Managing Cold End Cost

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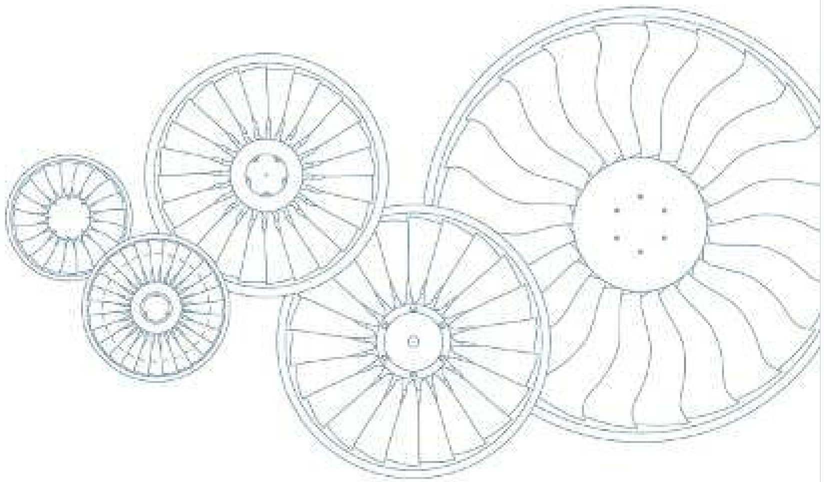

Agenda

- Cost breakdown
- Shop visit, split of material cost
- Influencing factors towards engine MRO
- On-wing maintenance
- Engine overhaul
- Repair strategy
- Shop visit planning
- Life expectancy alignment with LLPs
- Summary

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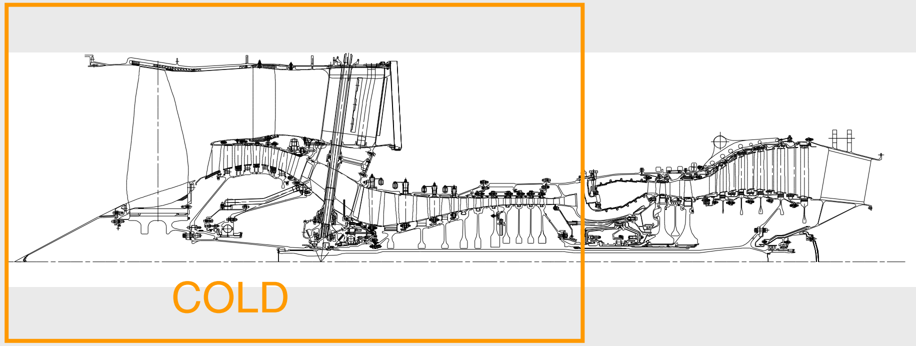
Cost breakdown

- Geometrically the larger part of the engine
- At SV 30% of material cost, (mainly HPC 20%)
- Typical SV
  -> 50% Parts / 50% Labor



Examples:

- Complete HPC Airfoil set: approx. 450 000 USD list price
- HPC Rotor 300-400 000 USD
  Life Limit for 20 000 Cycles
  -> 15-20 USD / Cycle

"Simple" Priorities

- Full usage of LLP Life
- Longevity of compressor parts

Disclaimer: all information on costs and performance given in this presentation are rough order of magnitude only, based on typical 2 engine, single aisle aircraft operations. They are only used to illustrate the general correlations between technical and financial decisions.

