



EPRI /DOE CT Diagnostic Health Monitoring Program

**Condition Monitoring Workshop
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Presentation Summary



- **Program plan for advanced CT health management**
- **Technology descriptions**
 - **Signal processing & model-based sensor validation**
 - **Fault detection/isolation and diagnosis**
 - **“Hot section” damage assessment**
- **Key tasks of program work scope**
 - **Combustor health module, performance diagnostics, vibration fault detection and component prognostics**
- **Field site descriptions**
- **Closing remarks**

CT Life Management Solution



RUN

- Multi-skilled, Lean Operations Workforce
- Boost Capacity Output
- Operating Costs: Performance and Damage
- Avoid Availability Losses via Diagnostic Monitors

**Optimal
Inspection
Interval**

INSPECT

REPAIR

REPLACE

**Limit Damage
Consequence**

Unmet Needs for Monitoring



- **Limited diagnostic capability.**
- **Often require the assistance of expert interpretation, which devalues their effectiveness as mainstay production tools.**
- **On-line monitoring of component life to allow assessment of when forced-shutdown might occur.**
- **On-line indication of component degradation to alert operators to failures that could propagate through the unit.**
- **On-line risk assessment of extending the outage to determine whether it is possible to operate for extended periods.**

EPRI/DOE CT Diagnostic Health Monitoring Program



- **Combustion Turbine (CT)/Combined Cycle (CC) Diagnostic Health Monitoring**
- **\$ 1.6 Million**
- **3 years starting October 1, 2001**
- **EPRI, Impact Technologies, Boyce Consultancy, and Progress Energy (CP&L)**
- **Norm Holcombe, DOE Project Manager**

CT Condition & Health Monitoring Benefits



- **Computer-based CT condition & health monitoring predictive systems offer the potential for:**
 - reduced nuisance shutdowns & unplanned outages
 - optimum engine operation
 - continuous real-time maintenance scheduling
 - extended time between overhauls based upon determination of remaining component life
 - protection against catastrophic failure via real-time fault assessment

Program Goals



- **Improve reliability, availability and maintainability (RAM) and overall performance/capacity factor of combustion turbines by developing advanced health monitoring and management techniques**
- **Develop a suite of intelligent software tools integrated with a diagnostic monitoring platform that will, in real time, interpret data to assess the “total health” of combustion turbines.**

Methodology



- **The project team will apply and adapt know-how developed under prior DOD/Navy/NASA programs aimed at advanced health monitoring of aviation gas turbines.**
- **The project team will develop advanced probabilistic and artificially intelligent performance and mechanical fault diagnostics algorithms, sensory validation and recovery modules, and prognostics for maintenance-intensive CT areas.**

Description of the Technology



- **The Combustion Turbine Health Management System (CTHM) will consist of a series of dynamic link library (DLL) programs residing on a diagnostic monitoring platform that accepts turbine health data from existing monitoring instrumentation.**
- **The DLL modules will integrate real-time anomaly detection, diagnostics of performance and mechanical faults, and the prediction of critical component remaining useful life (RUL) and turbine degradation.**

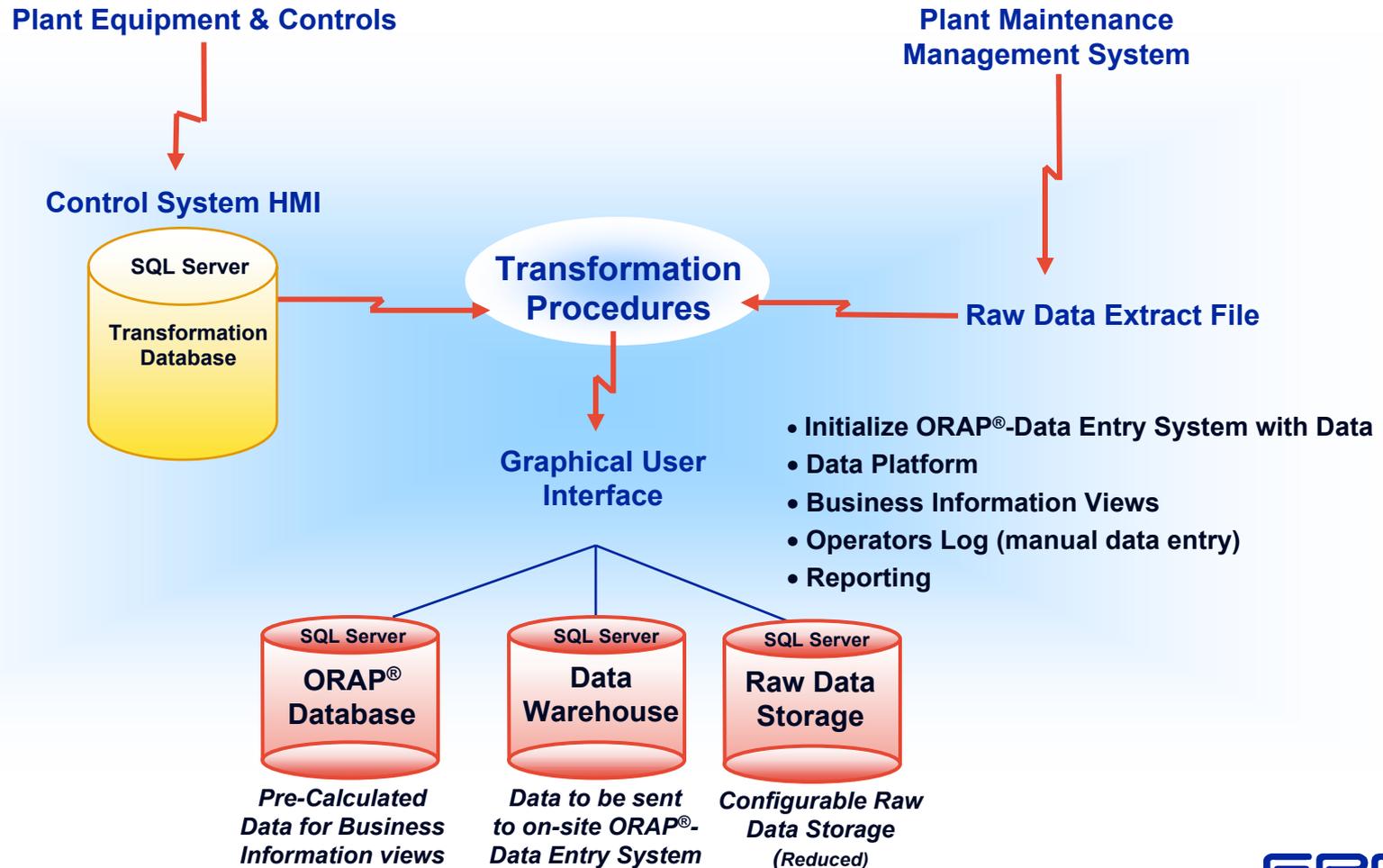
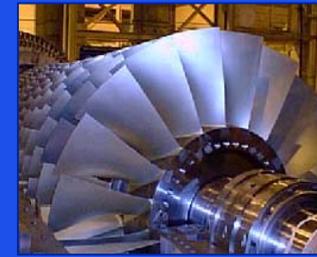
EPRI/DOE - CT Program

