Life Prediction of Critical Turbine Components Using Prognosis

By

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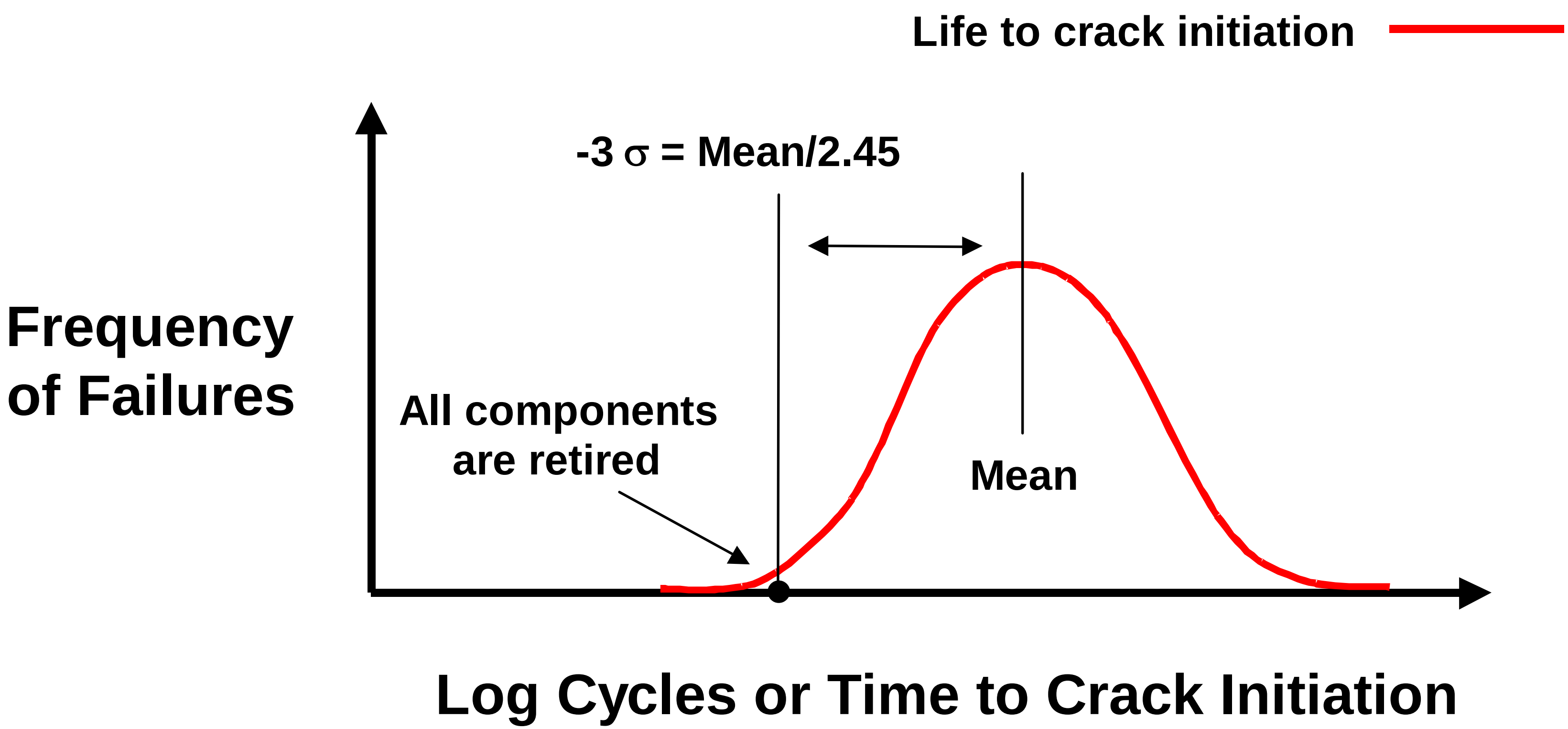
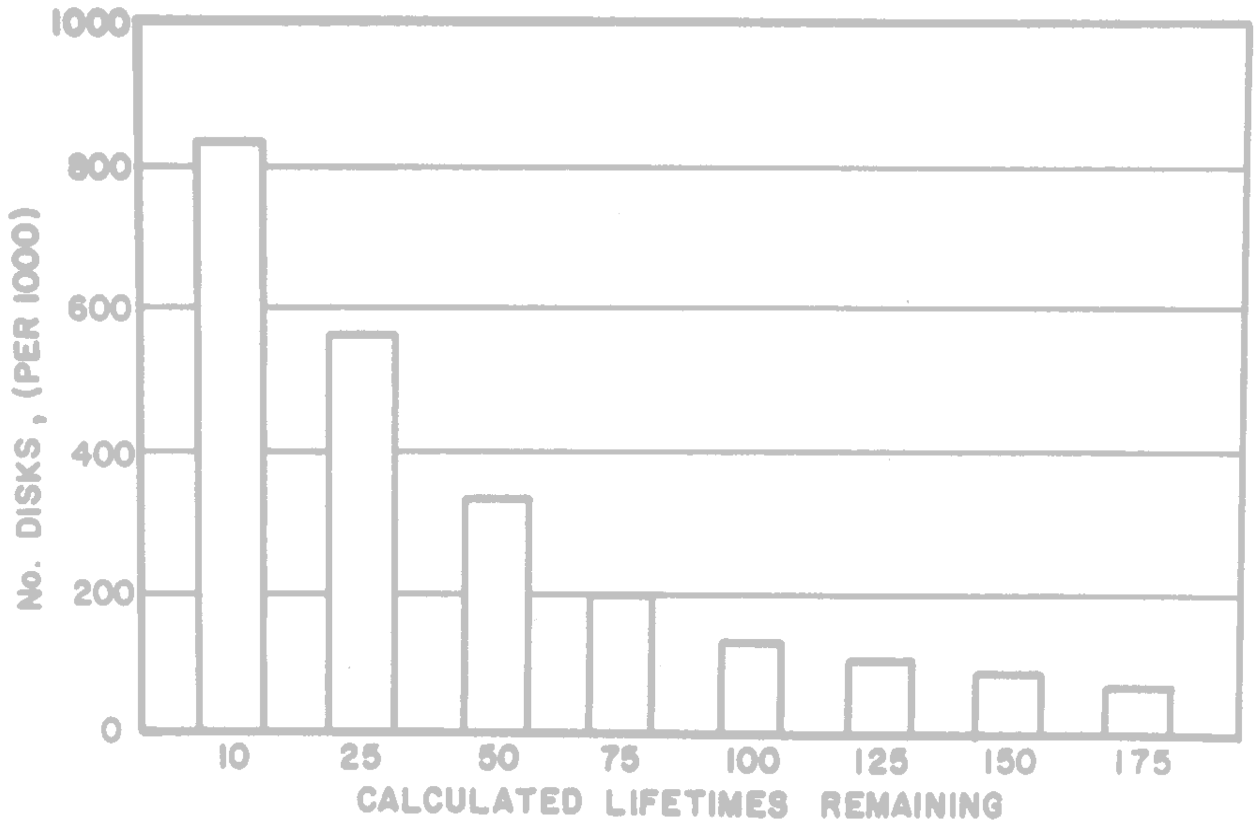
Safe Life LCMM Philosophy (1/1000 probability of crack initiation)

