COMBUSTION TURBINE (CT) HOT SECTION COATING LIFE MANAGEMENT

U.S. DOE NO.: DE-FC26-01NT41231

**Semi Annual Report
October 1, 2001 – March 31, 2002**

Principal Authors:

R. Viswanathan
K. Krzywosz
S. Cheruvu
E. Wan

Subcontractors

Southwest Research Institute
Turbine Technology International

Submitted by

R. Viswanathan
EPRI
3412 Hillview Avenue
Palo Alto, CA 94304
August 9, 2002

Disclaimer

“This (describe material) was prepared with the support of the U.S. Department of Energy, under Award No. DE-FC26-01NT41231. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE”.

COMBUSTION TURBINE (CT) HOT SECTION COATING LIFE MANAGEMENT

1.0 ABSTRACT

The integrity of coatings used in hot section components of combustion turbine is crucial to the reliability of the buckets. This project was initiated in recognition of the need for predicting the life of coatings analytically, and non destructively; correspondingly, three principal tasks were established. Task 1, with the objective of analytically developing stress, strain and temperature distributions in the bucket and thereby predicting thermal fatigue (TMF) damage for various operating conditions; Task 2 with the objective of developing eddy current techniques to measure both TMF damage and general degradation of coatings and, Task 3, with the objective of developing mechanism based algorithms. This report is a record of the progress to date on these 3 key tasks. Two supporting tasks relating to field validation (Task 4) and economic analysis (Task 5) have not yet been initiated.

TABLE OF CONTENTS

	Page
2.0 INTRODUCTION	6
3.0 EXECUTIVE SUMMARY	7
4.0 TASK 1: REFINEMENT AND VALIDATION OF HSLMP	9
4.1 Experimental	9
4.2 Results and Discussion	9
4.3 Conclusions	11
5.0 TASK 2: COATLIFE FOR ADVANCED METALLIC COATINGS AND TBCs	11
5.1 Task 2.1 Thermal Barrier Coatings	11
A. Experimental	11
B. Results and Discussion	13
5.2 Task 2.2 MCrAlY Coatings	13
A. Experimental	13
B. Results and Discussion	14
C. Conclusions	15
6.0 TASK 3: NDE OF COATINGS	16
6.1 Experimental	16
6.2 Results and Discussion	17
6.3 Conclusions	20

LIST OF GRAPHICAL MATERIALS

		Page
Figure 1	Finite Element Model and Metal Temperature Distribution of GE7FA+e 2 nd Stage Bucket	10
Figure 2	Flow Vectors in the 7FA+e 2 nd Stage Bucket Tip Shroud Region	10
Figure 3	The 3D-Finite Element Model for SW501FC 1 st Stage Blade	11
Figure 4	Microstructure of As-Deposited MCrAlY Coating	14
Figure 5	Cyclic Oxidation Behavior of MCrAlY Coating At 1450°F (1066°C)	15
Figure 6	F-SECT System	16
Figure 7	Three Layer Inversion Model for GT33+ Coating	18
Figure 8	Normalized Impedance vs Frequency Curves	19

2.0 INTRODUCTION

The objective of this project is to improve the reliability, availability and maintainability (RAM) of combustion turbines (CTs) by developing advanced technology for assessing and managing the life of protective coatings on CT blades and vanes.

In recent years, combustion turbines (CTs) have become the equipment of choice for power generation by both electric utilities and independent power producers. Continuing advances in design concepts and in structural materials and coatings for CT hot-section components have enabled increases in rotor inlet temperature resulting in major efficiency gains. These high temperatures mandate the use of coatings on hot section components (blades and vanes) to protect them from oxidation. Degradation of these protective coatings represents a major profitability challenge for turbine owners. Coating life usually dictates blade refurbishment intervals – which typically are shorter than desired for baseload units. Downtime for coating inspection and replenishment requires dispatch of less-efficient generating equipment or purchase of replacement power. Coating failures can lead to rapid, severe damage to the superalloy substrate, warranting blade replacement. Replacement of a conventionally cast alloy blade row can cost up to \$3 million in the case of directionally solidified or single-crystal blades with internal cooling. Unavailability costs can run up to \$500,000 in lost revenues per day for a 500MW combined cycle plant. Blade failures can also cause downstream damage in the turbine, causing prolonged outages and revenue loss. Moreover, losses to electricity customers due to disruption in supply can also be very substantial. A proper life management system for coatings represents a major step in preventing such major losses to the CT owner and to society at large.