Work Scope

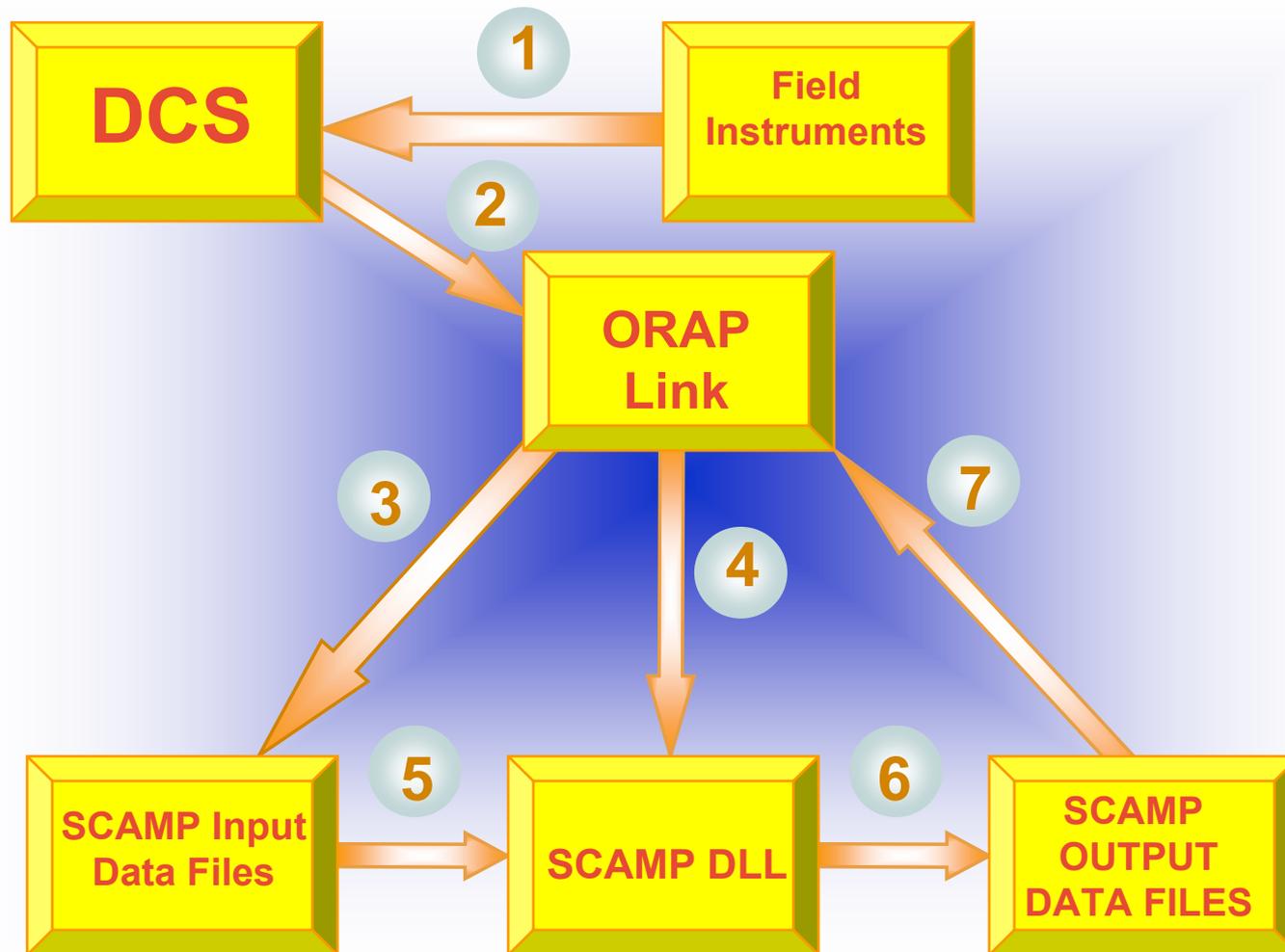


- **Comprehensive CT sensor validation module**
 - Model-based and signal processing based techniques
- **Performance fault diagnostics module**
 - Automated trending and fault pattern classification and fusion
- **Combustion process diagnostic module**
 - Automated assessment of EGT spread, fuel flow rate, manifold and supply pressures, vibration/dynamic pressure, emissions data.
- **Vibration fault diagnostic module**
 - Rotordynamic and bearing fault frequency analysis
- **Critical component prognostics module**
 - “Hot section” RUL projections based on usage profiles and statistical analysis

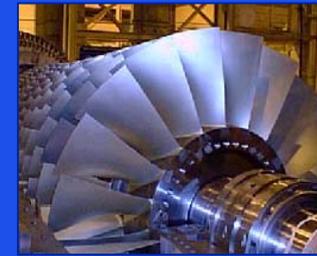
ORAP-Link Diagnostic Monitoring Platform