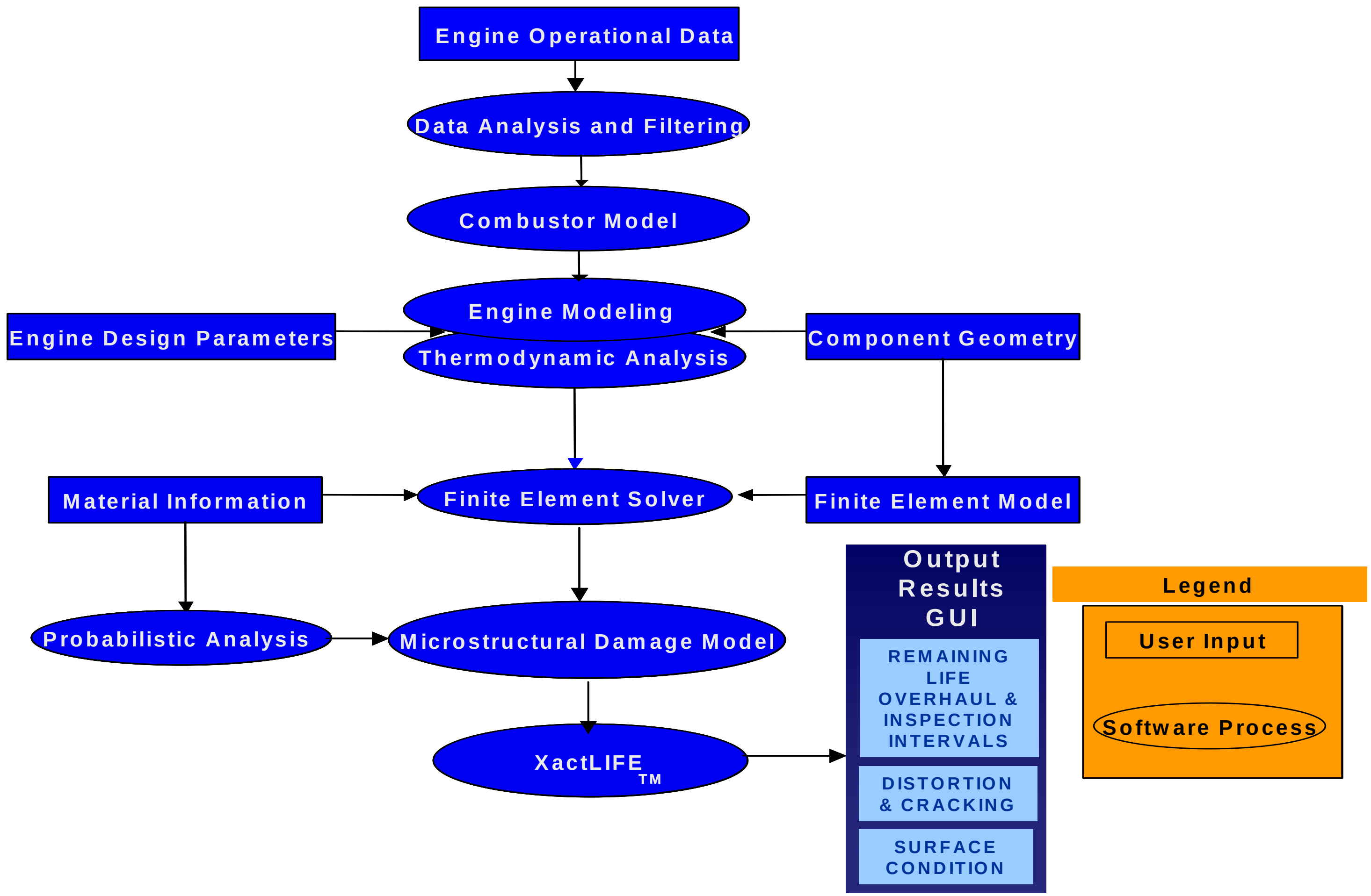


Remaining Life of Safe Life Expired Discs



USAF Study

XactLIFE System Architecture (Patent Pending)



Prognosis Based Engineering Assessment of Rotors

- Determine the ***temperature*** and stress profiles that the components are exposed to in a specific engine operating environment

- Consider the effect of operating loads on crack initiation life in different rotors

- Identify the most fracture prone rotor

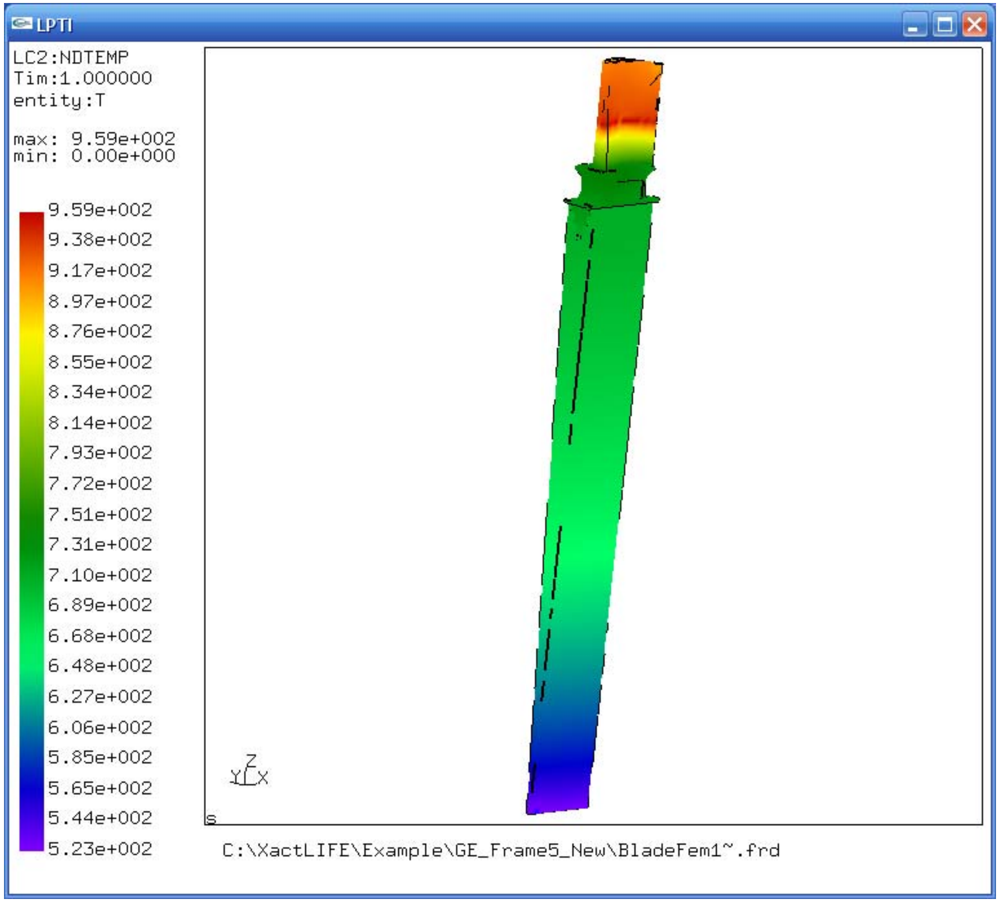
- Determine the primary and secondary fracture critical locations of the rotor(s) and predict a safe operating interval for the engine

- Consider the effect of NDI detection limit/uncertainties on the future safe operation of the engine and select the most appropriate NDI technique for inspecting the individual rotor locations.

