Titanium Rotors in Military Aero Engines - Designed to Weight and Life

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Engine Specification

- purpose of the engine
- mission profiles
- power and thrust
- fuel consumption
- engine size and weight
- reliability characteristics
- maintainability figures

Derived requirements for rotors

- functionality
- rotor life (6000 to 25000 cycles equivalent to 30 to 40 years in service)
- rotor weight (to be minimised)

Rotor parts

- exposed to elevated temperatures
- high loads
- high rotational energy

⇒ significant damage in case of failure

high safety levels are required

classified as 'critical'

⇒ turbine rotors: Nickel base superalloys

compressor rotors: Titanium alloys

Titanium alloys demands

- **commercial aerospace**
  - air frames
  - aero engines

- **military**
  - aerospace
  - other military use

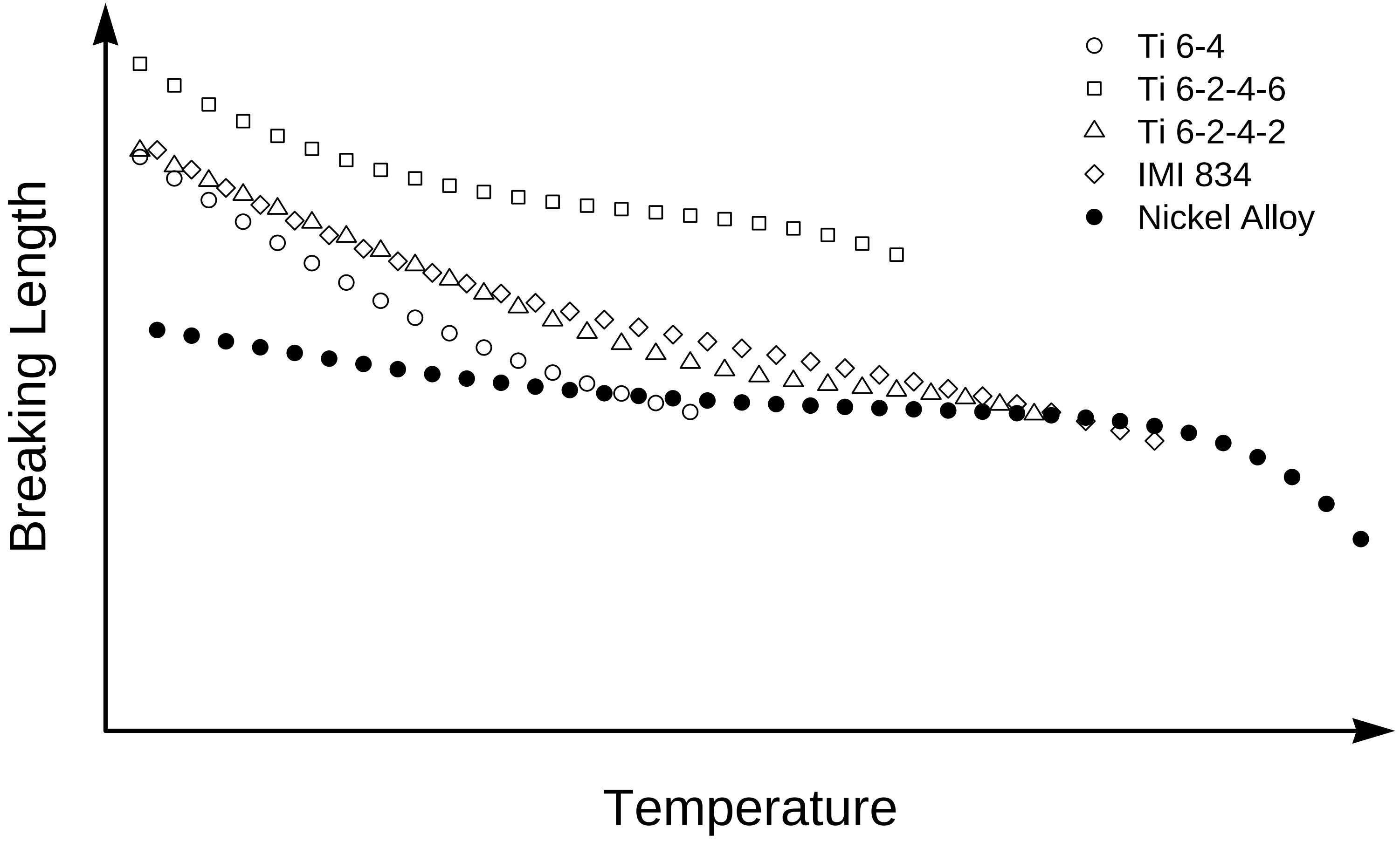
- **non-aerospace commercial**
  - golf club market
  - medical instruments