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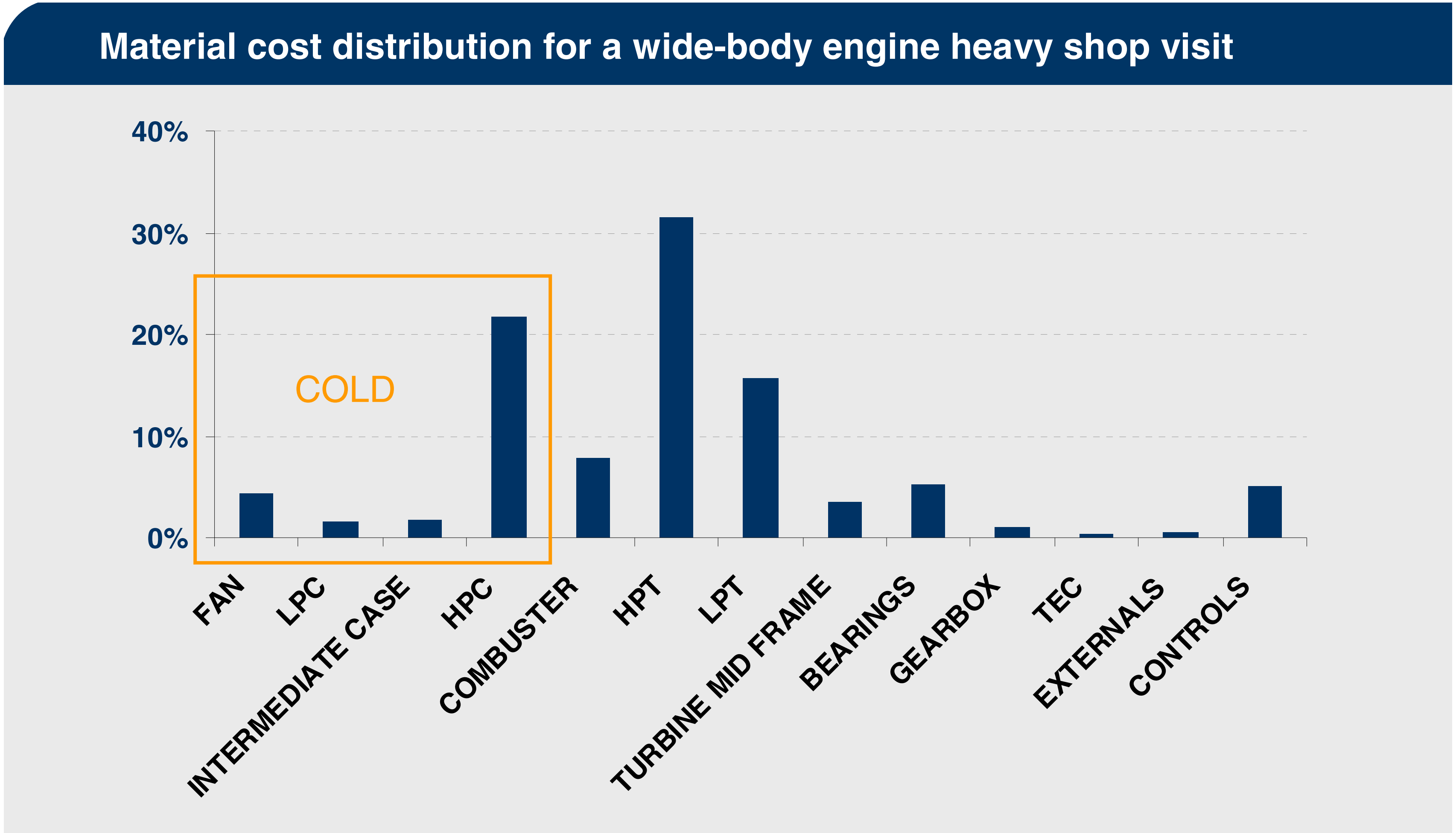
Shop visit, split of material cost



