Maintenance interval extension

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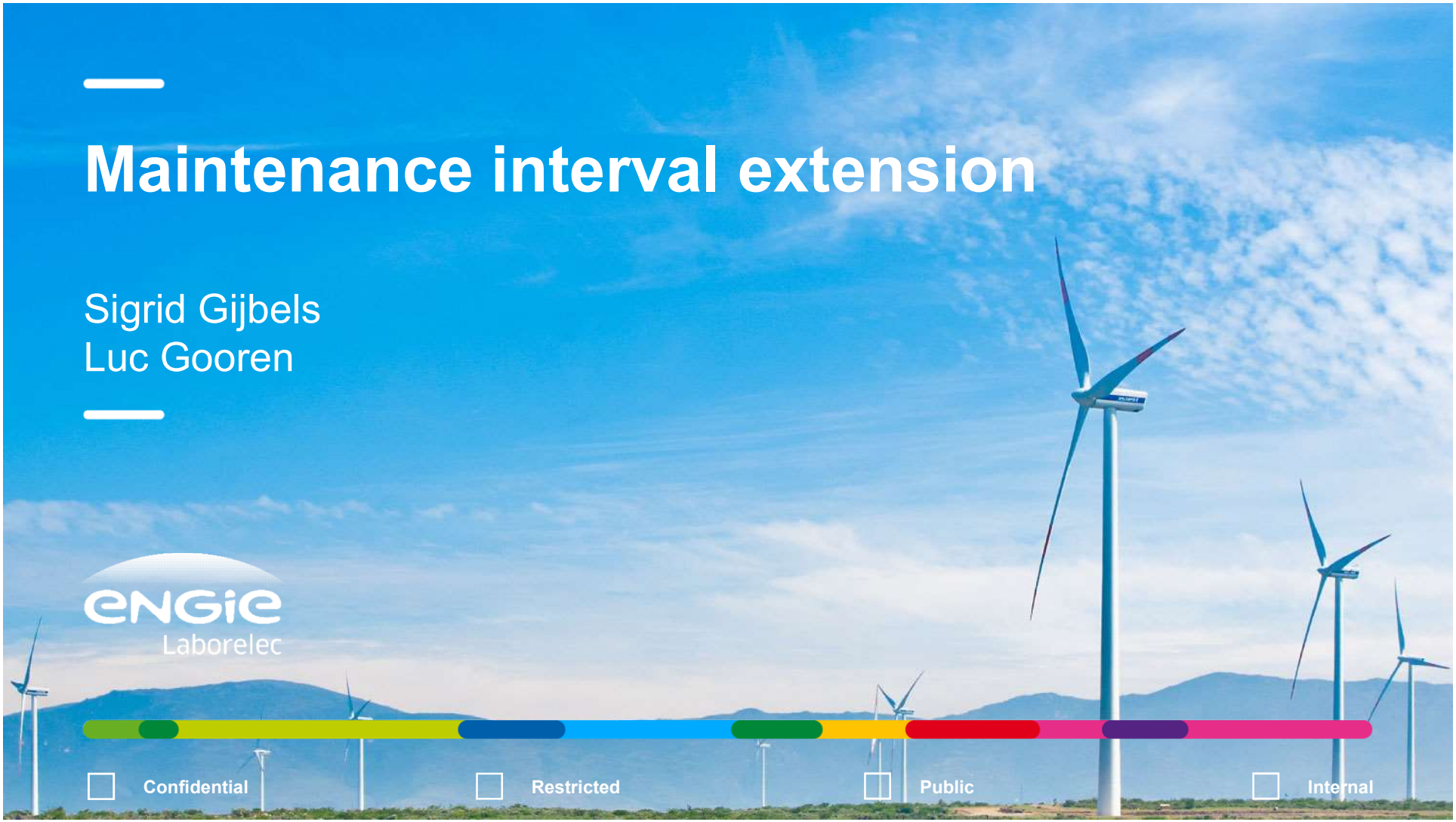

ENGIE Laborelec

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ENGIE Laborelec
Company presentation

- Laborelec is a leading **expertise** and **research** center in **electrical power technology**.
- Founded in 1962, Laborelec has **over 55 years** experience in the power sector.
- Laborelec is a **cooperative company** with ENGIE and independent grid operators as shareholders.