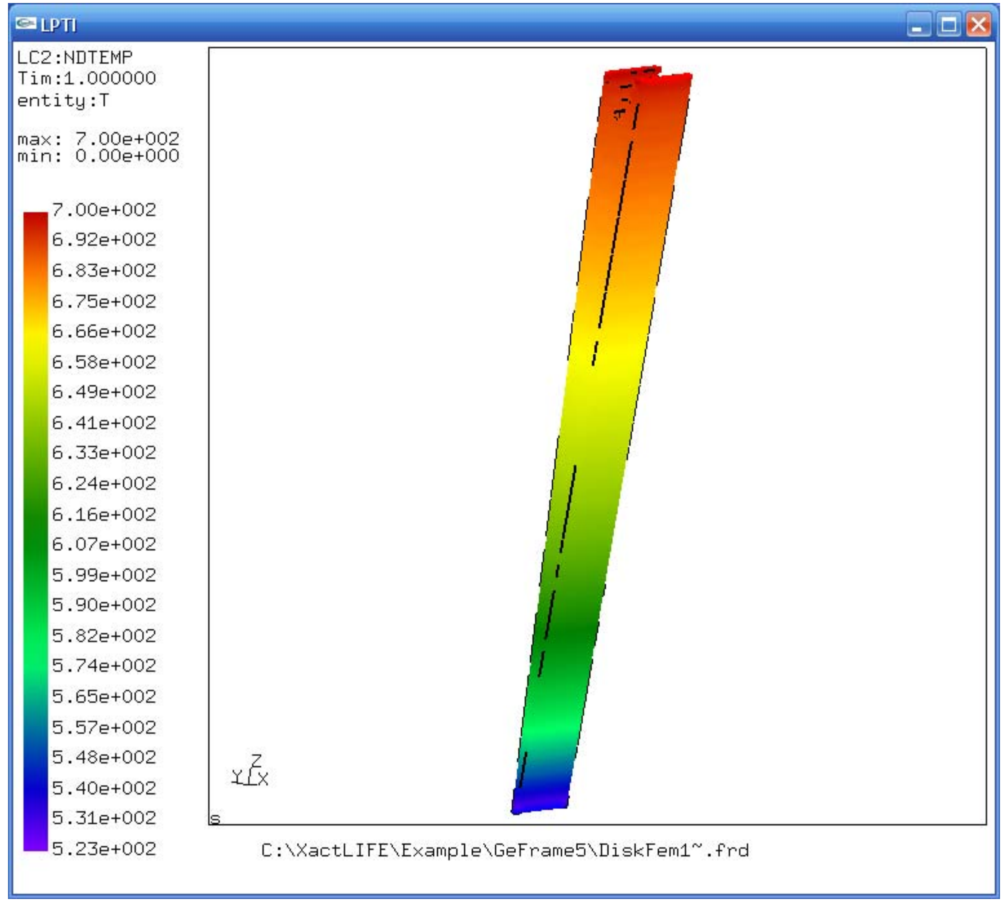
- Design new NDI probes if necessary

Temperature Profile Frame 5 blade/Disc Combined

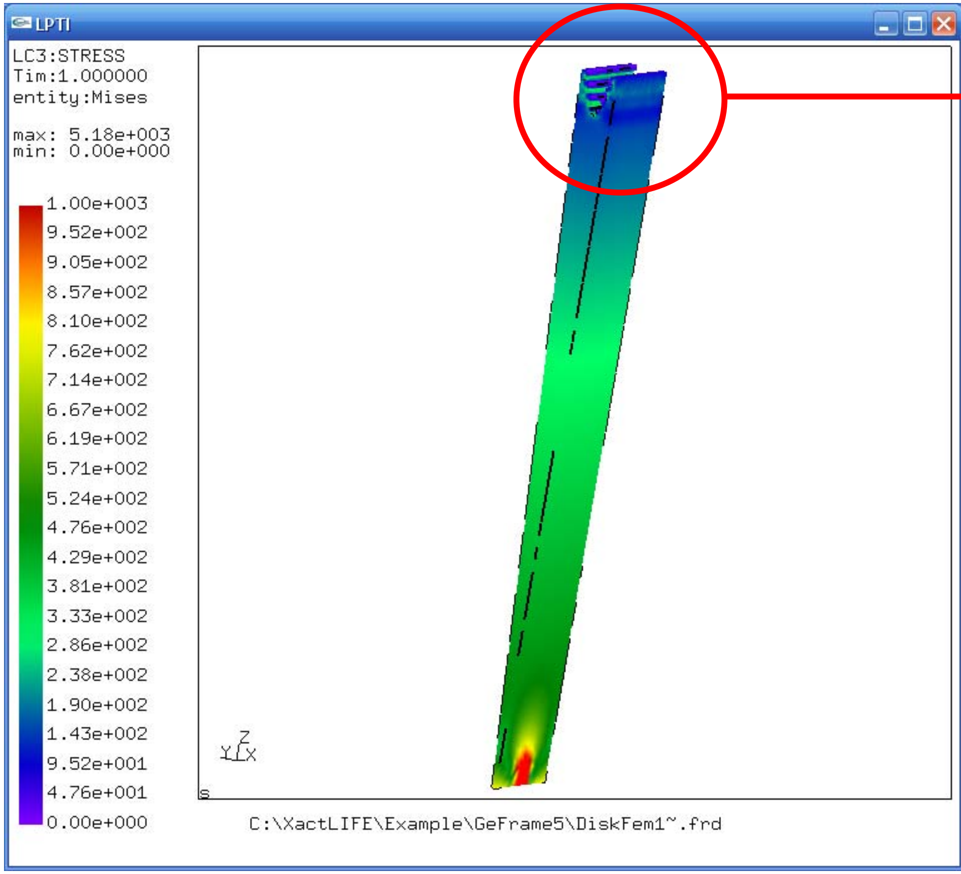
Bladed Disc

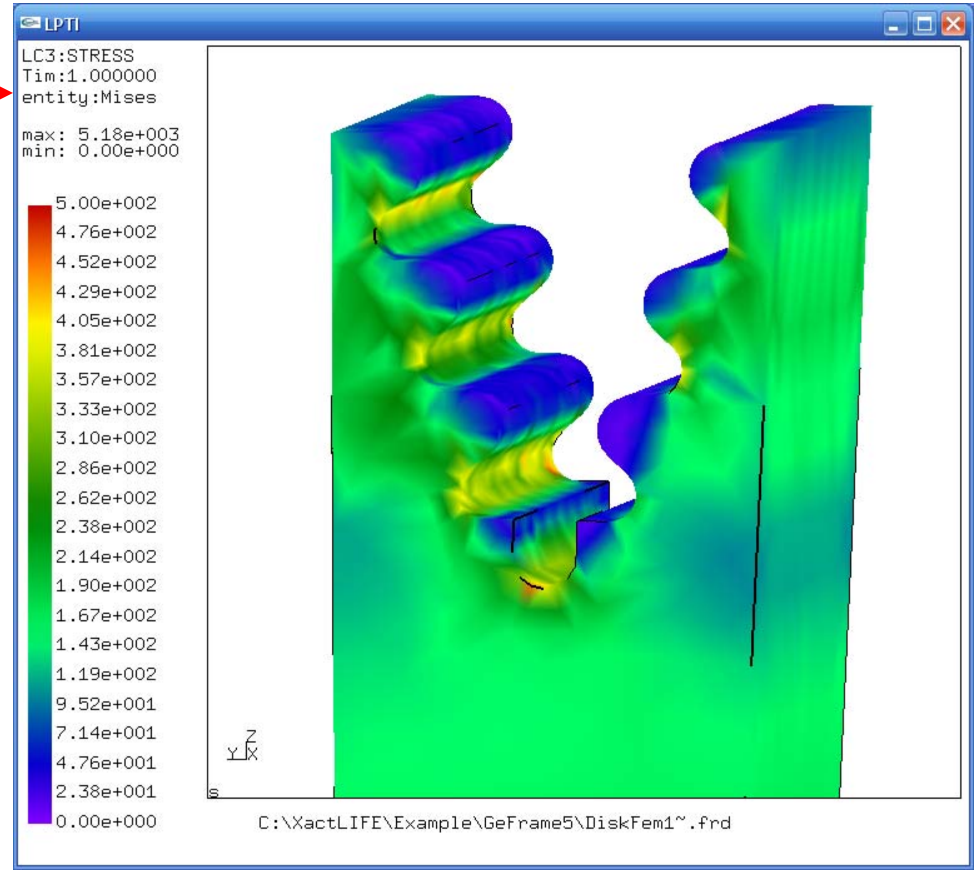


Stand Alone Disc

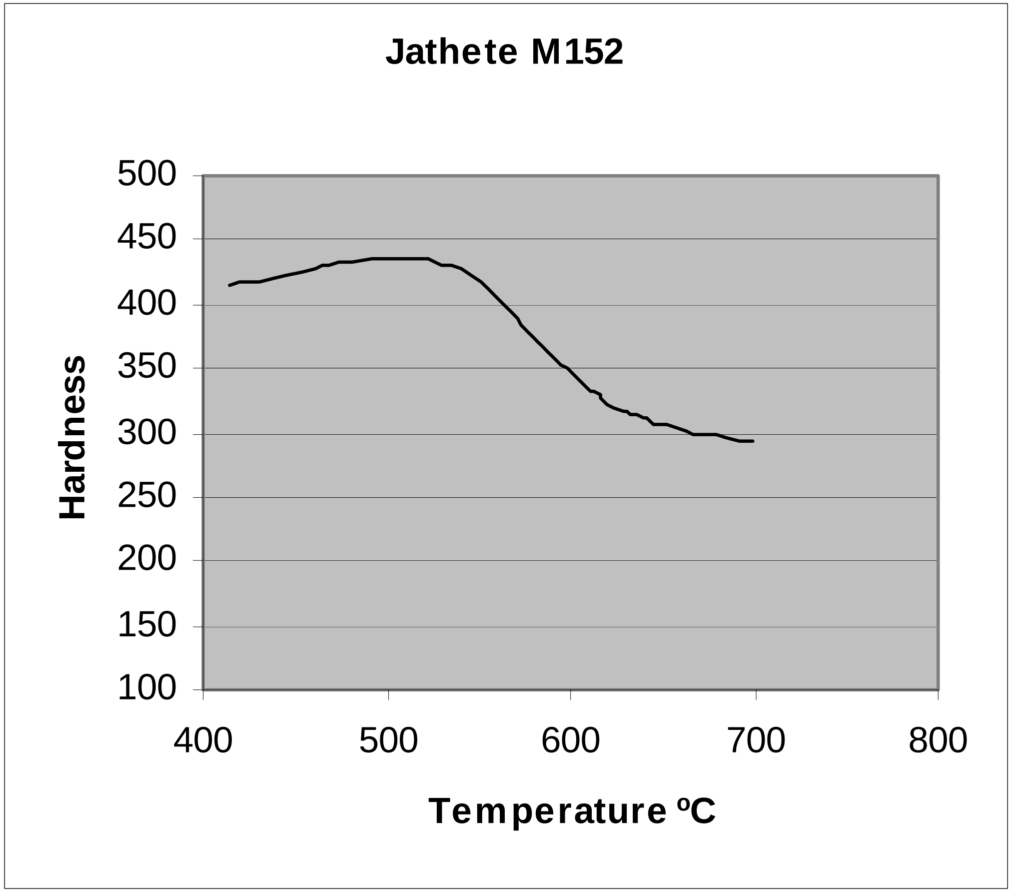


Stress Profile Frame5





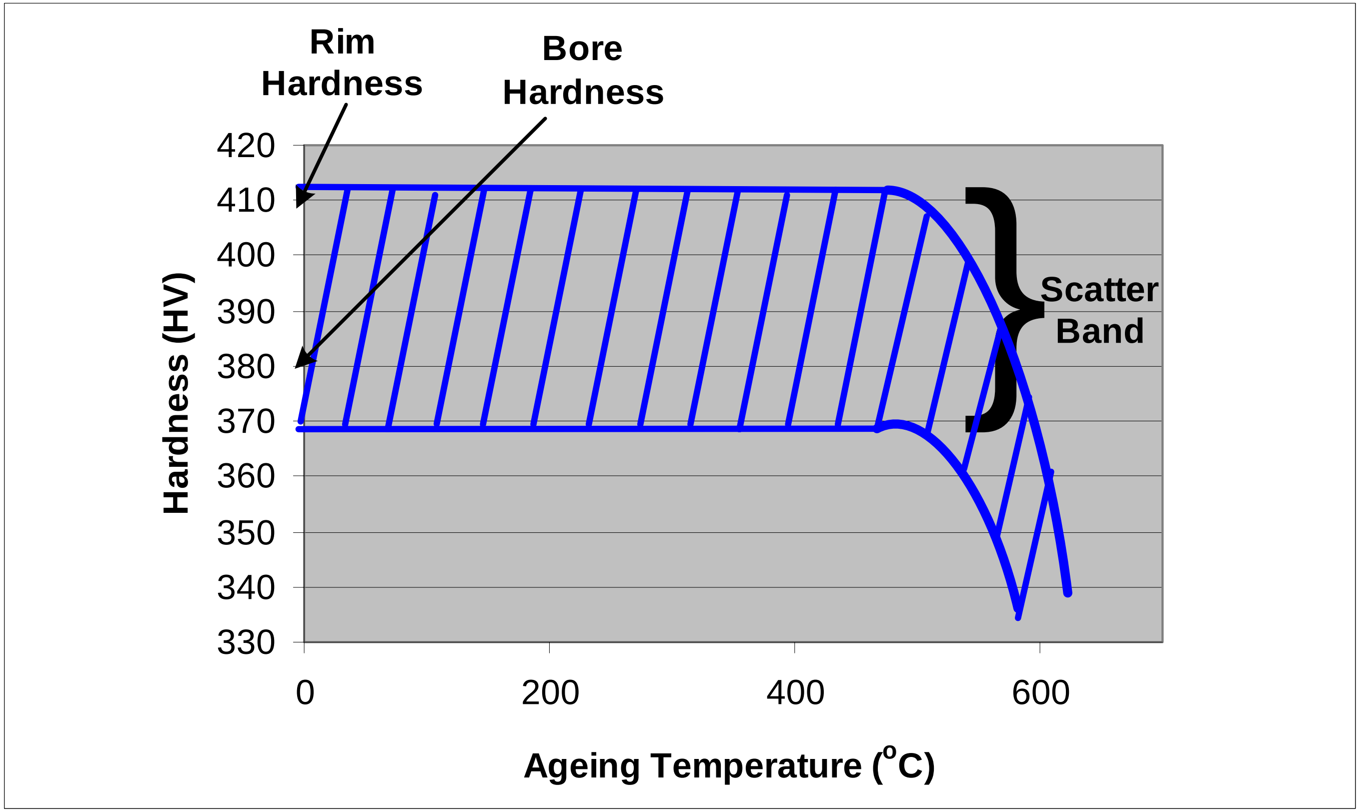
Jethete M152 Hardness Behavior



Frame 5 M152 Hardness Based Metallurgical Assessment of Discs

Jethete M 152 Stainless Steel

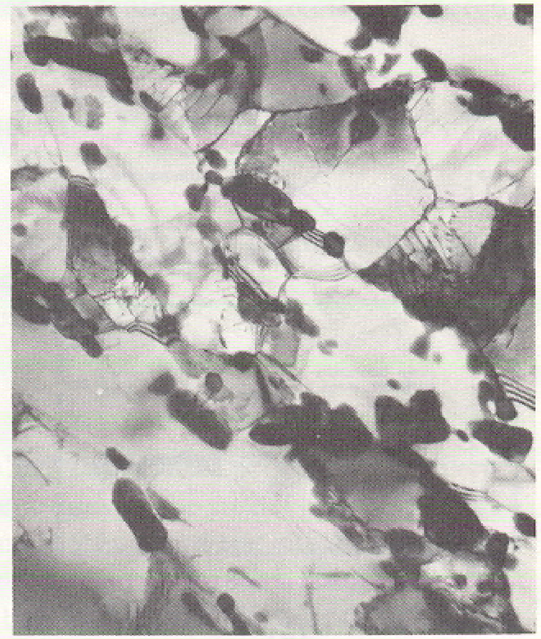
C 0.08 – 0.13 wt%
Cr 11,0 – 12.5 wt%
Mo 1.5 – 2.0 wt%
V 0.25 – 0.4 wt%
Ni 2.0 – 3.0 wt%



Disc bore hardness was 380HV and all that can be concluded is that the disc rim temperature is less than 500ºC

Electron microscopy based assessment of M152 Turbine Disc Steel (Thin foil / Replica)