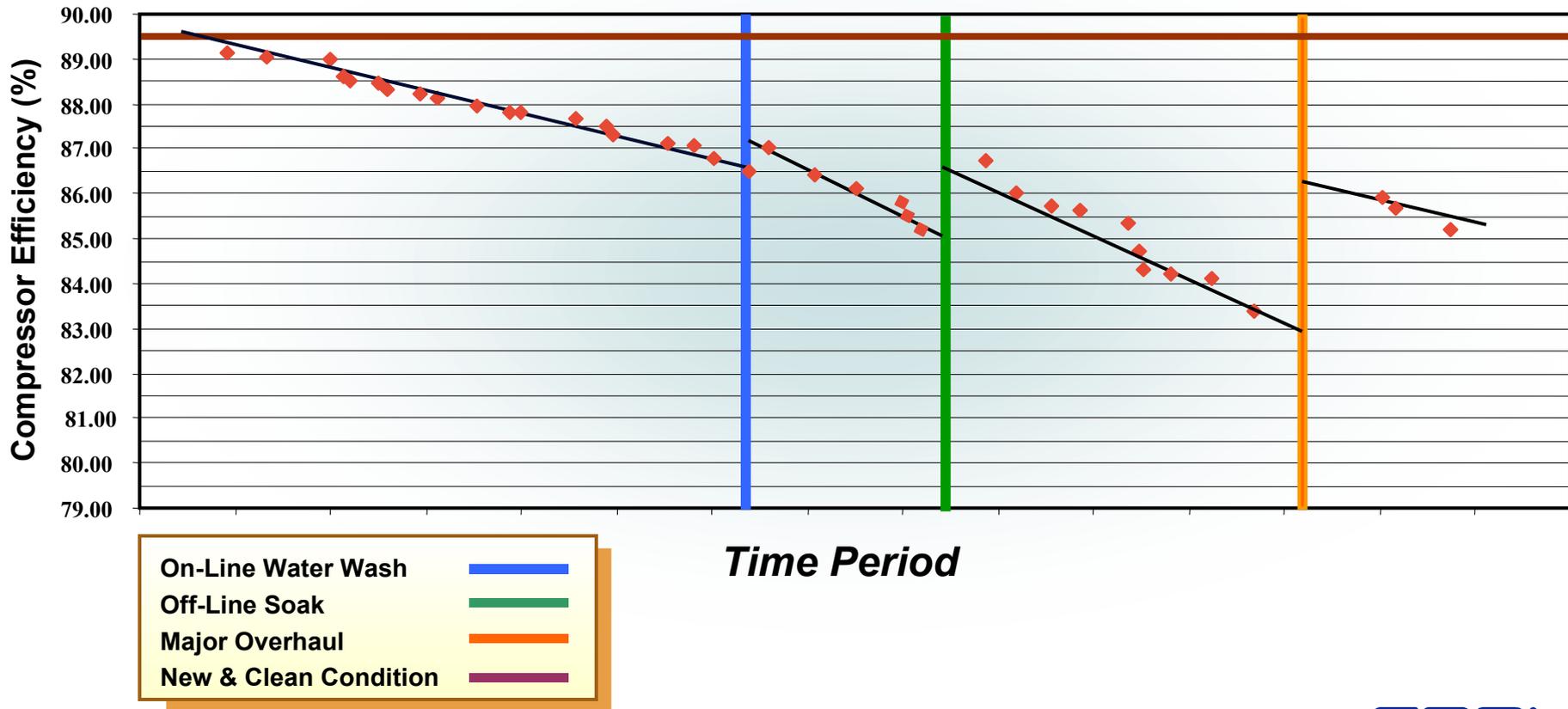
SCAMP DLL Software Functional Flowchart



SCAMP DLL Compressor Performance Display



Gas Turbine Compressor Efficiency



Damage Assessment Monitoring



INPUT

Monitoring Platform
SCAMP

Firing Temperature

Duration

Termination Flag (for TMF)

FORMULATION

Life Consumption Tracking Module

Written as a DLL

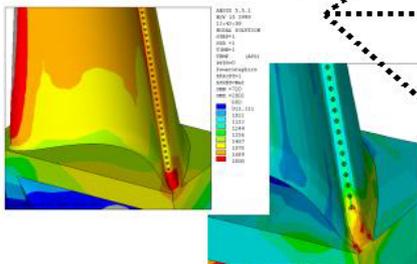
OUTPUT

Coating Life
TMF
Creep Life
TMF+Creep

SIMULATION

Step 6

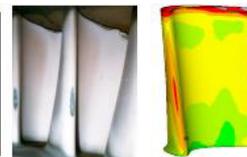
Identify critical locations on component.



Developed into **matrix** which tabulates **damage accumulation rates** for selected critical locations based on results derived from Life Management Platform studies of each condition.

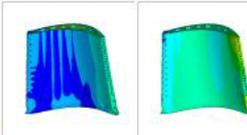
Assess Coating Degradation

Process temperatures through COATLIFE



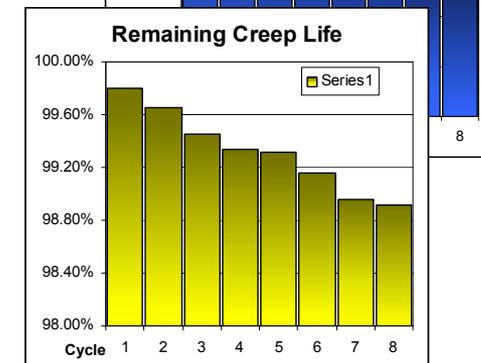
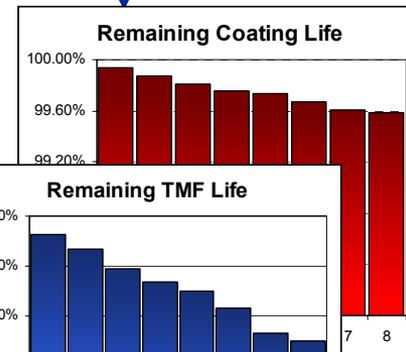
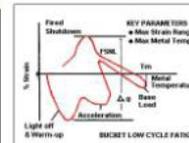
Assess Creep Fatigue Damage