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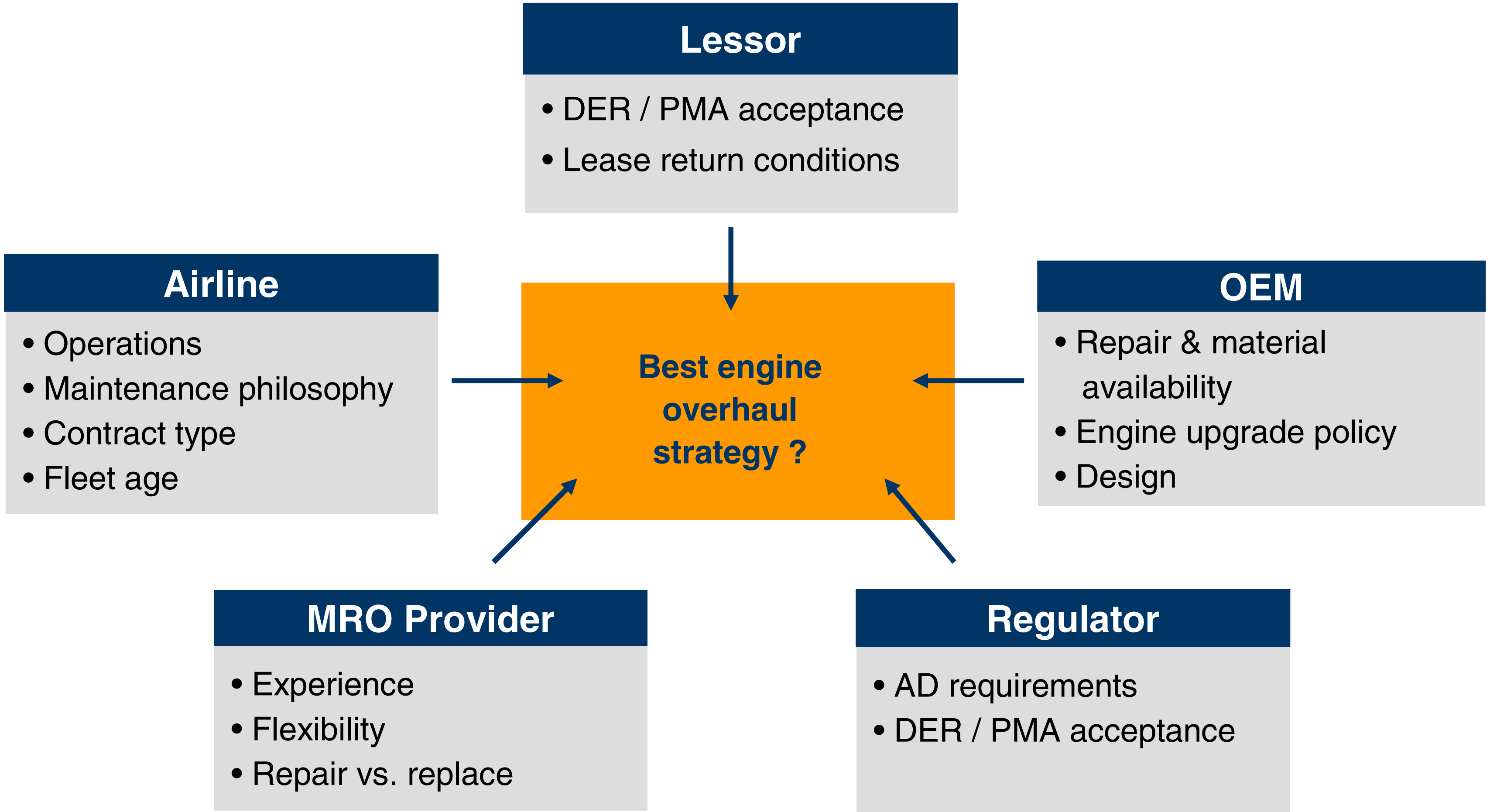
Influencing factors towards engine MRO



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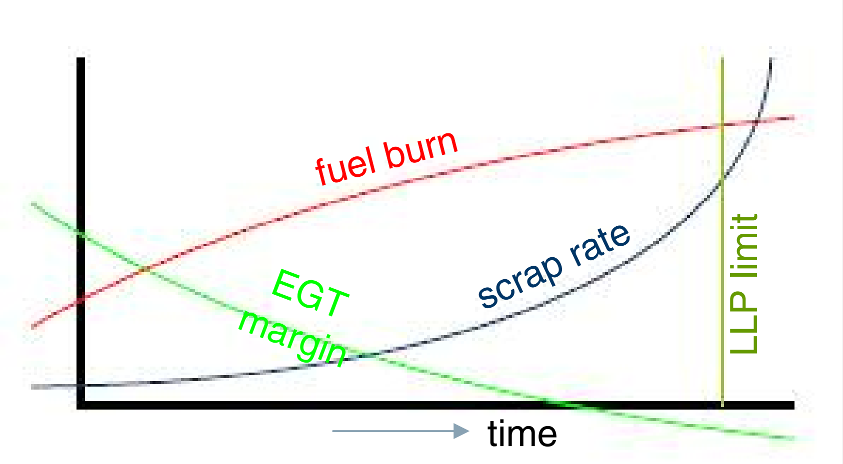
On-wing maintenance (tools)

