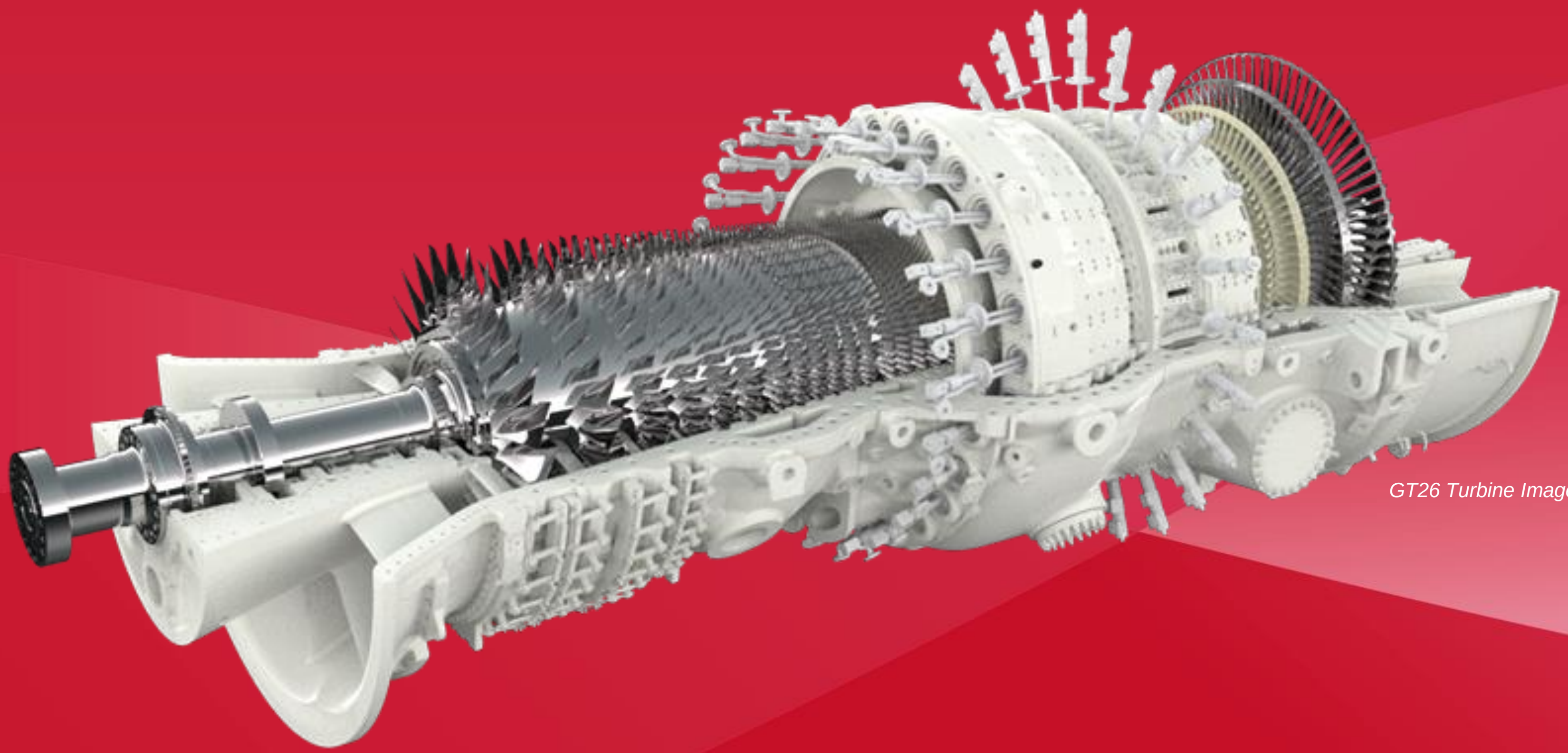

GT26 Turbine Image

GT26 Gas Turbine Life Extension – A Case Study

Dr Laurie Brooking, CEng MIMechE

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SYSTEMS AND ENGINEERING TECHNOLOGY

FRAZER-NASH CONSULTANCY

Presentation Overview

Agenda

- Introduction to Frazer-Nash Consultancy
- Gas Turbine Asset Life Cycle
- Background and Business Need
- The Approach
- Conclusions

Project Overview

- Frazer-Nash Consultancy recently supported a GT 26 Operator to increase availability and reduce costs by extending the OEM recommended inspection intervals.
- This was achieved by the application of creep model informed calculations to determine the accumulated damage, rather than the conservative assumptions which underpin Equivalent Operating Hour (EOH) calculations.

