Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Gas Turbine PHM at NLR

Wilfried Visser (wvisser@nlr.nl)

Overview

- Introduction Gas turbine R&D at NLR
- JSF - PHM project
- Integrated Lifing Analysis for Gas Turbine Components

Gas turbine R&D at NLR

- ***Structures and Materials***
- ***Performance analysis and Simulation***
- ***Emissions***
- ***Sensors and Instrumentation***

JSF - PHM project

Dutch PHM Consortium (DPC)

- PHM technology R&D
  - Lifing analysis
  - Model based diagnostics
  - Data mining
  - Sensors
  - Hydraulics / fuel system PHM

PHM technology research

- **Goal: establish relations between**

  monitored engine parameters

  and

  engine structural condition, integrity and (sub)system functioning

- **Monitored parameters**
  - engine performance (rotor speeds, pressures, temps etc.)
  - sub-system performance (oil, fuel, accessory gearbox, bearings etc.)
  - parameters from advanced sensors (oil/gas debris, emissions, acoustics? .....?)

PHM technology research (2)

- ***from monitored data to engine condition (diagnostics and prognostics)***
- ***Empirical vs. analytical modeling approach***
  - often hybrid approach
- ***modeling tools:***
  - GSP *(see NLR_ENGSIM.PPT)*
    - from monitored data to detailed gas condition data:
      - e.g. dynamic TIT response
    - performance monitoring technologies
  - gas flow / heat transfer (CFD) modeling tools
    - from GSP results to heat transfer data
  - life consumption modeling tools (SB dept.)

PHM technology research (3)

- **Focus on limited number of propulsion system PHM issues**
  - PLM project (“from FACE via GSP and other models to life consumption data”)
    - tools: FACE, GSP, ???
  - differential gas path analysis
    - tools: GSP
  - vibration analysis (fourier analysis)
    - main bearings / gearboxes / drive shafts
      - (STOVL lift fan ! drive shaft made by URENCO?)
  - learn from helicopter HUMS experience ((h)afd. VH, SB, I)
  - Cougar EuroHUMS ground station operational at VH dept.

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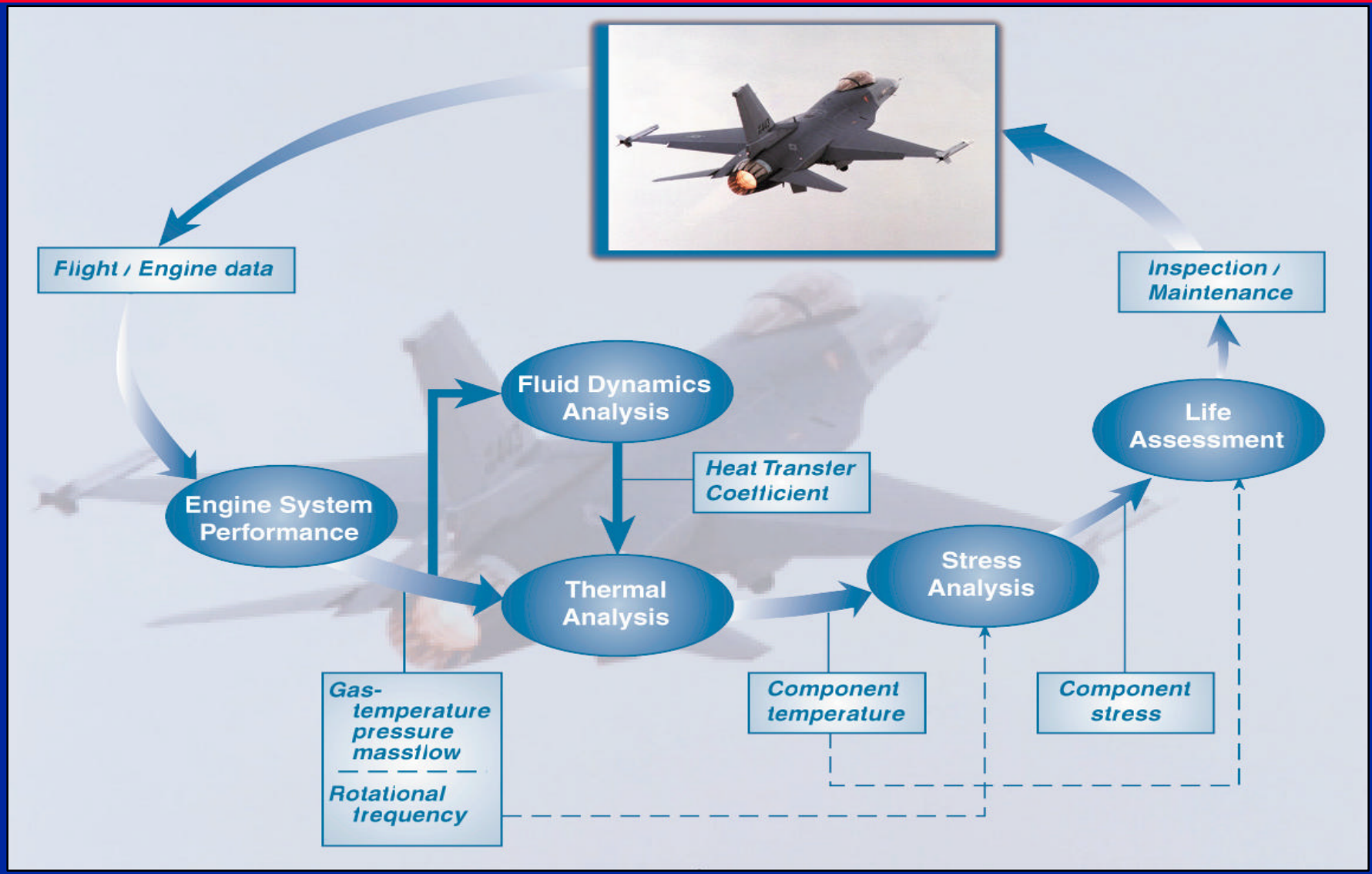
Integrated Lifing Analysis for Gas Turbine Components



