Rotor Life Assessment
A Reference Report

11° IGTC: Dispatchable technology & innovation for a carbon-neutral society

10-11 OCTOBER 2023, BRUSSELS

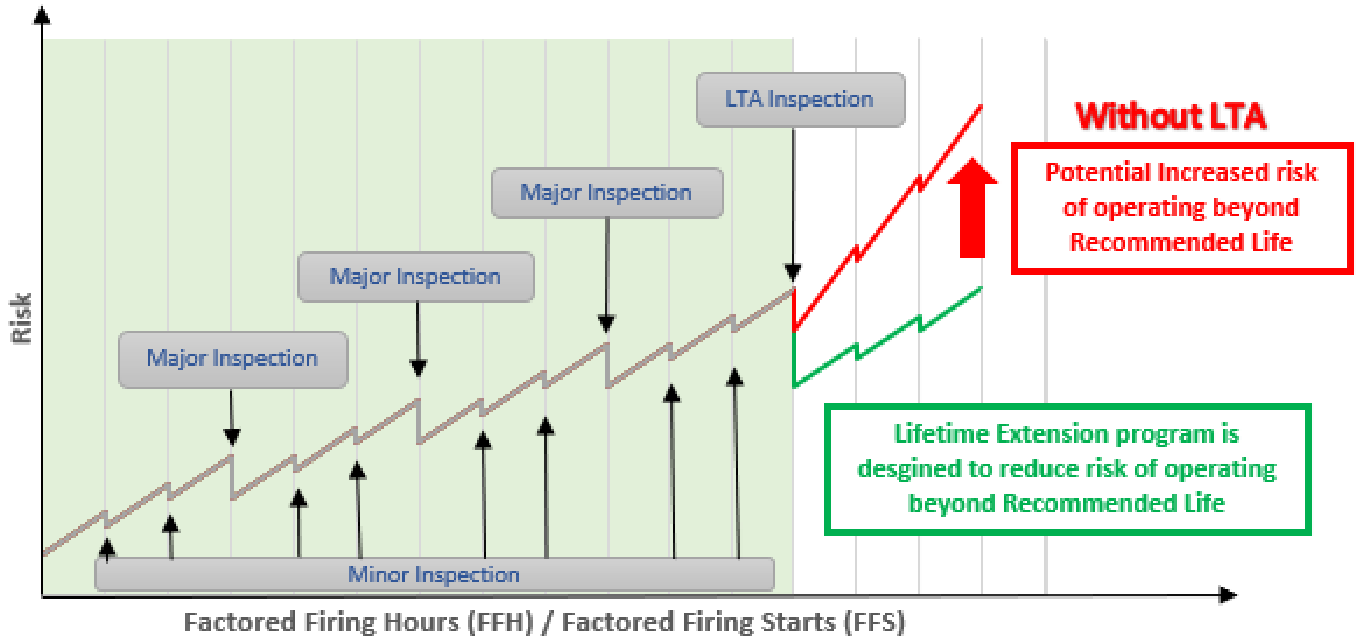
EthosEnergy

Agenda

- Rotor life definition
- Lifetime assessment process
- Flight engine procedures for life limiting parts

Rotor LTA/LTE Program

- Rotors have a finite life according to OEM guidelines. Degradation mechanism:
  - Hours related damages: creep and oxidation (exposure to load and temperature for prolonged time periods)
  - Starts related damages: low cycle fatigue due to cyclic operation (numer of starts, load changes, trip, etc…)
  - Interaction of degradation mechanisms could worsen the situation depending on materials, stress (strain) levels, op. conditions
- A dedicated inspection regime is required at certain factored fires starts (or equivalent starts), factored fired hours (or equivalent hours) or a combination of both
- Failure to perform these inspections leaves the gas turbine at greater risk for failure



Depending on the OEM, the gas turbine configuration, rotor inspection interval is between 3000-7000 FFS (ES) or 100’000 – 200’000 FFH (EH)

