Geometry Restoration. May 2002.

The present study provides guidance to combustion turbine operators, quantifying the extent of blade surface and geometry degradation in terms of power loss and heat rate increase. An economic model illustrates how an optimum maintenance interval depends on the blade row involved, extent of degradation, time-wise variation of the degradation, cost of maintenance and fuel and power sales revenue. The steps needed to make an assessment of the effects of axial compressor degradation on combustion turbine power output and heat rate are described and examples are provided. The degradation factors include increased roughness, erosion, increased tip clearance and foreign object damage. Results of multi-stage axial compressor simulations are given for the effects on compressor efficiency and air flow due to the degradation of any blade row. The effects of the compressor losses on power and heat rate are determined from cycle analyses. Finally, the economic benefit is assessed based on a model for the rate of degradation, cost of repair, cost of fuel and power sales revenue. The results are presented in a manner useful for practical application to determine the extent and frequency of compressor repair.

GEN20-08. Cost of Cycling Gas Turbines. November 2001.

CTC^2 members identified a potential project concerning the costs of cycling gas turbines in 1999 and requested that at study be conducted to determine to what extent component degradation during the start and cycle would exhaust life and require a new or reworked components. Structural integrity was contracted to survey CTC^2 members to determine their experience with component life and to develop an Excel spreadsheet that would permit users to quickly estimate the cost of a start.

Thermo- Mechanical Fatigue (TMF) damage for each start was estimated using the General Electric approach, where start factors including hot, warm or cold conditions are considered as well as ramp rates, whether normal or peak loads are achieved. This is much preferable to the Siemens-Westinghouse and Alstom approach where each start is assigned a number of equivalent operating hours. In this approach, the equivalent operating hours (10 or 20) is divided by the expected life of the component (25,000 hours) for a life fraction consumed. This is then multiplied by the cost of the component to get the cost of a start.

The information was programmed into an Excel workbook, "Cost of a Start" provided with this report on a 3.5" floppy disk. The workbook consists of 13 separate sheets, each of which prompts the user to enter information regarding the start-up, how long the unit generated electricity, cost of components and fuel and selling price of the electricity generated. The workbook calculates the cost of the start and the subsequent run and then subtract the costs to generate the electricity and the component damage to determine if the start-run was profitable from an economic standpoint.

Two example problems are provided to assist the user in interpreting results. After a few uses, it becomes apparent that the important factors are the length of the generations run and the selling price of the electricity (assuming most users have long term contracts for fuel and do not have to rely on the spot market) in determining whether a particular start/run was economical.

The spreadsheet is sent in the protected mode with no password. Users who have a working knowledge of Excel will easily be able to customize the workbook to suit their own history of component wear.

GEN20-10F. Control System Specification for Turbo Power and Marine Combustion Turbines. August 2002.

This report embodies a general retrofit specification for Turbo Power & Marine (TPM) FT-4 Twin Pac simple cycle combustion turbine control systems. This document is not intended to be a purchase specification, but can be used as a guide in the preparation of more specific documents applicable to particular units and users.

This document is not applicable to: combined cycles, SCRs, CEMs, industrial drives, nor to machines with dry low NO_x or advanced combustion systems.

GEN20-10GE. Control System Specification for General Electric Industrial Type Combustion Turbines. April 2002.

This report embodies a general retrofit specification for General Electric simple cycle combustion turbine control systems. This document is not intended to be a purchase specification, but can be used as a guide in the preparation of more specific documents applicable to particular units and users.

This document is not applicable to: combined cycles, SCRs, CEMs, industrial drives, nor to machines with dry low NOx or advanced combustion systems.

GEN20-10Pt1. Control System Specification for Combustion Turbines. December 2001.

This report embodies a general retrofit specification for simple cycle combustion turbine control systems. This document is not intended to be a purchase specification, but can be used as a guide in the preparation of more specific documents applicable to particular units and users.

This document is not applicable to: combined cycles, SCRs, CEMs, industrial drives, nor to machines with dry low NOx or advanced combustion systems.

GEN20-10W. Control System Specification for Westinghouse Combustion Turbines. April 2002.

This report embodies a general retrofit specification for Westinghouse simple cycle combustion turbine control systems. This document is not intended to be a purchase specification, but can be used as a guide in the preparation of more specific documents applicable to particular units and users.

This document is not applicable to: combined cycles, SCRs, CEMs, industrial drives, nor to machines with dry low NOx or advanced combustion systems.

GEN20-17. Dry Low NO_x Operation Impacts on Combustor Parts Wear. April 2002.

CTC^2 members identified a potential problem with dry low NO_X combustors and requested that a study be conducted to determine the extent, if any, of the dry low NO_x combustors causing excessive wear of combustor parts. Structural Integrity Associates was contracted to survey CTC^2 members to determine their experiences with dry low NO_X combustors and to identify which manufacturers units were experiencing excessive wear problems, what diagnostic tools could be used to detect wear on combustion components and estimate the economic impact of this problem on annual operating costs.

Most of the members contacted had very little or no operating experience with dry low NO_x combustion systems. Overall, the GE systems tended to have problems related to wear or fretting, particularly in the liner collar. One user is suggesting several fixes. The Westinghouse systems had problems with wear, fretting and cracking in the combustor baskets and transition pieces, with several reported cases of portions of these components entering the hot gas path and causing consequential damage. The one reported case of a Siemens V94.3a showed considerable wear after less than two years of service, requiring replacement of several combustion components.

While it is factual that the dry low NO_x (DLN) combustion system gives rise to pressure pulsations and the “humming” that accompanies these pulsations, problems with fretting, wear and transition piece cracking have been found on both Westinghouse and GE machines in the past, suggesting that DNL aggravates the situation, but is not necessarily the root cause of these problems.