Process Stress/Strain for Operating Period

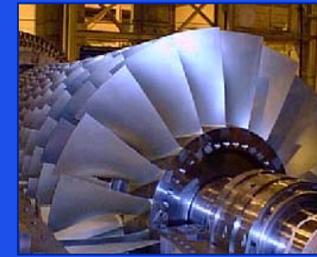


Assess Thermal Mechanical Fatigue

Process stress/strain for given load cycles

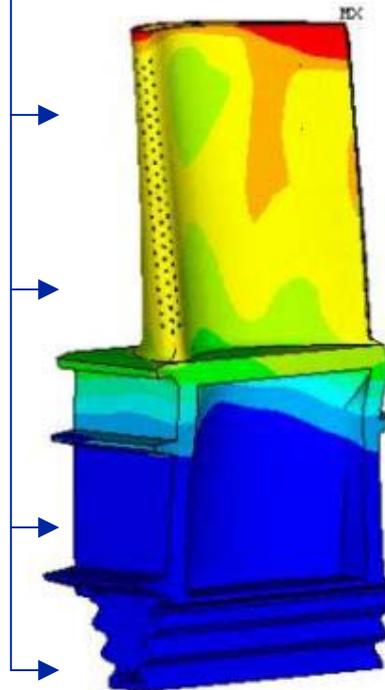


Damage Accumulation Matrix



Monitoring Platform
SCAMP

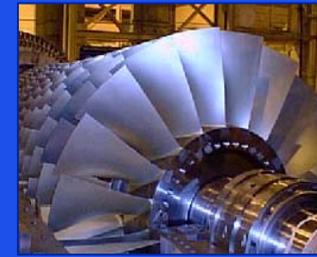
Firing Temperature, Event Type and Duration



Metal Temperatures, Stress, Strain

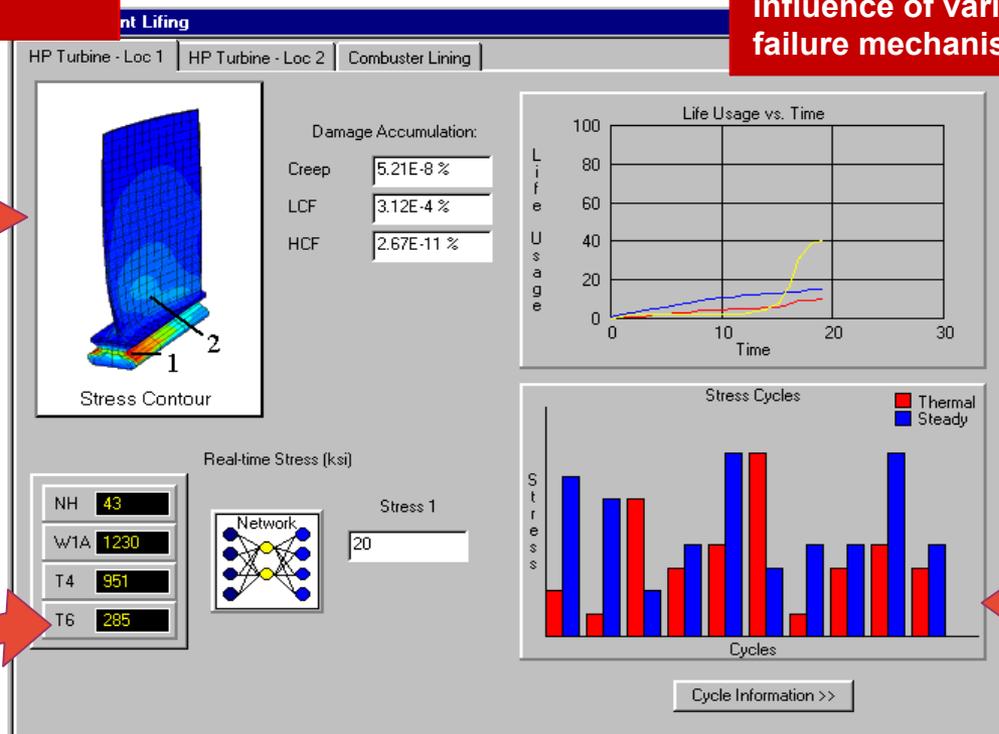
DAMAGE ACCUMULATION RATES (DATABASES FROM LMP)								
	Event Type →	Average Load (%)				Type of Start (For TMF only)		
	Critical Location	100	90	80	60	Normal	Fast	Emergency
COATING LIFE	Lead Edge	Estimates of oxidation life (hours) using temperatures derived from LMP aero-thermal analysis						
	Trailing Edge							
	Suction Side							
TMF LIFE	Lead Edge	Estimates of TMF life (cycles) using strain ranges derived from LPM aero-thermal analyses of trips at each of the different load factors and for each of the different types of start-up conditions. Termination flag (signifying type of event) will guide selection of appropriate TMF life from matrix.						
	Trailing Edge							
	Suction Side							
	Cooling Slot							
CREEP	Mid Span Profile -35% bh (Internal)	Estimates of creep (%) using temperatures derived from LMP						
	Cooling Slot							
C+TMF	Cooling Slot	Estimates of Interaction TMF and Creep						