- Our competencies cover the **entire electricity value chain**: generation, transmission & distribution, RES, storage, for the industry and other end-users.
- We put a strong focus on the **energy transition** and the 3D's : **decentralization**, **decarbonisation** and **digitalisation**.
- We offer specialised **services**, **R&D** and **products** in each of these domains, to companies in **all parts of the world**.

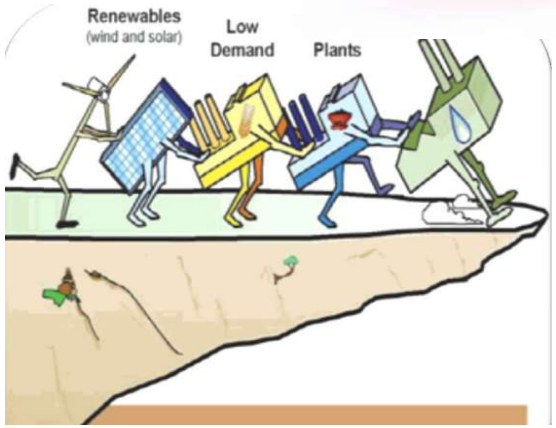
European energy market evolution

Energy market is no longer profitable for many plants

Competitive market
No capacity payments

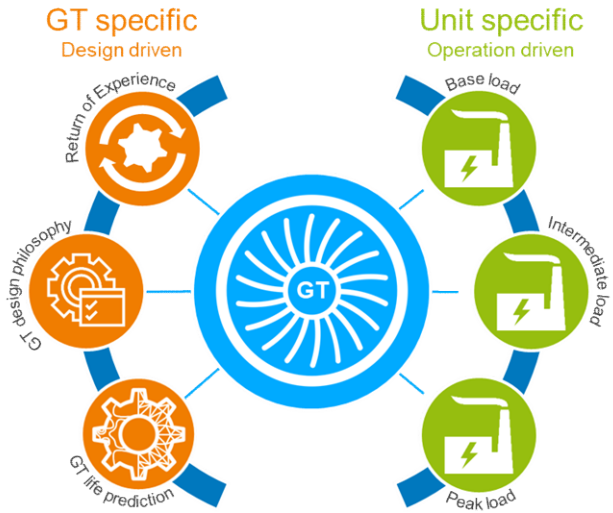
LOW ENERGY PRICES
+
LOW OH

= LOW REVENUES



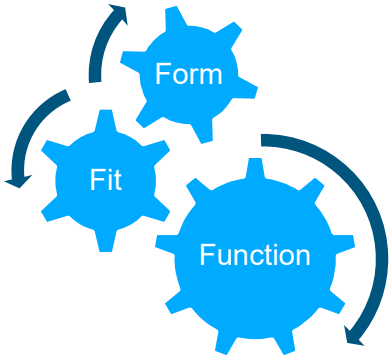
Maintenance interval extension

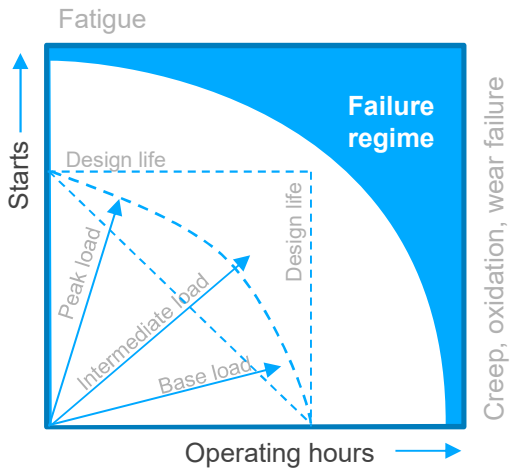
- Maintenance Interval Extension (MIE) is a product for GT end users in challenging market conditions who need to reduce maintenance cost
- GT maintenance schedule is based on OEM recommendation and conservative (and commercial driven)
- What if maintenance could be optimised?
- Optimisation of the maintenance interval
  - Extension of inspection interval
  - Extension of reconditioning interval
  - Extension of part life