- ECM (e.g. MTU Engine Condition Monitoring):
  Highly positive tool that can give you exact insight on the health of the engine
- Borescope blending: positive, if engine is overall in good condition
- Engine wash: up to 10°C EGT gain
  Everything that reduces EGT is highly positive, reduces load on hot section, translates directly to increased engine life and reduced scrap rates
- On-wing/-site maintenance to increase OWT (e.g. Top/Bottom Case)
- On-wing handling can greatly contribute to engine life
  (Cleanliness of the runway / Erosion)
- Derate and full usage of the runway with partially loaded A/C

Colliding objectives: long TOW vs. low scrap rate
Goal: finding the best point in time for replacing the engine

On-wing maintenance (system)

- Over time EGT margin deteriorates, fuel burn increases, scrap rate increases
- Hard limit LLP life
- With On-wing handling and maintenance these curves can be modified



Examples:

- 5°C more EGT after SV translate to 700-900 h increased service life
- Compressor wash increases EGT margin
- Derated operations slow down the loss of EGT margin

Objective: on wing maintenance for reduced fuel burn and increased TOW

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Engine overhaul

- Engine use
- EASA / DER approved repairs
- PMA policy
- Airfoil repairs
- Optimized clearances
- Extra changes for performance improvement (e.g. ERCoat^{nt})

- What is planned with the engine in the next run?
- Cost, Asset value, Lease conditions
- Cost, Asset value, Lease conditions
- Aerodynamic quality
- Added cost for matching of components
- Investment compared to benefit

- Quality and reliability are of paramount importance
- Shop support with detailed Know-How necessary to analyze impact of overhaul
- Customer and engine specific workscoping needed to achieve best value

Technical fact:
All the high load of the turbines is only necessary to turn the compressors

Engine overhaul (individual workscoping)

Shop visit cost

Reliability & performance

Customized workscope per engine

On-wing time
EGT margin
Fuel burn

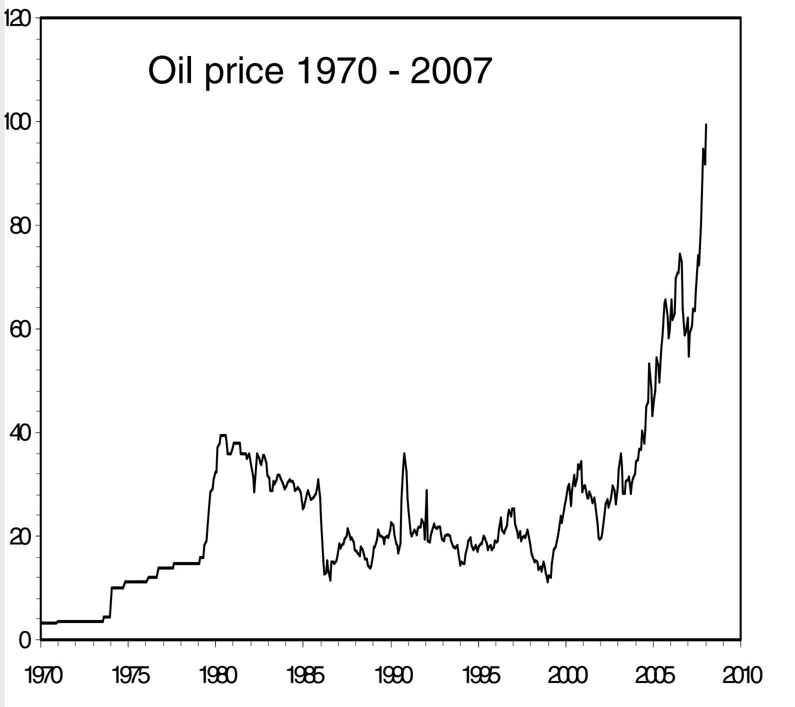
Goal: Find right balance to the customer's benefit

Engine overhaul (special workscoping)

- Increasing possibilities to build business case due to fuel price increase
- Direct link in Airline between MRO and Operations essential