The life management activities covered in this project for coatings directly impact the objectives of increasing RAM of CTs. Accurate life management techniques optimize refurbishment intervals and operating practices, thereby avoiding unplanned outages. Currently, coating refurbishment intervals are dictated by empirical, fleet-specific (rather than unit-specific) manufacturer recommendations based on the concept of “equivalent operating hours (EOH).” The new technology generated in this project will enable machine-specific calculations of coating remaining life and direct measurements of the same using non-destructive evaluation (NDE) techniques.

The project is intended to develop improved analytical and nondestructive evaluation techniques to assess the consumed life and/or estimated life of protective coatings on CT blades and vanes, and then integrate these techniques with economic risk-based decision-analysis tools to optimize run/repair/replace decisions. The project is defined along five major technical tasks including:

- Task 1. Refinement and Validation of Hot Section Life Management Platform (HSLMP)
- Task 2. COATLIFE for Advanced Metallic Coatings and TBCs
- Task 3. NDE of Coatings
- Task 4. Field Validation of COATLIFE and NDE
- Task 5. Economic Risk-Based Decision Analysis

This report summarizes results from the first three tasks. Tasks 4 and 5 have not yet been initiated at this time.

3.0 EXECUTIVE SUMMARY

In Task 1 geometric data for both a W501FC 1st stage blade and a GE 7FA+e 2nd stage blade each have been assembled. Data for a GE 7FA+e 2nd stage blade was collected from samples at the Richmond plant operated by Progress Energy. A W501FC 1st stage sample blade provided to TTI was cut into segments in order to obtain details of the internal geometry. All measurements have been consolidated into formats as required to construct appropriate finite element models used by life management platform. At present, an aero-thermal model of the 7FA+e 2nd stage blade has been constructed to include the capability to perform a heat transfer analyses of the external gas flow and internal cooling flow associated with the bucket. Initial metal temperature distributions were obtained by iterating the heat conduction and heat transfer models. A tip leakage flow analysis was pursued to refine the prediction of heat transfer near the tip shroud region. In parallel with the 2nd stage bucket work, a finite element modeling for the S-W W501FC 1st stage blade has been completed based on the aforementioned measured data.

The objective of this task 2 is to develop the capability of the COATLIFE code to handle spallation life prediction for TBCs that are being used in advanced turbines manufactured by major domestic OEMs and to enhance COATLIFE to cover broader range of MCrAlY coatings for oxidation life prediction. The COATLIFE model treats coating degradation mechanisms that are applicable to TBC spallation, and bond coat degradation resulting from loss of aluminum. Isothermal oxidation tests at three temperatures are being conducted on TBC coated GTD 111 and IN-738 specimens with two different bond coatings.

Cyclic oxidation tests on MCrAlY coated specimens have been conducted to determine the constants for COATLIFE model. Cyclic oxidation testing at a peak temperature of 1066°C (1950°F) was completed. Test at a peak temperature of 1010°C (1850°F) has been initiated. At both temperatures, the specimens initially gained weight due to formation of oxide scale with thermal cycles and then the specimen lost weight due to domination of scale spallation with increasing thermal cycles. The β -phase in the coating provides aluminum for the oxide scale formation. The loss of aluminum due to spallation of oxide scale results in coating degradation. Metallurgical evaluation of the thermal exposed specimens is in progress. Volume of fraction of β -phase and aluminum content in the coating is being determined as a function of thermal cycles. Results showed that the β -phase in the MCrAlY coating was completely consumed after 2000 one-hour thermal cycle exposure at a peak temperature of 1066°C (1950°F). These results are used to validate the COATLIFE model.

With respect to the NDE task, (Task 3) a major accomplishment during this reporting period is receiving the Frequency Scanning Eddy Current Tester (F-SECT) system from the manufacturer. This system, which operates on a proprietary eddy current hardware with high stability and sensitivity is used to acquire the fraction of the probe impedance that depends on the small conductivity and permeability variations between the different layers.

Testing was done on an aged first stage blade specimen with duplex coating obtained from Korea Western Power. The evaluation was focused on the suction (convex) side of the specimen. Data was obtained from 16 square grids identified in increasing order from the leading edge to the trailing edge. They were marked alphabetically along a row of blade sections; A through N from the platform to the blade edge.