Maintenance interval extension
How is it done

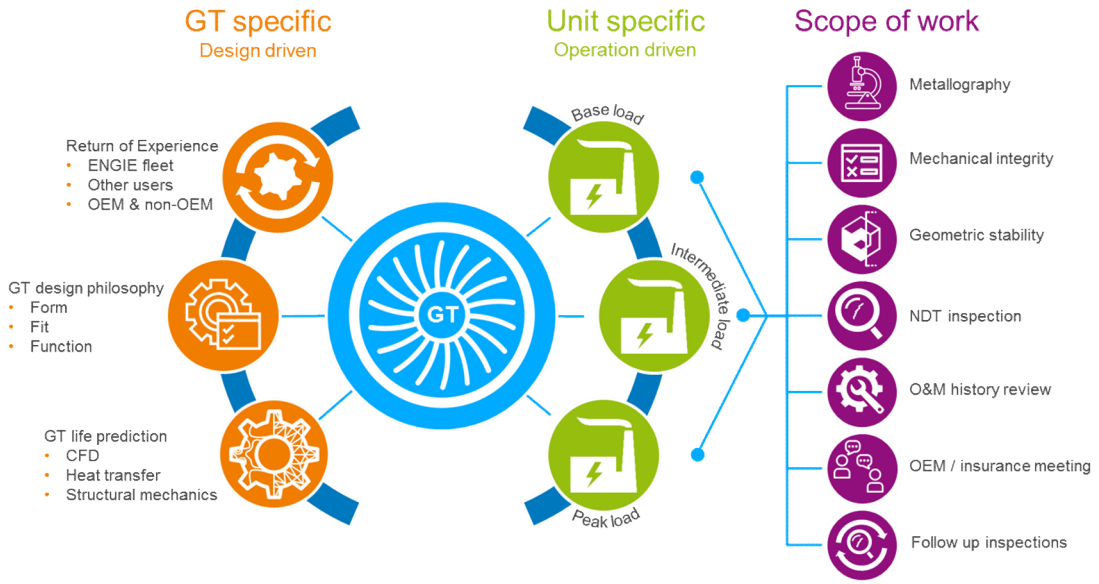
- Thorough knowledge and understanding of GT design and operation
  - — Good understanding of FFF (form, fit, function)
    - Form — Geometry, weight
    - Fit — Interface, material technology, thermodynamics
    - Function — Actions that the part is designed to
  - — The effect of operating regime must be understood
    - Base-, intermediate-, peak load operation
- This allows to predict and extent your maintenance





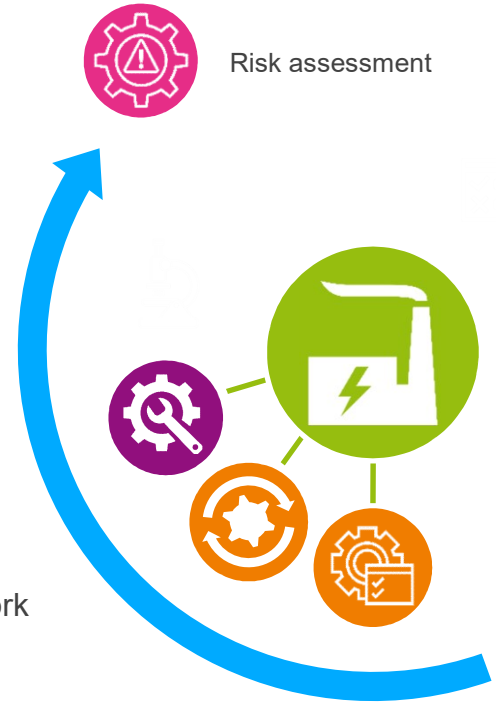
Maintenance interval extension
How is it done

- GT specific
  - In-house Laborelec knowledge
  - ENGIE fleet REX
  - Life prediction tools
- Unit specific
  - Base-, intermediate-, peak load operation
  - Input from client / unit
  - Scope of work depending on available input & GT specific knowledge



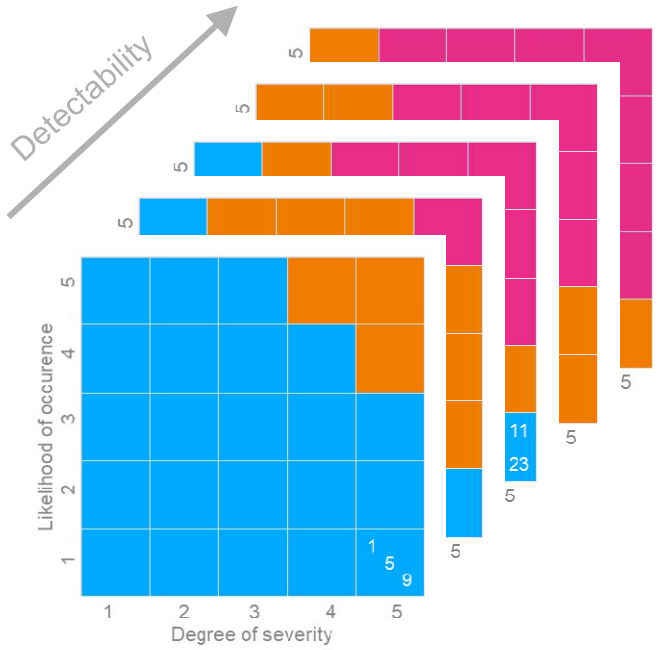
Maintenance interval extension
Feasibility assessment