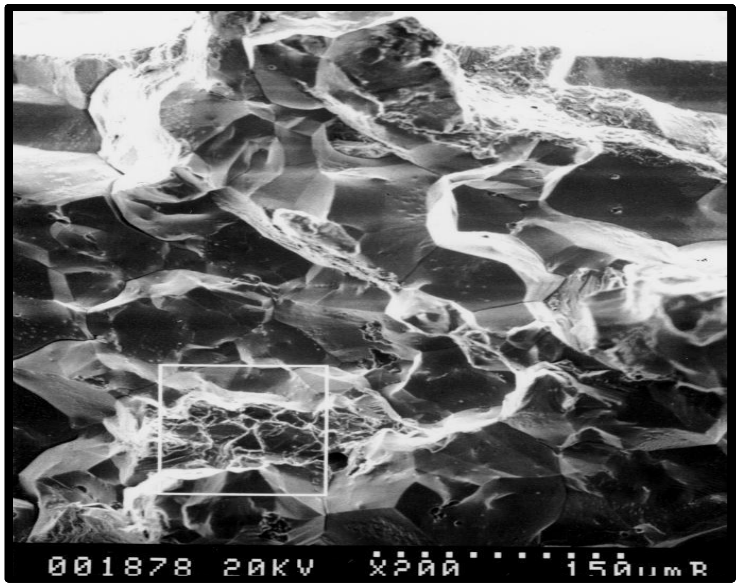
30,000h/500^{o}C

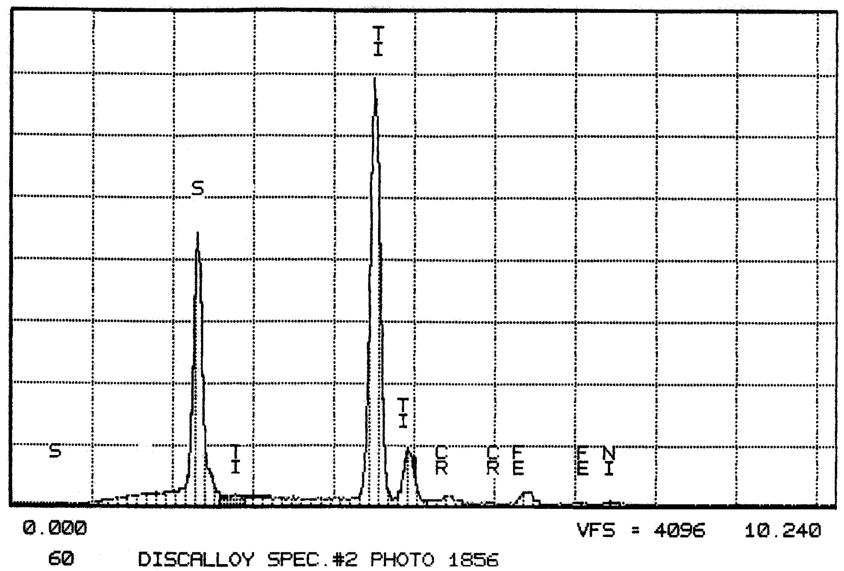


30,000h/550^{o}C

No noticeable change in secondary carbide morphology below 500^{o}C (Schinkel et. al., ASM International, 1983). No over-temperature exposure or rim temperature does not exceed 500^{o}C during service

Sub-Surface Crack Nucleation Sites in Turbine Discs





Replica technique is only good if surface connected cracks are present

XactLIFE Based Frame 5001P Disc Creep Life (Mid-East Client)

Rim Temp. ºC	415 ºC (predicted)	450 ºC (assumed)	500 ºC (assumed)
Rim Life In Hours	360,000 (predicted)	100,000 (assumed)	20,000 (assumed)

In this case lower bound creep crack initiation life was estimated to be 360,000 hours