Health Monitor/Predictor – Lifing Prognostics



Custom critical component life modules show real-time damage accumulation

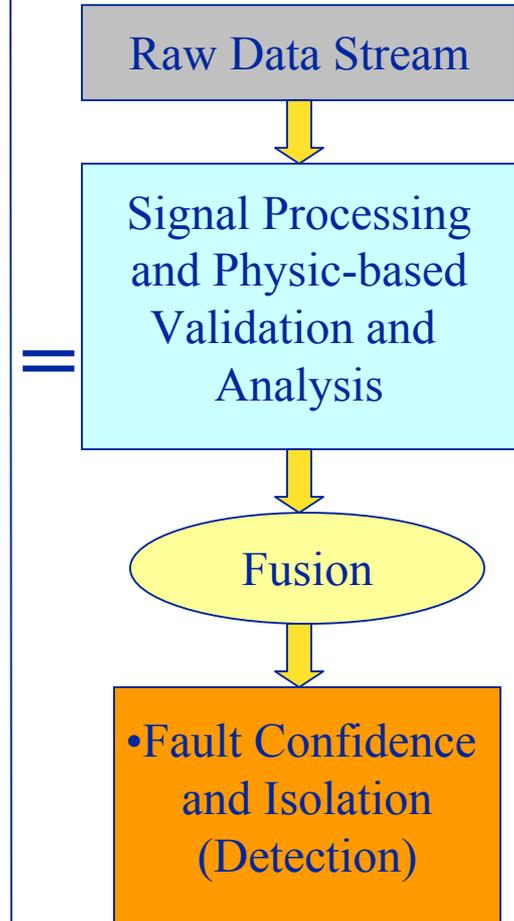
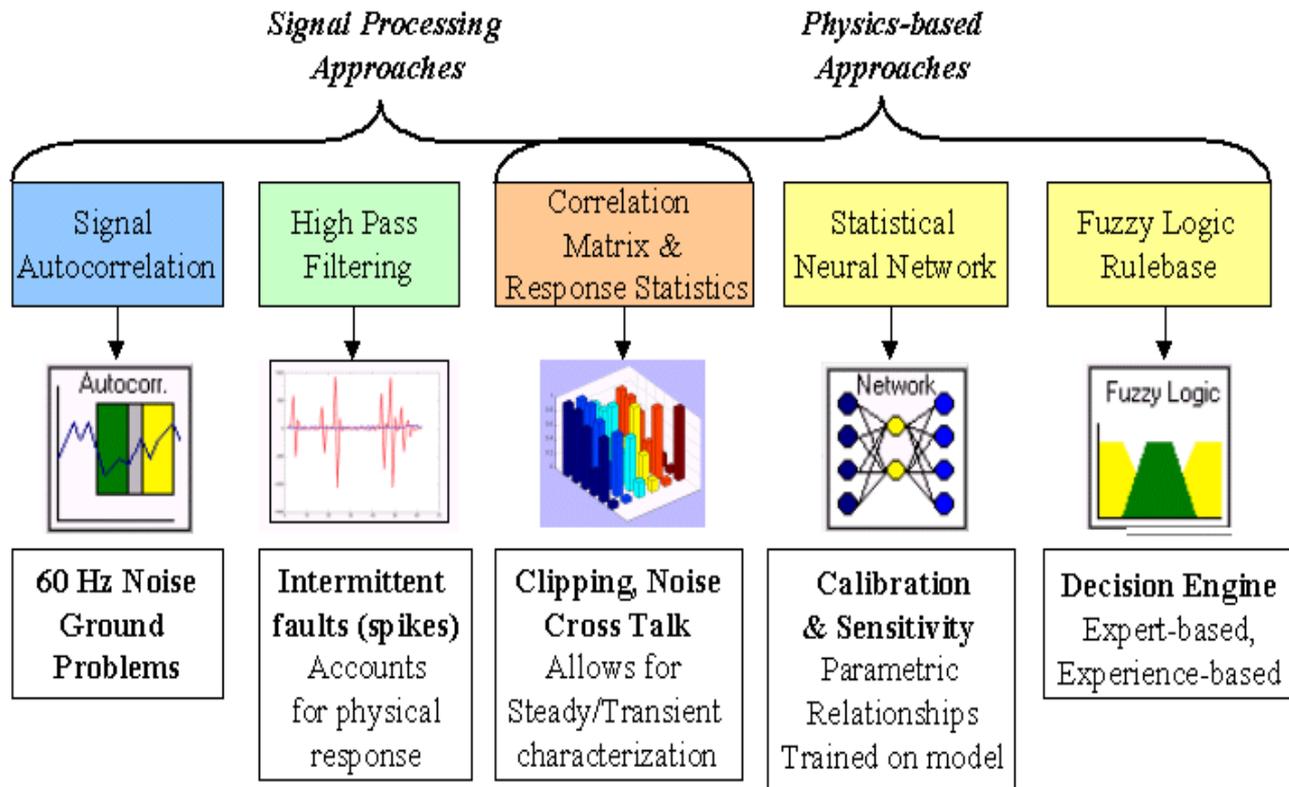
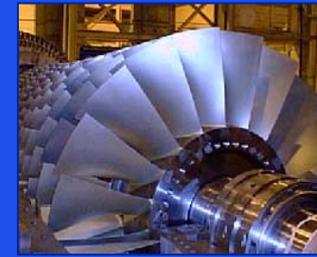
Remaining life chart illustrates the influence of various failure mechanisms



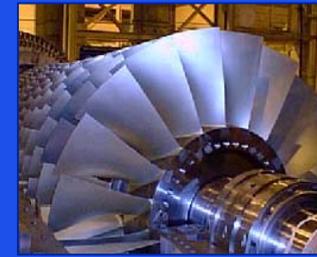
Critical location stresses are virtually sensed with a trained Neural Network