Detection of these pressure pulsations and “humming” is accomplished by mounting piezo-electric transducers onto the outside of the combustion section of the turbine and monitoring both the frequency and magnitude of the signals over the load range of the unit. This is done by both GE and Westinghouse is developing a system that will permit users to monitor their machines in the future, but there has been no commercial offering as of this report. Very little information is provided to users as to the allowable magnitude and frequency of these pressure pulsations and the most common method of control is to reduce load when the “humming” becomes clearly audible.

HRSG20-14. Life Extension Techniques for HRSGs in Cycling Service. October 2001.

With the advent of deregulated power generation, more and more combined cycle and cogeneration plants are being operated in a cycling mode. This can cause accelerated wear and tear on the heat recovery steam generator (HRSG), especially if it was not originally designed to accommodate cycling.

This report reviews the negative impacts cycling can have on an HRSG. Those impacts can be grouped into two main categories: those related to thermal stress and those related to water chemistry. Thermal stress related problems are principally caused by either ramping at excessive rates or by thermally shocking metal parts during start-up or shutdown. Water-related problems can ultimately almost all be traced back to poor lay-up practices. This report describes techniques that can be employed to mitigate or even eliminate these problems. The techniques include both changes in operating procedures and modifications or additions to plant equipment. Recommendations for design changes are provided for both existing plants and for new, yet to be built, combined cycle plants.

WE20-06. For Sealing Blade Tips in Industrial Gas Turbine Compressors. December 2002.

The efficiency of an axial compressor is reduced by loss of air through the gap between tips of the blades and the wall of the case. This loss can also reduce revenues from industrial gas turbines. Abradable coatings on the case wall can eliminate these losses by sealing this gap. As the turbine spins up the full speed, blades stretch and the tips cut a groove into the abradable material creating the airtight seal.

Abradable systems created by combining four different bondcoat materials and five different topcoats are evaluated in this study. Mechanical, thermal and corrosion tests are used along with rub tests in a high-speed rig that simulates typical operating conditions to select two abradable systems for trial as tip seals in SWPC W501-type turbines. A computational flow model predicts that an abradable seal could increase turbine compressor efficiency as much as 0.5%. Payback in less than six months is projected for base-loaded machines, and less than two years for peaking-duty machines.

GE21-06. Thermal Heat Transfer Analysis for GE First Stage Nozzle. December 2004.

This project has been initiated due to the needs of a more detailed temperature study under various firing temperatures and for different Thermal Barrier Coating (TBC) materials for the 1st stage nozzle of a GE 7EA turbine. The overall purpose of the project is to prepare an optimized TBC thickness and generate a design specification for various TBC parameters. Parameters such as firing temperature, TBC thickness and TBC material are considered. The complexity of influence parameters on nozzle temperature distribution dictated the selection of only the most critical sets of temperatures and two representative TBC materials. Very broad research of the problem, namely in Europe and Japan, addresses the various TBC materials, methods of application, and future trend of TBC thermal protection. However, limited information is available on actual temperature distributions in nozzles subjected to different firing and cooling temperatures.

This effort is to determine a correlation between firing and cooling temperatures, TBC thickness, and TBC material in relation to temperature distribution on the nozzle substrate surface for GE 7EA 1st stage nozzle. The hope is to derive a guiding method, utilizing the latest computational methods in the industry today, that illustrates how to control the surface nozzle temperature with simple temperature predicting tools. This prediction is provided in both graphical and tabular formats to depict the substrate surface temperature versus TBC thickness prediction.

GEN20-07. Gas Turbine Performance Improvement through Component Redesign. July 2002.

The designs of several popular gas turbines (GE 7EA & 7FA, Siemens-Westinghouse 501F & 501FC) are reviewed. Performance derivatives are calculated for the gas turbines in simple cycle operation, based on design point cycles synthesized for each machine.

Among the concepts evaluated are improved rotating airfoil (blade) alloys, application of TBC to blades and stationary airfoils (vanes), reduced turbine tip clearance, application of brush seals and re-design of vane segments to allow use of superior coatings.

Concepts for design improvement, along with a qualitative explanation of the benefit, are presented. Qualitative results for each concept are presented in tabular form. Budgetary estimates for program and implementation costs are presented for the purpose of enabling a cost-benefit analysis.

GEN20-13. Correlation of Blade Path Temperature Spreads. March 2000.

The purpose of the study was to determine if a “signature” correlation exists between BPT and component degradation. A correlation of the blade path temperature (BPT) spread with fuel nozzle deterioration and combustor can location was completed. The use of the average BPT and the BPT differences was found to be the best approach to assessing the impact of fuel system deterioration. A turbine gas path was modeled and analysis performed to develop an algorithm that relates the BPT data to specific combustor cans. The most important cause of increased BPT spread was found to be the differences in fuel flow to the combustors. Several other causes of BPT spread were investigated. The effect of hot section deterioration on the BPT pattern was found to be minor.

GEN20-15. Performance Monitoring Software Survey. October 2002.

A survey was conducted of 20 vendors who supply performance monitoring software for simple cycle combustion turbine and combined cycle power plants. Performance monitoring software provides information on the thermodynamic performance of power plants. Typically the software indicates both the actual performance and the expected performance of the plant.

The results of the survey have been compiled and impartial comparisons of the vendors' packages are provided including information on price and software capabilities. Background information is also provided on the causes of performance degradation in combustion turbines.

GEN21-15. Accelerate Deployment of Aftermarket Parts. May 2003.