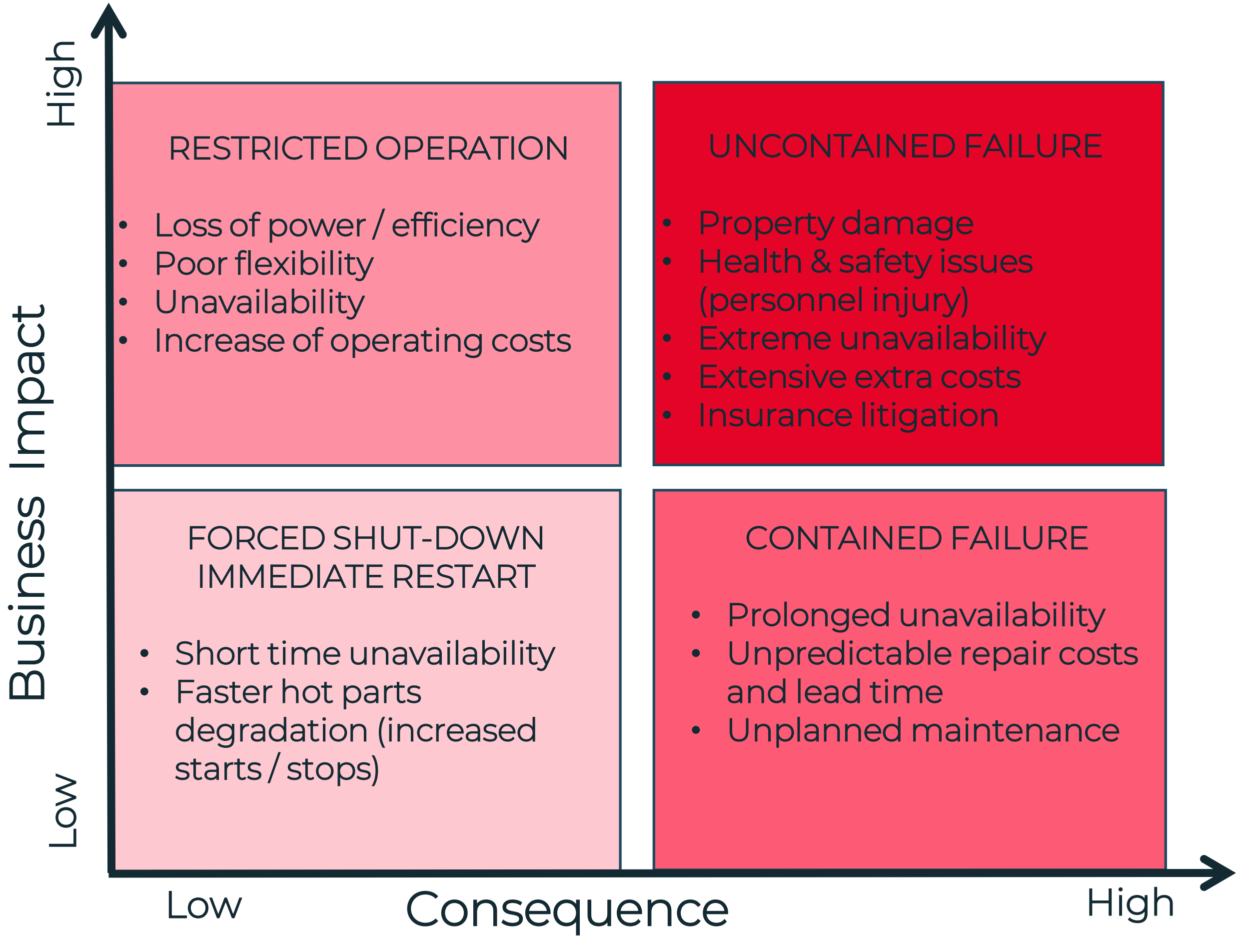
Potential Consequences

Consequence of Failure

Failure occurrence can lead to one or more of the following issues to the end user:

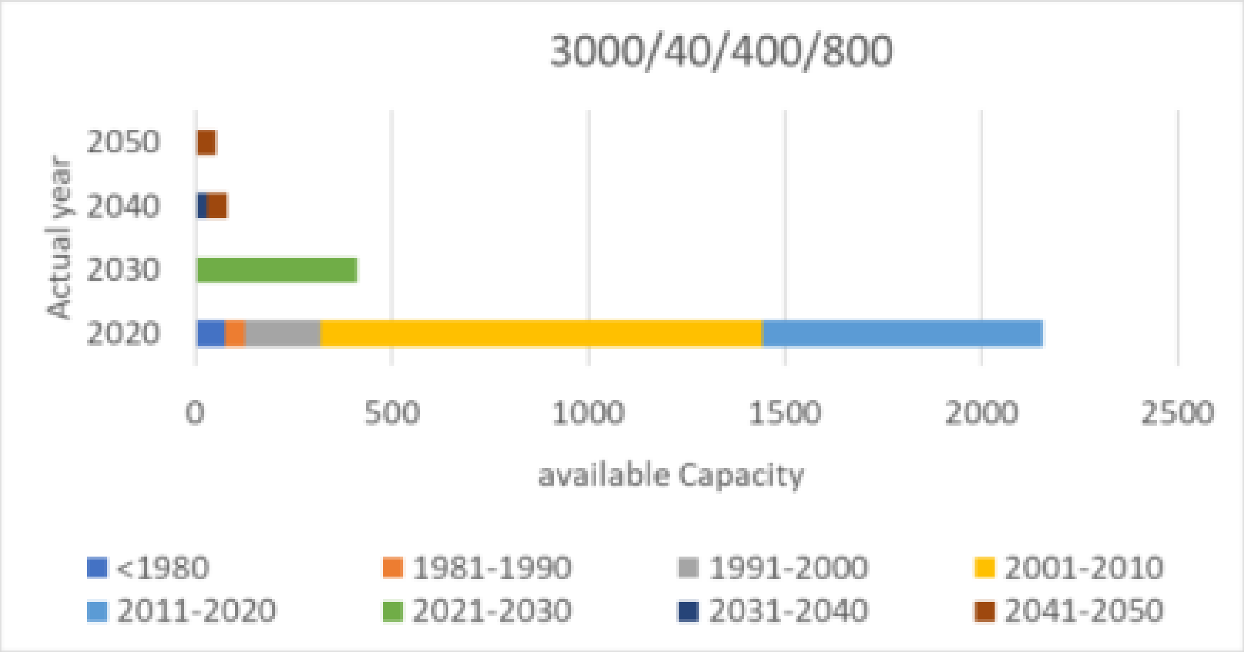
Severity

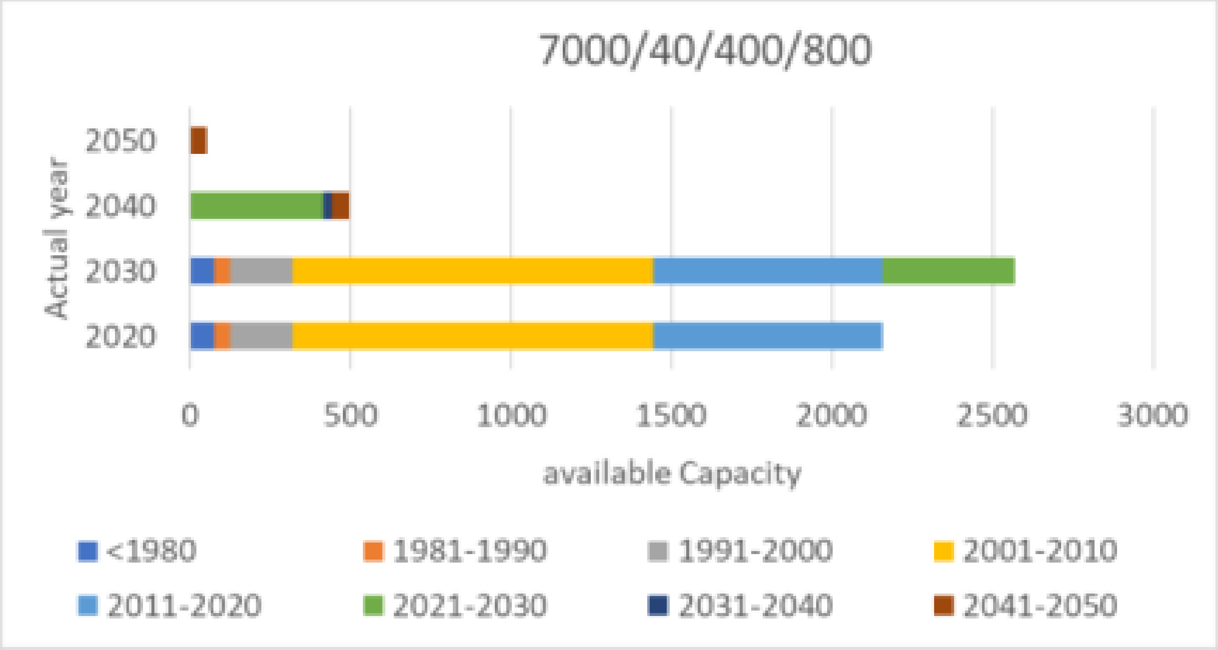
- Forced Shut-down and Immediate Re-start
- Restricted Operation (e.g. loss of power)
- Contained Failure (e.g. Blade or Bucket liberation)
- Uncontained Failure (e.g. wheel burst)



