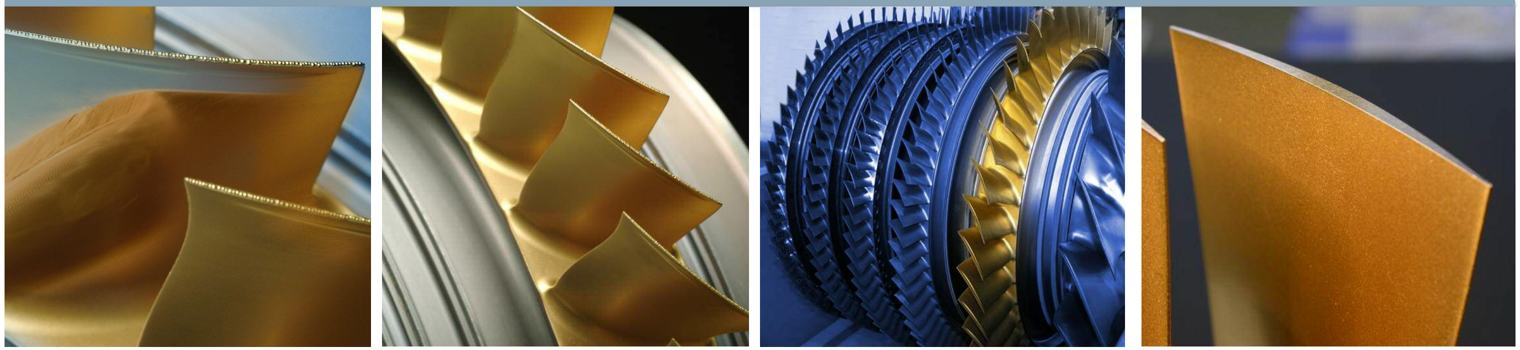


New environmental friendly systems - erosion resistant coatings as a means to green engines

P. Langholf

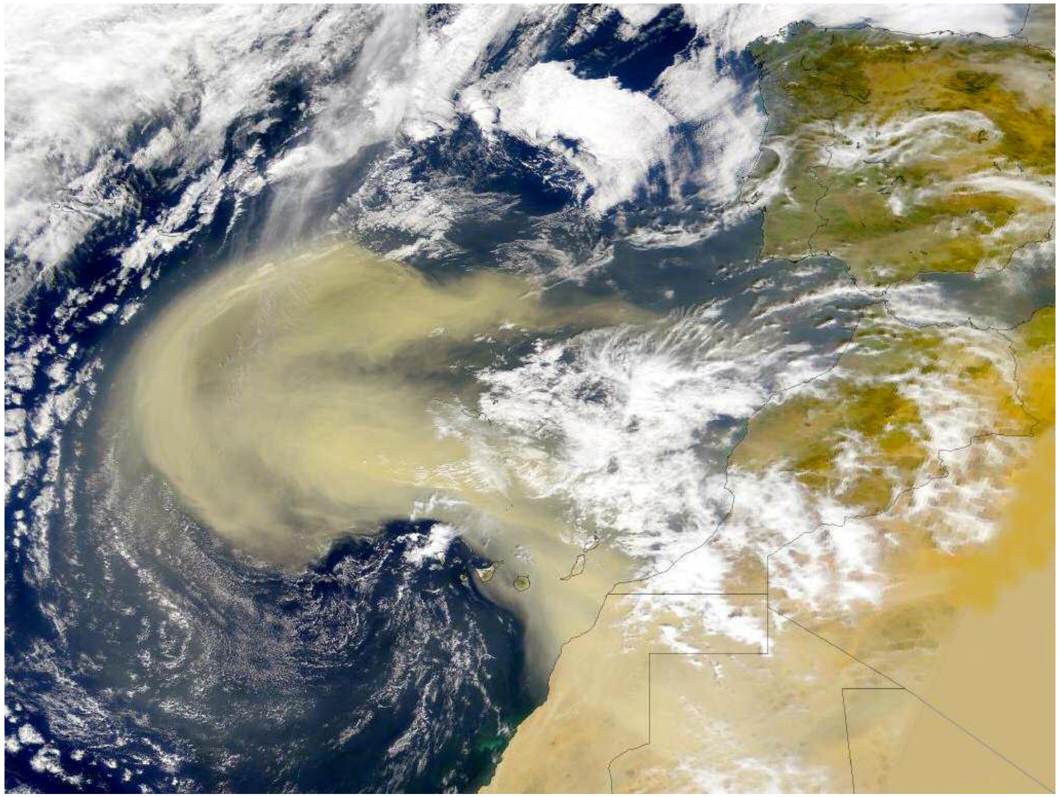
W. Eichmann, F. Heutling, T. Uihlein
MTU Aero Engines GmbH

IntAIRCOAT, 15 May 2008

Agenda

- Environmental challenges for engines
- Erosion behavior in a compressor
- The adverse effects & consequences of erosion
- MTU^{Plus} solution ERCoat^{nt}
- ERCoat^{nt} properties & testing
- Advantages of ERCoat^{nt}