- Feasibility assessment to justify MIE programme
  - Review of O&M inspection reports
  - Witness or perform on-site inspections
  - Operational history of the unit
  - Return of experience (REX) input
  - GT design philosophy
  - Risk assessment and mitigation plan for desired interval
  - Risk mitigation plan & REX dictates the MIE programme scope of work



Maintenance interval extension
Feasibility assessment

- Risk matrix of every component of the rotor and all possible damages (will be included in report)
- Risk based on
  - Degree of severity
  - Likelihood of occurrence
  - Detectability
- Low risk (blue): Acceptable risk
- Medium risk (orange): There is an increased risk due to the age and condition of the components, but acceptable with precautions taken and unit condition
- High risk (purple): Unacceptable risk

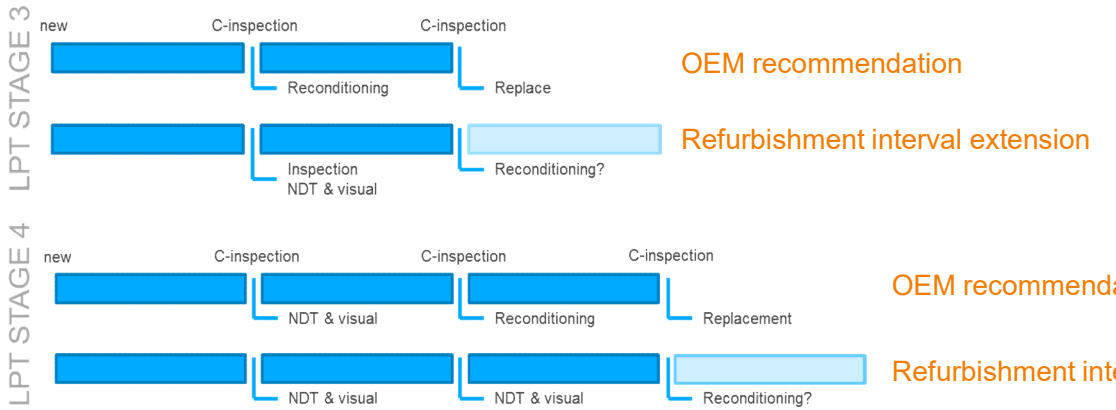


Maintenance interval extension
MIE program

- The MIE scope is uniquely defined to mitigate the high risks
- It may include (metallurgical) examination of ex-service hardware and stress simulations
- Future follow up of unit/part condition by borescope inspection, review of inspection documents, etc.
- Early involvement of the insurer is key
  - Insurance companies perceive an outage a risk
  - An independent view on the turbine shows the insurer that care is being taken of the equipment

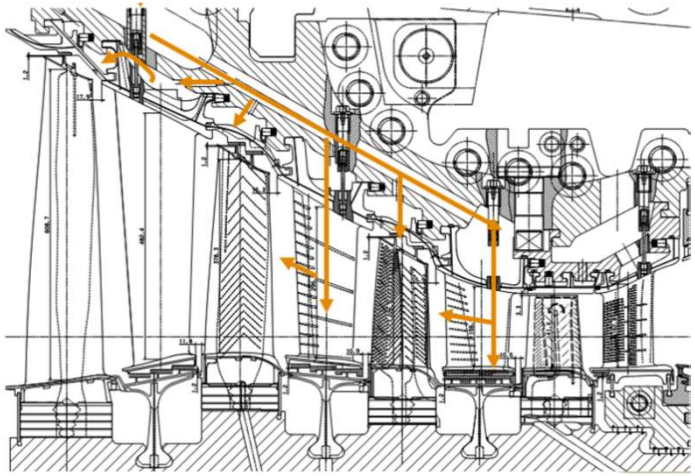
Maintenance interval extension
Example

- C2-inspection during summer 2017
- The aim was to skip reconditioning of LPT stage 3 and 4