Relevant stress cycles are accumulated

CT Sensor Validation Technologies

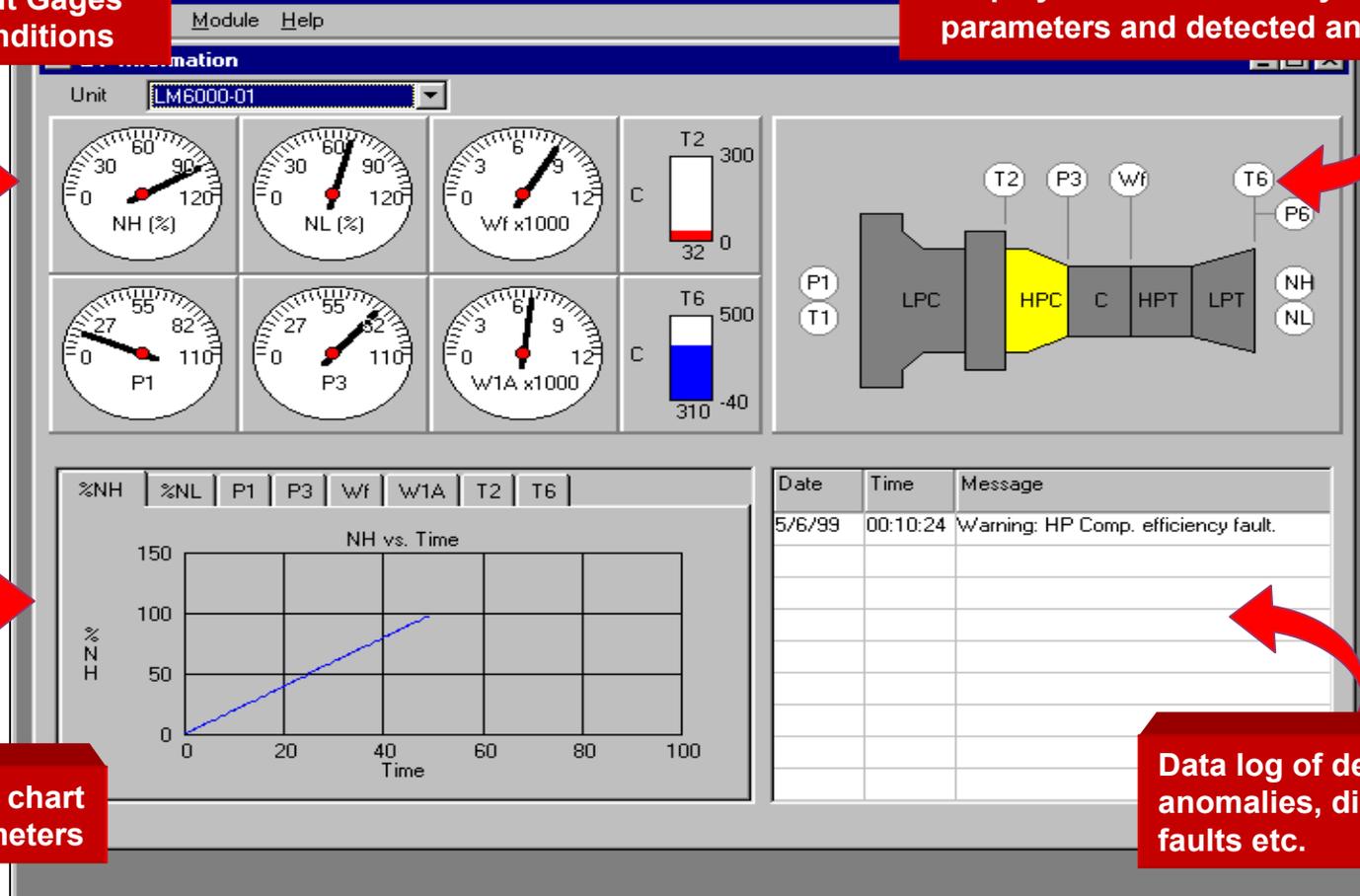


Health Monitor/Predictor – Main Screen



Virtual Instrument Gages show current conditions

Displays real and Virtually sensed parameters and detected anomalies



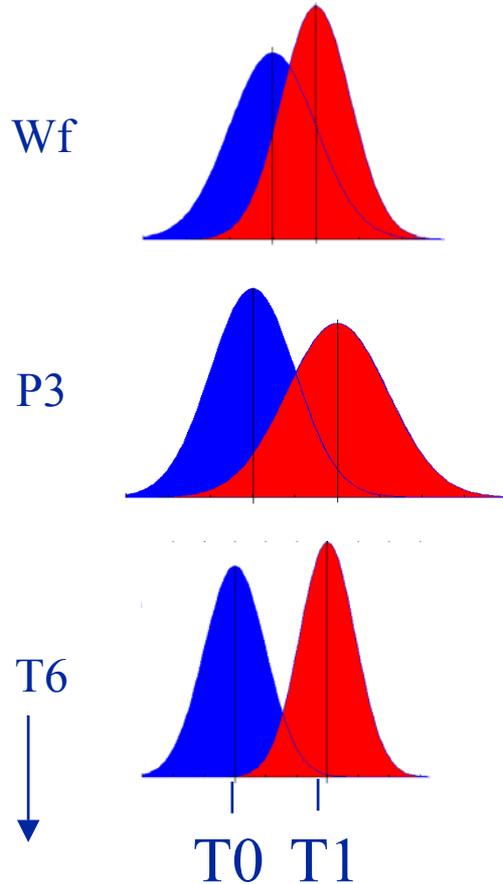
Real-time scroll chart of critical parameters

Data log of detected anomalies, diagnosed faults etc.