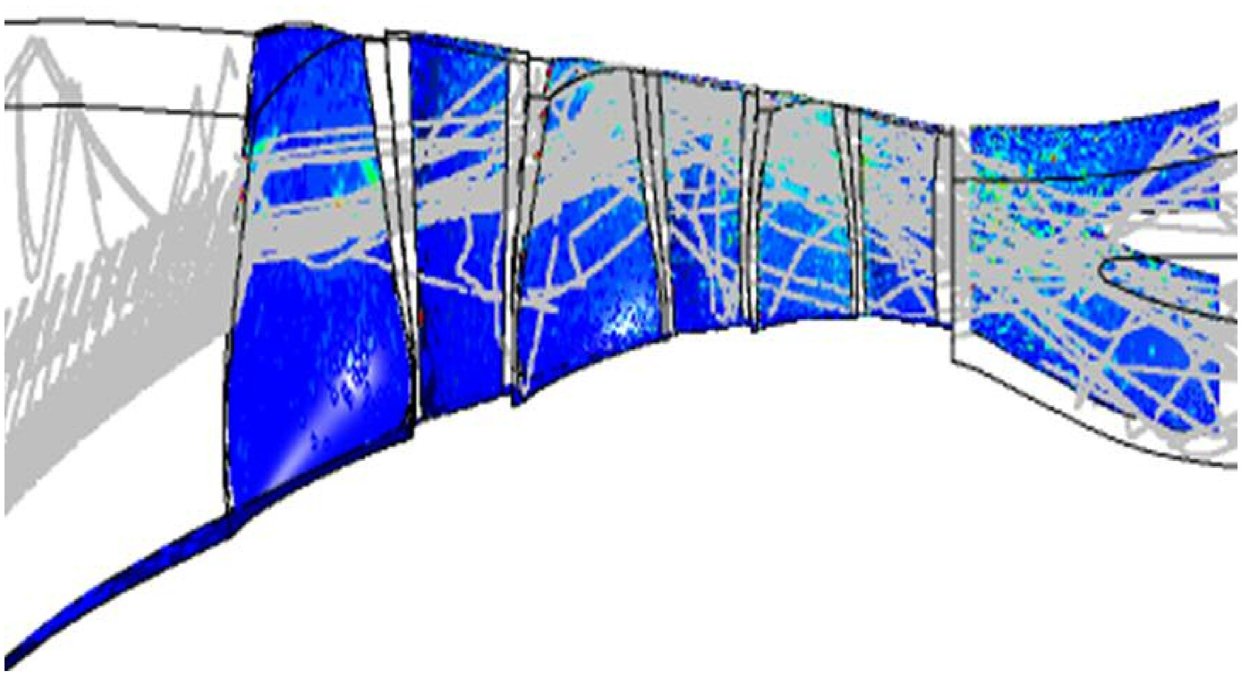
Environmental challenges for engines - sand, snow, salt and ice



Challenge: Developing a technology that finally and successfully reduces the damage of erosion to an absolute minimum

Erosion behavior in a compressor

Side view



Simulation of particle trajectories and simulation of wear of blades and vanes in a compressor show areas of maximum attack by erosion and need for coating