With the recent boom in the combustion turbine industry, original equipment manufacturers, OEM's, have been hard pressed to keep pace with demand for spare parts in sufficient quantity to meet customer needs. This has been most evident in the capital parts market. Driven by increased demand and decreased supply, prices have been increasing, some as much as 16% annually when averaged over the last 10 years.

This dynamic market has prompted several companies to investigate and evaluate and in some cases enter into direct competition with the OEM's, and have started manufacturing many of these spare parts. These companies, either aftermarket service providers, or in some cases end users, have invested millions in developing their manufacturing capabilities. In order to accomplish this, many factors must be thought through. Factors such as:

- ❖ Scope of supply – What parts should be targeted
- ❖ Alternatives – Are there already alternatives to the OEM's which are currently offering these parts
- ❖ Partnerships – Is it better to partner with another similarly situated entity rather than go it alone
- ❖ Manufacturing – What technology is required to accomplish this, and what are the options for acquiring the capabilities
- ❖ What is the risk / reward ratio

These factors, of course, provide for a whole array of sub-factors as well. As part of the evaluation of the risk / reward ratio, one of the significant sub-factors, to which a great deal of attention and effort must be paid, is the legality of pursuing such a strategy and business philosophy. This of course opens up the issue of patent infringement.

The right of an inventor to legally protect his or her invention is a right guaranteed by the 1st Article of the US Constitution. Gas turbine OEM's, in particular General Electric, GE and Siemens Westinghouse Power Corporation, SWPC, utilize patents liberally, and between the two companies have in excess of 56,000 patents which have been assigned to them. (Patents for inventions by corporate employees, which have been assigned to their respective employers). In their efforts to compete with these two manufacturers, non-OEM's must invest significant resources into evaluating these patents before they can commence manufacturing or selling such parts, without infringing existing patents. With infringement defined broadly, by one attorney specializing in such issues, as, “the manufacturing, offering for sale, or selling any product which includes the elements of even one claim made within a patent filing, is guilty of infringing that patent.”

This paper attempts to, qualitatively, shed light on what steps must be taken by any entity, which desires to reverse engineer, enhance engineer, or manufacture parts, which by be patented. It is by no means a exhaustive dissertation on the subject, and can offer no hard and fast guidelines in avoidance of infringement, rather this paper examines the patent process, dissects some of the patents issued to either SWPC or GE, claim by claim, in an effort to offer suggestions and guidelines for avoiding infringing the patents.

GEN21-19: Combustion System Dynamic Monitoring. September 2002.

Monitoring combustion system dynamic pressure has, so far, been performed largely by the Original Equipment Manufacturers (OEM), and primarily after modifying or changing the combustion hardware, to ensure that the new hardware performs in accordance with OEM requirements. However, as the user community becomes more comfortable with the technology, and as they gain in knowledge and understanding of the advances turbine systems and their inherent complexities, especially as it relates to dry combustion systems, what was once considered “Black Art” and the realm of the OEM Engineering Specialist, is now beginning to find acceptance as another weapon in the arsenal, in an attempt to control maintenance cost.

All combustion processes, although for the purposes of this report we will concentrate on dry NO_X combustors, result in an inherent pressure release, called “thermoaccoustic” pressure. In very basic terms, the combustion system pressure is directly proportional to the combustion efficiency of a dry NO_X combustor. By design, these combustors are intended to burn a homogenous, or completely pre-mixed fuel and air mixture, at a fuel lean ratio, or one in which there is less than the stoichiometric, or ideal, fuel to air ratio. However, due to inefficient mixing, local “pockets” of diffusion mode flame may be present, which will demonstrate a higher combustion pressure than the pre-mixed flame. By monitoring these pressure pulses, the O&M Professional can gain insight into the health of the combustion system. Some of the problems, which can be detected through the proper application and use of one of these systems, are shown below:

- Combustion system hardware incipient failure
- Fuel control valve calibration
- Fuel nozzle pluggage/bypass

- Fuel gas purity problems

GEN21-20: A Concept for Measurement of Creep Deflection in Latter Stage Turbine Blades. September 2002.

Creep is the expected failure mode for latter stage (stages 2 & 3 in GE 7E and 7F machines, stages 3 & 4 in Siemens-Westinghouse 501F machines) turbine blades. The topic of airfoil creep is briefly reviewed. Measurement of the creep deflection in the blades after service will enable correlation of blade growth with operating hours and help assess the validity of the hours-based retirement criterion.

This report provides the CTC^2 member with a concept for a blade creep measurement tool that can be used on a wide range of latter stage blades. Fundamental issues pertinent to accurate measurement, as well as consideration affecting the results interpretation, are discussed.

GEN21-17: Quality Control Specification for Gas Turbine Repair Facilities. June 2004.

This specification establishes the requirements for Quality Control Programs to be implemented and maintained by combustion turbine repair facilities. This specification is applicable to facilities performing repairs or refurbishment of components in the hot gas path, which includes turbine rotating, turbine stationary and combustor section components. The purpose is to ensure that the repair shops are satisfying industry best practices in the following areas:

- Welder Certification
- Heat Treatment & HIP equipment (calibration and operation)
- Moment weighing equipment (calibration and operation)
- NDE equipment operation and calibration
- Dimensional checking equipment

The accompanying audit specification checklist allows users of repair facilities to perform a comprehensive audit to determine the suitability of repair facility's existing Quality Control Program.

GEN22-05: Metallurgy of GT Alloys. March 2004.

The objective of this work was to conduct literature survey to determine the existing published work on the five GT alloys: MAR-M-247, NIMONIC-263, RENE'N5, GTD-111 AND GTD-222. The report contains the information about the alloys composition, fabrications methods, physical and mechanical properties, heat treatments, repair techniques and environmental properties.