Analysis of data simultaneously yields the thickness and the electromagnetic parameter, thus characterizing each layer of the coating. The electromagnetic parameter is electrical conductivity for non-magnetic materials, electrical conductivity to magnetic permeability ratio for paramagnetic materials.

All acquired data were automatically stored in a data bank, which was later extracted to the three-layer inversion model. The F-SECT system software was based on a MATLAB 6 shell, through which the following functions have been implemented:

- Instrument set-up
- Data acquisition
- Data normalization
- Data analysis

This inversion results were finally exported to the Excel environment where loci curves are plotted for interpretation purposes. The overall coating conductivity defining severe loss of coating, nominal remaining coating, base metal, craze cracking and possible corrosion coupled with craze cracking to the base metal were found to be clearly defined in the upward and downward trajectories, which is defined in detail in the results and discussion section.

Based on metallographic investigation done on similar samples by the F-SECT equipment manufacturer and past field experience revealed EPRI's evaluation of the loci curve representation to be true. This accomplishment is very encouraging. However, additional testing and confirmation by destructive sectioning is needed to verify and validate the NDE results.

Another major milestone was attained in May 2002 to secure additional blade samples by signing a Memorandum of Understanding (MOU) document between EPRI and Korea Western Power Company. This joint agreement signed and executed at the EPRI Charlotte facility will allow EPRI to access four additional 1st stage buckets coated with GT-33+ coatings. In return, Korea Western Power will have access to results generated from these four samples. They include results of NDE measurements, estimates of optimal hot gas path inspection interval, estimates of remaining coat life, and estimated EOH to initiate airfoil cracking observed on such 1st stage blade buckets.

4.0 TASK 1 REFINEMENT AND VALIDATION OF HSLMP

4.1 Experimental

A fully integrated engineering study was performed for each hot section component. The aero-thermal model includes all relevant details of the internal and external geometry. The HSLMP was used to perform the following series of studies: (1) Construct aero-thermal models and apply temperature dependent properties. In the 1st stage blade, a serpentine type of internal cooling strategy will be modeled. In the 2nd stage, a span-wise cooling scheme will be modeled (2) Analyze internal cooling and external heating. (3) Analyze heat conduction to calculate metal temperatures. (4) Iterate aero-thermal model. (5) Calculate mechanical and thermal stresses at coating and substrate locations. (6) Formulate the temperature and stress at critical locations. (7) Define load cycles and operating parameters, based on guidance provided by plant operators. (8) Estimate damage rate. For 1st stage blade this will account for coating oxidation, TMF and creep. For the 2nd stage blade, the damage rate will focus on creep. (9) Calculate life and contrast results against OEM formulations of equivalent operating hours (EOH).

4.2 Results and Discussion

Details of critical components have been obtained and Task 1.1 has been completed. The geometric data for both W501FC 1st stage blade and GE 7FA+e 2nd stage blade have been collected with sufficient detail to proceed with the next task. An aero-thermal analysis has been performed on the 7FA+e 2nd stage blade. A converged solution was achieved by iterating between the heat conduction model and external heating/internal cooling model. The calculated metal temperature distribution obtained by this method is shown in Figure 1. The predicted level of metal temperatures (~900°C) appears to be reasonable based on the coating oxidation life expected for a 2nd stage blade.

To further improve the heat transfer prediction in the tip shroud region, a tip leakage flow model was constructed for the 7FA+e 2nd stage blade. Examples of the calculated flow vectors are shown in Figure 2.

A three-dimensional finite element model of the W501FC 1st stage blade has been generated (shown in Figure 3). The model features a (7)-pass cooling channel, (5)-row pin-fin, and a cooling slot along the trailing edge. The model also includes a layer of elements to represent the bonding coat and a layer of elements to represent a ceramic coating on the external surface.

Figure 1 – Finite Element Model and Metal Temperature Distributions of GE 7FA+e 2nd Stage Bucket

Figure 2 – Flow Vectors in the 7FA+e 2nd Stage Bucket Tip Shroud Region

Figure 3 – The 3-D Finite Element Model of W501FC 1st Stage Blade

4.3 Conclusions

A preliminary assessment of metal temperatures for the 7FA+e 2nd stage blade has been completed. Initial metal temperatures predicted by the model appear to be reasonable. A tip leakage flow analysis was pursued to further refine the heat transfer prediction in the tip shroud region. The refinement appears to be successful in terms of being able to produce a numerical solution. Additional review is underway to assess that the results produced are reasonable, and/or to identify any further refinements that should be incorporated into the model. Given the present level of progress and success associated with modeling the 7FA+e 2nd stage blade and the thermal/mechanical loadings involved, no significant obstacles are foreseen to preclude the completion of both the coating oxidation life and creep damage studies within the originally projected schedule and budget.