Need for rotor extension

- Installed base gas turbines (Power Generation / Utility) due to the increase feed of renewables, is moving more and more from base load operation to two shifts (400 starts/year) and finally to peaking mode (800 starts/year). Accelerated life consumption.
- Between 2030 and 2040 the installed capacity won't be enough to satisfy the global energy demand.





- Hence the technical need of rotor lifetime extension

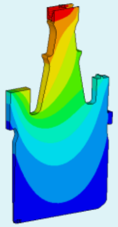
Rotor LTA/LTE Program

Generic	Unit-Specific	
PHASE 1 ***Design Analysis***	**PHASE 2** ***Customer Unit-Specific Evaluation***	**PHASE 3** ***LTE Scope of Work Implementation***

PHASE 1
Design Analysis

Engineering approach to gain the complete stress and temperature distribution of all rotor parts, building the predictive twin model of the rotor.

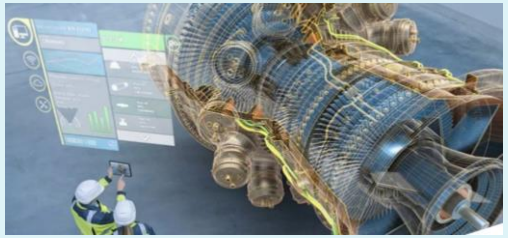
– Material characterization
– Geometrical characterization
– Main operational data & operating conditions
– Predictive model creation
– Determination of critical parts and critical areas



PHASE 2
Customer Unit-Specific Evaluation

Predictive model tuning on specific unit, starting from:

– Operation history: Hours & starts, operational mode, fuel, major events, abnormal condition...
– Maintenance history: inspections & repairs
– Operating data from the control system
– Definition of an inspection plan (including dedicated NDT)



PHASE 3
LTE Scope of Work Implementation

Detailed Inspections, Overhaul & Manufacturing:

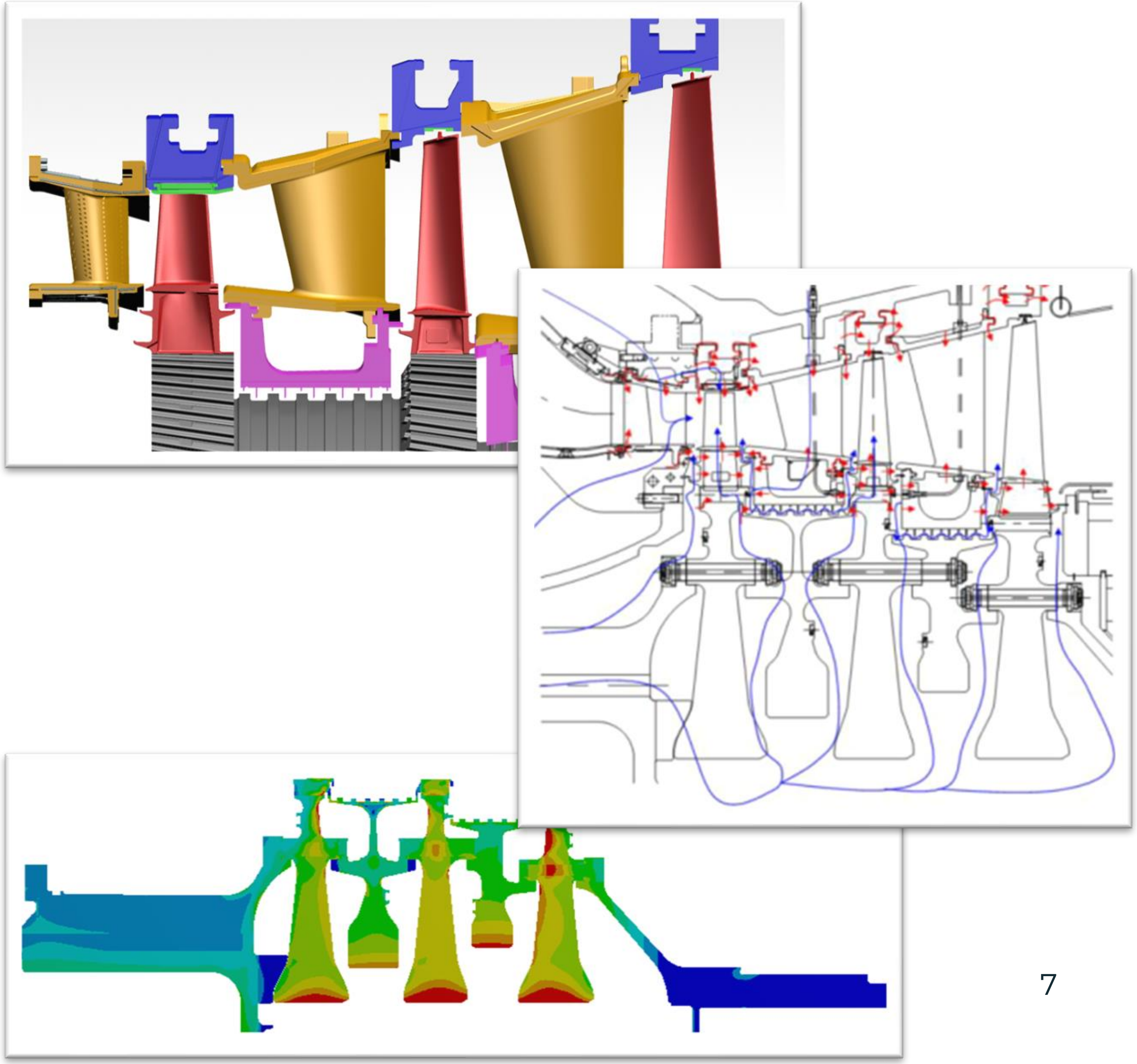
– Rotor inspection based on the defined plan
– Critical parts residual life evaluation and consequent recommendation on replacement / repair
– Manage any out of design operating condition
– New critical parts manufacturing
– Rotor reassembly with critical parts replacement

Predictive | **Reactive**

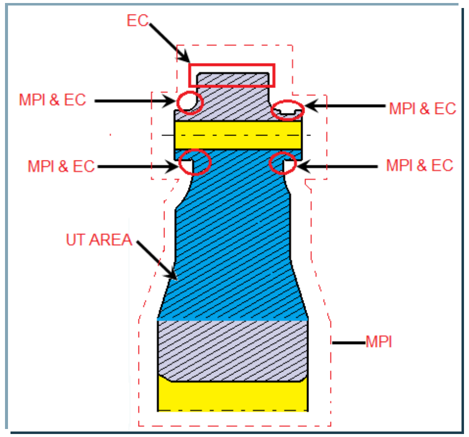
Results of detailed inspections are factored into Predictive Process Guidelines

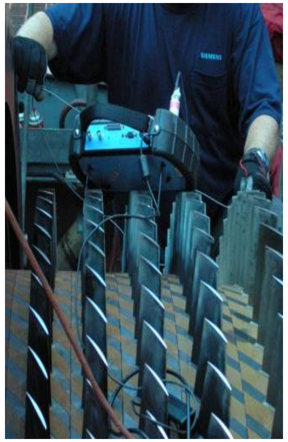
Rotor LTA/LTE: Phase 1 Predictive model

- Phase #1 consists of evaluating the complete rotor stress and temperature distribution in any operating conditions
- Geometry & Material characterization
- Definition of the boundary conditions:
  - P, T, Aerodynamic loads distribution
  - Secondary Airflow Network
  - Engine: controls parameters (Actual data)
- FEM steady state, transient: all rotor components are evaluated for stress, temperature, and operating conditions
- OEMs have access to the design information