The adverse effects of erosion

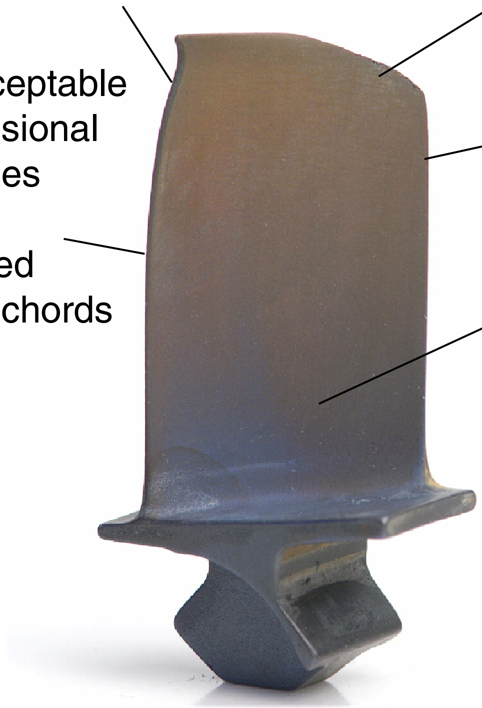
Blunted leading edges and/or curling

Unacceptable dimensional changes like reduced blade chords

Blade shortening and cracks

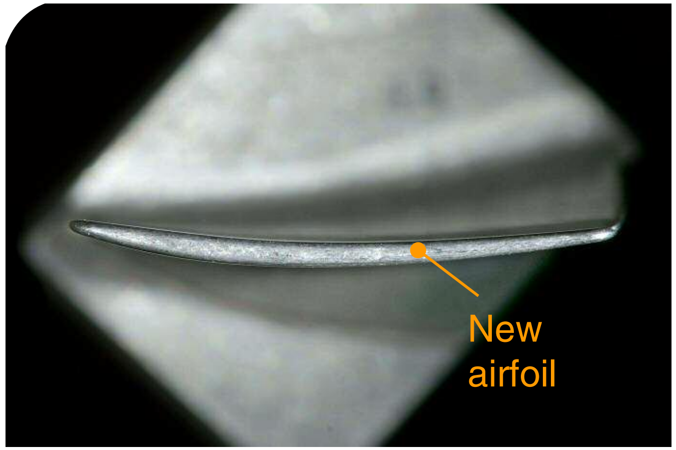
Sharpened trailing edges

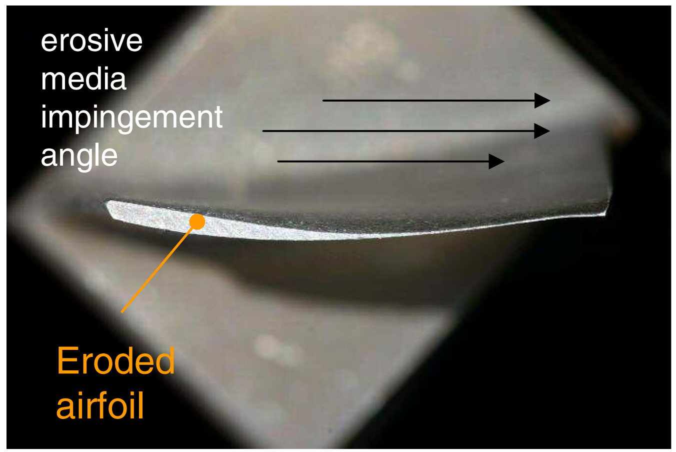
Material removal from pressure side



Damaged blade

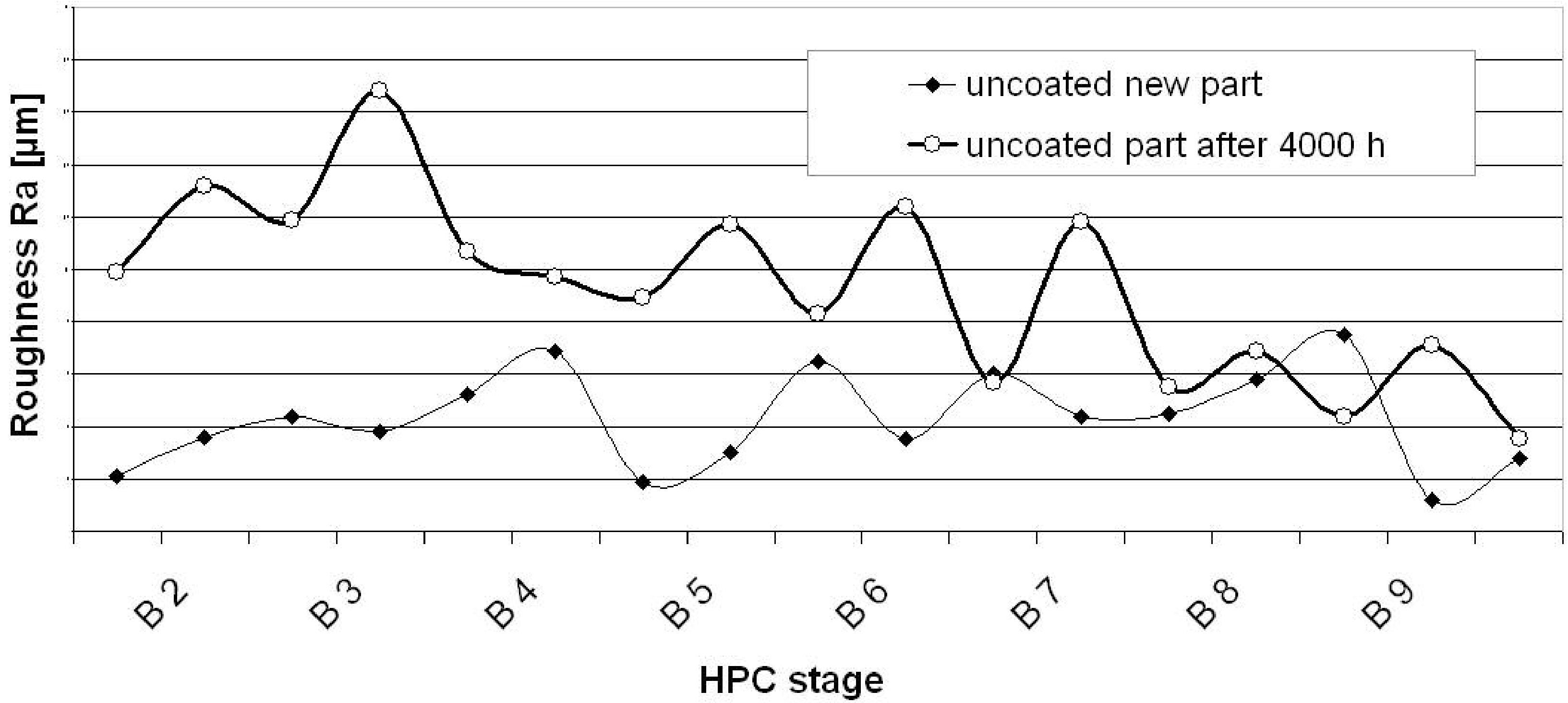
Virgin blade





Influence of erosion on surface roughness

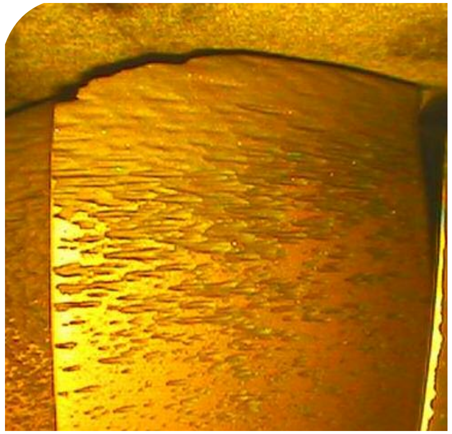
Change of airfoil roughness by erosion during engine life



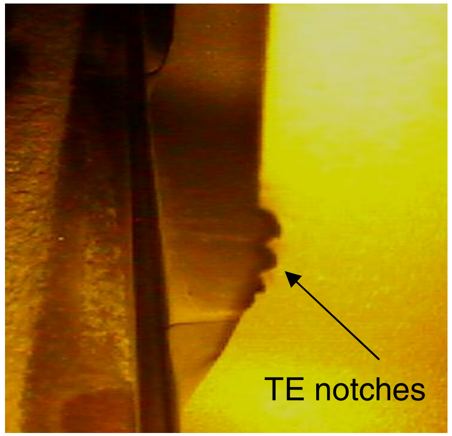
Surface roughness of eroded compressor blades (after 4,000 flight hours approx.) compared with the surface finish of virgin parts.