Lessons Learned

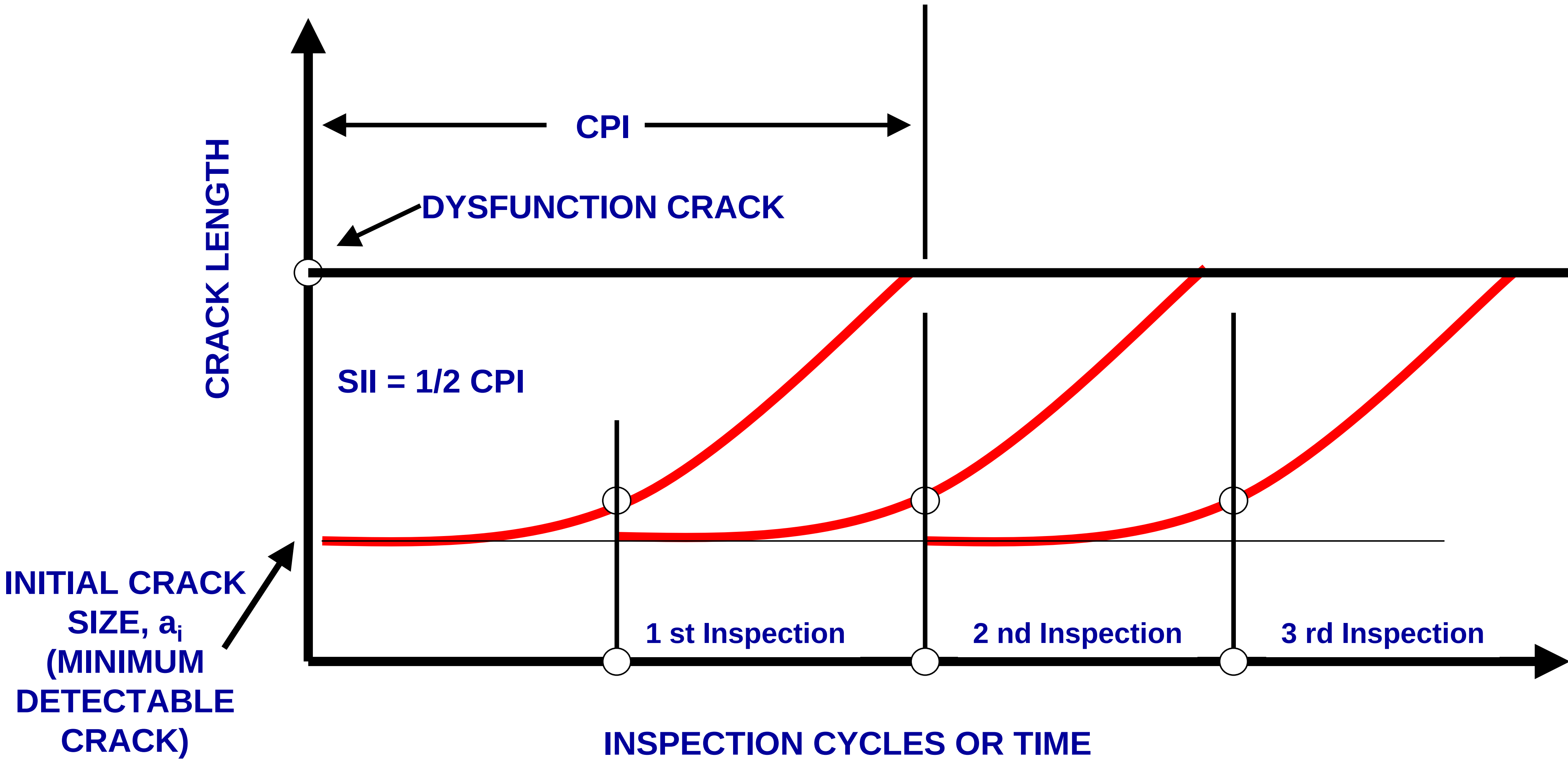
- Accurate assessment of the disc rim temperature is vital for assessing the residual life range available for life extension for a specific engine operating environment
- Rim temperature can only be determined through gas path modeling and heat transfer analysis
- Hardness checks and replica assessment only indicate whether the discs have been subjected to any over-temperature effects during service
- Replicas can only be used to detect any surface connected flaws.
- Return to service interval prediction involves detailed engineering assessment of the engine as a whole.

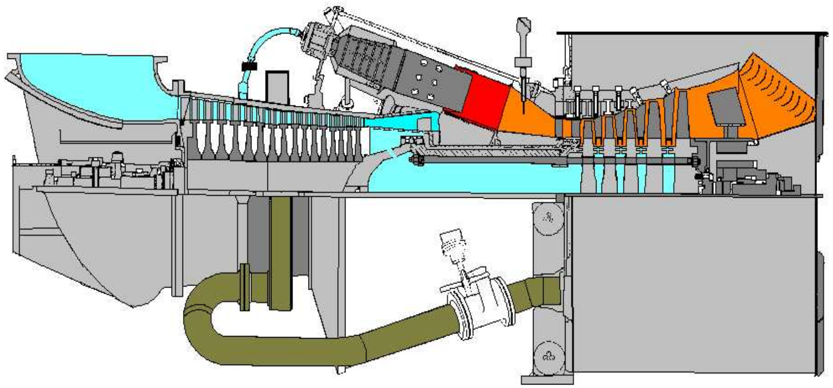
PROGNOSIS BASED SAFE INSPECTION INTERVAL OR RETURN TO SERVICE INTERVAL PREDICTION FOR W-101 ENGINES