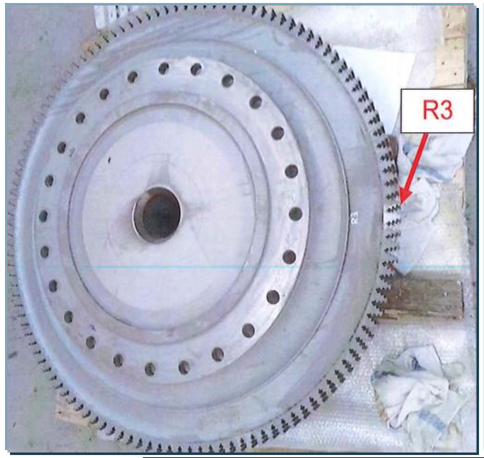


Rotor LTA/LTE: Phase 2 Operating history & Inspection plan



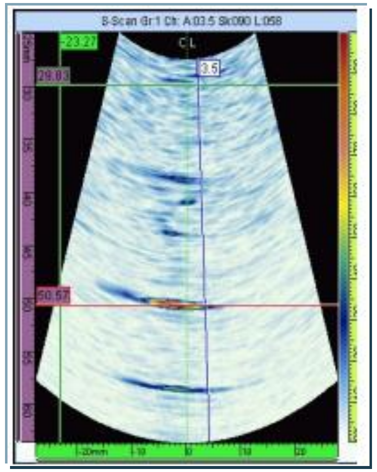


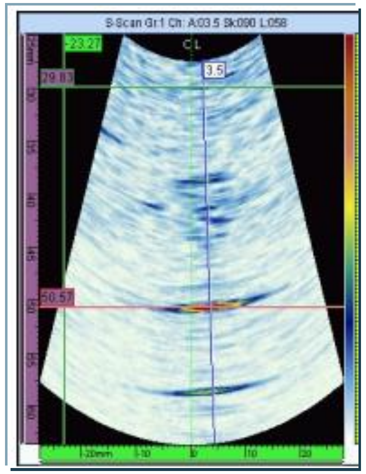
Eddy Current Inspection: Devoted to detect very small surface and near-surface defects; the technique is added to MPI just on critical areas



Brinnell Hardness: To gain information on potential material embrittlement (if any)

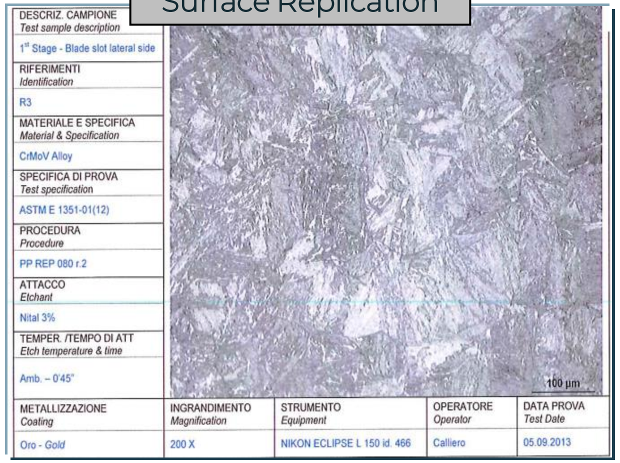
Surface Replication: To gain information on material over-ageing (if any)



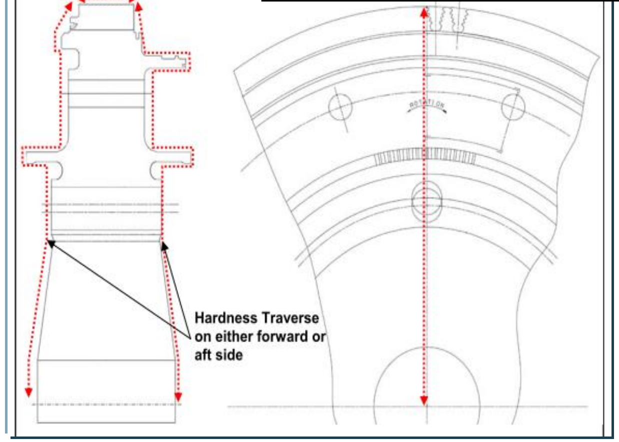


Phased Array Ultrasound: To investigate the wheels core regions to exclude creep / fatigue indications / flows