The consequences of erosion

- **Short service life of engine components**
  - high maintenance cost
- **Increased risk of in-flight shut downs**
  - cracked blades
  - cracked vanes
- **Degradation of compressor efficiency**
  - higher thermal load on the turbine
  - increased SFC
- **Simple single layer TiN coatings do not improve the situation**



Eroded Blade

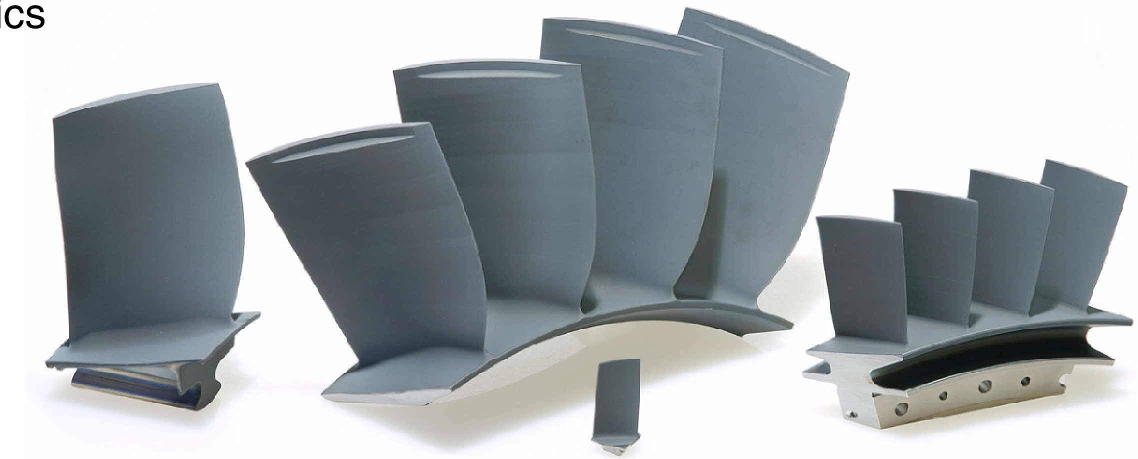


Eroded Vane

MTU^{Plus} solution ERCoat^{nt} – coating definition

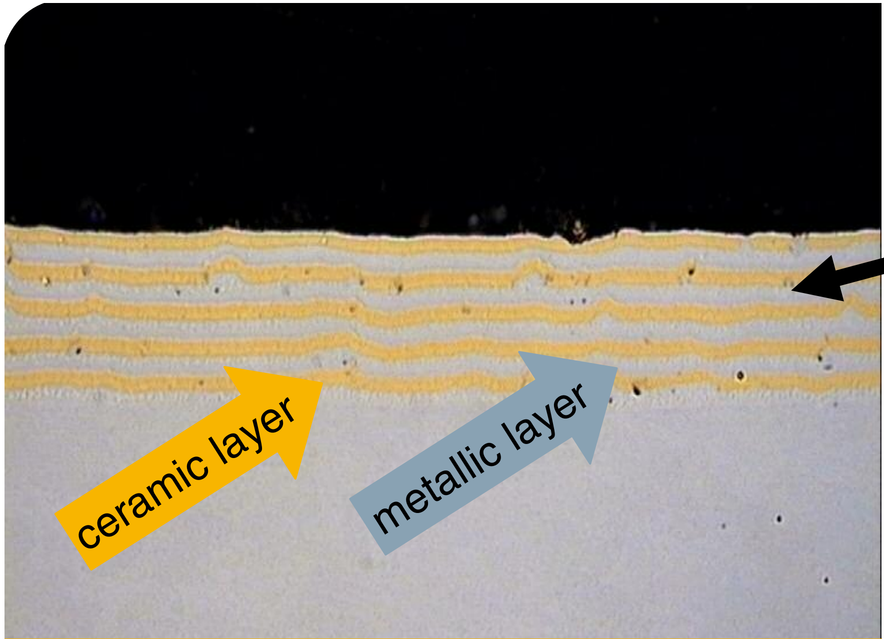
The erosion-resistant coating is a multi-layer coating deposited by physical vapor deposition using the latest nanotechnology

- 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

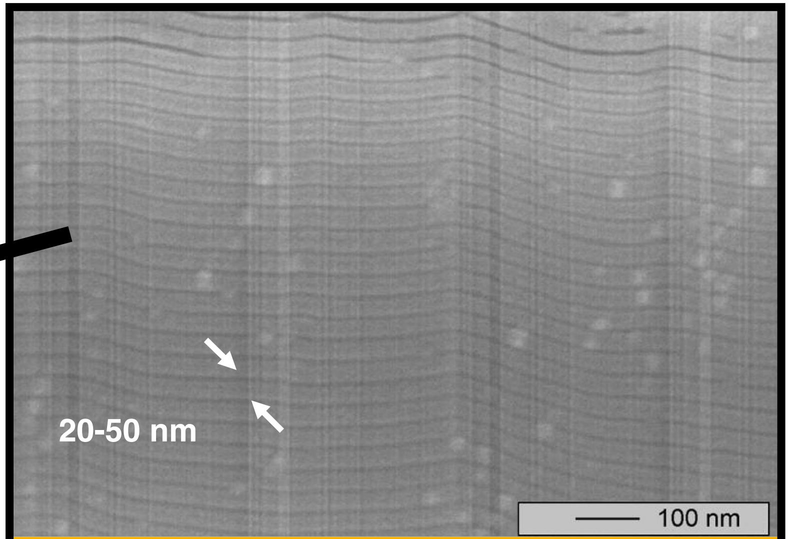


High temperature ERCoat^{nt} on different types of airfoils

MTU^Plus solution ERCoat^nt – coating structure



Microstructure of nanostructured multi-layer coating with hard ceramic and soft metallic single layers deposited by physical vapor deposition