PDVSA Fleet, Maracaibo,

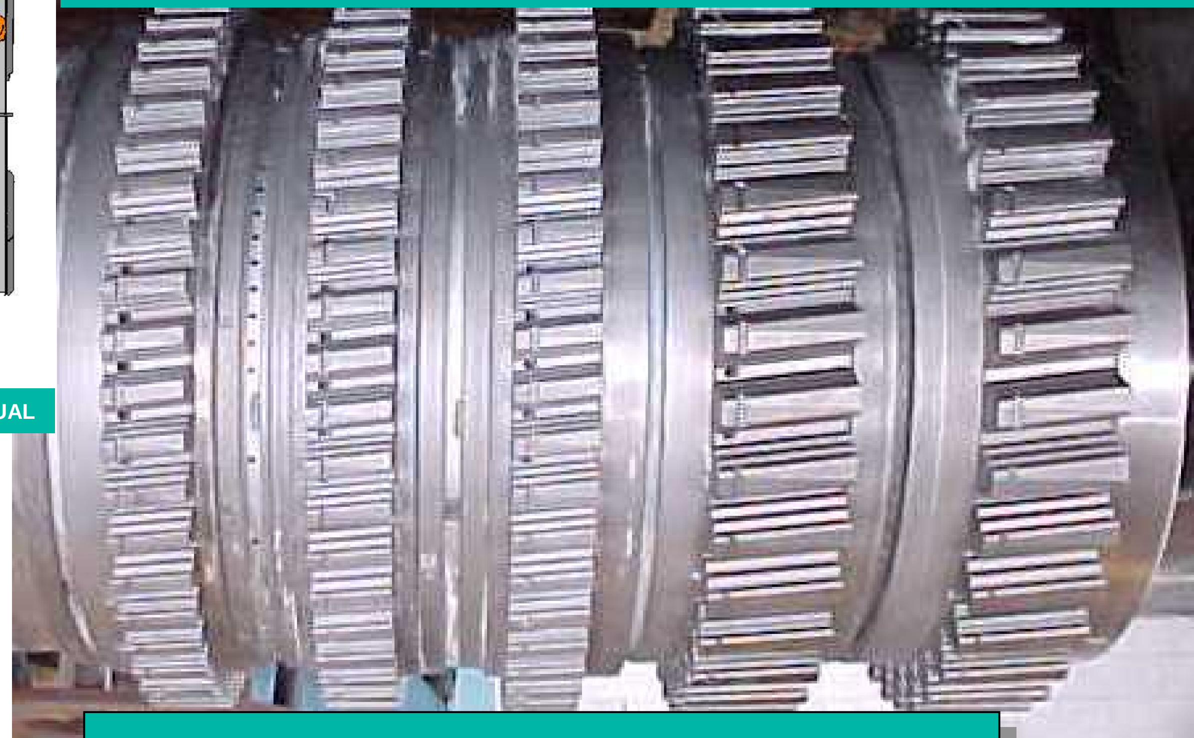
Venezuela

LIFE CYCLE MANAGEMENT OF TURBINE DISCS/SPACERS MIL-STD-1783





SOURCE: TURBINE MANUAL

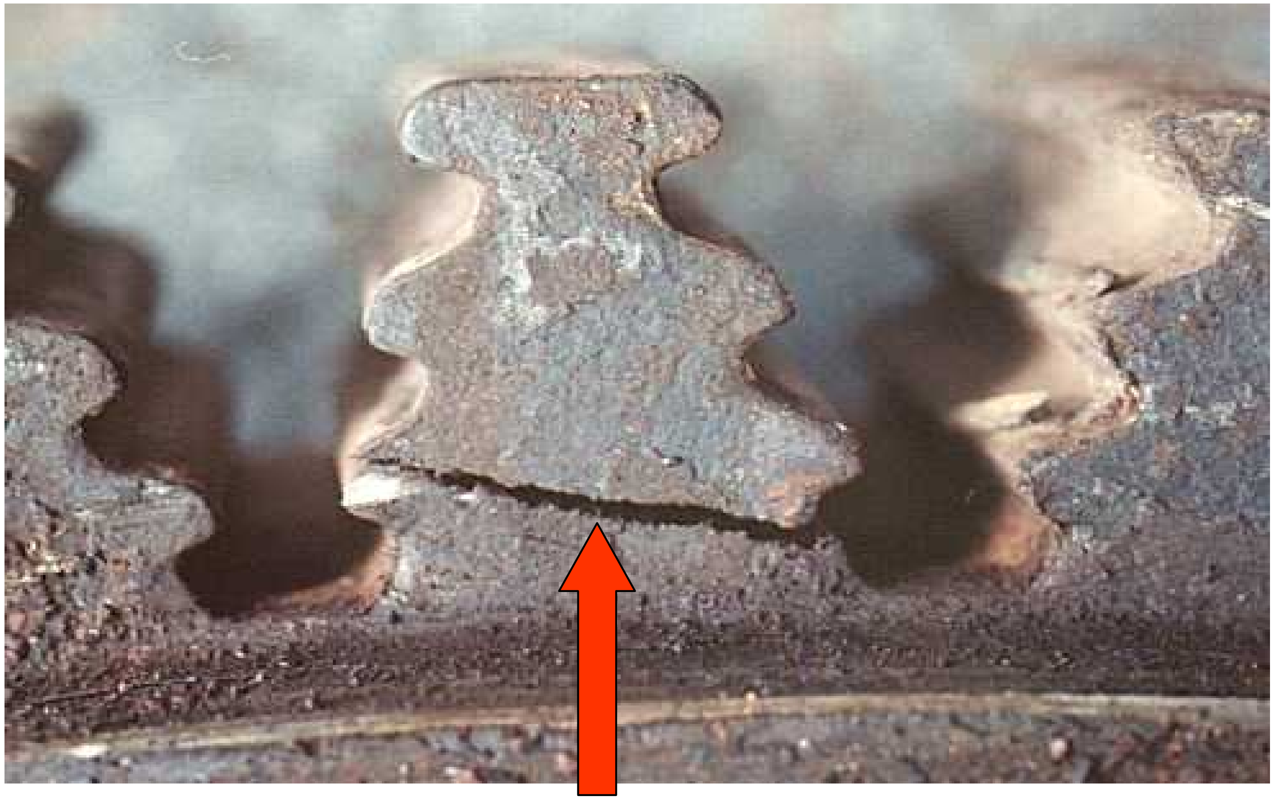


HOT SECTION ROTOR

SINGLE SHAFT GAS TURBINE
9950 HP

SPEED 6300 RPM

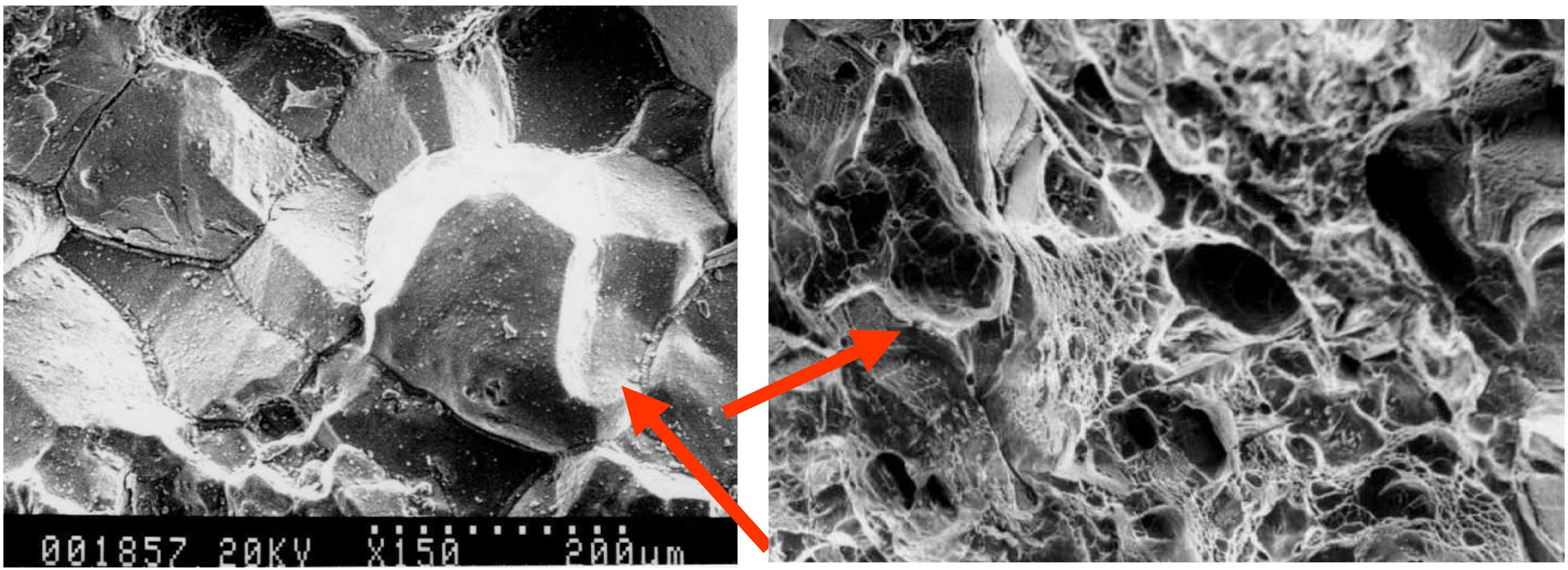
EXTENDED DAMAGE TO THE TURBINE HOT SECTION



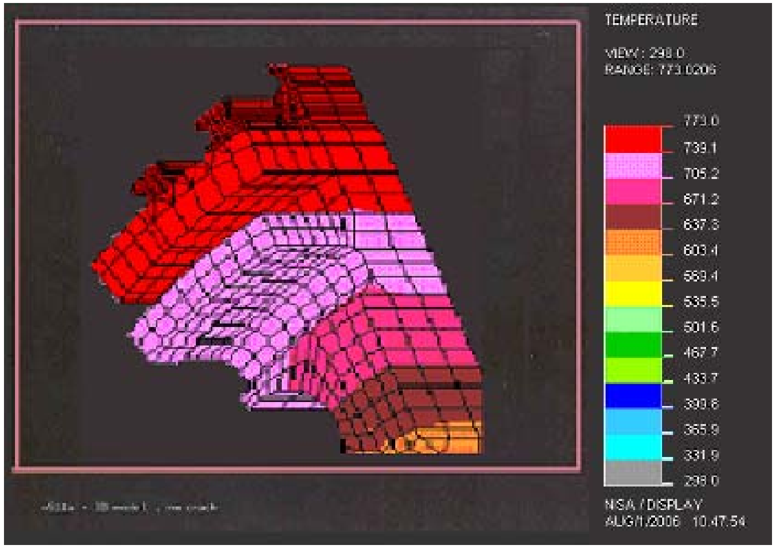
CRACK AT THE FIRTREE BOTTOM SERRATION DETECTED DURING OVERHAUL INSPECTION

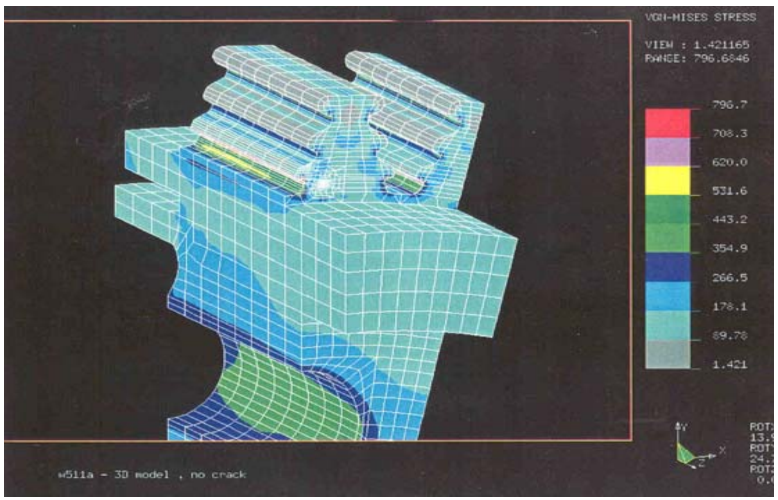
IDENTIFICATION OF CRACK INITIATION AND PROPAGATION MECHANISMS