Characteristics of Titanium alloys

- high strength
- low density
- low Young's modulus
- low coefficient of thermal expansion
- remarkable corrosion resistance
- good ductility
- weldable and forgeable

Titanium alloys used in compressor rotor parts

	Characteristics	Temperature Range	Cost
Ti 6-4	good tensile properties, creep resistance, high fatigue strength	up to 325 °C	100 %
Ti 6-2-4-6	higher strength at elevated temperatures	up to 450 °C	160 - 170 %
Ti 6-2-4-2	good tensile and creep properties	up to 540 °C	125 - 130 %
IMI 834	increased tensile strength, creep resistance, acceptable fatigue strength	up to 600 °C	380 - 400 %



Breaking length of Titanium alloys (compared with Nickel)

Life Cycle Costs

- **Cost of development**
  conceptual and detailed design
  design verification and validation
  in-service development and modifications

- **Cost of procurement (investment)**
  production and engineering support
  engine support investment (e.g. spares)
  quality control and warranties

- **Cost of ownership**
  operating personnel and consumables (e.g. fuel, oil)
  material (spare parts) and maintenance man hours

Modern compressor design

improved compressor efficiency (combined with carefree handling, low weight, short length) requires

- low number of stages
- low number of blades per stage
- robust wide chord airfoils