Surface Replication



Hardness Evaluation



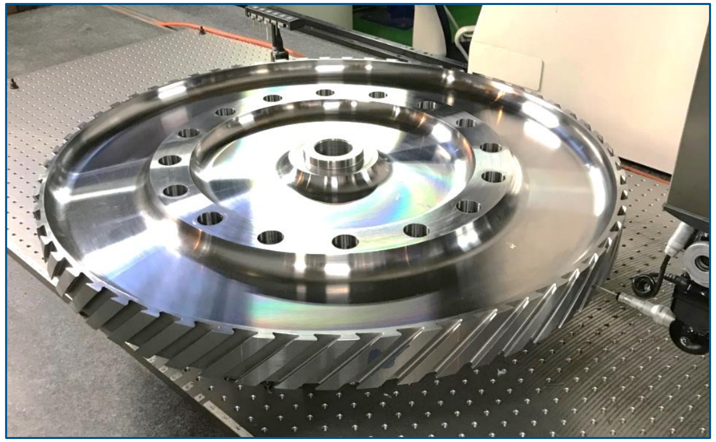
Rotor LTA/LTE: Phase 3 Rotor Inspection & Critical Rotor Parts Replacement

- Rotor disassembly
- Components inspection
- Components replacement (new discs manufacturing)

Note: health monitoring tech may be used:

- on-line monitoring systems for actual measurement of degradation: difficult on rotating components
- Predictive maintenance based on wide experience

De-stacking and Stacking



New discs manufacturing

Unit rotor balancing

Individual disc balancing

Applicability of aero engine LTA procedures

- Engine lifetime is defined as the lifetime of structural components, maily rotor parts
- Main failure mechaninsm is LCF/TMF (starts/stops, thrust variation)
- Life limitation is often a legal requirement for safety reason
- «Safe life» has been the lifing methodology: number of cycle before crack initiation.
- Undetectable anomalies were not considered by the method: hence «damage tolerance» approach for LTA (probabilistic fracture mechanincs – Advisory Circular 33.14-1)
  - First level of probability: integrated probabilistic approach that considers defects initially present (statistical size distribution). Event rate estimation compared with DTR (Design Target Rate)
  - Second layer of probability: Probability of Detection (POD) depending on the inspection technique
  - Third level of probability: part exposure. Opportunity to inspect when parts become naturally accessible (no downtime to inspect them)
- While LTE on Aero Engines required heavy re-certification, it can be considered on land based GT with some limits:
  - Aero Engine fleet much bigger (reliability of probabilistic approach)
  - Easier to dismantle and to sacrifice for testing (lower costs)
  - Different operating conditions (less repeatible on land base)
  - Wider and different range of materials on land base GT

Conclusion

LTA/LTA solutions is what users are looking for future operation. It is beneficial a collaborative approach to establish a generic lifing protocol which provides guidelines to properly understand / reduce the risk and plan in advance.

While LTA/LTE Rotor Programs carry a lot of advantages for GT users:

- Cost – effectiveness: OPEX instead of CAPEX, minimized capital invested while effectively running old assets.
- Resource – effectiveness: the program gives concrete contribute to circular economy; environmental savings can be quantified through an LCA (Life Cycle Assessment) and communicated to the customer
- Opportunity to introduce modifications on rotor components to reduce local stresses

There are still some gaps to be filled:

- Availability of data when approaching a probabilistic analysis is crucial. Hence OEM advantage to access much more information especially on material properties.
- Thermo-mechanical destructive tests are recommended to validate the models
- Some degradation mechanism (corrosion, fretting) are difficult to incorporate into the predictive model as well as the combined effect of creep and LCF
- Limitations on methods of inspection can leave uncertainty on risk assessment (creep is hard to evaluate on discs steeple, grain boundary segregation on Ni-base alloy is very hard to detect…)
- Easy to model a localised damage but complex to evaluate the effect on a global level