Outline

- ***Description of integrated analysis tool***
- ***Applications:***
  - creep life of 3rd stage turbine blade
  - crack growth life of 2nd stage fandisc hub
- ***Conclusions and potential***

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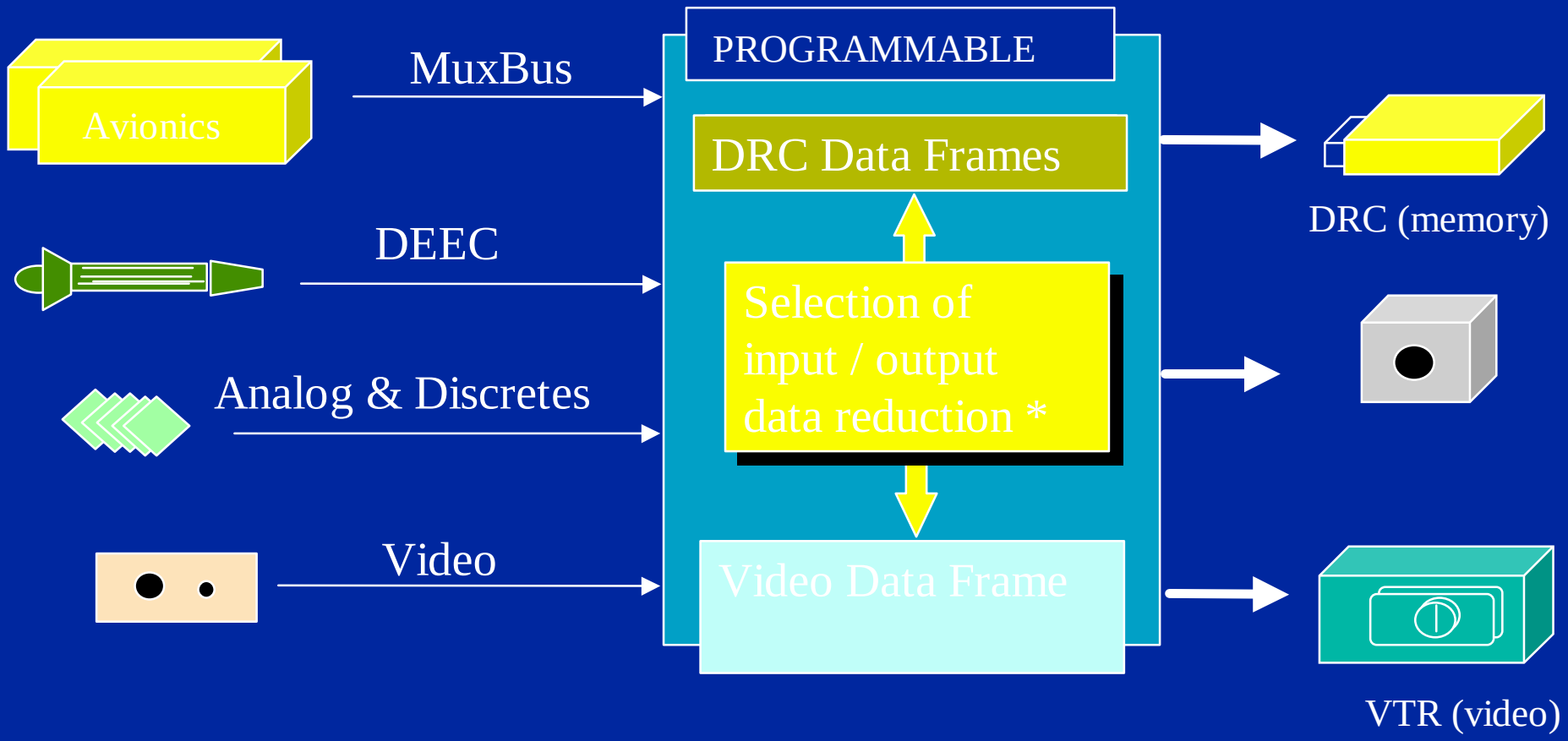
FACE system