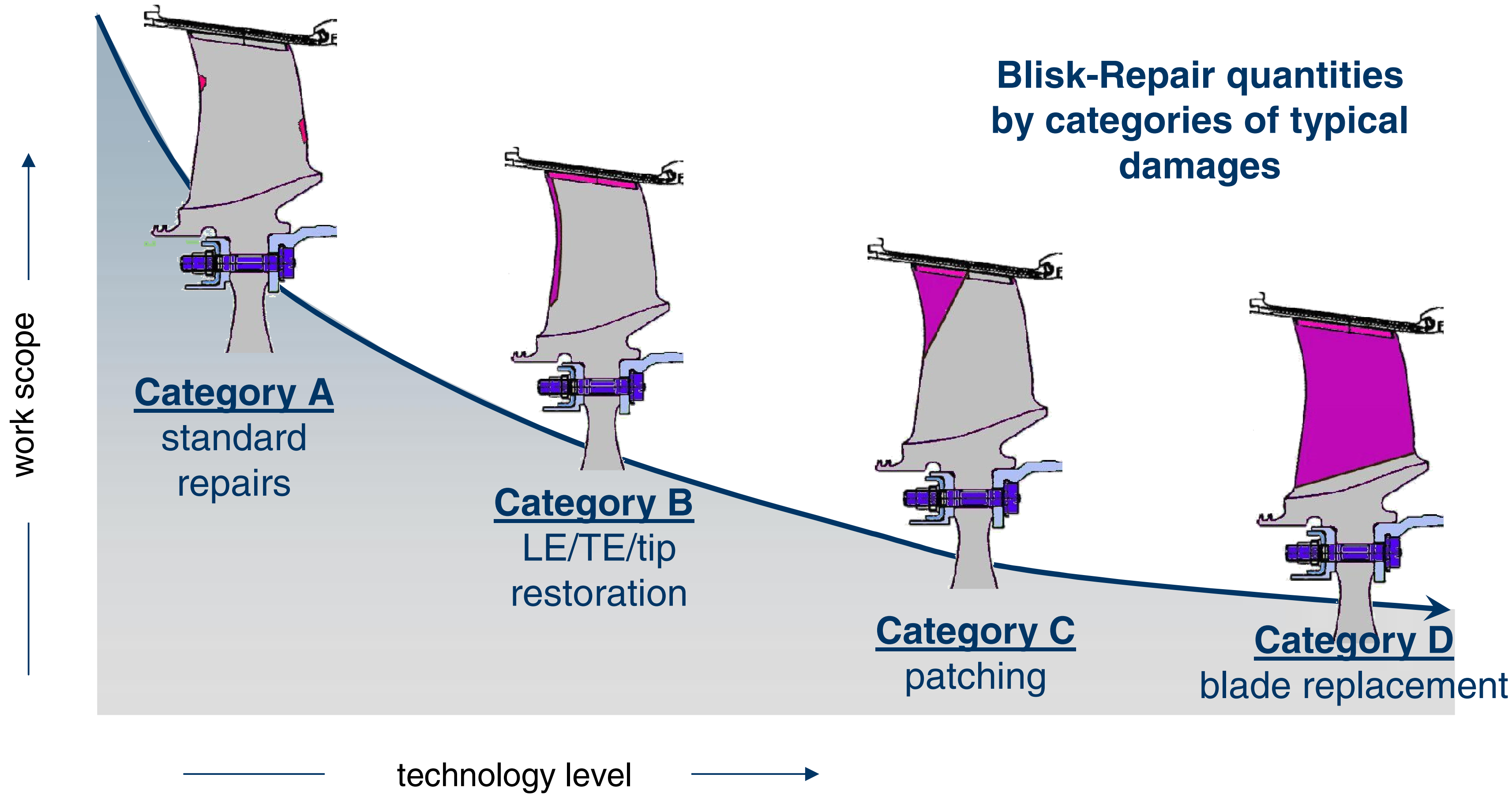
Effect of special workscopes have to be analyzed. e.g.:

- Tip clearance (very important)
- Surface finish (under research, texturing and roughness design ongoing)



Strong potential with shops that have OEM background and knowledge of the trade factors and the effects on the engine

Engine overhaul (Blisk)



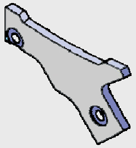
Engine overhaul (Blisk)

- MTU started with repair development in the 90's
- Long time experience, approved techniques and trained employees
- Three key technologies were developed and patented
  - Plasma Key hole welding
  - Adaptive Milling
  - Local Heat Treatment

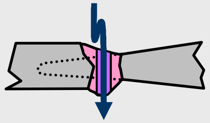
- First Blisk was repaired and certified in Dec. 2007
- Coming from new programs MTU qualified innovative new techniques for Blisk repair
  - Inductive High Frequency Pressure welding (IHFP)

Engine overhaul (Blisk)