Introduction to Frazer-Nash Consultancy

10 UK Offices

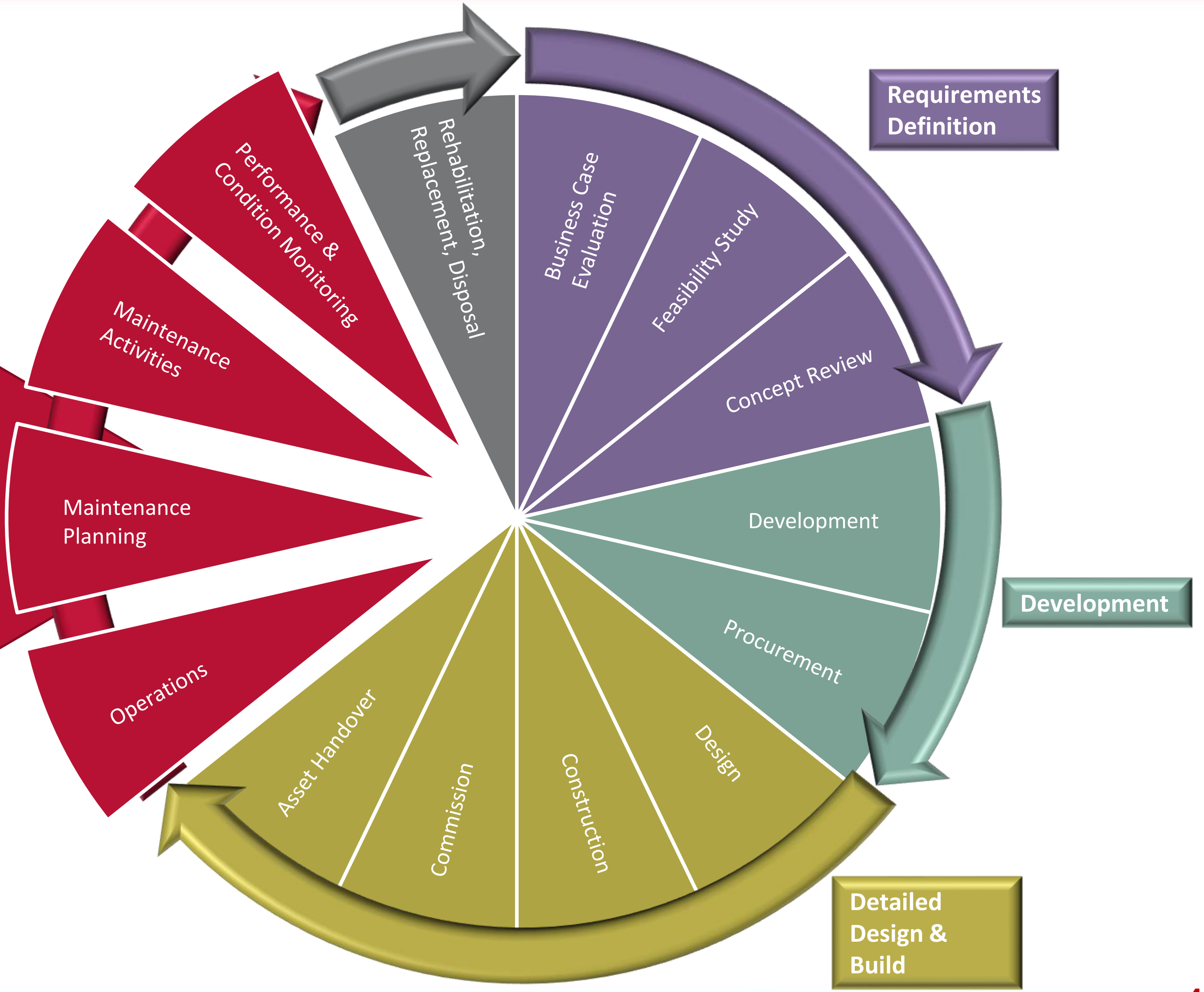
3 Australian Offices

Frazer-Nash is a leading systems and engineering technology consultancy. We're known for our work across aerospace, transport, nuclear, marine, defence and power and energy sectors. We provide expertise in asset integrity, design, materials performance, analysis and modelling, security, resilience, cyber and information technology.