OEM recommendation

Refurbishment interval extension

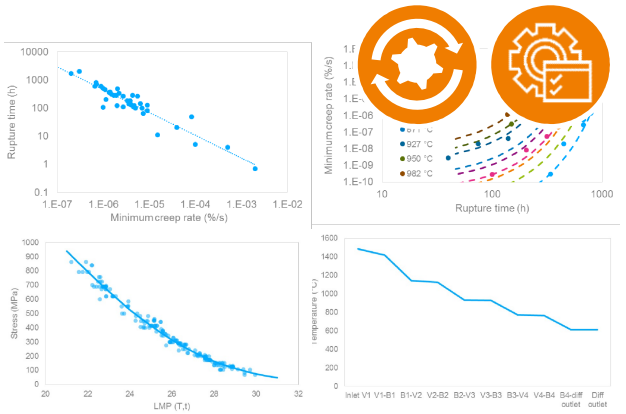


OEM recommendation

Refurbishment interval extension

Maintenance interval extension
Example

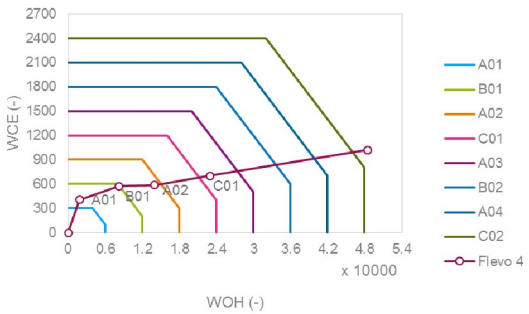
- Identified risks of LPT B3
  - Microstructure soundness
  - Internal surface condition
  - Mechanical properties
  - Tip shroud deflection
- Scope of work LPT B3
  - Life time analysis (LTA) on ex-service LPT B3
  - On-site NDT inspection
  - On-site 3D scanning



Feature	LPT B3
Material	Mar-M247
External coating	MCrAlY
Internal coating	-
Internal cooling	Turbulated cavity
Tip	Double knife edge seal tip shroud

Maintenance interval extension
Example

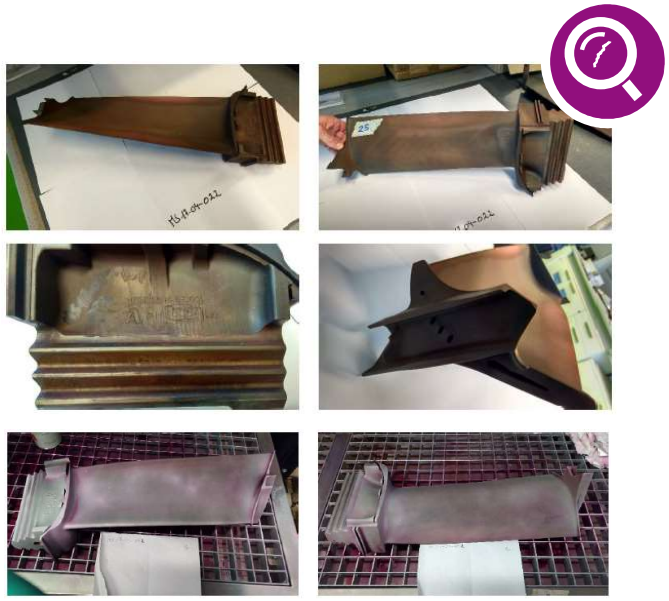
- Ex-service LPT B3 available
- Review of inspection reports
- EOH, OH, starts, trips, etc



Counter	Ex-service	In-service	UOM
Operation hours	22,905	-	Hours
Equivalent operating hours	29,914	31,992	Hours
Weighted operating hours	22,906	28,298	Hours
Weighted cyclic events	700	-	-
Starts	168	272	-
Trips	53	-	-