Brittle Creep Fracture in Discaloy



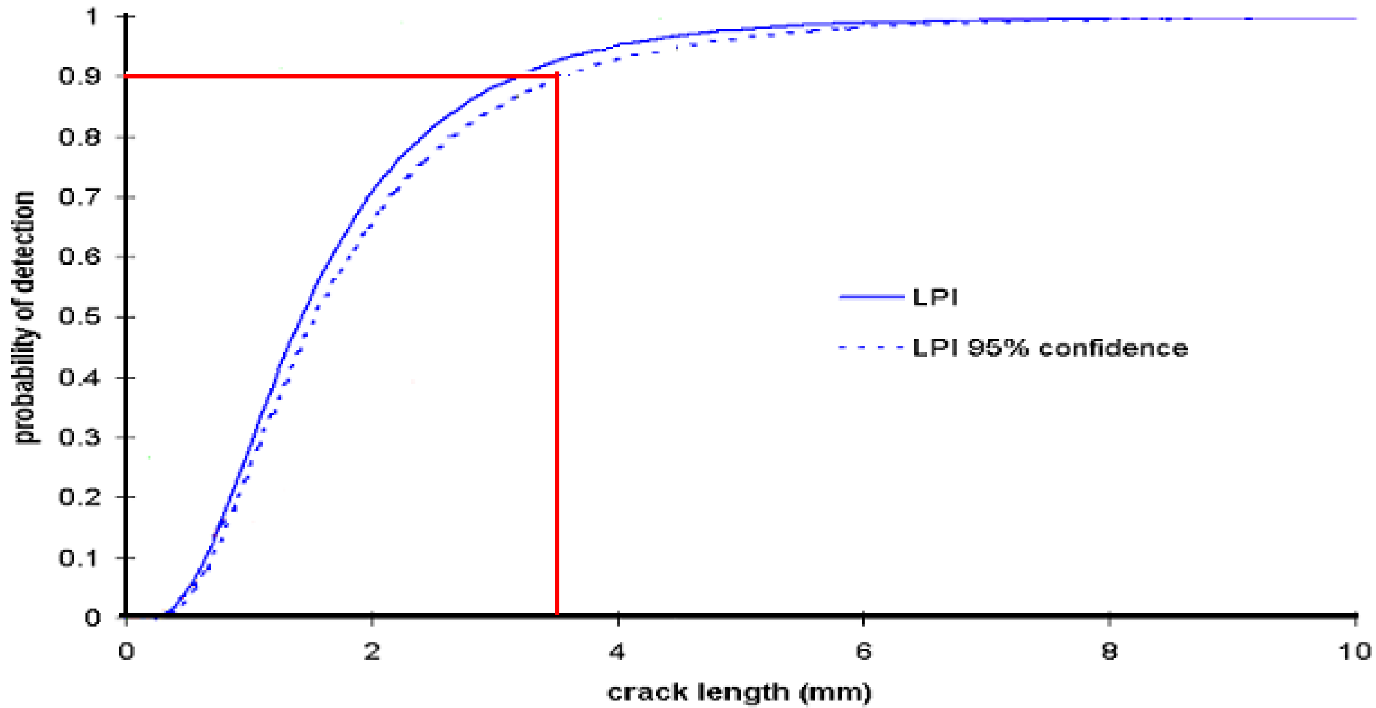
FEM Based Fracture Mechanics Analysis



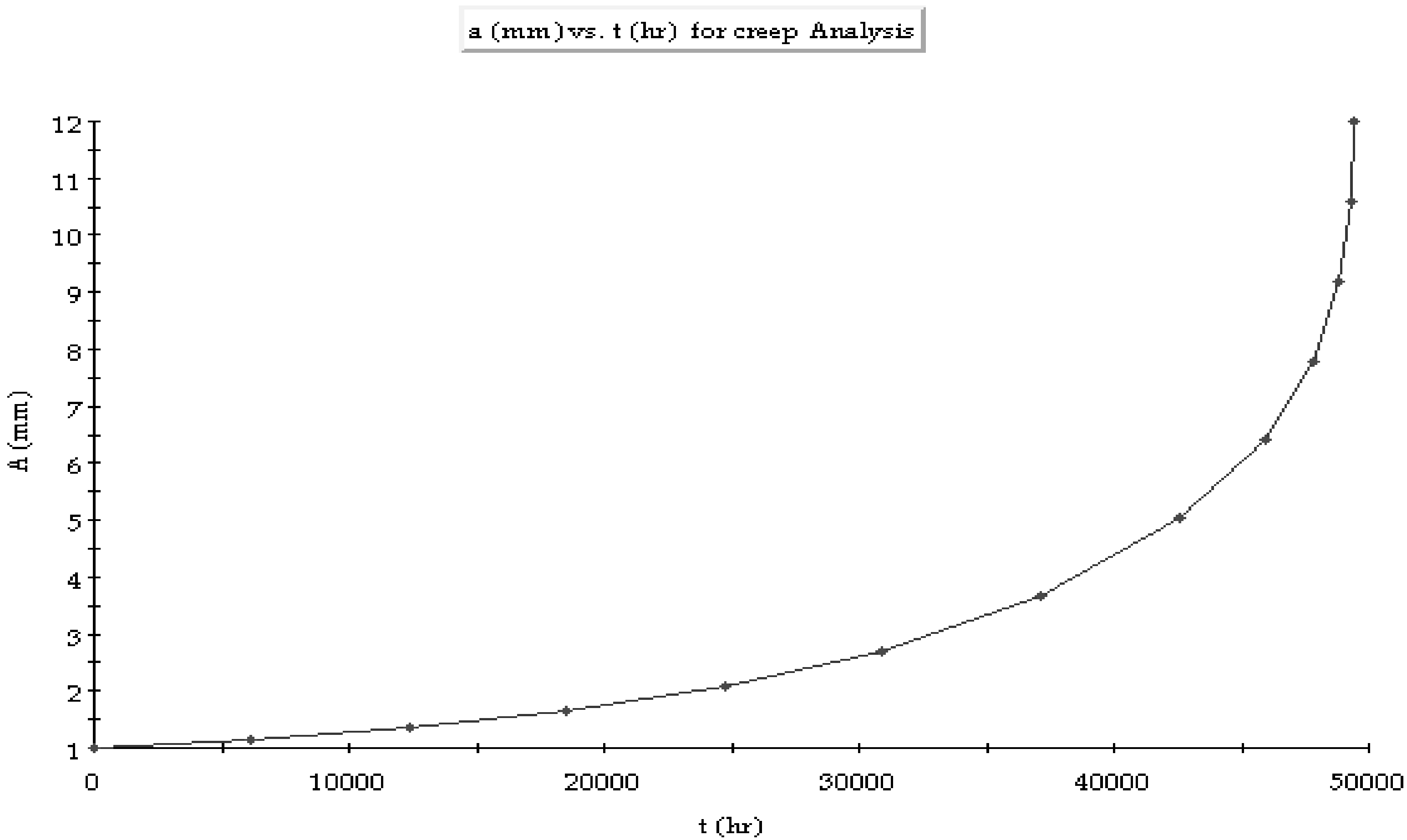


- Stress-temperature profile of the part (boundary conditions)
- Identification of fracture critical location (crack nucleation / initiation based)
- Determine ‘a’ v/s K Correlation
- Choose damage evolution models (Short CCGR and Long CCGR)
- Conduct creep crack growth based safe inspection interval or overhaul interval prediction analysis

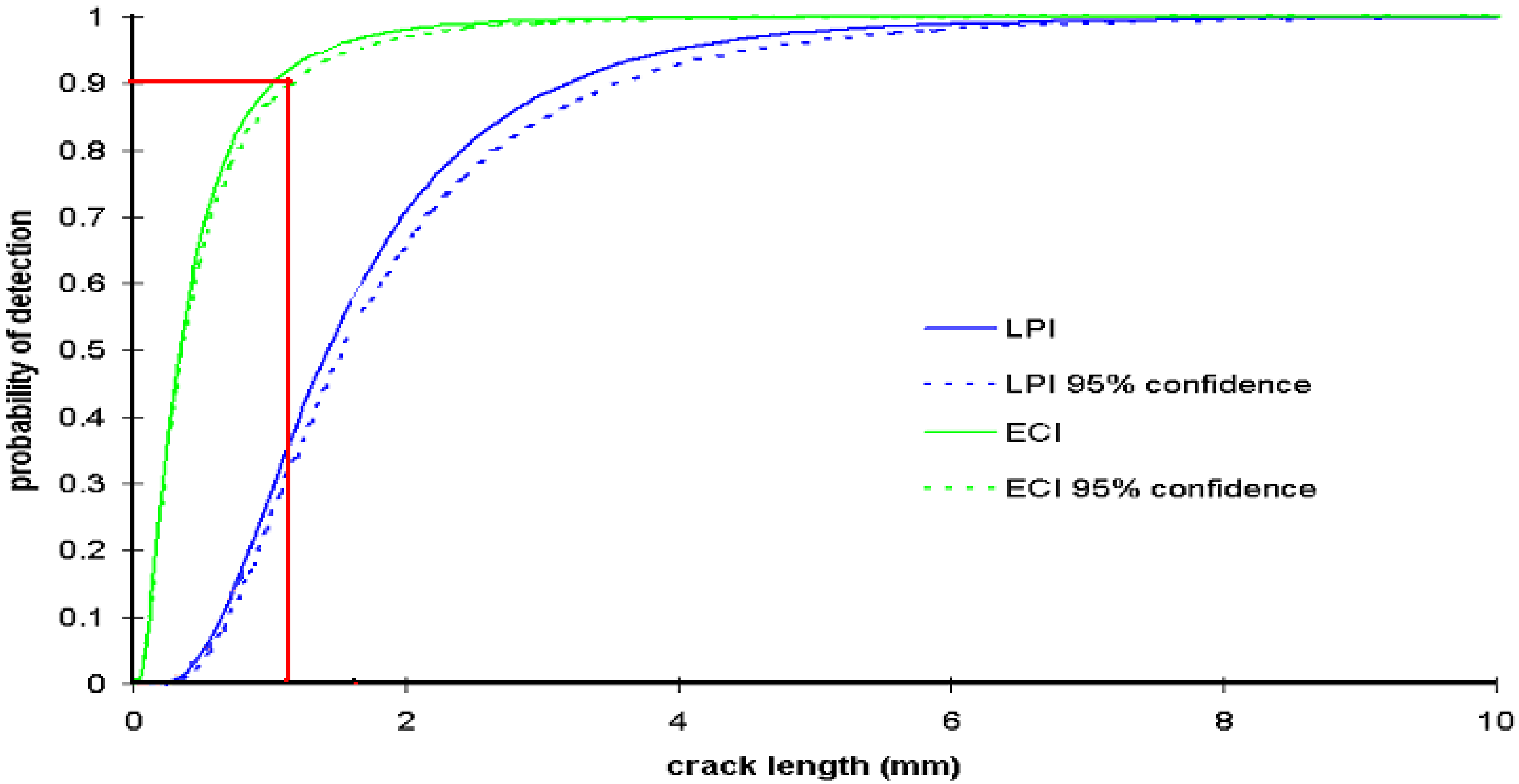
Probability of Detection Of Disc Cracks Using LPI