Gas Turbine Asset Life Cycle

Operation & Maintenance

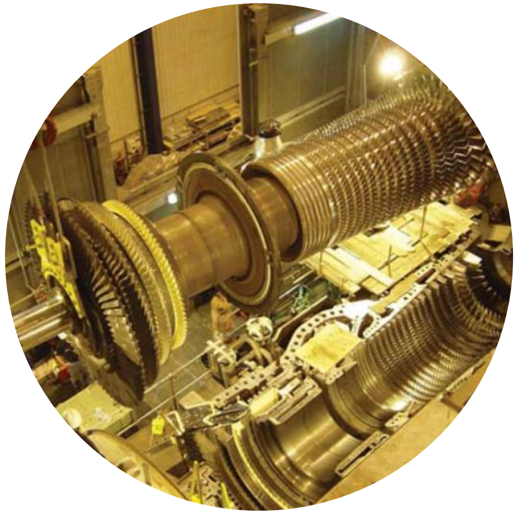
- Reliability, Maintainability, Availability (RAM)
- Root Cause Analysis
- Remaining Life Assessment & Life Extension
- Outage Planning & Support
- Asset Integrity
- Asset Management
- Performance Analysis
- Risk Based Equipment Life Management
- Design Modifications
- Online Condition Monitoring
- Electronic Control & Instrumentation
- Noise & Vibration
- Safety



Background, Business Need & Objectives

Power Plant Facility

- 420 MW Combined Cycle Gas Turbine (CCGT) power plant opened in 2000
- One GT26 turbine with an ABB steam turbine in a single-shaft configuration
- Baseload operating conditions diverged to load-following mode



Business Need

- Station wanted to maintain high availability
- Inspection intervals restricted to OEM design limits
- Planned ‘C’ inspection outage would incur significant cost and forgo opportunity
- Required evidence to justify extension of inspection intervals and support discussions with OEM

Objectives

- Develop a method to capitalise on the margin between conservative design lifing approaches and actual operational life
- Provide understanding of the risks associated with specific operational modes at the facility

The Approach - Overview

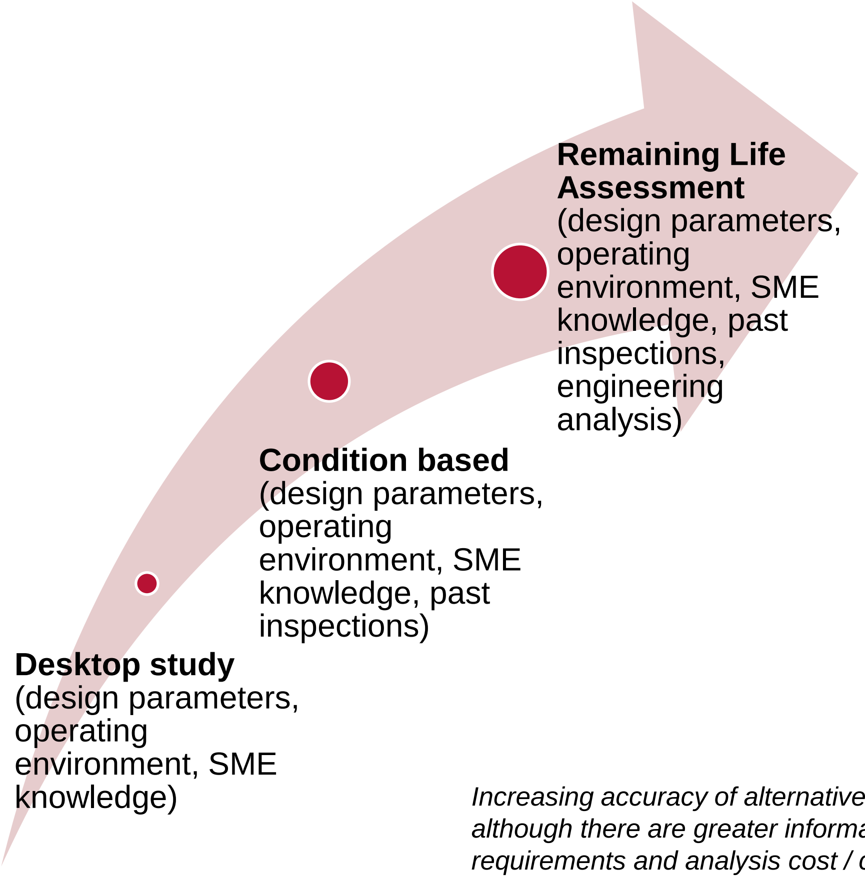
- **Step 1**
  - Review OEM inspection interval philosophy
- **Step 2**
  - Apply the OEM EOH calculation to establish a baseline
- **Step 3**
  - Define an enhanced EOH calculation using normalised creep modelling to assess the damage accumulation to date
- **Step 4**
  - Review operational concepts, degradation laws and actual operating data, providing an indicative result of the available credit
- **Step 5**
  - Predict gas temperatures affecting the hot gas path components
- **Step 6**
  - Determine probable metal temperatures and undertake a normalised creep calculation for each component
- **Step 7**
  - Normalise the enhanced EOH calculation using the normalised creep model, providing a measure of the available credit to defer an inspection