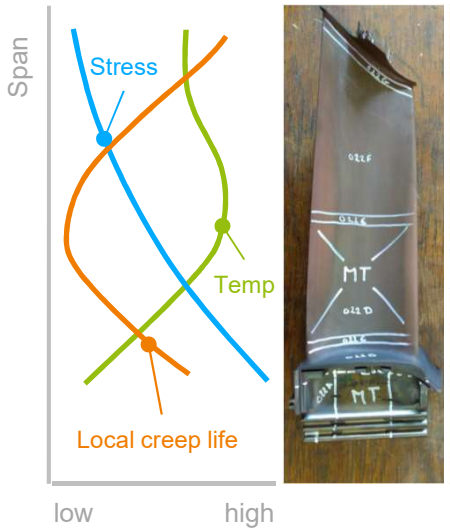
Maintenance interval extension
Example

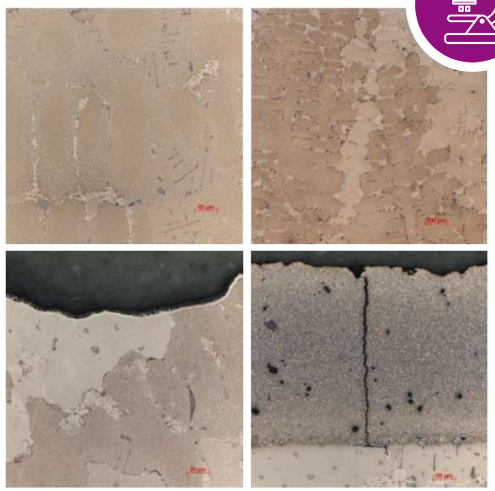
- Visual inspection of spare ex-service set
  - In a good condition
  - Tip shroud contact surfaces in good condition
- NDT inspection
  - No indications were observed



Maintenance interval extension
Example

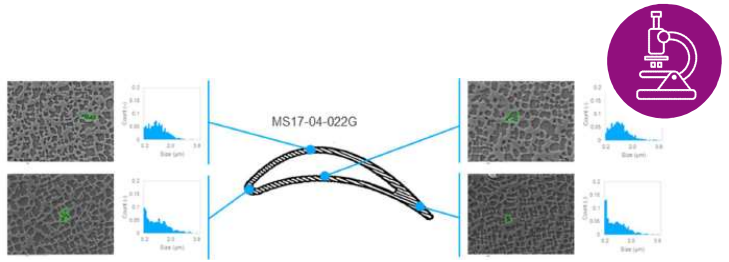
- Cut-up scheme
- Microstructure is in a good condition
- Coating is in good condition
- Internal surface shows little oxidation



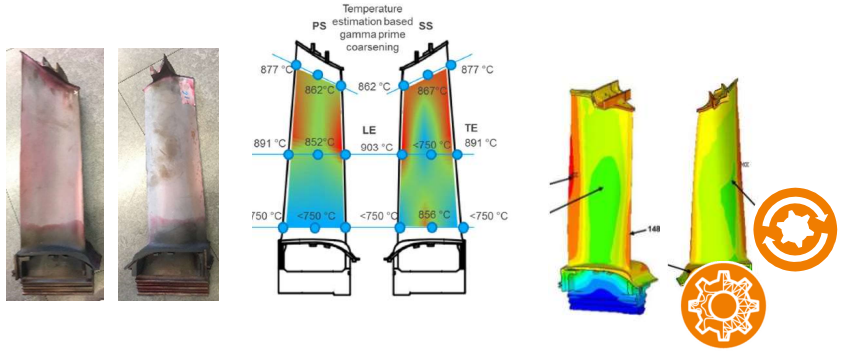


Maintenance interval extension
Example

- Metal temperature estimation based on gamma prime coarsening
- Measured at all sections and airfoil side

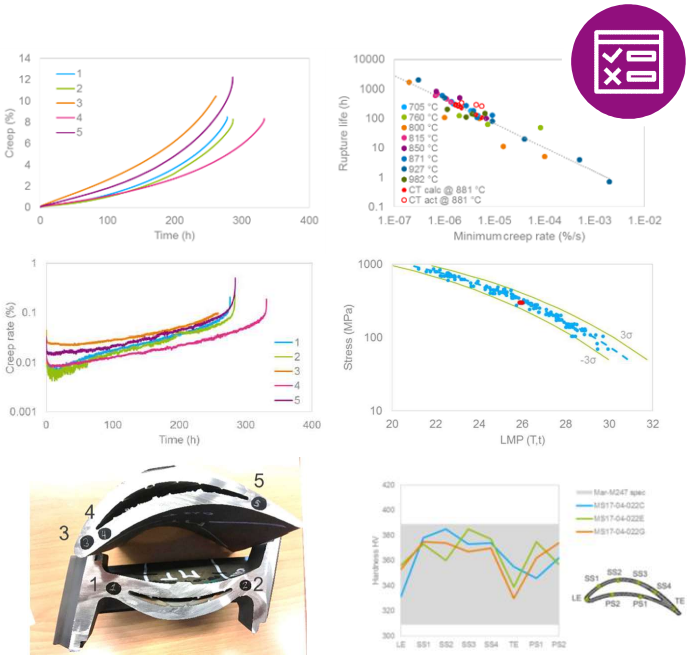


- Temperature distribution shows a reasonable agreement with ex-service airfoil decolouration
- Metal temperature is not excessively high, i.e. blade is well cooled