Nanostructure

ERCoat^{nt} properties

- Coating thickness 5 to 50 µm
- Frequency change negligible
- Strength of coated blades sufficient to accommodate all loads including stall and surge events
- Long-term oxidation stability up to 500°C…650°C
- Rub-in behavior unchanged or improved
- FOD notches can be blended within normal design limits w/o HCF strength losses

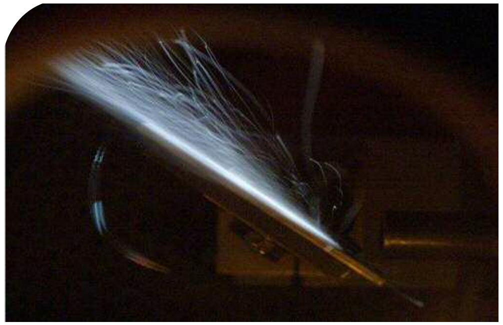
Endurance test with 4.000 cycles / 1.300 hours

ERCoat^{nt} testing - methods

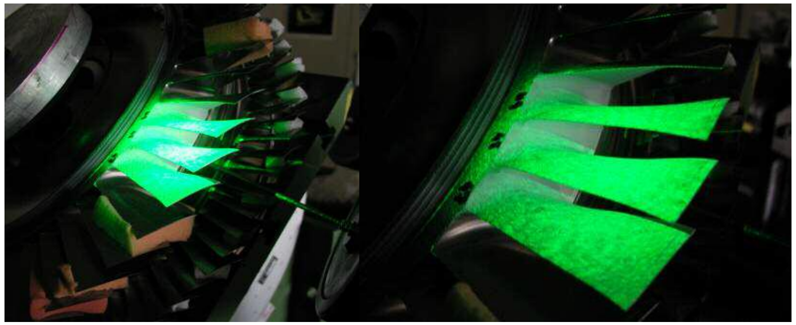
- Safety for all engine conditions like surge, stall, ice and FOD must be guaranteed
- A selection of necessary facilities for testing of the coatings at engine related conditions

Erosion tests
High-cycle and low-cycle fatigue tests
Bend tests
Oxidation tests
Corrosion tests
Metallographic examination
Scanning electron microscopy (SEM)
Non-destructive testing (NDT) methods

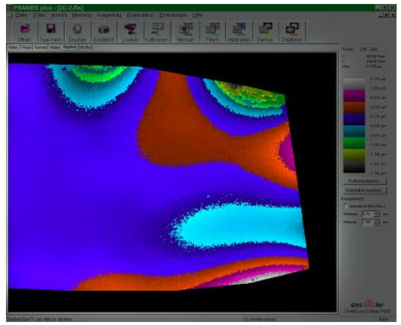
Evaluation of test data and results by MTU's engineering staff