The Approach - OEM Inspection Interval Philosophy

Step 1

- Review OEM inspection interval philosophy

- Inspection schedules are set by OEM recommended EOH calculations
- The EOH is an indicator of the accumulated damage
- Calculations vary between turbine class and OEM
- Typically applied as part of Long Term Service Agreements (LTSAs), and can act to reduce operator risk.
- EOH calculation approaches are typically very conservative
- Application of a credible alternative to EOH can help operators:
  - Increase availability
  - Reduce maintenance costs
  - Extend equipment life



Increasing accuracy of alternatives to EOH, although there are greater information requirements and analysis cost / complexity

The Approach - GT26 OEM Maintenance Interval (GER3620P)

Step 2

- Apply the OEM EOH calculation to establish a baseline

$$EOH = \sqrt{(V \times S)^2 + (A \times OH)^2}$$

Variable	Description
EOH	Equivalent operating hours
S	Number of starts
V, X, W, A	Penalty Factors (These include fuel, starts weighting and operating hours)
OH	Operating hours

Type	Interval (EOH)	Description
'A' inspection	6,000	Remote visual inspection of the hot gas path components (no engine disassembly)
'B' inspection	12,000	As 'A' inspection, with additional checks of control systems, protection systems and auxiliaries (no engine disassembly)
'A' inspection	18,000	Remote visual inspection of the hot gas path components (no engine disassembly)
'C' inspection	24,000	Disassembly of the turbine for detailed condition assessment of the rotor and hot gas path components

Operation	Actual Number of Hours Accrued	Equivalent Hours Accrued
Part Load $TIT_{\_LP1}$<1280°C	3,732	2,799
Base Load $TIT_{\_LP1}$≥1280°C	373	373
Total	4,107	3,173

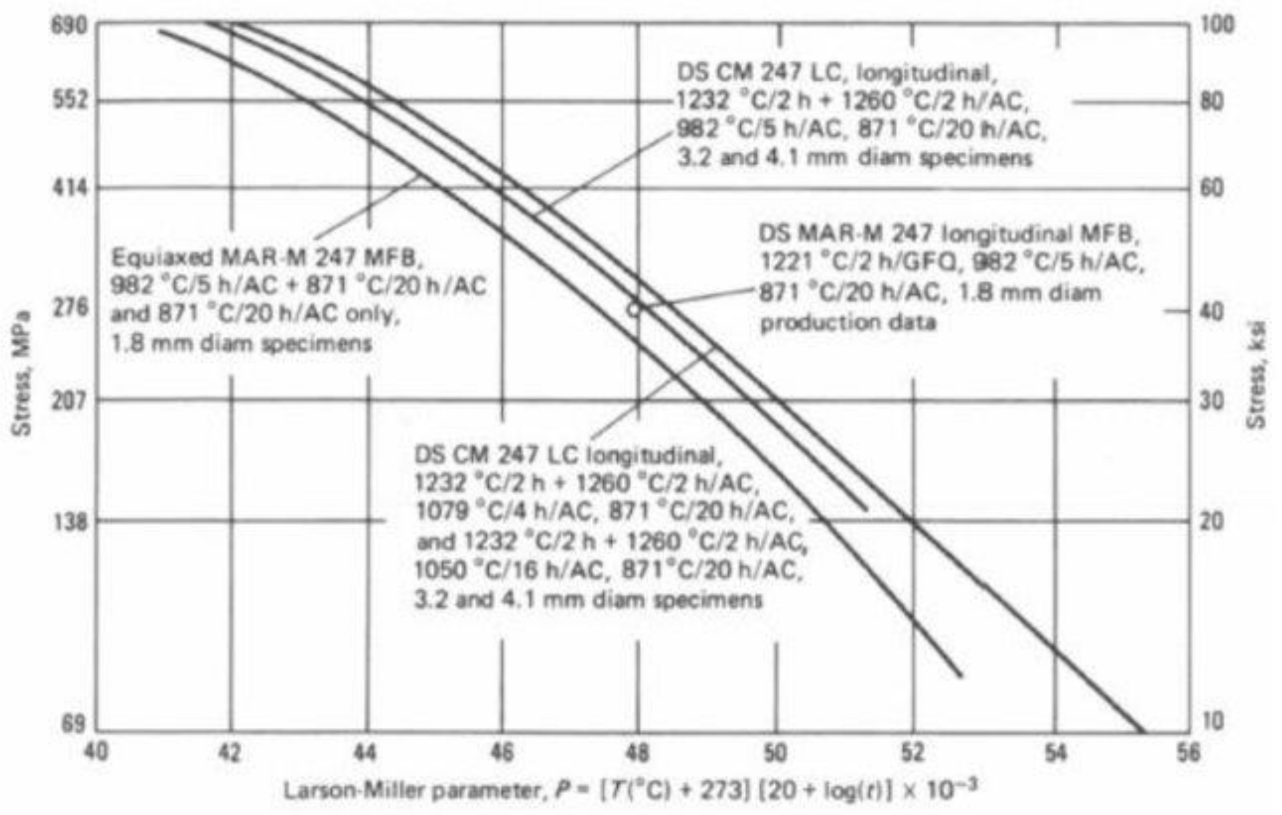
- Typical OEM methods calculate the EOH as a function of starts and operating hours
- Inspection intervals are determined from EOH
- For our case study the calculated EOH worked out at 77.3% the actual hours operated