5.0 **TASK 2: COATLIFE FOR ADVANCED METALLIC COATINGS AND TBCs**

5.1 Task 2.1 Thermal Barrier Coatings

5.1A Experimental

Three shank sections of GTD-111 DS blades and three shank sections of IN-738 blades retired from Frame 5002 engines were procured for machining test coupons. The shank sections operate at a much lower temperature than the airfoil section of a blade and, as a result, the material at the shank section is not expected to degrade during service. The structure and properties of the material at the shank section represent the initial, as heat-treated condition.

Compositional measurements were made at selected locations on the GTD-111 and IN-738 shank sections using energy dispersive x-ray spectroscopy (EDS). The composition of blade materials is given in Table 1.

Table 1 Chemical Composition of GTD 111 and IN 738 Test Materials (wt. %)

Blade	Al	Ti	Cr	Co	Mo	Nb	Ta	W	Ni
GTD 111	3.2	5.2	14.4	9.2	2.1	--	4.0	3.2	Bal
IN 738	3.8	3.6	16.0	8.3	1.9	1.1	2.1	2.2	Bal

About 150 cylindrical specimens (0.36 inch diameter and 1.5 inch long) were removed from the GTD-111 and IN-738 blade shank sections using an electro-discharge machining process. The specimens were ground and polished to remove the recast layer and were shipped to the coating vendor, Turbine Airfoils, Coatings, and Repairs (TACR), for application of bond and yttria stabilized zirconia coatings. A low pressure plasma spray process (LPPS) was used to apply a MCrAlY (CT 102) coating to all specimens. The composition of the powder is given in Table 2. After application of MCrAlY all specimens were given a vacuum diffusion treatment at 1121°C (2050°F) for two hours. After the diffusion heat treatment, an approximately 10 µm thick layer of platinum was applied by electroplating on half of the specimens. Siemens-Westinghouse uses the platinum plated MCrAlY as a bond coating for TBC-coated parts of advanced turbines. Following electroplating, the specimens were given a vacuum diffusion heat treatment at 1121°C (2050°F) for two hours. All MCrAlY and platinum plated MCrAlY specimens were then given an aging treatment at 843°C (1550°F) for 24 hours prior to the application of the top ceramic coating, a standard yttria stabilized zirconia, by using an air plasma spray (APS) process. The chemical composition of the ceramic coating powder is given in Table 3.

Table 2 Chemical Composition of CT 102 Bond Coating Powder (wt%)

Al	Co	Cr	Ni	Y
8.0	Balance	21.0	32.0	0.5

Table 3 Chemical Composition of Ceramic Coating Powder (wt.%)

Al_2O_3	Fe_2O_3	SiO_2	TiO_2	Y_2O_3	HfO_2	ZrO_2
0.13	0.02	0.27	0.09	7.69	1.85	Balance

Multiple TBC coated specimens, four systems (two substrates and two bond coats), are aged in there different furnaces, which are maintained at three temperatures, 1010°C (1850°F, 1038°C (1900°F), 1066°C (1950°F). It is planned to remove one specimen form each substrate/coating system at predetermined intervals for metallurgical evaluation.

5.1B Results and Discussions

Metallurgical characterization of the specimens in the as-coated condition is in progress. Isothermal exposure testing of the TBC-coated specimens at 1010°C (1850°F), 1038°C (1900°F) and 1066°C (1950°F) has been initiated. The specimens have been exposed for approximately 300 hours to date.

5.2 Task 2.2 MCrAlY Coating

5.2A Experimental

Flat rectangular specimens were machined from the shank sections of GTD-111 buckets using an electro-discharge machining process for thermal cycling tests at two peak temperatures. TACR applied MCrAlY (CT-102) coating on these specimens using a LPPS process. The composition of the coating powder is given in Table 2. Following application of the coating, the specimens were given a vacuum diffusion heat treatment at (2050°F) for two hours and an aging treatment at 843°C (1550°F) for 24 hours.