GEN99-01-2: Optimum Predictive Maintenance Procedures for Air-Cooled Generators. August 2004.

Air-cooled electric generators have proven to be one of the most reliable components of a gas turbine power station. Over the past 10 years increased use of air-cooled generators in simple and combined cycle power plants has increased their share of the US power supply. While very reliable, the older air-cooled generators still require considerable maintenance due to accumulation of dirt on the windings and deterioration of the insulation due to exposure to excessive temperatures and stresses due to thermal, mechanical and electrical sources. Traditionally, maintenance has been conducted at calendar-based intervals as dictated by the manufacturer. Over the past several years there has been a move from preventive maintenance toward predictive maintenance based on equipment condition. This report reviews industry data collected from utilities, manufacturers and service providers and develops predictive maintenance strategies based on a combination of on-line monitoring techniques and electrical testing designed to optimize major maintenance based on machine condition. This trend toward predictive maintenance has been shown to be effective for other power plant components and involves making a trade-off between costs associated with major maintenance and acceptance of a risk of continued operation. These opposing factors can best be balanced by associating the costs of each and balancing them through Financial Risk Optimization to maximize the value of maintenance expenditures. The FRO technique is discussed and presented in the form of an Excel workbook that allows operations personnel to calculate the financial risks and rewards in a clear, simple manner.

GEN 21-11: TBC Performance Effects on General Electric Frame 7EA Combustion Turbines. November 2005.

TBC materials extend the life of combustion turbine components subjected to elevated temperatures and increase resistance to oxidation and cracking. At the same time, the presence of TBC can cause heat rate performance degradation. In addition, thicker applications of TBC material are subject to spalling (i.e.: loss of TBC material). When a lower base metal temperature is desired, the solution is not as simple as applying a thicker TBC. All of the variables must be considered. A prediction for the substrate surface temperature for first stage buckets is necessary to indicate the specific Thermal Barrier Coating (TBC) thickness application that may provide the best approach, considering both thermal protection of the buckets and total life cycle costs.

This project provides a steady state finite element heat transfer analysis of the first stage turbine bucket in a GE MS7001EA combustion turbine. The project examines the sensitivity of the bucket substrate temperature at the several locations on the bucket for two different TBC Materials (YSZ and Advanced – Neodymium Zirconate) and three different TBC thicknesses:

- 3 mils
- 9 mils
- 12 mils

Based upon these results, data tables have been created to allow a user to determine the effects that TBC will have on their components by listing the expected bucket substrate temperatures for the full range of TBC thicknesses studied for two different types of TBC material. In addition, an automated spreadsheet tool has been created to allow for extrapolating the results for different combustion turbine firing temperatures.

GEN21-11: TBC Performance Effects on General Electric Frame 7FA Combustion Turbines. November 2005.

TBC materials extend the life of combustion turbine components subjected to elevated temperatures and increase resistance to oxidation and cracking. At the same time, the presence of TBC can cause heat rate performance degradation. In addition, thicker applications of TBC material are subject to spalling (i.e.: loss of TBC material). When a lower base metal temperature is desired, the solution is not as simple as applying a thicker TBC. All of the variables must be considered. A prediction for the substrate surface temperature for first stage blades is necessary to indicate the specific Thermal Barrier Coating (TBC) thickness application that may provide the best approach, considering both thermal protection of the blades and total life cycle costs.

This project provides a steady state finite element heat transfer analysis of the first stage turbine bucket in a GE MS7001FA combustion turbine. The project examines the sensitivity of the bucket substrate temperature at the mid cross section location of the blade for two different TBC Materials (YSZ and Advanced – Neodymium Zirconate) and three different TBC thicknesses:

- 5 mils

- 10 mils
- 15 mils

Based upon these results, data tables have been created to allow a user to determine the effects that TBC will have on their components by listing the expected bucket substrate temperatures for the full range of TBC thicknesses studied for two different types of TBC material. In addition, an automated spreadsheet tool has been created to allow for extrapolating the results for different combustion turbine firing temperatures.

GEN21-11: TBC Performance Effects on Siemens Frame 501D5/D5A Combustion Turbines. November 2005.

TBC materials extend the life of combustion turbine components subjected to elevated temperatures and increase resistance to oxidation and cracking. At the same time, the presence of TBC can cause heat rate performance degradation. In addition, thicker applications of TBC material are subject to spalling (i.e.: loss of TBC material). When a lower base metal temperature is desired, the solution is not as simple as applying a thicker TBC. All of the variables must be considered. A prediction for the substrate surface temperature for first stage blades is necessary to indicate the specific Thermal Barrier Coating (TBC) thickness application that may provide the best approach, considering both thermal protection of the blades and total life cycle costs.

This project provides a steady state finite element heat transfer analysis of the first stage turbine blade in a Siemens Power Corporation Model 501D5/D5A combustion turbine. The project examines the sensitivity of the blade substrate temperature at the mid cross section location of the blade for two different TBC Materials (YSZ and Advanced – Neodymium Zirconate) and three different TBC thicknesses:

- 5 mils
- 10 mils
- 15 mils

Based upon these results, data tables have been created to allow a user to determine the effects that TBC will have on their components by listing the expected blade substrate temperatures for the full range of TBC thicknesses studied for two different types of TBC material. In addition, an automated spreadsheet tool has been created to allow for extrapolating the results for different combustion turbine firing temperatures.

GEN21-11: TBC Performance Effect on Siemens Frame 501F Combustion Turbines. November 2005.