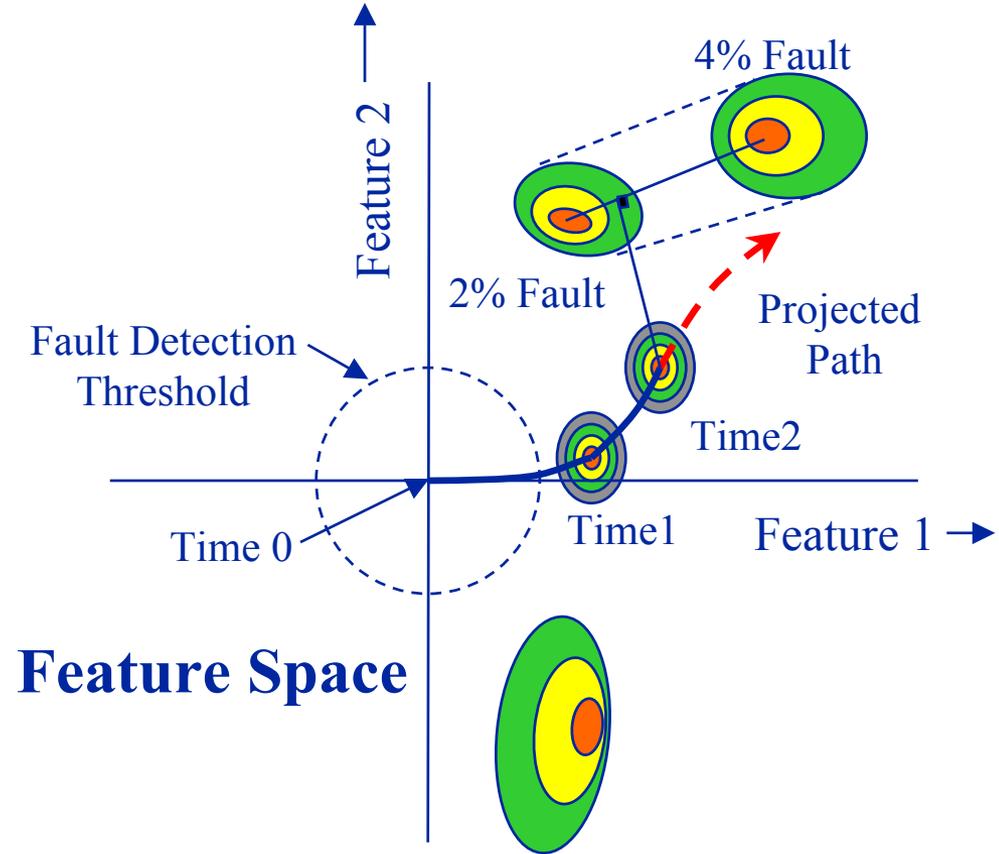
Probabilistic Fault Classifier



Gas Path Parameter Shifts over Time



Track and Predict Path



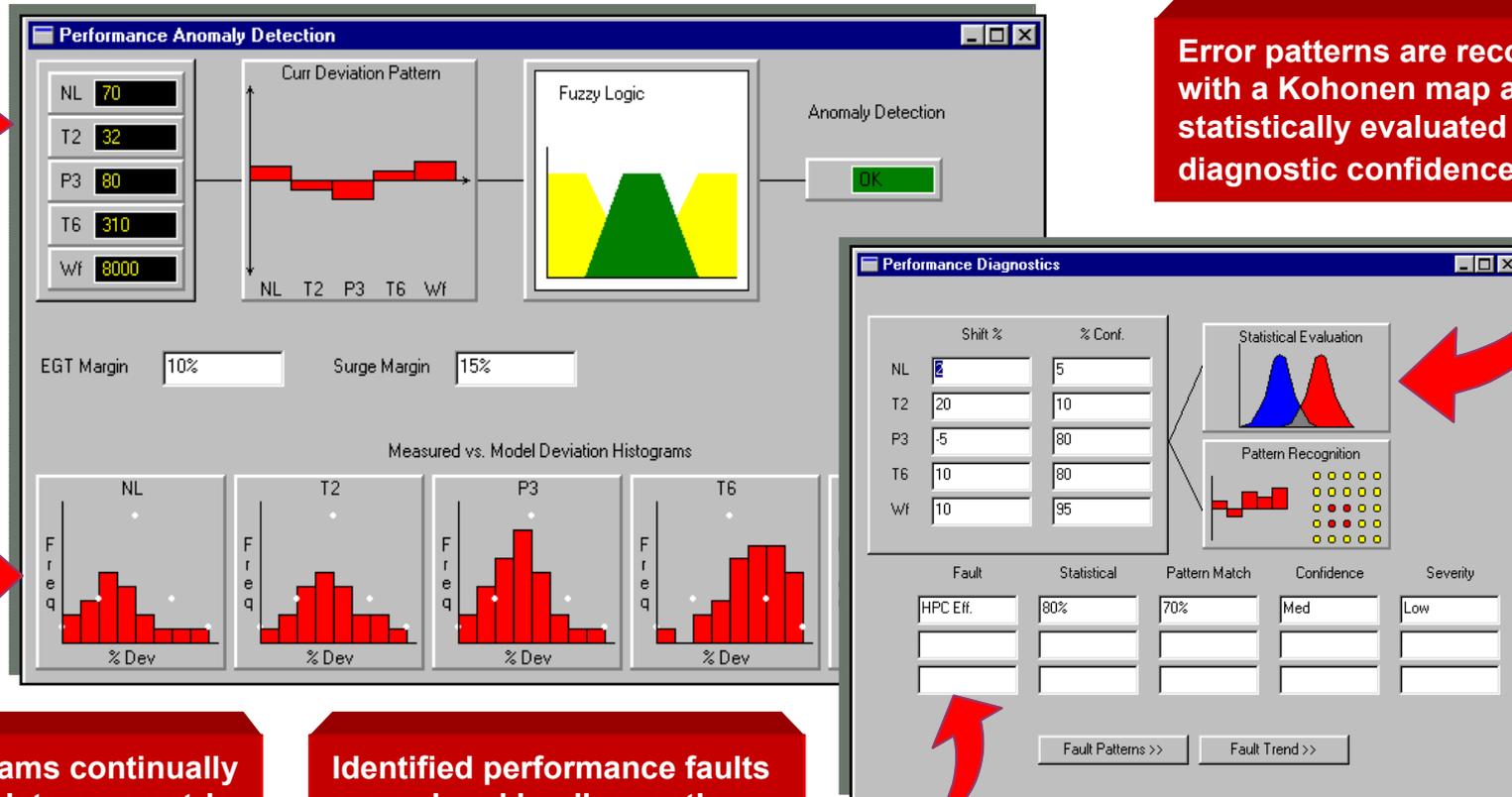
Health Monitor/Predictor - Performance Anomaly Detection & Diagnosis



Current values are gauged against baseline values at the current operating condition

Statistical processing and fuzzy logic evaluate if a performance anomaly is occurring

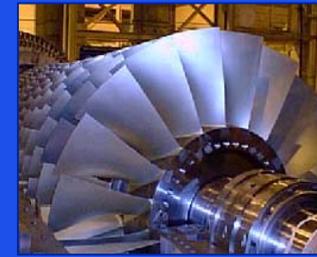
Error patterns are recognized with a Kohonen map and statistically evaluated for diagnostic confidence



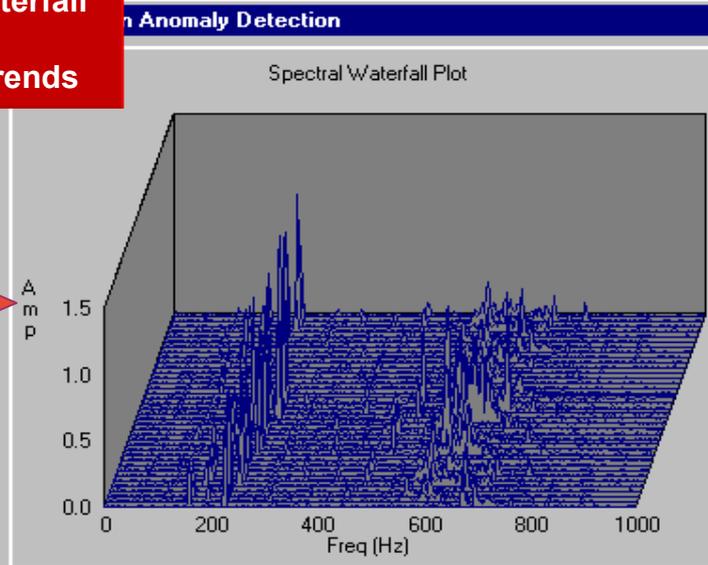
Histograms continually accumulate parametric baseline deviations