The Approach - Alternative component life assessment method for

Step 3

- Define an enhanced EOH calculation using physics-based relationships to assess the damage accumulation to date

- A relationship based on an established creep model was defined which is appropriate for hot gas path components
- The calculation methodology followed a normalised approach, providing the benefit that the absolute temperature and stress was not required as an inputs
- Temperature change about a nominal metal temperature results in damage accumulating at a slower (or faster) rate when temperatures below (or above) the nominal metal temperature occur
- Material data may be the IP of an OEM, requiring SME knowledge to perform the analysis



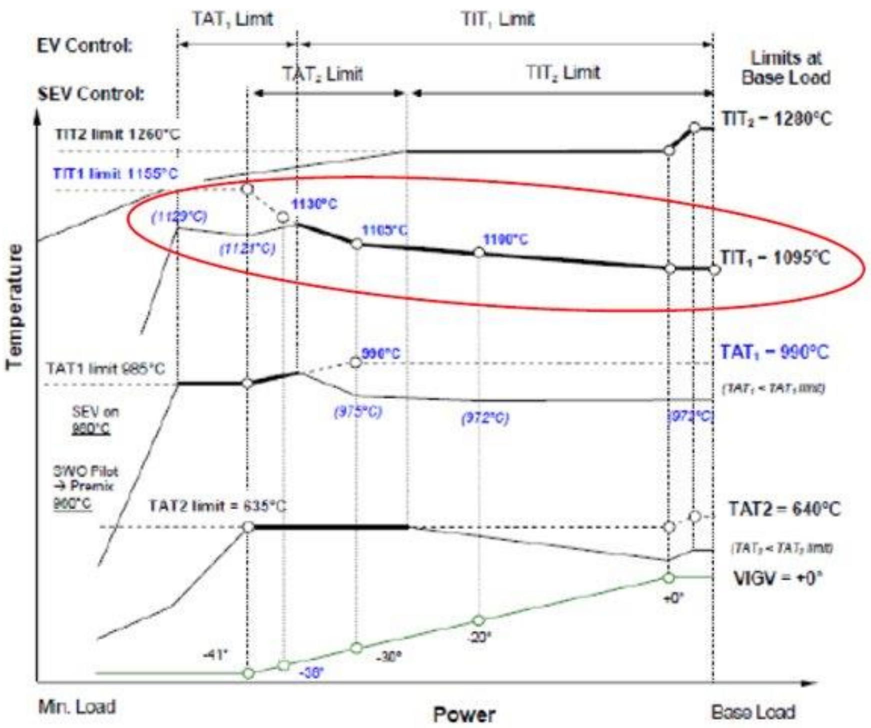
Larson-Miller curves for three Nickel Alloys in the GT26 hot gas path