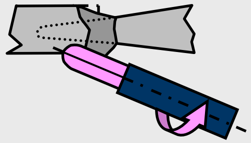
Applying key technologies for commercial Blisk repair



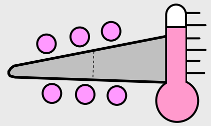
Manufacturing spare part



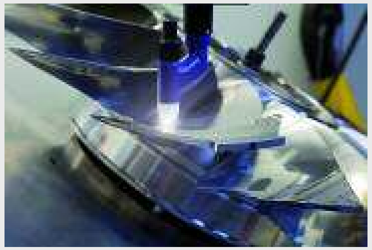
Joining by by Plasma Arc

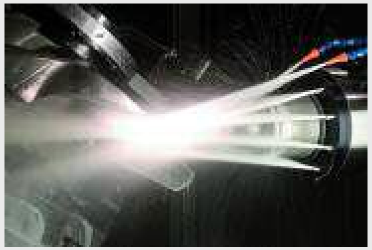


Adaptive Blisk Repair Milling



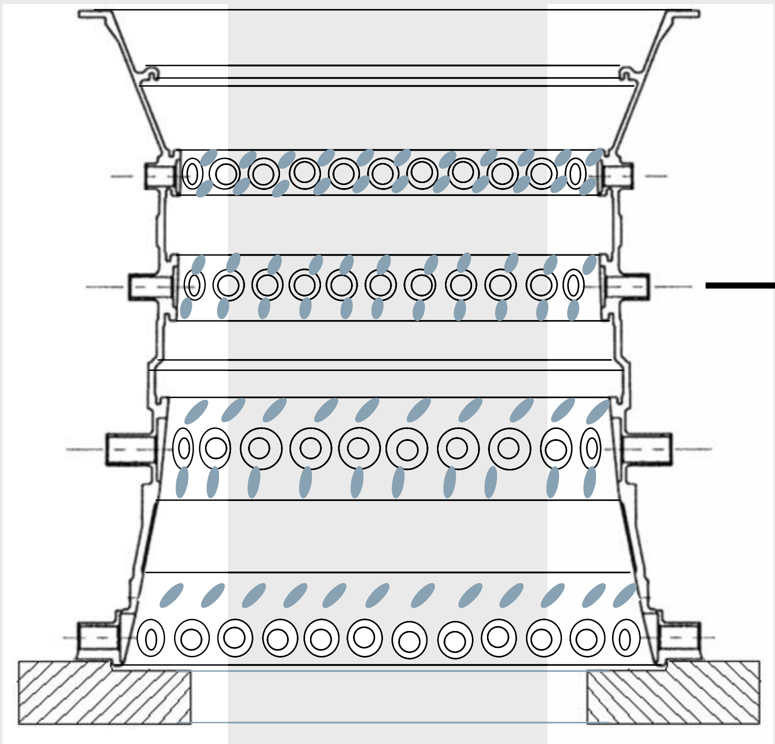
Local heat treat-ment by induction

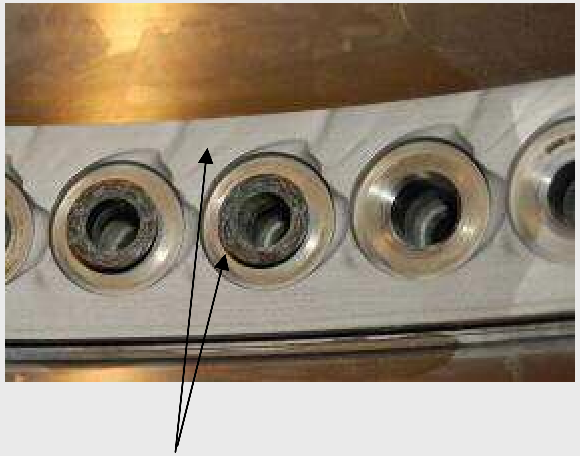




Engine overhaul (casings)

- V2500 HPC Front Case Erosion repair





Washed out areas to be repaired by plasma spray to as new condition

- Also available: CF6-80 HPC Casing VSV Bushing repair

Engine overhaul (airfoils)