TBC materials extend the life of combustion turbine components subjected to elevated temperatures and increase resistance to oxidation and cracking. At the same time, the presence of TBC can cause heat rate performance degradation. In addition, thicker applications of TBC material are subject to spalling (i.e.: loss of TBC material). When a lower base metal temperature is desired, the solution is not as simple as applying a thicker TBC. All of the variables must be considered. A prediction for the substrate surface temperature for first stage blades is necessary to indicate the specific Thermal Barrier Coating (TBC) thickness application that may provide the best approach, considering both thermal protection of the blades and total life cycle costs.

This project provides a steady state finite element heat transfer analysis of the first stage turbine blade in a Siemens Power Corporation Model 501F combustion turbine. The project examines the sensitivity of the blade substrate temperature at the mid cross section location of the blade for two different TBC Materials (YSZ and Advanced – Neodymium Zirconate) and three different TBC thicknesses:

- 5 mils
- 10 mils
- 15 mils

Based upon these results, data tables have been created to allow a user to determine the effects that TBC will have on their components by listing the expected blade substrate temperatures for the full range of TBC thicknesses studied for two different types of TBC material. In addition, an automated spreadsheet tool has been created to allow for extrapolating the results for different combustion turbine firing temperatures.

GEN22-13: Quality Control Requirements for Thermal Barrier Coating Applications. January 2005.

This specification establishes the requirements for Quality Control Programs to be implemented and maintained by combustion turbine thermal barrier coating (TBC) facilities. This specification is applicable to facilities performing TBC on new or refurbished components in the hot gas path, which includes turbine rotating, turbine stationary and combustor section components. The purpose is to ensure that the coating shops are satisfying industry best practices.

The accompanying audit specification checklist allows users of TBC coating facilities to perform a comprehensive audit to determine the suitability of the coating facility's existing Quality Control Program.

GEN23-06: The Cost of Cycling a HRSG. May 2004.

A great deal of study has been completed relative the effects of cycling of combined cycle combustion turbine power generating facilities and cogeneration plants. The vast majority of those efforts have focused on the combustion turbine. Little has been done relative to the balance of plant or more specifically the Heat Recovery Steam Generator (HRSG). While a combustion turbine is the most costly plant component from a capital expense as well as operations and maintenance standpoint, the costs associated with operating and maintaining the second most costly component, the HRSG, also warrants attention.

The purpose of this effort is to correlate actual user cost data for cyclic induced HRSG damage to the design bases for purpose of developing generalized costs relative to cycling. This is a follow-up to the CTC2 study documented in Report No. HRSG20-14, "Life Extension Techniques for HRSGs In Cycling Service" that identified major problems encountered in cycling a HRSG as well as the best practices for mitigating those problems. The final result of this study is a Microsoft Excel workbook that provides a straightforward method for estimating the Cost to Cycle a HRSG.

GEN23-07: Survey of Aftermarket Component Suppliers. October 2004.

This report will provide the reader with a snapshot of companies that are currently active in the manufacture or sales of combustion turbine components, for all major heavy-duty industrial gas turbine manufacturers and the most commonly used turbine models. This report is complemented by GEN 23-08, "Survey of Non-OEM Refurbishment Firms" and GE 22-17, "DLN 1.0 Combustion Hardware", and together provides a comprehensive listing of all non-OEM parts and services providers. This report is further complemented by a searchable Microsoft Access Database that can provide the user with a complete listing of providers to fit their particular needs.

GEN23-08: Survey of Non-OEM Refurbishment Firms. October 2004.

This report will provide the reader with a snapshot of companies that are currently active in the repair and refurbishment of combustion turbine components, with particular emphasis on the hot section components for all major turbine manufacturers and the most commonly used turbine models. This report is complemented by GEN 23-07, “Survey of After Market Component Suppliers”, and GE 22-17, “DLN 1.0 Combustion Hardware”, and together provides a comprehensive listing of all non-OEM parts and services providers. This report is further complemented by a searchable Microsoft Access Database that can provide the user with a complete listing of providers to fit their particular needs.

GE24-12: An Embedded Combustion Turbine Maintenance Monitor for Mark V and Mark VI General Electric Turbine Control Systems. September 2004.

This report documents the work that was performed under CTC^2 2004 Project GE24-12, Timer and Counter by Bruce R. Fick Consulting, Inc of Jasper, GA. This project was instituted to develop a report, that provides technical guidelines for the implementation of custom software within the GE Mark V and Mark VI combustion turbine controls; that facilitates the real time, automatic calculation of combustion turbine maintenance factors, factored hours of operation and factored number of starts in accordance with GE publication GER 3620J.

This report provides detailed descriptions of the additions and modifications to the turbine control sequence program and configuration files, which are necessary to implement the Maintenance Monitor function within a GE Mark V and GE Mark VI turbine control systems by qualified engineering personnel.

GE24-13D1: Tuning Procedure for General Electric DLN-1 Combustion Systems. March 2005.

This document addresses some specific operational problems associated with the 7EA DLN-1 combustion systems. General procedures for troubleshooting and correcting these operational problems are presented. The specific issues addressed here are

1. NOx or CO emissions out of compliance at base load in premixed mode
2. NOx or CO emissions out of compliance at part load in premixed mode
3. Failure- to-transfer into premixed mode

The use of primary fuel split modulation is the main tool for tuning emissions problems. The effect of primary split on NOx and CO emissions is discussed, and specific procedures are given on how to adjust control constants in order to change split. The impact of combustion dynamics in emissions tuning is discussed.