The Approach - Indicative available credit

Step 4

- Recalculate the EOH based on material properties, degradation laws and actual operating data, providing an indicative result of the available credit

- Some turbine components get hotter when load is increased, while other components get cooler and vice versa
- Understanding this relationship is fundamental to predicting temperature, and subsequently the accumulated damage
- The Operation Concept, which underpins the OEM EOH calculation, defines the relationship between load and temperature
- Since this GT was installed, multiple ‘Operation Concepts’ have been implemented after each ‘C’ inspection (3 in total)
- Significant differences between the latest Operating Concept and prior versions



Operating concept applied from 2015

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The Approach - Predicting Gas Path Temperatures

Step 5

- Predict gas temperatures affecting the hot gas path components

- Metal temperatures experienced by the hot gas path components are critical to defining the creep life
- A normalised creep calculation estimates the relative difference in creep life at different temperatures
- In this case, a linear extrapolation was performed from the HP inlet temperature to the LP inlet temperature to determine the local gas temperatures
- Instrumentation can provide further accuracy when determining the local temperatures and accumulated damage

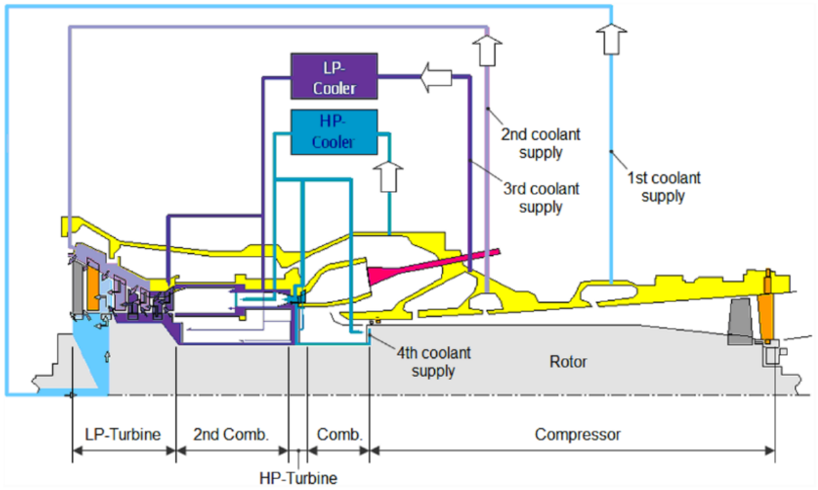

Illustration of the cooling flow paths within the GT26

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The Approach - Calculating Metal Temperatures and Creep Life

Step 6

- Determine probable metal temperatures and undertake a normalised creep calculation for each component

- Operating data was grouped into 2.5°C temperature “bins”
- A normalised creep damage calculation was performed for each temperature bin
- The OEM EOH uses a stepwise model, while our enhanced EOH uses an exponential creep law
- This method allowed application of a knockdown factor, corresponding to a creep law for each temperature “bin” when operating at any load point