For metallographic evaluation, a transverse section was removed from a coated specimen. The section was mounted in a conductive mounting media, polished using standard metallographic techniques, and examined under optical and scanning electron microscopes to characterize the coating structure and determine the chemical composition of the coating either in the as-coated or post-exposed condition. The composition of the phases in the coating was determined using Energy Dispersive spectroscopy (EDS) and the volume was determined using quantitative metallographic techniques.

Cyclic oxidation tests were conducted using a facility designed and fabricated at Southwest Research Institute. The test facility consists of a furnace, a forced air cooling system, a coated superalloy frame for suspending test specimens, and a computer controlled moving arm that transfers specimens in and out of the furnace and to the cooling system. For cyclic oxidation testing, coated specimens were inserted into the furnace, which was maintained at a desired peak temperature and held at that temperature for 55 minutes prior to moving them into the cooling system. Following cooling the specimens for 5 minutes, to room

temperature, the specimens were then reinserted back into the furnace. The tests were interrupted at predetermined intervals to weigh the specimens.

5.2B Results and Discussion

Metallurgical characterization of the as-coated specimen was completed. The results showed that the coating was dense and exhibited a duplex structure consisting of β -phase (aluminum rich) particles in a matrix of γ (solid solution of Ni, Cr, and Co). Figure 4 shows typical microstructure of the coating. Thickness of the coating is about 10 mils (254 μm). Chemical composition of the coating was determined using EDS and the results are shown in Table 4.

Table 4 Chemical Composition of MCrAlY Coating (wt. %)

ELEMENT	AL	CR	Co	NI	Y
WEIGHT %	8.1	20.8	36.7	33.9	0.5

Figure 4 Microstructure of as-deposited MCrAlY coating.

Cyclic oxidation testing at a peak temperature of 1066°C (1950°F) was completed. The weight change results are shown in Figure 5. As expected, the specimens initially gained weight due to formation of oxide scale with thermal cycles, up to approximately 200 thermal cycles and then the specimen lost weight due to domination of scale spallation with increasing thermal cycles. The scatter in the weight loss data also increased with increasing thermal cycles. Variation of uncoated areas on the edges of the specimens is, in part, responsible for this scatter. A small bolt was tack-welded to one of the edges of each specimen to facilitate rotation of the specimen during the application of coating. The tack-welded region was ground prior to cyclic oxidation testing. Variation of oxide scale spallation from these ground and uncoated regions can result in a pronounced weight changes.

Figure 5 Cyclic Oxidation Behavior of MCrAlY Coating at 1950°F (1066°C).

Cyclic oxidation testing on the coated specimens at a lower peak temperature of 1850°F has been initiated and the specimens have been exposed for 800 one-hour thermal cycles to date. The specimens showed weight gain due to formation of protective oxide scale on the coated specimens.

5.2C Conclusions

- Microstructure of the MCrAlY coating exhibited β -phase particle in a matrix of γ .
- The β -phase in the coating was completely consumed after 2000 one-hour thermal cycles exposure at a peak temperature of 1066°C (1950°F).

6.0 TASK 3: NDE OF COATINGS

6.1 Experimental

The FSECT system, shown in figure 6, runs on a dedicated hardware that performs high stability and high sensitivity eddy current measurements in the 500 KHz - 10 MHz frequency range. In this range the F-SECT system carries automated frequency scanning at a rate of approximately 3 frequency points per second. The data collected by the system are analyzed by proprietary software, based on a simplified model of the interaction between the material and the electromagnetic field. The material is represented as a flat 2 or 3 layer material. The analysis simultaneously yields the thickness and the electromagnetic parameter, thus characterizing each layer. The electromagnetic parameter is electrical conductivity for non-magnetic materials, electrical conductivity to magnetic permeability ratio for paramagnetic materials.

Figure 6 F-SECT system

The frequency scanning unit, physically separated from the PC, performs the basic functions of a high performance eddy current instrument, including:

- pure sine-wave excitation of probe transmitter coil,
- pre-amplification and high-stability balancing of the HF signal across probe receiver coil,
- two-phase synchronous demodulation of the balanced signal to obtain its in-phase and quadrature components (LF components),
- analog-to-digital conversion of LF components.

Probe

The standard probe supplied with the F-SECT instrument is a high-frequency self-balanced probe specifically optimized for use with MCrAlY coatings on Ni-base super alloy substrates.