When emissions cannot be corrected though the use of fuel split alone, additional options are presented for trying to correct the problem. Separate approaches to solving emissions problems are presented for base load and part load premixed operation. Lastly, the problem of the failure to transfer into premixed mode is discussed, and techniques for correcting the problem are presented.

GE24-13D2.6: Tuning Procedure for General Electric DLN-2.6 Combustion Systems. June 2005.

This document presents procedures for performing combustion tuning on DLN-2.6 combustion systems. These combustion systems are found on GE 7FA, 7FA+ and 7FA+e combustion systems.

The common reasons for tuning a DLN-2.6 combustion system are

1. To follow OEM guidelines recommending that tuning be performed after any combustion system hardware is replaced
2. To monitor and minimize combustion dynamics as they change in response to seasonal ambient temperature variations
3. To troubleshoot emissions or dynamics excursions outside permitted levels during normal unit operation

The first two items deal with tuning when there may not be any specific problem with the unit. They involve tuning to ensure that the combustion operation is optimized, that is, operating with sufficient NOx and CO margin while at the same time minimizing combustion dynamics. The third item involves tuning to troubleshoot a combustion-related problem. Typically, in a troubleshooting situation, a review of historical turbine and emissions data is first recommended before commencing with tuning. In all cases, tuning is primarily carried out through the modulation of either two or three fuel split schedules which control the spatial distribution of fuel within the combustion system.

This document starts with an overview of the DLN-2.6 combustion system and dynamic trends that are characteristic of the DLN-2.6. Then specific tuning guidelines are presented discussing the control constants and methods for modulating split schedules, examples of emissions and dynamics trends that can be expected, and a general method for establishing final split schedules. For units that employ high temperature fuel heating, the impact of fuel heating on dynamics and combustor tuning is discussed. Finally, additional means are presented for tuning emissions at base load when split adjustment is not sufficient to bring NOx into compliance.

GEN24-04: Assessment of Software Tools for Parts Tracking in Combustion Turbine Based Power Plants. September 2004.

In the power generation industry today, there is a need to track the life expended, repairs/repair ability and locations of capital parts. This is becoming more critical since several original equipment manufacturers (OEM) of gas turbine equipment are beginning to indicate that the operating profile of both their mature (E class) and advanced (F class) combustion turbines can have a significant and negative impact on the lifetime characteristics of hot gas path parts such as; stationary vanes/nozzles, rotating blades, combustor parts and turbine rotors. The impact is reduced time to required maintenance, as well as reduced life of critical high cost parts. The cost implications can be significant. Consequently, there is a greater need and burden on owner operators and asset managers to track the condition of these high cost capital parts, to determine scrap versus repair options, to develop realistic/empirical expectations for life based on operating profiles, and to manage the cost implications and impact.

This assessment was undertaken to developed evaluation criteria and provides an objective review of several commercially available parts tracking tools in response to the requirements for tracking gas turbine hot section parts. The assessment summarizes each tool evaluated against a list of predetermined evaluation criteria that are intended to identify elements that are deemed necessary to the ability to perform the parts tracking functions.

GEN24-05: Selective Catalytic Reduction (SCR) Catalyst Life Expectancy Study for Combined Cycle and Simple Cycle Gas Turbines. November 2005.

The SCR Catalyst Life Expectancy Study was conducted to develop a tool that could be used to plan the replacement of SCR catalysts for combined cycle and simple cycle combustion turbines that utilize SCR for control of nitrogen oxides. The study also evaluated mitigation measures that may increase SCR catalyst life, examined the impact of catalyst design margins in an attempt to determine how catalyst volume may affect catalyst life, and identified emissions monitoring problems that resolved malfunction conditions.

The CTC2 SCR Life Expectancy committee developed a survey that was sent to 211 facilities that included over 1000 combustion turbines at both combined cycle and simple cycle generating plants. In addition, three sites were selected for follow-up site visits and further study. In general, the results of the study have shown that SCR catalysts for combined cycle plants have lasted longer than the supplier warranties, and overall ratings were "as expected" or "better than expected." Simple cycle facilities with hot-SCR systems have been around fewer years, and all hot-SCR systems surveyed had problems related to premature catalyst degradation, ammonia slip, ammonia injection problems, flow distribution and monitoring.

GEN24-06: NDE In-Situ Monitoring of Combustion Turbine Components. April 2005.

The objective of this project is to evaluate new and novel NDT techniques and equipment that are commercially available for performing in-situ inspections of operating CT hot sections as well as in shop inspection of new or refurbished hot section parts. The project approach involved performing extensive literature and vendor surveys to determine what novel potentially applicable inspection techniques were available. This yielded ten NDT candidates for consideration and review:

- Laser Scanned Liquid Penetrant
- Digital Radiography
- Krypton Power
- Thermography
- Laser Shearography
- Laser Acoustic Ultrasonic Waves
- Laser Induced Fluorescence
- Acoustic Emission
- Multifrequency Array Eddy Current
- Phased Array Ultrasonics

Three NDT methods were selected for further detailed evaluation

- Acoustic Thermography
- Multifrequency Array Eddy Current
- Phased Array Ultrasonics

GEN24-07: Dual Fuel Reliability of Low NO_X Systems. December 2004.

A study about the reliability of dual fuel low NO_X combustion turbine power generation plants was conducted by Quietly Making Noise, LLC (QMN) for the Combustion Turbine and Combined Cycle (CTC^2) Users' Organization. The objective of the study was to obtain and evaluate plant design and operating data and information in order to assess potential problems or issues associated with the reliability of combustion turbine dual fuel low NO_X systems. QMN also conducted additional research into certain issues that emerged as common causes of decreased reliability, including fuel quality and fuel storage methods. Since the survey was directed at low NO_X dual fuel combustion turbine technology, the power plants targeted for the survey were those that operate on pipeline grade natural gas fuel and a liquid hydrocarbon fuel.