which cause extremely high stresses in conventional blade root fixings

→ blisk (bladed disk) ⇒ saves weight, avoids extremely high stresses

→ bling (bladed ring) ⇒ saves more weight, increases stresses

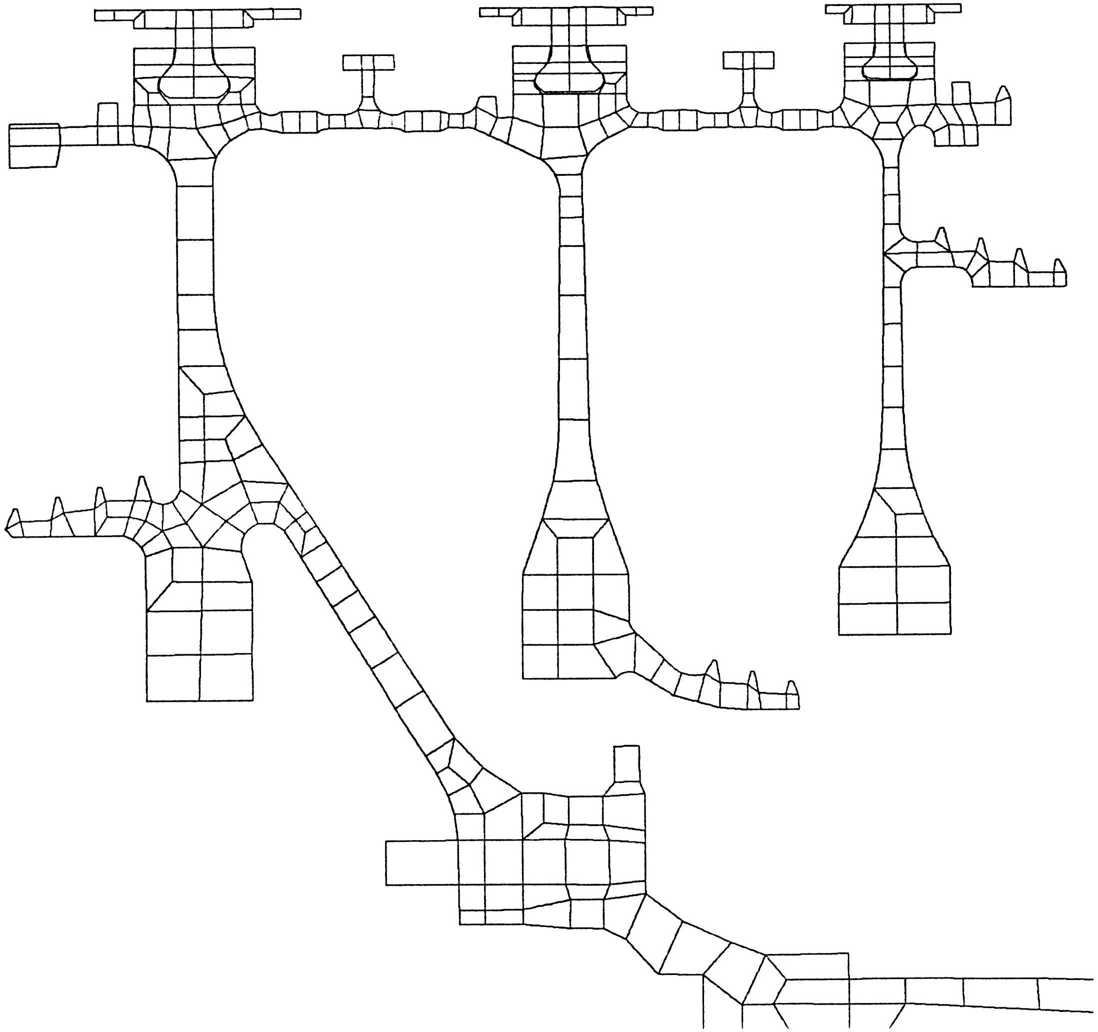
Improvement of design process

- integrated teams with members of all disciplines
- reviews with participation of experienced specialists
- monitoring the technical progress and project costs
- application of improved tools and improved assessment techniques
- better simulation and more precise prediction
- reduced test efforts