Erosion test



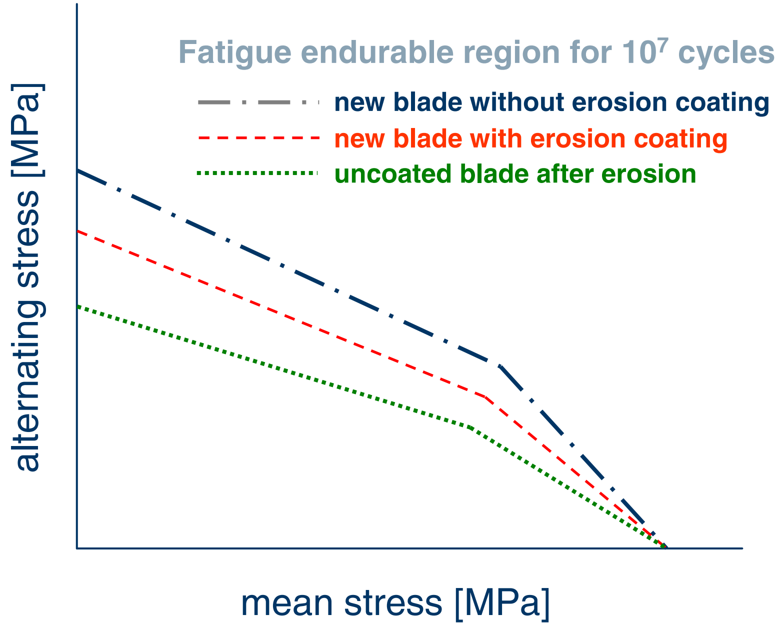
HCF test



Holographic test

ERCoat^{nt} testing – Fatigue tests

HCF strength

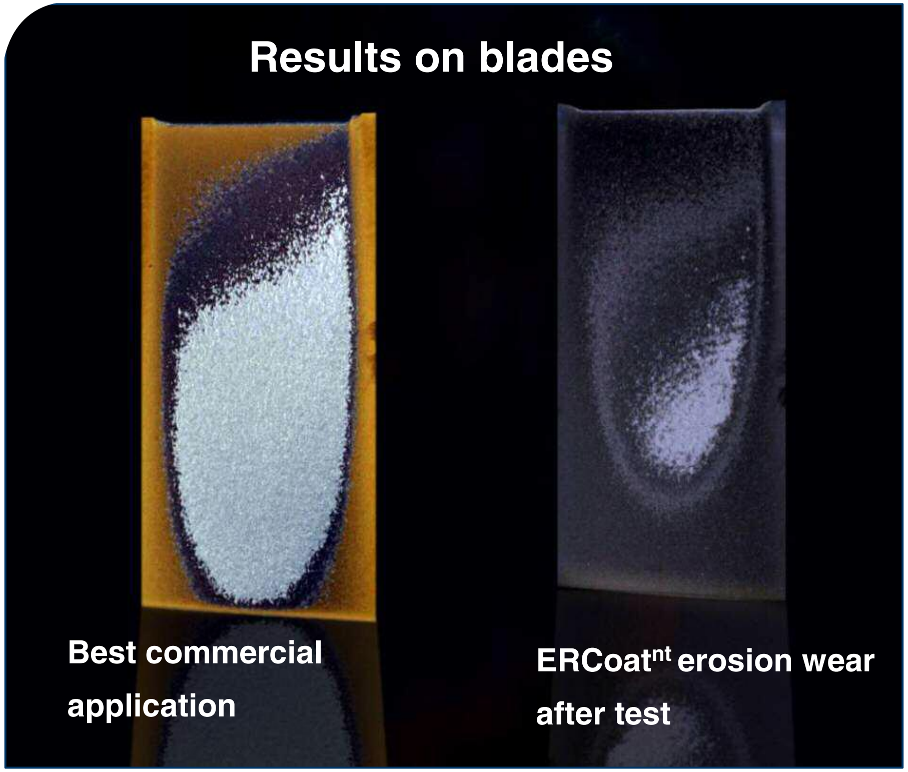


Basis for the Goodman Lines are HCF tests on airfoils with and without erosion coating.

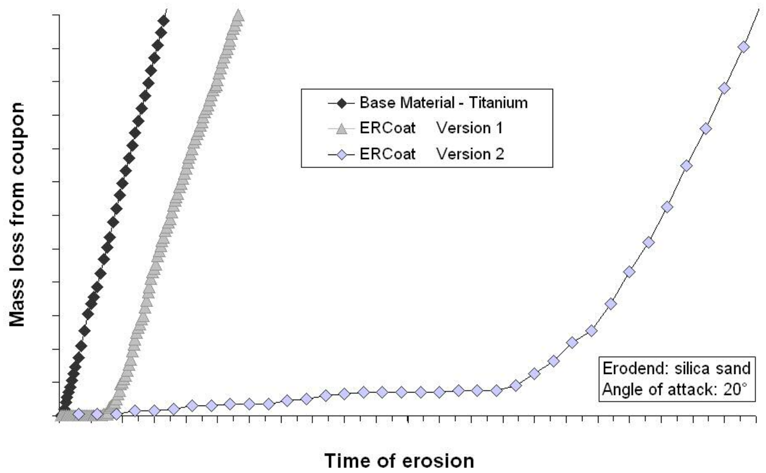
Depending on coating system and airfoil geometry the influence on HCF strength for coated airfoils ranges from a debit of 0% to a max. of 10% compared to eroded blades with a debit of 30% and more.

ERCoat^{nt} testing - results

Results on blades



Results on specimens



Matched with the best in the industry so far!

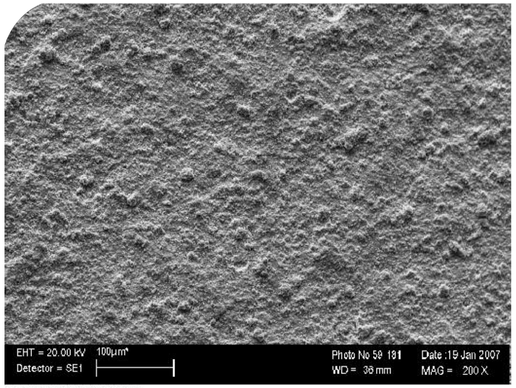
ERCoat^{nt} testing – oxidation and corrosion tests

- **Oxidation test with coated IN718** - 650°C/100h/air:
  No oxidation of coating

- **Oxidation test with coated Ti6242** - 450°C/500h/air:
  No oxidation of coating

- **Corrosion test** - Salt spray test according to ASTM-B117:
  No corrosive attack

- **TMF test** 50°C – 400°C with static load:
  No influence on LCF strength



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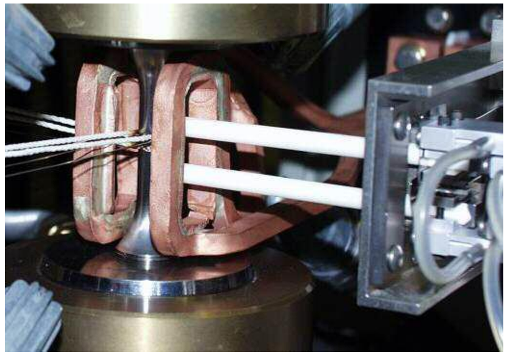
No change of surface topography



Thermo mechanical fatigue test

ERCoat^{nt} withstands thermal, oxidative and corrosive exposures

EASA approval of ERCoat^{nt}

- EASA approval necessary for all EASA repairs; FAA acceptance automatic

- Stringent requirements:
  - DOA (Design Organization Approval)
  - extensive documentation
  - extensive testing

- EASA approval documentation is the leading documentation for all companies under EASA-Regulations