This report discusses the plant design and operating data gathered and provides information regarding the primary problems and issues being encountered with the reliability of combustion turbine dual fuel low NO_X systems. A summary of the survey responses in presented, along with recommendations for the next steps in evaluating this industry problem to move toward resolution and an overall improvement in reliability for this type of power plant.

GEN24-11: Generator Performance Monitoring Techniques Survey. February 2005.

In response to a recent increase in generator-related problems causing outages of combustion turbine generation units, a survey was conducted of 67 companies which either manufacture combustion turbine generators and/or exciters, or offer products and/or services for monitoring the condition of those generators. Monitoring techniques investigated include on-line performance monitoring software, partial discharge monitoring and other fault detection products and testing services. The results of the survey have been compiled and impartial comparisons of the companies' technique(s) are provided, including information on capabilities and price. Comments from reference users of the technique(s) are also provided when available.

The survey report includes background information which describes in detail the recent upward trend of generator-related outage issues and provides an overview of common problems which can lead to generator failure.

GEN25-06: Evaluation of Inlet Air Filters. September 2005.

Ambient air filters provide critical protection to the internal parts of combustion turbines by removing airborne contamination. The effect of this process is to reduce or prevent erosion and fouling of the turbine compressor blades. Secondary benefits include this same protection to cooling air passageways, fuel atomizing jets and hot gas parts. The means of accomplishing this are an integral component within any successful installation.

This report reviews the criteria for selecting inlet air filter elements and provides an overview of the intake filter "systems" in which they are installed. Applicable codes and industry standards are reviewed, as they apply, and the design and performance characteristics necessary to achieve the desired results are presented.

GE25-02EA: Specification for Overhaul of MS7001 E/EA Compressor and Turbine Rotors. November 2005.

This specification identifies the requirements for overhaul of GE MS7001 Model E/EA gas turbine compressor and turbine rotors. Rotor overhaul shall be performed in a Service Shop properly qualified as described in Section 5.1 of this document. The specification includes provisions to completely disassemble (unstack) both rotors as well as overhaul of both rotors without unstacking. Detailed technical and processing requirements are included to safely and efficiently return mechanically sound, well balanced rotors to the field.

GE25-02FA: Specification for Overhaul of MS7001 F/FA Compressor and Turbine Rotors. November 2005.

This specification identifies the requirements for overhaul of GE MS7001 Model F/FA gas turbine compressor/turbine rotor assemblies. Rotor overhaul shall be performed in a Service Shop properly qualified as described in Section 5.1 of this document. Given the 2-bearing design such that the rotor is shipped to a qualified shop in one assembly, this specification includes provisions to inspect/overhaul the rotor without breaking the marriage coupling between the compressor and turbine rotors, and thus does not address complete disassembling (unstacking) the individual compressor and turbine rotors. As industry knowledge of the Frame 7F/FA rotor is acquired over time, this specification will be amended to include uncoupling and compressor/turbine rotor unstacking procedures. Detailed technical and processing requirements are included to safely and efficiently return mechanically sound, well balanced rotors to the field.

GE23-12: Investigation of Frame 7/9FA Maintenance Interval Extensions. August 2006.

The Original Equipment Manufacturers (OEM's) recommended maintenance intervals for today's "F" class combustion turbines are influenced by duty cycles (hours, starts, cycles, load and trips), which are measured in terms of equivalent or factored hours and starts. In today's market, there is significant concern over parts life and reparability… with operating plants being challenged by parts life limits and cycles-driven maintenance requirements. There is a strong desire, driven by the economics of the plant, to extend the number of hours or starts (equivalent or factored) between major inspections (combustion, Hot Gas Path, Major)… and to effectively manage the time to perform the inspections.

Data from the ORAP® database maintained by Strategic Power Systems, Inc. ® (SPS™) on actual inspection intervals and times to perform, for these major inspections was reviewed to determine the field experience on extending these intervals. Additionally, operators were surveyed to understand their experience, and to qualitatively assess the part condition and reparability of the hardware at these inspections.

GE26-02: Coking of GE 7EA and 7FA Fuel Oil Check Valves – Review and Experience with Alternative Solutions. December 2006.

Liquid fuel check valves, which are located very near the combustion chambers on GE dual fuel gas turbines, have been a problem for decades. During operation on natural gas, the liquid fuel lies stagnant in the tubing runs leading to each chamber. The high ambient air temperatures near the combustion chambers cause the stagnated fuel oil to form coke deposits within the check valves and they lose their ability to seal. Leaking check valves result in trip-outs when attempts are made to transfer to liquid fuel during operation. They also prevent starting up on liquid fuel. The OEM has made many check valve design and supplier changes over the years and, more recently, has introduced a couple of cooling schemes aimed to overcome these problems. Unfortunately, check valve redesign and supplier changes have not resolved the problem and the more recent cooling schemes have not been well received – particularly for end users that would have to retrofit them at their own expense.

Alternative, non-OEM attempts to address this problem have come from two directions. Two check valve manufacturers have initiated new designs and several sets of these new components have been placed in service. One design is water cooled; the other is not cooled, but is said to be more resistant to coke formation and more capable of maintaining a seal. Two alternatives have emanated from the turbine owners themselves. One alternative relocates the existing check valves to a cooler location within the turbine compartment. The other adds redundant check valves. The redundant check valves are located in a cooler area and act as a back-up to the existing valves. This report reviews and critiques all of these alternatives and reports operating experience to date for each of them.