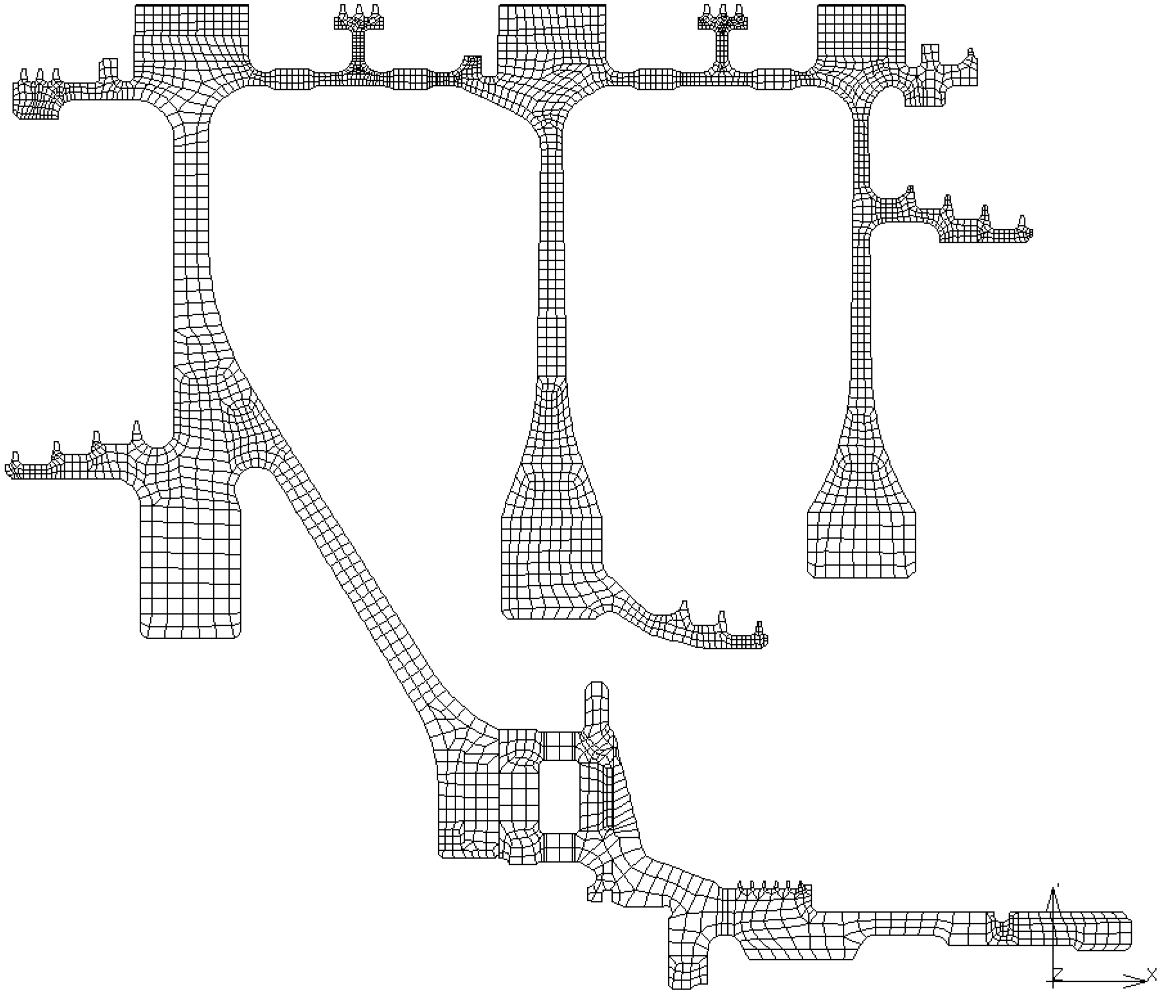
Re-assessment of a given component

Comparison of a component designed in 1979 and re-assessed in 1999

- FE tools and computing capacity dramatically improved
- accuracy improved due to finer FE meshes
- computing time reduced (but additional load cases investigated)
- costs saved: reduced computing and assessment time
- additional non-countable value: increased confidence in design



Coarse FE mesh for RB199 IPC (1979)



Refined FE mesh for RB199 IPC (1999)

Examples for cost reduction in manufacturing

- for certain compressor blades low surface roughness was specified to obtain the required efficiency; however, it turned out that the same efficiency could be achieved with increased roughness.

- changing the reference system for dimensioning of another rotor blade could reduce the rejection rate; quality was significantly improved without additional costs.

- the number of critical features indicated in some design drawings could be reduced to such really necessary; test and documentation expenditure were thereby minimised.

- tolerance bands could be extended for certain geometric dimensions without negative effects to the properties of the components.

- some manufacturing steps (e.g. deburring) which were done manually in the past, can now be replaced by machine manufacturing.

Exploitation of part's life potential

- what is the real life potential of the part?
- how is life consumed under operational usage?

Means for cost reduction

- improvement of the lifing concept and the life prediction procedures
- utilisation of a portion of the crack propagation life
- accurate accounting of life consumption during operational usage