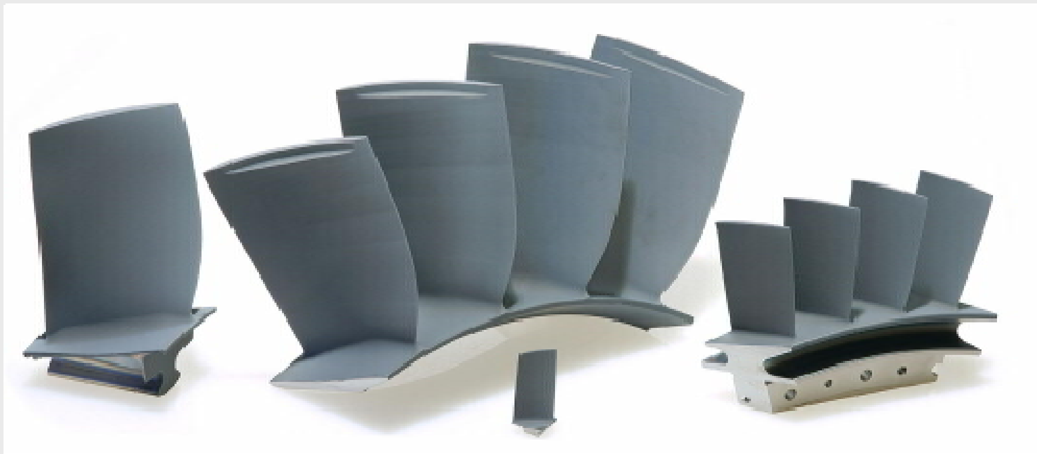
Sand erosion leads to:
- Short service life of engine components
- Increased risk of in-flight shut downs
- Degradation of compressor efficiency

Eroded Blade

MTU^{Plus} solution ERCoat^{nt}:

multi-layer coating deposited by physical vapor deposition

- High temperature resistant
- An up to tenfold life time improvement depending on operating environment
- No influence on aerodynamics
- Protects also blade tips
- Corrosion resistant
- Stripping possible



High temperature ERCoat^{nt} on different types of airfoils

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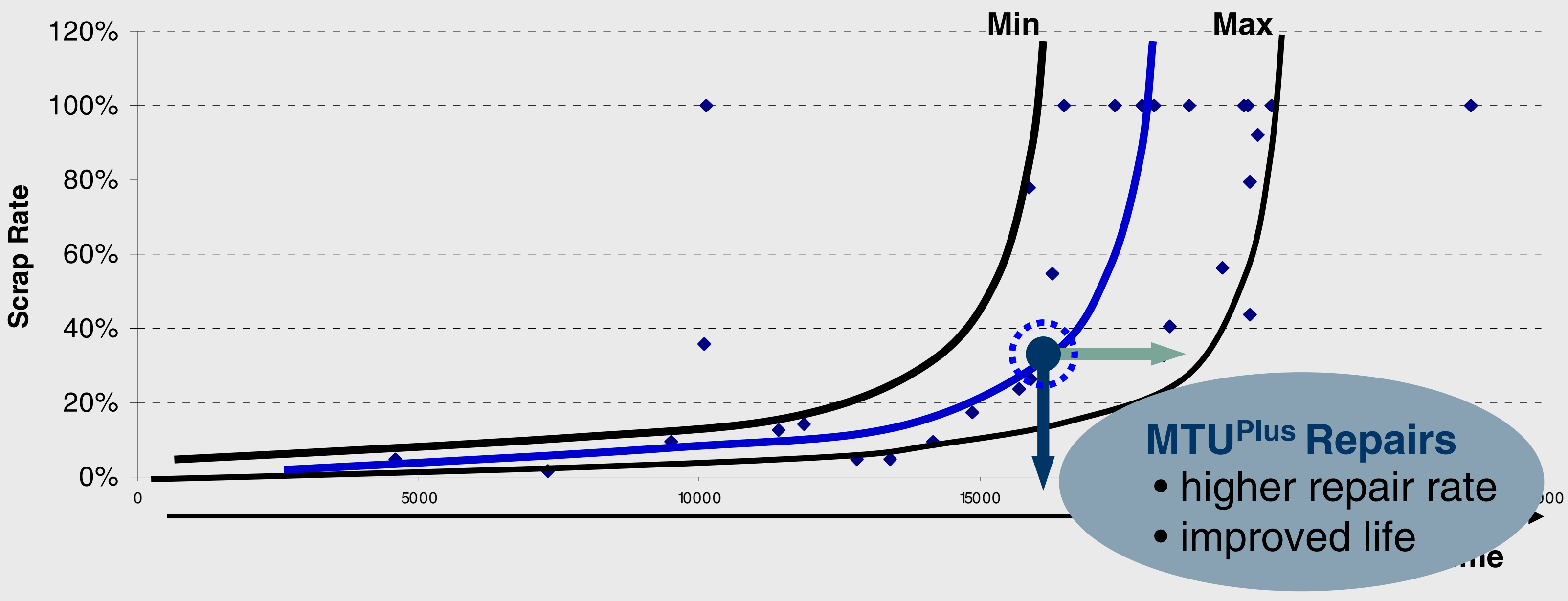
Repair strategy