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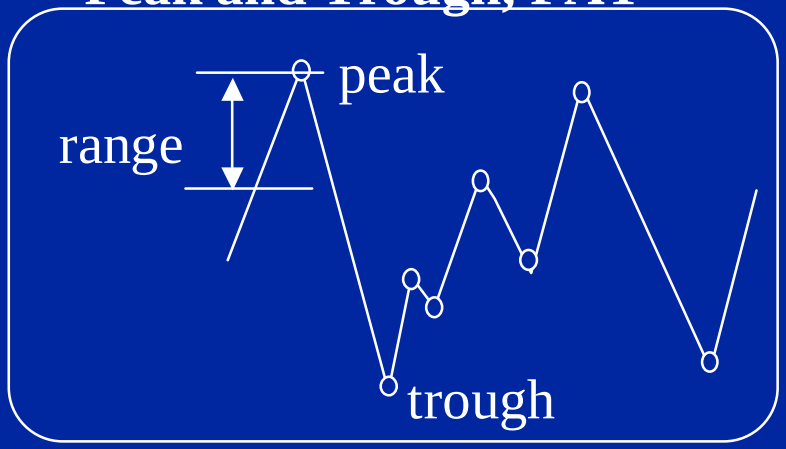
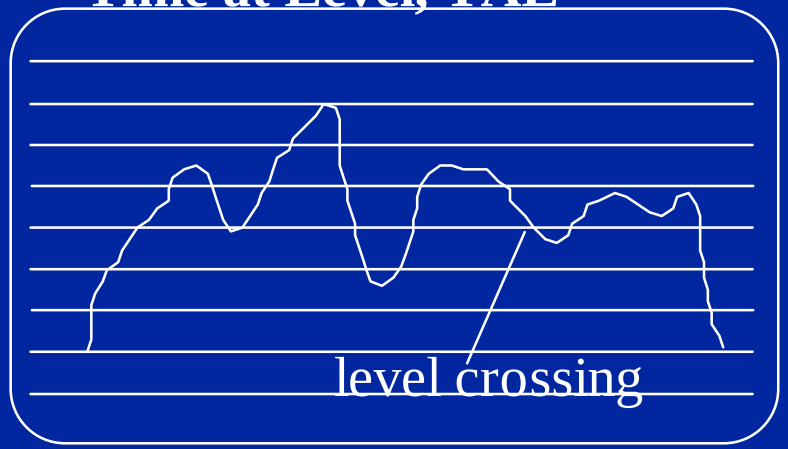
Data reduction algorithms