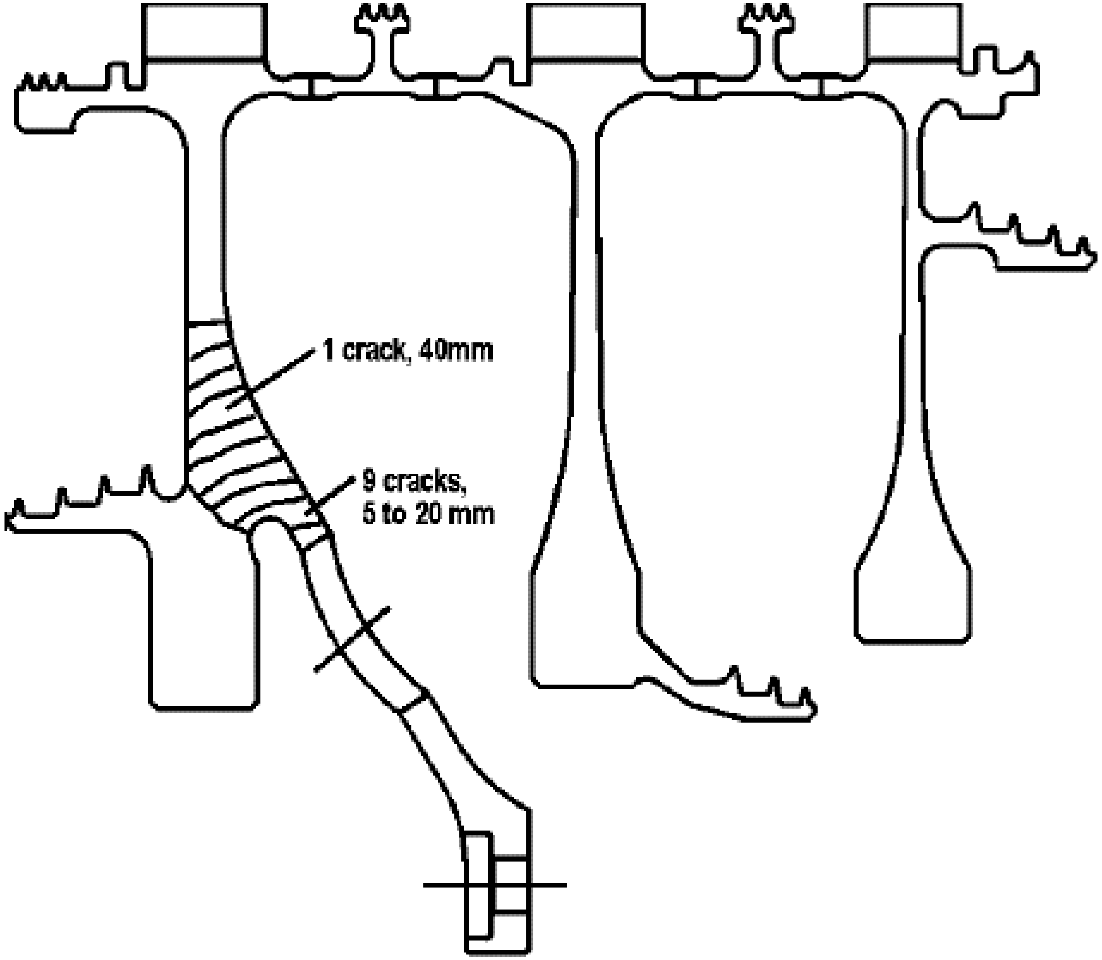
Concepts to establish component life

- **Crack initiation life**
  - a new part is free of defects
  - a defect (e.g. a fatigue crack) is generated in service
  - the part's life is expired when the defect has been created

- **Crack propagation life**
  - a new part contains an initial defect (where the defect behaves like a crack)
  - the crack propagates under service loading
  - the part's life is expired when the crack enters the phase of part dysfuction

- **Safe life** (crack initiation and crack propagation)

  the part's life is the number of cycles which the weakest individual of a population can endure until the life expiration criterion is reached