Reference conductivity samples

The two flat samples, supplied with the system, have homogeneous conductivity in the range of Ni-base super alloys (0.7-0.85 MS/m). The difference in the conductivity values of the samples is about 10%. The samples are used to carry out normalization of acquired data, before model based analysis is applied.

System Software

System software is based on a MATLAB 6 shell, through which the following functions have been implemented:

- Instrument set-up
- Data acquisition
- Data normalization
- Data analysis

6.2 Results and Discussion

The F-SECT System is capable of providing both qualitative and quantitative information about multi-layer coating conditions. Currently, the supplied system is equipped to handle both two-layer and three-layer inversion problems. For two-layer problem, the basic variables of interest are top coating layer thickness, L_1 , top coating layer conductivity, σ_1 , and the semi-infinite base layer of σ_2 . For three-layer problem, the variables of interest extend to top two coating layers, L_1 and L_2 , associated coating conductivity values of σ_1 and σ_2 , and the semi-infinite base layer of σ_3 .

Two-step normalization was performed to obtain coil impedance that is free of coil lift-off and to some extent probe-cable effects. The resultant normalized impedance, which becomes a scalar quantity, is approximated closely to the real part of the coil impedance.

The test coil is excited in the frequency range of 500Khz to 10MHz. The eddy current forward model assumes interaction of plane electromagnetic wave at multiple exciting frequencies with a layered material structure. An iterative inversion algorithm is then performed to minimize differences between the forward model results and the empirically obtained normalized impedance values to solve parameters of interests from both two- and three-layer problems. The normalized impedance is correlated closely to the ratio of

material conductivity to material permeability. Since material permeability is constant (1) for our testing purposes, the normalized impedance values correlates directly to material conductivity values.

Using a 3-layer model, the following conductivity values (σ_1 , σ_2 , and σ_3) are estimated after fixing the values of multiple layers obtained from metallographic investigation. This is shown graphically as Figure 7.

Figure 7. Three-Layer Inversion Program Model for GT 33+ Coating

In general, the normalized impedance value is higher for normal duplex coating with no degradation of top coating – see position 9 impedance loci curve of Figure 8. As beta-phase depletes due to operation, the overall coating conductivity decreases due to lowering of aluminum content. This causes the normalized impedance loci curve to shift downward. This effect is shown as impedance loci curves at positions 8 and 13 of Figure 8. When there is no more aluminum left in the topcoat, there will be little difference in the conductivity values of the base metal from the combined beta-depleted topcoat and NiCoCrAlY bond coat. The GTD 111 bare metal shows up as straight flat line – this basically shows the homogeneous conductivity value of the GTD 111, which was determined to be around 7.8×10^5 S/m.

For duplex coating, such as GT33+, we have the highest conductivity value from the top aluminized coat (of around 12×10^5 S/m), followed by intermediate value of NiCoCrAlY bond coat at around 8.8×10^5 S/m. When the impedance loci curve follows a negative trajectory, this is an indication of conductivity decrease caused by the presence of crazed cracking. This is illustrated in the Figure 8 as impedance loci curves at positions 7 and 17. The extreme downward trajectories at positions 4 and 5 are indicative of corrosion of GTD 111 substrate and/or some of those crazed cracks penetrating into the base metal. The presence of crazed cracking is visually confirmed at those two areas closer to the leading edge, denoted as positions 4 and 5. Additional testing and confirmation by destructive sectioning is eventually needed to verify and validate NDE findings.

Figure 8. Normalized Impedance vs. frequency showing qualitatively the response of impedance loci curves from normal coating, degraded top coating, crazed cracking with coating degradation, and to possible base metal corrosion and/or cracks penetrating into the GTD 111 substrate.

Work is still in progress with EPRI subcontractors, namely, Victor Technologies and Jentek Sensors. Victor Technologies is currently working on enhancing the 4 and/or 8-layer algorithm for coating evaluation into the final software while Jentek Sensors are working on a 7-channel meandering winding magnetometer (MWM) array probe to perform characterization study of aged GT33+ duplex coated blade.

6.3 Conclusions

The result obtained on the one GT33+ blade sample tested with the three-layer inversion modeling is encouraging with regards to distinguishing coating TMF cracking from general degradation by Al depletion. However to solidify the NDE results, further metallurgical evaluation of the tested blade is necessary. The results obtained will enable us to co-relate the ground truth data with the NDE data and initiate baseline projections for future sample testing.