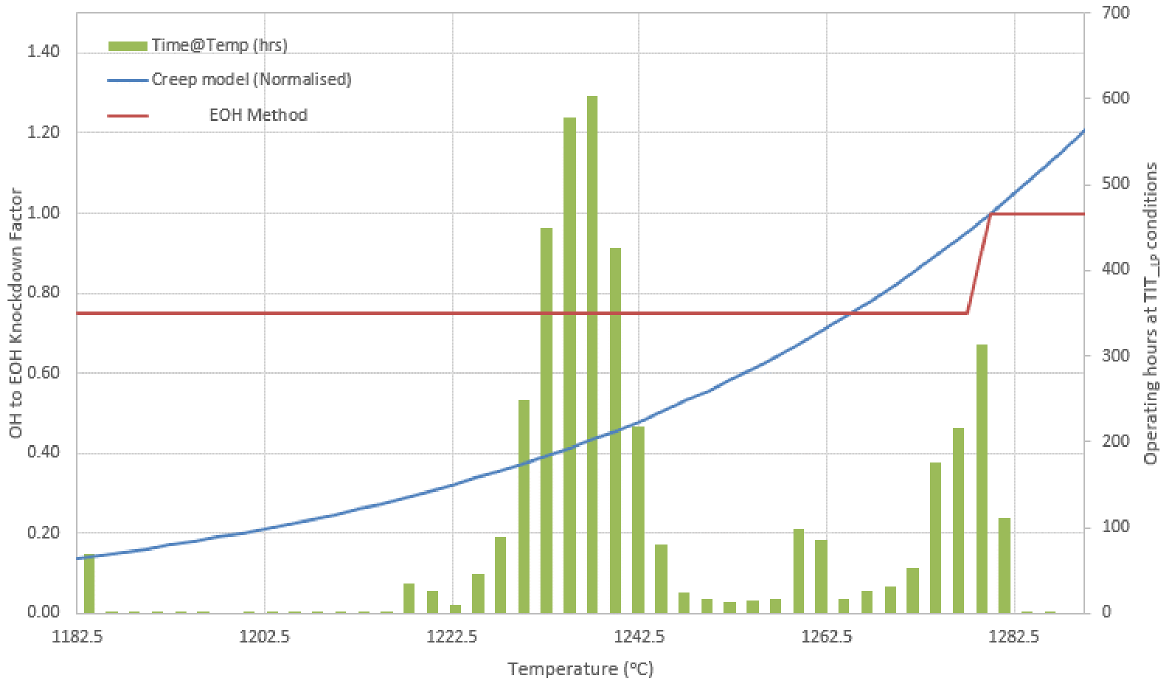


Illustration showing the normalised creep model, the EOH model, and the expended operating hours based on HP turbine inlet temperature (top) and LP turbine inlet temperature (bottom)

The Approach - Determine the Available Credit to defer an Inspection

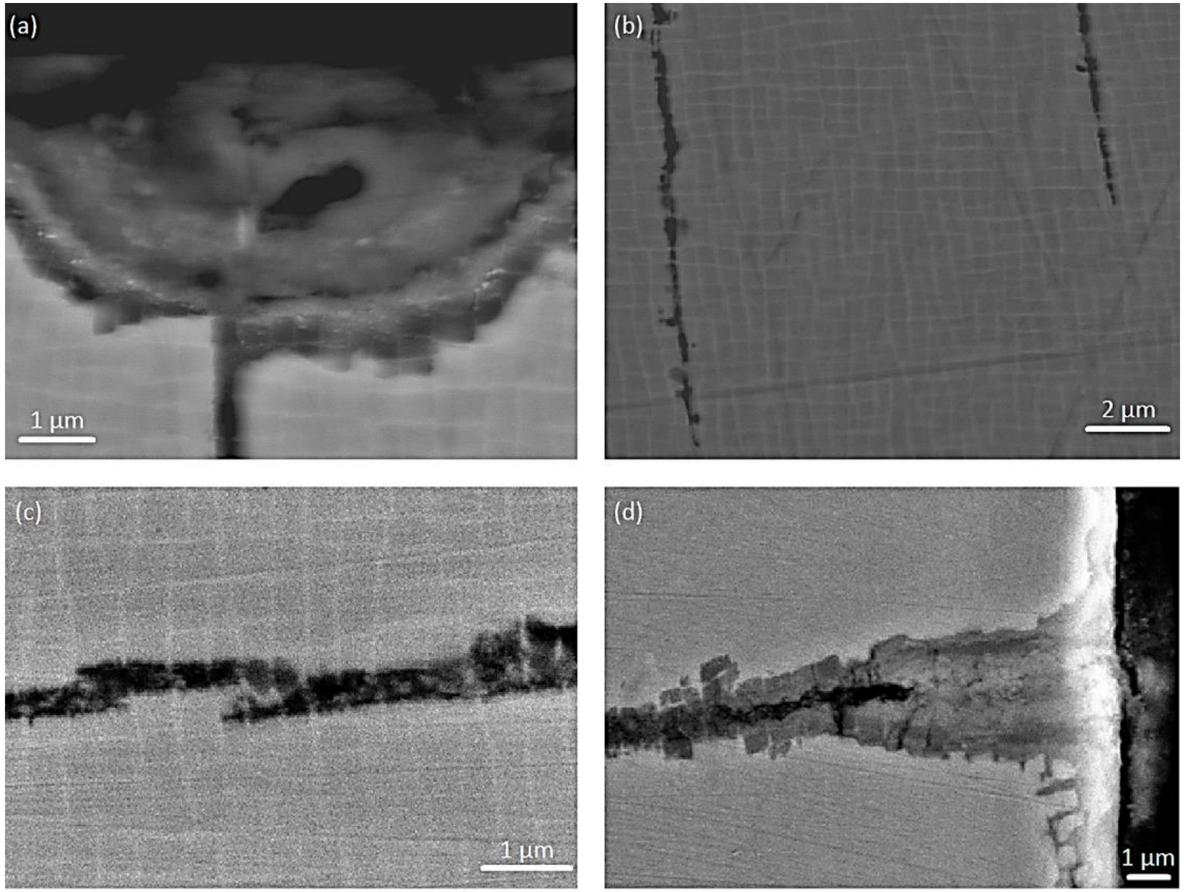
Step 7

- Normalise the enhanced EOH calculation using the normalised creep model, providing a measure of the available credit to defer an inspection