Identified performance faults are ordered by diagnostic confidence and severity level

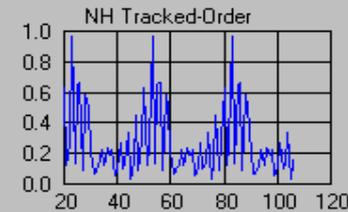
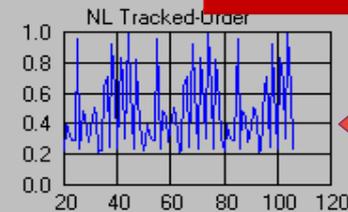
Health Monitor/Predictor – Mechanical Fault Detection



Real-time Spectral Waterfall plot captures speed dependent vibratory trends



Scroll chart of Tracked Order responses



NL	0.23235
NH	0.15533
BB	4.06578
PK	0.07622



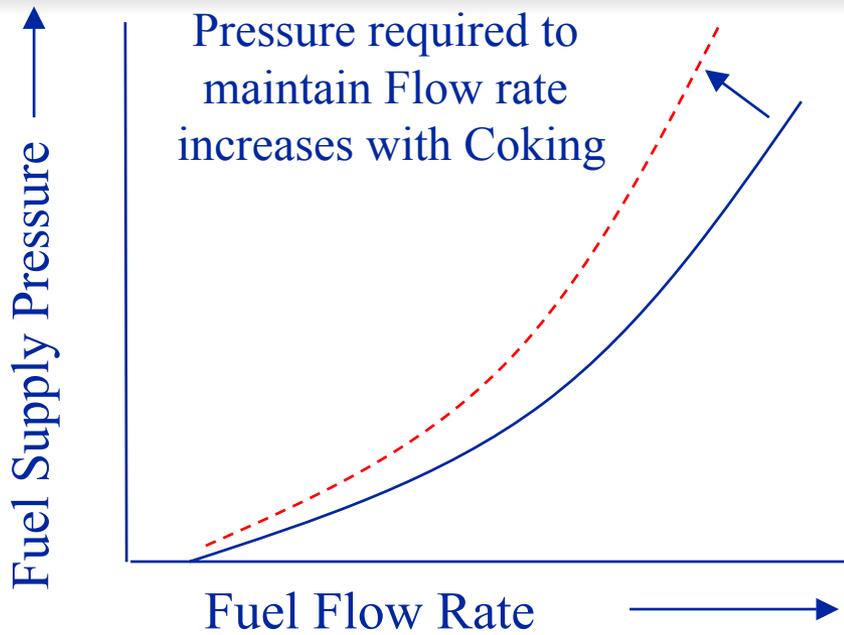
Anomaly

OK

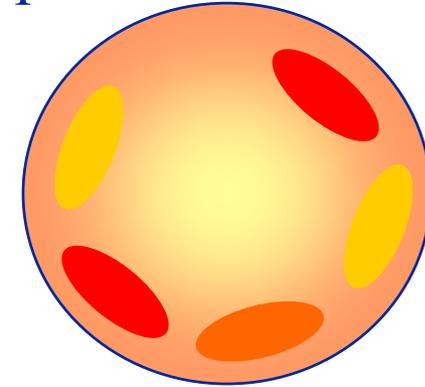
NL peak value	0.99291
NH peak value	0.96723
BB peak value	6.6085
PK peak value	0.80565

Vibration data is intelligently assessed for mechanical faults

Combustion Process Diagnostics

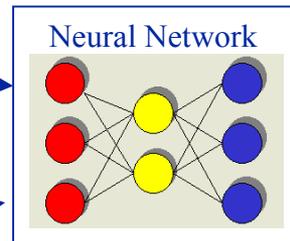


Exhaust Gas
Temperature Distribution



$$EGT_Ave = \Sigma Temps(t) / N$$

- 1) Supply/Flow Rate
- 2) EGT_Ave
- 3) Individual Temps



- 1) Overall Health/Severity
- 2) Ranked Faults

CP&L and FPC (Progress Energy)



- **Various Software Programs to Interface**
 - **ORAP-LINK, PI, TIGER, EMAP, PassPort, OEM's DCS**
- **Operating Historical Databases Available for Harvesting**
- **Various Manufacturers, Types and Models**
- **79 Frame Units**
- **24 Aero Units**
 - ▶ **GE 7EA (4) Cycled**
 - ▶ **GE 7FA (2) Cycled**
 - ▶ **GE 7FA+e (12) Cycled**
 - ▶ **GE LM6000 (1) Base Loaded**
 - ▶ **West 501AA (11) Peaker**
 - ▶ **West 501D5A (2) Peaker**
 - ▶ **West 501FC (2) Base Loaded (1) Combined Cycle**
 - ▶ **West 501FD (1) Cycled**

Future Plans



Major Activities Planned For Next Six Months

- **Initiate Sensor Validation Module**
 - This module will validate the integrity of key gas path sensor signals and predict important parameters that are not sensed in the CT for performance assessment.
- **Initiate Performance and Fault Diagnostic Module**
 - This module statistically detects the manner in which performance parameters are shifting over time and then correlate these shifts with degradation issues associated performance.

Closing Remarks



- **Need exists for monitoring systems that:**
 - Optimize performance
 - Define risk of extending operating periods
 - Monitor component degradation
 - Provide early warning of system faults
- **The combustion turbine health management (CTHM) system developed under this project will be a dramatic improvement over currently available techniques for turbine monitoring and diagnostics.**
- **The CTHM will, for the first time, enable real-time anomaly detection and diagnostics of performance and mechanical faults in addition to the prediction of critical component remaining useful life and turbine degradation.**