Titanium in Aero-Engines
Developments and the Way Forward

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Engine ACARE* environmental targets for 2020

Reduce perceived external noise by 18 dB Cumulative

Reduce fuel consumption and CO₂ emissions by 20%

Reduce NOₓ emissions by 80%

Targets are for new engines and whole industry relative to 2000

The ACARE targets represent a doubling of the historical rate of improvement...

* Advisory Council for Aerospace Research in Europe
The Drive for Cost

- History of air transport shows a continuous reduction in real price of travel whilst airline margins are also falling
- To meet airlines’ requirements we must continuously raise our standards of technology to achieve improved performance while driving cost down
- It is critical that we reduce the cost of materials and processes since these underpin final engine cost

Fares (1992 US cents per revenue passenger kilometer)

Profit/loss (constant 1992 $b)

Source: DTI analysis of ICAO data
Materials in a current civil engine

Alloy Content

- **Steel**: 25%
- **Nickel**: 40%
- **Titanium**: 30%
- **All Others**: 5%
Materials
Ti Disc alloy temperature capability

Temperature Capability (°C)

- Near-α Alloys
- High strength α-β Alloys
- Aerofoil ‘fire line’

- α-β Alloys

Titanium Disk Alloy Development

Alloy development for increased strength & temperature capability

- **Ti6-4** Workhorse alloy up to 300°C
- **Ti6246** High strength alloy up to 450°C
- **Ti6242** Near alpha alloy up to 525°C
- **IMI 834** Optimised creep & fatigue strength alloy up to 600°C

![Titanium alloy microstructures](image)
Titanium in Discs – R-R 3 shaft history

Increasing temperature
Decreasing space
= Increased Ni alloy use

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<tr>
<th>Year</th>
<th>Ti685</th>
<th>Ti829</th>
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Higher temperatures - Aluminides

**Ti Aluminides for lower density & greater temperature capability**

- Cast and wrought technology development underway
- Cast 45-2-2XD™ early medium strength alloy
- High strength & temperature capable wrought alloys e.g. TNB

Cast 45-2-2XD™

Wrought TNB
Titanium Aluminides (Gamma)

- Focussed on near net shape technologies
  - Casting process development
    - optimise mould filling
    - avoid costly machining operations (e.g., aerofoil)
- Design studies
  - Optimise root fixing and aerofoil geometries
  - Limit peak mechanical stress
- Material behaviour and validation
  - Understanding alloy / process / structure / property relationships
  - Material, component and engine testing
- Supply chain development
  - Partnerships with capable suppliers
  - Cost reduction opportunities

Large civil LPT blade
Weight Reduction - TiMMC & IMC

[Diagram of a jet engine with labeled parts: Compressor, Turbine, Nozzle, Ti MMC LP compressor blades and vanes, Ti MMC, IMC HP compressor blings, IMC LP turbine bling, Ti MMC, IMC actuator struts, Ti MMC LP compressor blings, Ti MMC compressor casings, Ti MMC shafts]
TiMMC Blings

Conventional disk & blades

Blisk - up to 30% weight saving

Bling - Ti MMC - up to 70% weight saving
Where next...

- New aluminide compositions & heat treatments
  - Improved properties at low cost

- Aluminide Composites
  - Orthorhombic matrix with high strength SiC fibers
  - Strengths >2000MPa at 650°C
  - Rotor concepts demonstrated
Leading Ti hollow Wide Chord Fan Technology

Clappered

- 1950's
- Solid
- Higher efficiency
- Lower noise
- High damage resistance

1st generation

- 1970's
- Honeycomb

2nd generation

- 1990's
- DBSPF* ‘girder’
- Low noise
- Low weight
- High efficiency
- High flow

3rd generation

- 2000+
- DBSPF* ‘girder’
- Low noise
- Low weight
- High efficiency
- High flow
The challenge from composites

Fan case
OGV
Filament-wound spinner
Fan Blade
Fan Containment case

Fan case liners
By-pass ducts
1. PROGRESS & PROMISE IN DISCONTINUOUSLY REINFORCED ALUMINUM
Benji Maruyama, Daniel B. Miracle, Air Force Research Laboratory, Materials & Manufacturing Directorate, WPAFB, OH 45433

Processes
Ti Blisks

- Weight
- Performance
- Design
Blisks - Repair Instead of Replace
Ti - Linear Friction Welding

- Cost
- Integrity
- Flexibility
- Optimised materials - hollow blades
Ti-Linear Friction Welding

- Cost
- Integrity
- Flexibility
- Optimised materials - hollow blades

Titanium 2011, Oct 2 - Oct 5, 2011, San Diego, USA

R-R Proprietary Information
Ti64-Metal Injection Molding

Green vs Sintered (Non Aerospace Parts)

Typical Structures

*Mechanical properties exceeds ASTM F1472 requirements*
Net-Shape Powder HIP

Model Tool

Powder Fill Cavity

HIP & Extract

- Critical to Net-Shape
- Predict Tool Cavity

- Mild Steel Tooling
- Powder Fill Can
  - Evacuate, Vibrate, Heat
- Seal

- Hot Isostatic Press
- Remove Can
  - Machine then Pickle
Finished Machined Ti64 Compressor Casing

75% reduction in machining time

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R-R Proprietary Information
Titanium 2011, Oct 2-Oct 5, 2011 San Diego, USA
Material life cycle...

- **Design**
  - new alloys
  - new processes
  - new operating regimes
  - lifing
  - etc

- **Make**
  - manufacturing
  - change control
  - concessions
  - etc

- **Certify + support in service**
  - underpins part life but
  - surprises in store:
    - WRT operation
    - WRT material behaviour

Driven by product requirements
Empirical iterative process

Mechanistic understanding
Demonstration of equivalence

Feedback loop – may take decades
Need fundamental understanding

- Physically based behavioural models
  - Improved right first time design
  - Accurate component life / durability prediction
  - Reduced life cycle cost and improved reliability
- Physically based process / structure / texture models
  - Optimised process routes for;
    - Yield
    - Material properties
- Rapid and accurate assessment of;
  - Manufacturing change
  - Non conformance
Conclusions

- Business drivers
  - *product reliability*
  - *(life cycle) cost reduction*

- Main developments – next 5-10 years
  - process / property / behaviour relationships – significant developments expected
  - Improvements in material & process modeling and component lifing methods
  - limited ‘new’ alloys for niche applications
  - increased application of near net shape technology, better buy/fly ratios
  - *(Low cost) powder production and manufacturing for low risk Ti systems and repair technologies*