Crack propagation at the RB199 IPC rotor

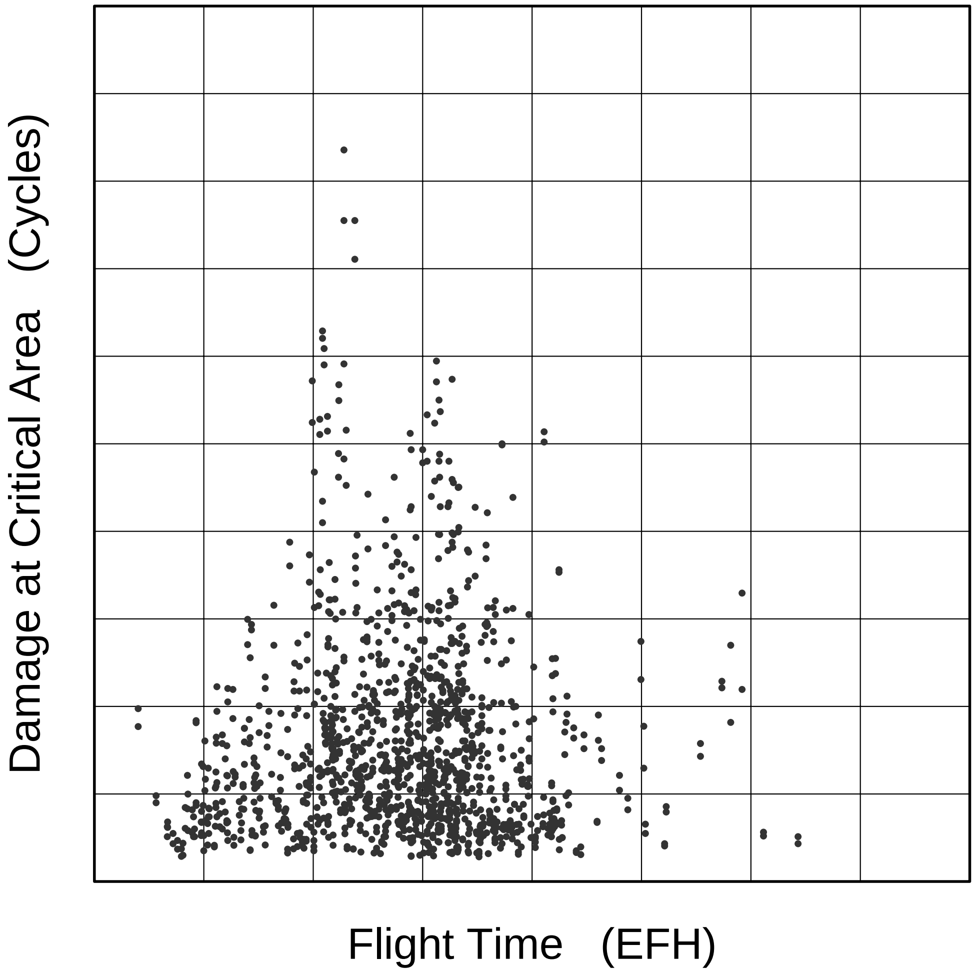
Monitoring the life consumption

Methods established for life usage monitoring

- traditional method based on flight time and β-factors
- individual on-board life usage monitoring

The individual method is equivalent to the process of structure mechanical assessment, i.e.

- actual mission profile (including engine intake conditions, pilot's reactions, etc.)
- calculation of performance parameters (thermal and mechanical boundary conditions)
- transient temperature development within components
- transient stresses (or strains) at critical locations of the parts
- accumulation of critical area damage