scrap rates vs. time



Need for Individual Workscoping and Fleet Staggering

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Shop visit planning

- Formula 1:
  - Before the race you decide on the strategy how many pit stops are optimal
  - This strategy is used for the race without flexibility
  - Race is finished after a precisely known distance

- Aircraft engine:
  - LLP Life is fixed but it is not the end of operations
  - Scrap rates should not be heavily increased to use up LLP life
  - Operational issues (SBs / ADs) can require great flexibility
  - Spare engines availability important for operations
  - Optimal is constant flow of overhauls, no "bunching"

Operator has to take fleet management into account when planning SV

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Life expectancy alignment with LLPs

Management of the workscope to provide life expectancy alignment with LLPs

- Full picture to be taken into account:
  - Fuel burn increase due to small workscope on cold section possible
  - Increased load on hot section due to reduced efficiency in compressor
  - Depends on further usage of the asset, long usage planned or end of lease / phase out

- No sense to stress the costly HPT Airfoils and burn a lot of extra fuel with low efficiency compressor just because the LLPs will be changed soon. Compressor should be kept to a good working standard as far as possible.

Independent MRO provider can focus on best value for customer

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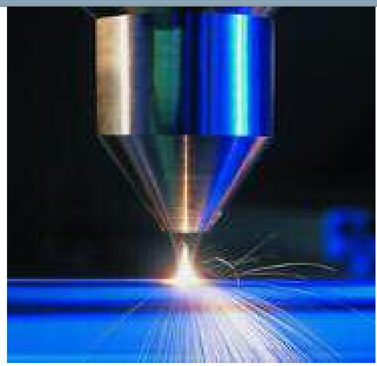
Summary

- Complex, multidimensional optimization for the whole system needed:
  - engine
  - fuel
  - operations

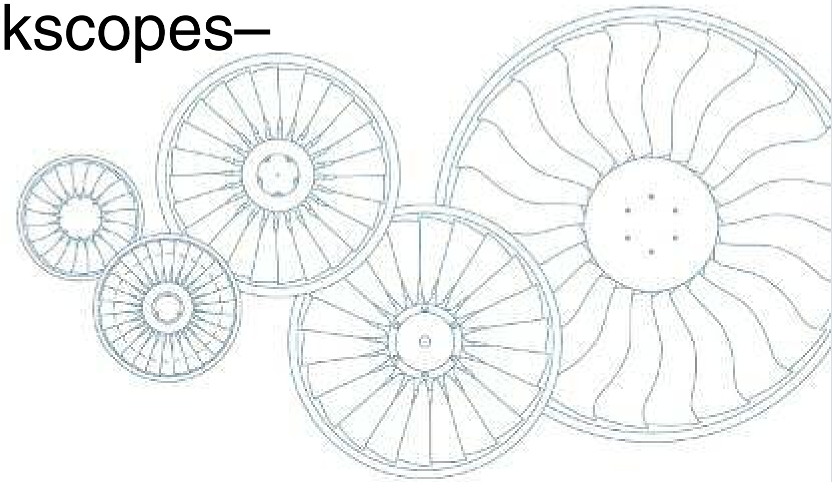
- Intelligent maintenance- and repair concepts are key to value optimized maintenance

- **MTU^{Plus} workscopes** and **MTU^{Plus} repair solutions** are effective, economic measures to address customer and environmental topics as:
  Reduction of overall cost
  Reduction of fuel burn

Managing Cold End Cost **ALONE** is not the solution !

MTU^{Plus} Repairs and MTU^{Plus} workscopes– our ^{Plus} is your Plus



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