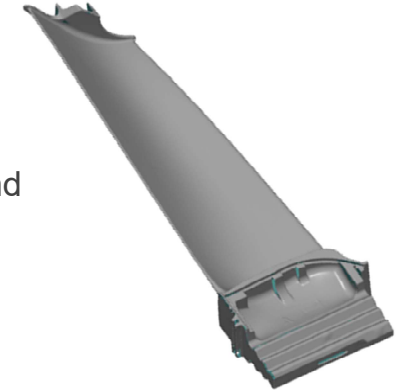
Maintenance interval extension
Example

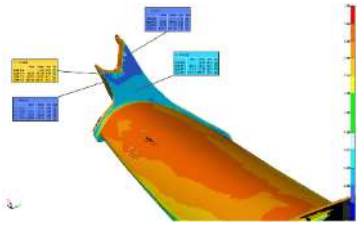
- Creep test
  - 2 samples from root section
  - 3 samples from airfoil section
  - All results are similar
  - No significant creep life consumed
- Hardness test
  - Hardness is well within the material specification

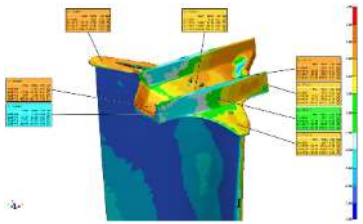


Maintenance interval extension
Example

- During the outage
  - 3D scanning equipment brought on-site to measure tip shroud deflection
  - 3D scan comparison of ex-service, new blades and reconditioned blades
- No deformation observed detrimental for continued operation





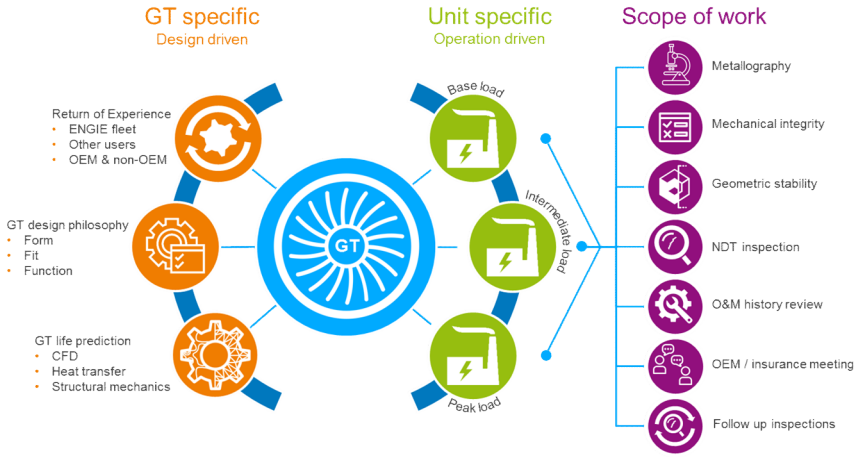


Maintenance interval extension
Example

- Based on the review of thermodynamics, structural mechanics, metallography and geometry it is concluded that reconditioning interval extension is possible
- This is enforced by
  - ENGIE experience from other types of gas turbine units with similar operating conditions
  - Independent scrap rate and cause review of similar GTs matches with findings
  - OEM does not see any show stoppers to skip reconditioning and agreed with outcome
- Due to timing one risk item of LPT B3 was not addressed and the part was replaced
- LPT V3, LPT V4 and LPT B4 are currently back in-service

Conclusion

- Maintenance interval extension covers extension of
  - Maintenance interval
  - Reconditioning interval
  - Life time extension
- MIE scope of work depends on operating regime and REX
- The structured approach provides the risk based opportunities for interval extension
- MIE reduces maintenance costs



We provide worldwide solutions to help our customers successfully come through the energy transition

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