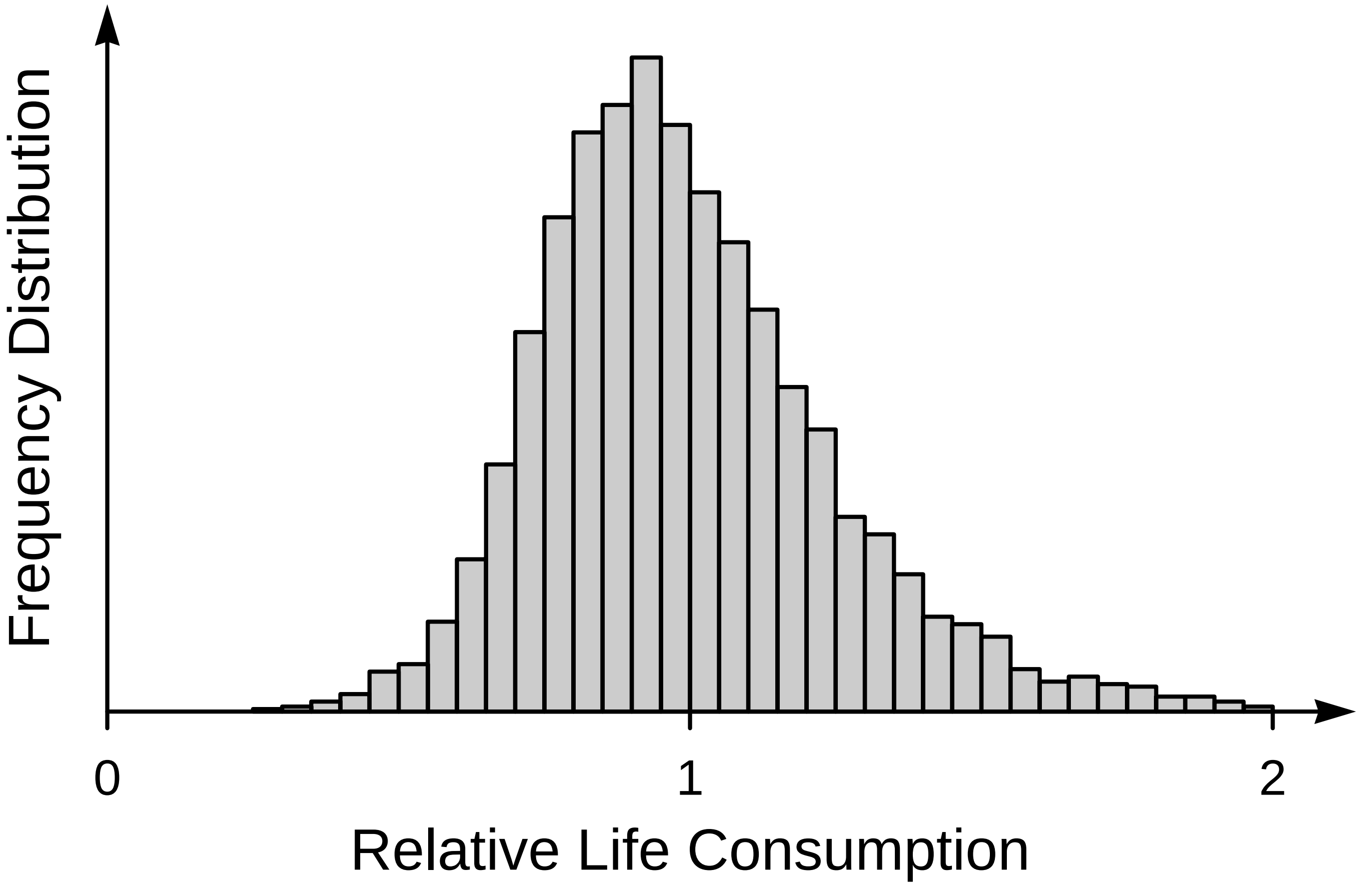
Life consumption versus flight time

Costs and benefits of a fleet wide individual life usage monitoring system

- significant invest for system development and introduction
- savings achieved with OLMOS: ten times higher than invest

Observations (providing additional non-countable value)

- actual distribution of fleet wide life consumption per engine
- in average, parts can be kept in service twice as long as with the traditional method
- risk of using a part in excess of the released life is avoided



Frequency distribution of cumulated life consumption

Conclusion

- Titanium alloys are used 'traditionally' in aero engine compressor rotors
- high strength and low density are key characteristics to fulfil the requirements
- Titanium alloys for higher stresses and increased temperatures drive costs
- improved concepts to establish component's life potential
- improved methods to monitor life consumption