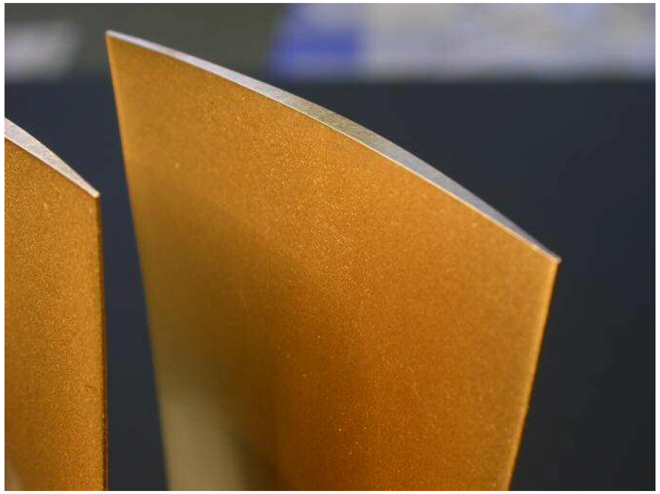
- Current status:
  - EASA approval for ERCoat^{nt} V2500 HPC (first set of coated parts is installed on a flight engine)
  - EASA approval for CF6-80C2 pending for mid 2008 (for the high loaded Blades Stg. 6-10 approval existing)

Coating plant capabilities

All process steps including pre- and post-processing and quality assurance can be performed in-house