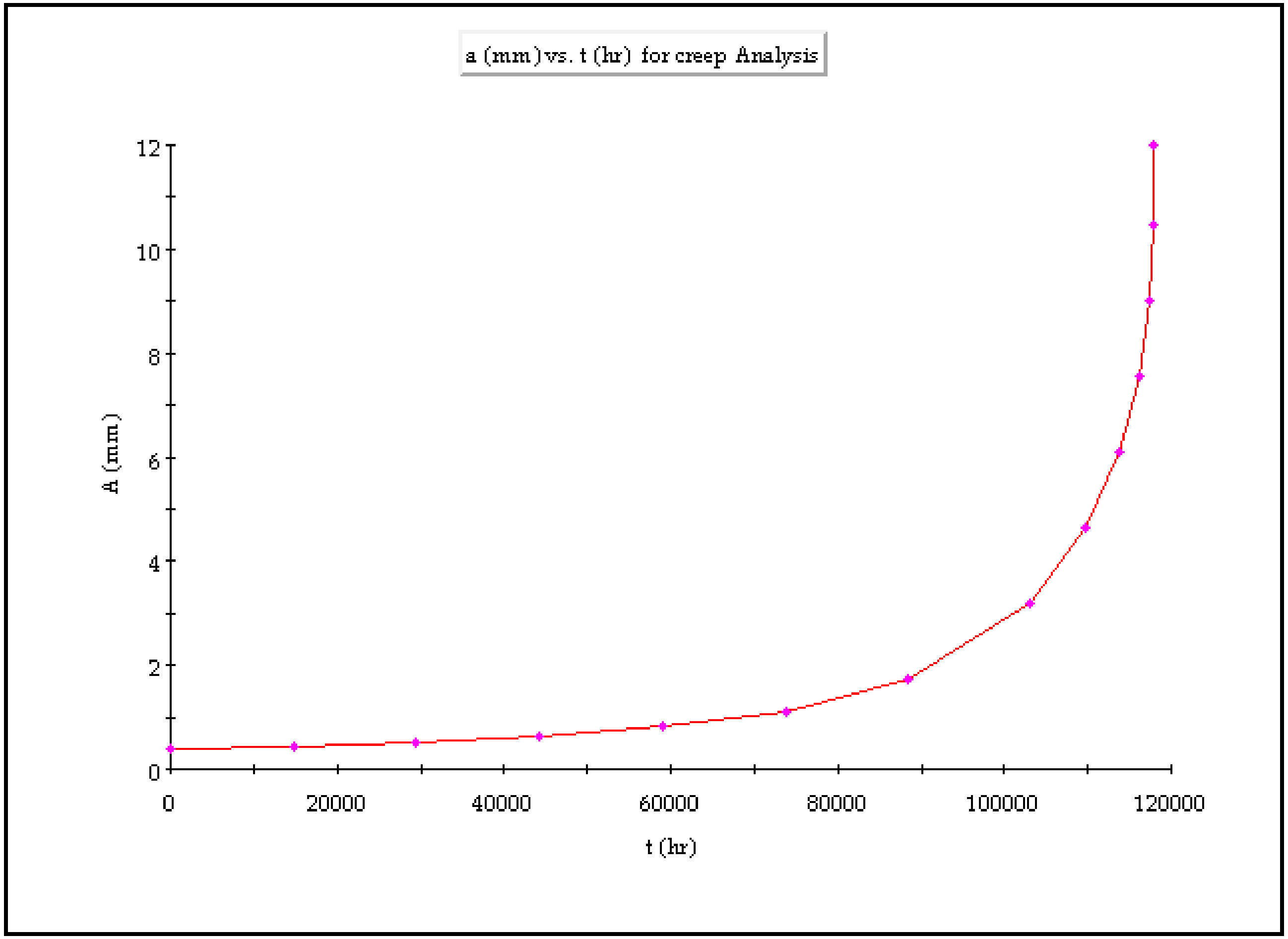
Safe Inspection Interval Prediction for LPI Technique Using Prognostics



Probability of Detection of Cracks Using LPI and ECI



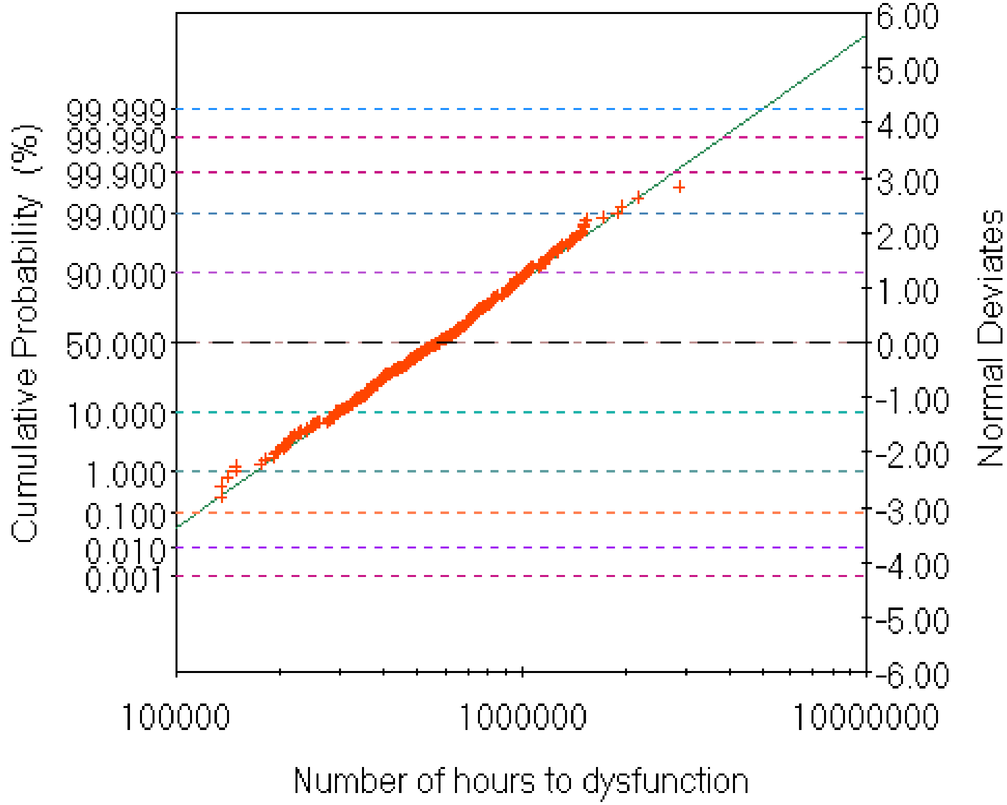
Safe Inspection Interval Prediction for ECI Technique Using Prognostics



PFM Analysis Using ECI Technique

No. of Disks = 436
Median = 565881.49 Hours
0.100 % F = 118551.60 Hours
Lambda = 13.25
dzeta = 0.51

Lognormal Analysis for Safe Inspection Intervals



W-101 Engine 10 Years of Experience Lessons Learned

- Use RFC based life cycle management philosophy to maintain discs and NOT DESIGN LIFE APPROACH. Fleet life increased from 150,000 hours to 300,000 hours

- It allows utilization of the crack initiation life of each and every individual part rather than only 1 in 1000 parts allowed by the Design life approach. Only retire discs when a crack is detected or wear is excessive.

- Select appropriate inspection technique to suit user needs

- Prognosis based LCMM saves users close to 50% on overhaul costs

What We Do Differently in Prognosis

- Residual Life Assessment Using XactLIFE

  - Precisely define the temperature gradient from bore to rim for the specific engine operating environment through engineering analysis
  - Use FE methods to determine thermal-mechanical stress gradients
  - Use physics based damage models to predict fracture critical locations and compute crack initiation life for a specific user
  - Use hardness checks and replication only for rough verification of T

- Inspection Interval Prediction Using XactLIFE

  - Predict a safe return to service interval for the specific user taking into account consequences of any flaws that may be missed during inspection or introduced during manufacturing or present as a metallurgical defect
  - Define quantitative NDI requirements for the user
  - Select most suitable NDI techniques for inspection and design probes if necessary

- XactLIFE Based Reliability Assessment and Risk Mitigation

  - Conduct probabilistic analysis taking into account material variability, usage variability and inspection uncertainly
  - Quantify engine reliability for future safe engine operation

Cost Savings

- Disc replacement costs are deferred on long term basis. In the case of W-101 fleet, PDVSA deferred $40 Million investment by more than 10 years.

- Overhaul costs are reduced by as much as 45-50% of the regular overhaul costs. PDVSA saved $2.5Million per year in reduced overhaul costs for the W-101 fleet.

- Other repair costs can also be reduced significantly

Thank You

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Prognostics Health Management

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