GEN24-10: Cost of Cycling a Generator. October 2006.

The CTC^2 membership has identified the "Cost of Cycling Generators" as a potential issue and general concern for further study. The focus of this study is the development of an Excel spreadsheet model that will take user specified input to develop the maintenance cost associated with cycling generators. Data from SPS's ORAP system is used to establish quantitative values that reflect the impact of cycling duty. Analysis of this data forms the basis for a model designed to create maintenance and cost estimates based on user specified plant characteristics and operational practices.

This report documents the data analysis process of the study as well as the development of the estimating model. It also provides the reader with instructions and explanations to the use of the Microsoft Excel spreadsheet application.

GEN26-01: Expansion Joint Selection Guide. November 2006.

The interconnection of the combustion turbine exhaust and the heat recovery steam generator allows for movement due to thermal and flow stresses created by the turbine exhaust. The means of isolating these stresses is through the use of an expansion joint. However, there are critical design features that must be considered to maintain the seal and prevent leakage.

This report studies the state of the art of high temperature expansion joints. Available technologies are reviewed, and the variables that affect performance and expected life are identified. Economics are also studied. The resulting information will assist a user with determining the best choice for their situation. Applicable codes and industry standards are reviewed and the design characteristics necessary to achieve the desired performance are presented.

GEN24-05: Selective Catalytic Reduction (SCR) Catalyst Life Expectancy Study for Combined Cycle and Simple Cycle Gas Turbines. March 2006.

The SCR Catalyst Life Expectancy Study was conducted to develop a tool that could be used to plan the replacement of SCR catalysts for combined cycle and simple cycle combustion turbines that utilize SCR for control of nitrogen oxides. The study also evaluated mitigation measures that may increase SCR catalyst life, examined the impact of catalyst design margins in an attempt to determine how catalyst volume may affect catalyst life, and identified emissions monitoring problems that resolved malfunction conditions.

The CTC^2 SCR Life Expectancy committee developed a survey that was sent to 211 facilities that included over 1000 combustion turbines at both combined cycle and simple cycle generating plants. In addition, three sites were selected for follow-up site visits and further study. In general, the results of the study have shown that SCR catalysts for combined cycle plants have lasted longer than the supplier warranties, and overall ratings were “as expected” or “better than expected.” Simple cycle facilities with hot-SCR systems have been around fewer years, and many hot-SCR systems surveyed had problems related to premature catalyst degradation, ammonia slip, ammonia injection problems, flow distribution and monitoring.

GEN 24-03: Equivalent Dense Vertically TBC Coatings. November 2007.

Dense vertically cracked thermal barrier coatings (DVC-TBC) are being used by General Electric to protect F class industrial gas turbine hot section components. DVC-TBC is produced by thermal spray processing and offers thermal protection along with strain tolerance for enhanced durability. In order to determine the current and future availability of DVC-TBC in the open market, two facets were explored. The first facet was a technical review of the patent database for this class of coating that identified the key patents and the companies that are actively pursuing protection via patent application. The technical details described in the patents were discussed and compared. The second facet was to contact independent coating and component repair companies to determine the status of DVC-TBC availability and development. It was discovered that a few companies currently offer independent DVC-TBC coatings, and others are in development.

GEN24-09: Generator Inspection & Overhaul Guideline. July 2007.

The maintenance guidelines was written to assist CTC^2 members assess the condition of gas turbine driven generators. They also serve to define the work scope for outage planning. The services of an experienced generator maintenance engineer should be utilized to assess the condition of generators that have been in service for more than 20 years. The owner's preventive and predictive maintenance program has an impact on how often the generator is opened up for inspection. Generators supplied by some manufacturers may require more frequent inspections. The maintenance guidelines will cover the following topics:

- Stator winding end turn bracing inspection
- Stator winding cleaning
- Stator core inspection
- Stator wedging inspection and testing
- Stator winding inspection
- Stator winding heaters
- Stator winding high voltage terminations
- Stator current transformers
- Field winding inspection
- Field forging and retaining rings
- Bearings and journals
- Collector ring inspection and maintenance
- Brush rigging inspection
- Brushless exciter inspection and maintenance
- Generator ventilation and cooling system

GEN27-08: Varnish Removal and Impact on Valve Operations. December 2007.

Varnish removal and the impact on valve operations are critical to understand in order to prevent and avoid severe extensive downtime and redundant expenditures. The most problematic issue with varnish is the operation and performance of servo valves. Lengthy downtime durations and excessive maintenance and parts sparing costs can be alleviated with the utilization of proper corrective actions. Fluid maintenance along with choosing the appropriate oil is essential for prolonging the lubricant's lifespan. No one corrective action can eliminate varnishing issues. Instead, various methods must be superimposed to attain the maximum varnishing containment potential. Such methods include the appropriate turbine oil selection, filter selection, oil monitoring and analysis, and varnish removal technology products.

This report provides the best practice guideline in controlling varnish in turbine lubricants along with the different causes and effect of oil degradation mechanisms. The scope of the assessment looks into ORAP® database to analyze problems due to varnishing issues for the historical and current time periods. In particular, careful attention is placed on servo valves since issues are more prominent with critical control systems. Performance comparisons of GE F and GE E class fleet units were identified to see if any correlations can be made between turbine design and varnishing problems. Qualitative data was collected form users and manufacturers to gain important insight on varnish problems, recommended corrective actions, and advisement on particular component suppliers. The best practices guidelines provide and define proper fluid maintenance, lubrication selection, and component supplier advisement. The best practices guideline allows users to attain the ability to mitigate and superimpose contaminant control practices to save their company a considerable amount of money.