Coating plant

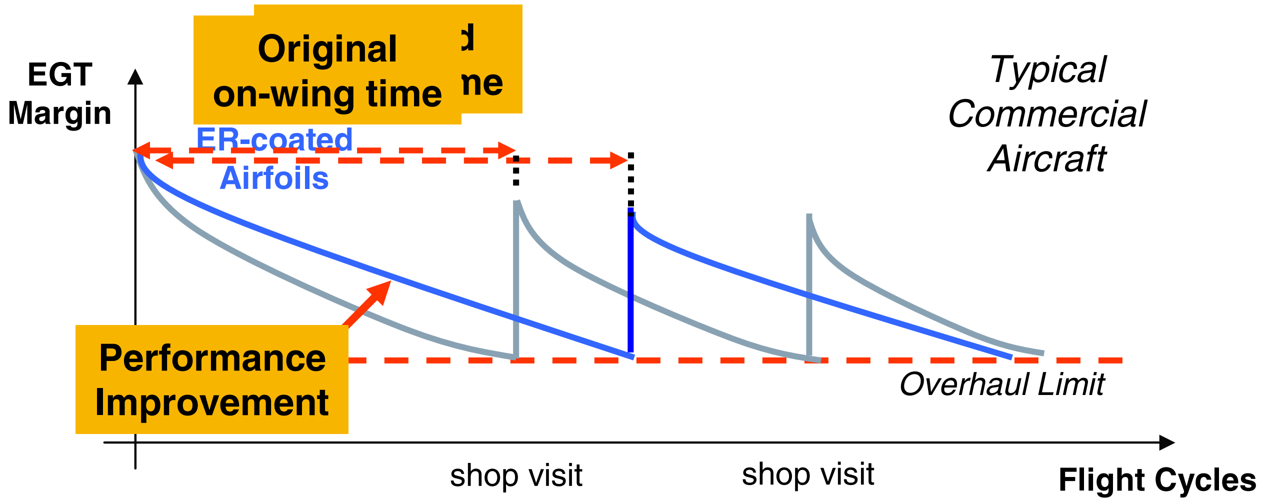
Coating plant with blue arc



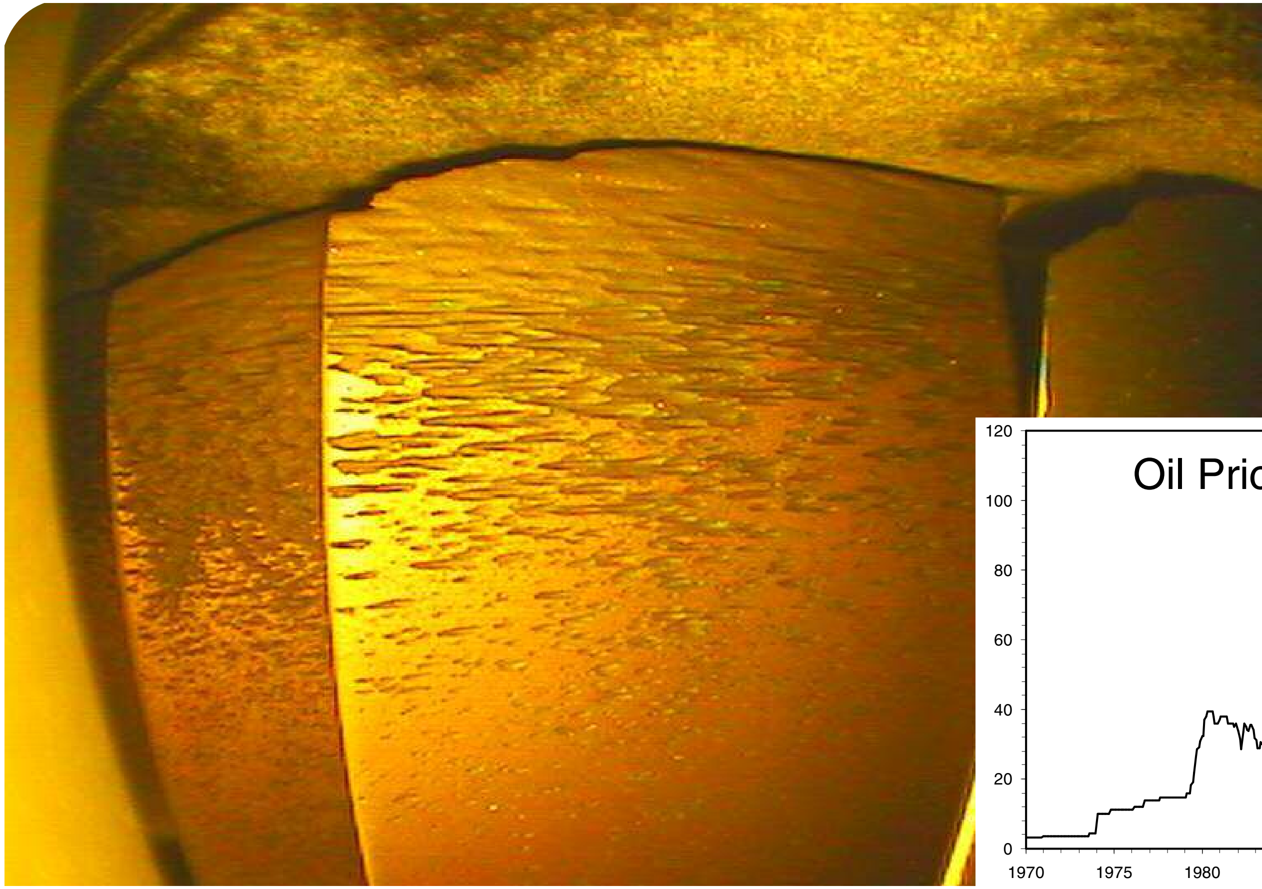
Grinding of coated blades

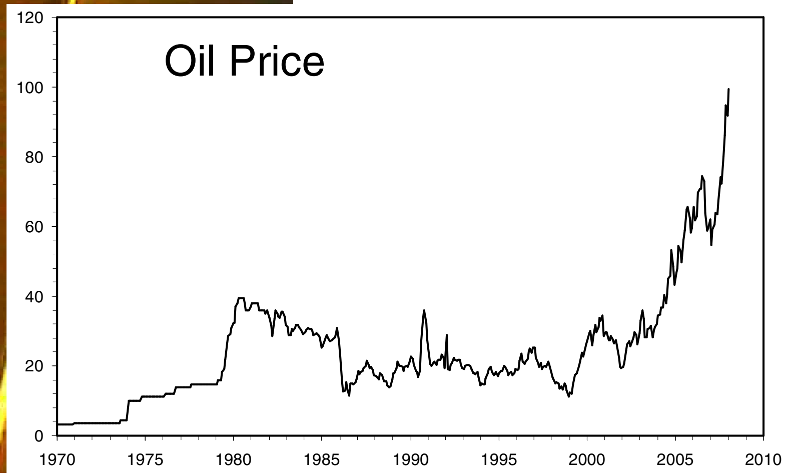
Advantages of ERCoat^{nt}

- **Increased engine availability**:
- Up to 1.000.000 US$ in savings by reduction of unscheduled compressor removal
- **Reduced scrap rate:**
  Reduced maintenance material cost by 20 to 40%
- **Improved flight safety:** e.g. no notching or cracking because of reduced chord length



Problems with exploding material cost?

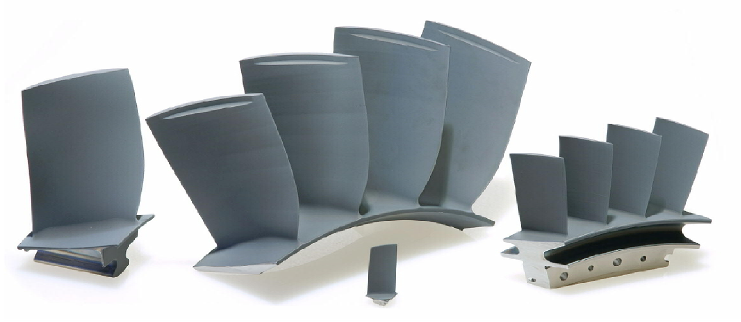


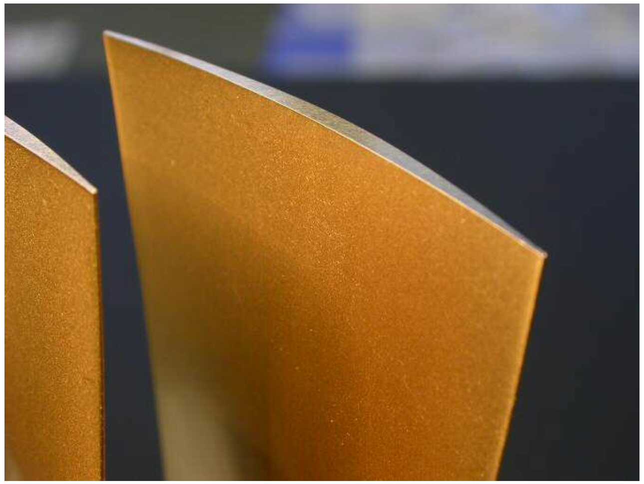


….. and eroding profits ?

Time for ERCoat^{nt}

(an MTU^{Plus} repair solution)





MTU^{Plus} repair solutions – our ^{Plus} is your Plus

Thank you for your attention!

ERCoat^{nt} Team: Wolfgang Eichmann
Dr. Falko Heutling
Philipp Langholf
Dr. Thomas Uihlein

Point of Contact: Philipp Langholf
philipp.langholf@mtu.de
www.mtu.de