Operation	Number of Hours	Consumed Life since last ‘C’ Inspection	
		EOH	Creep Law Enhanced EOH
Part Load $TIT_{\_LP1} < 1280°C$	3,732		
Base Load $TIT_{\_LP1} \geq 1280°C$	373		
Total	4,107	77.3%	53.0%

- The enhanced EOH method suggests that damage is accumulating at a slower rate than the OEM EOH calculation predicts
- The component with the highest enhanced EOH determines the available credit to defer an inspection
  - HP blades are the limiting component in this study, being capable of a further 29,500 EOH, or an extension of 23%
  - In comparison, the Stage 3 LP blades are capable of a further 47,200 EOH before replacements are required.

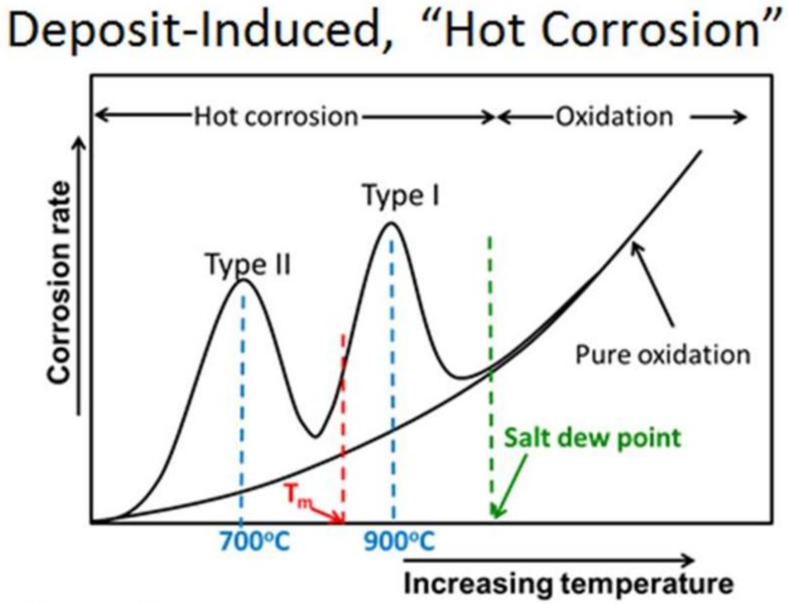
Extending the method to include hot corrosion screening



(a),(b) 800 MPa statically loaded three point bend specimen, 200 h (c),(d) 800 MPa statically loaded C-ring specimen, 100 h

- The operational hours (OH) concept and time spent operating at given temperatures and conditions can also be used to assess the risk of corrosion or stress corrosion cracking type behaviour

- We are working on developing methods to use insight on the risk certain modes of operation have to corrosion



Meier, Gleeson, U-Pitt

Conclusions

- There was opportunity for extension of the prescribed inspection interval by 23%

- The potential for extension is limited by the component with the lowest enhanced EOH, which will vary depending on how the turbine is operated

- Operators seeking to extend Turbine Inspection Intervals should consider:
  - The consequences of OEM updates to the underlying assumptions of EOH calculations, and the impact on subsequent inspection intervals
  - The OEM EOH method applies credit for part load operation, however:
    - At part load operation, the $TIT_{\_HP}$ temperature increases significantly and potentially increases the rate of damage accumulation, which is not reflected in the standard EOH calculation
    - The OEM's weight factor assigned to different load operations can be coarse, and does not follow any physical damage laws

- Operators can reduce the rate at which EOH is consumed through:
  - Performing a review of plant stability, operating philosophies and trading behaviour and the associated starts, trips, emergency switch offs, etc - these accounted for approximately 30% of the total consumed EOH in this study
  - Performing a review of plant stability, and the causes of Protective Load Shedding - this accounted for approximately 10% of the total consumed EOH in this study

Laurie Brooking

Email: l.brooking@fnc.co.uk

www.fnc.co.uk