Peak and Trough, PAT



Time at Level, TAL



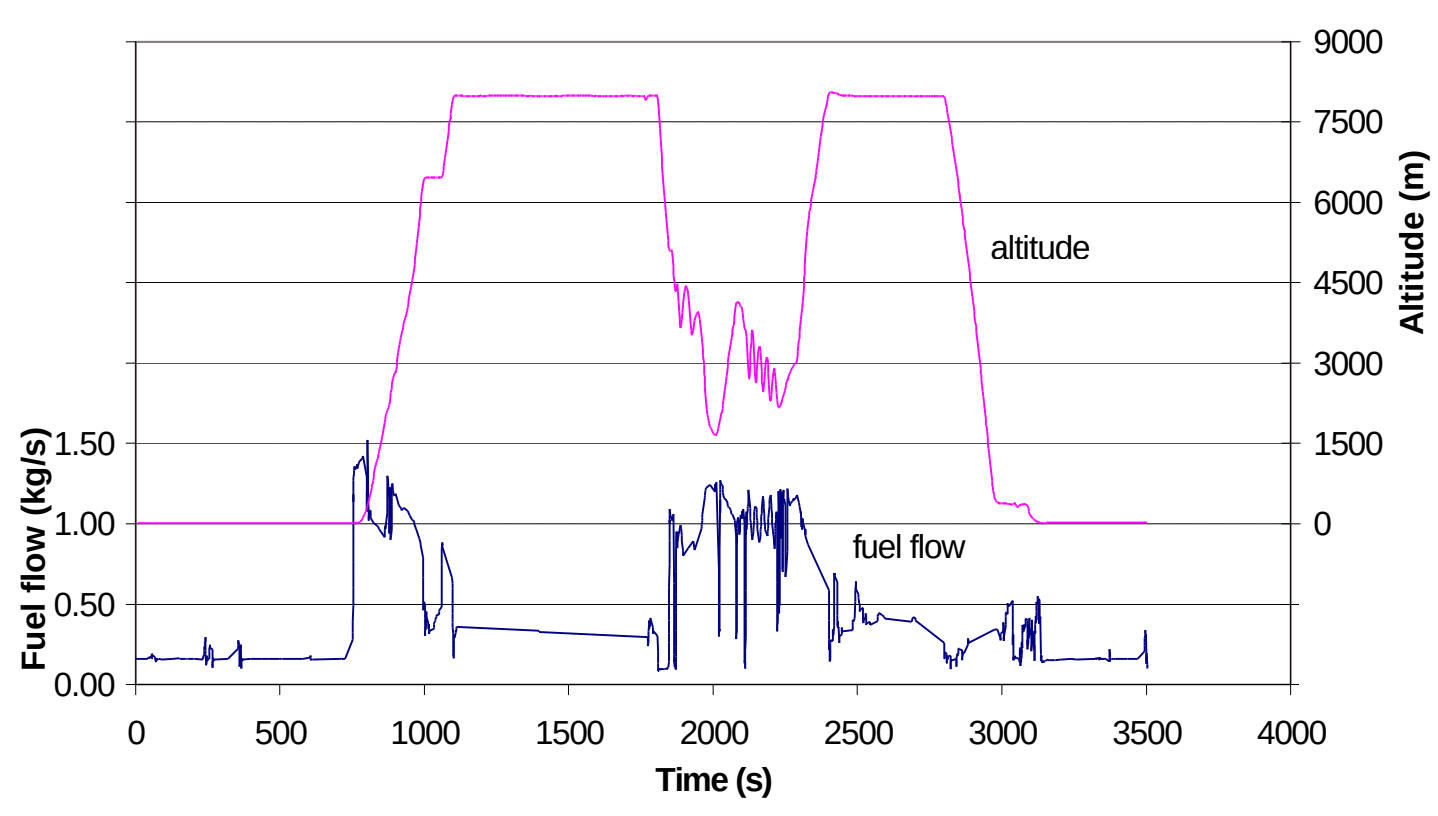
Airframe:
5 strain gages
vertical accel

Engine:
N2 / PLA

Engine:
PLA

Example FACE engine data

- Data acquisition system to measure real time operational flight and engine data



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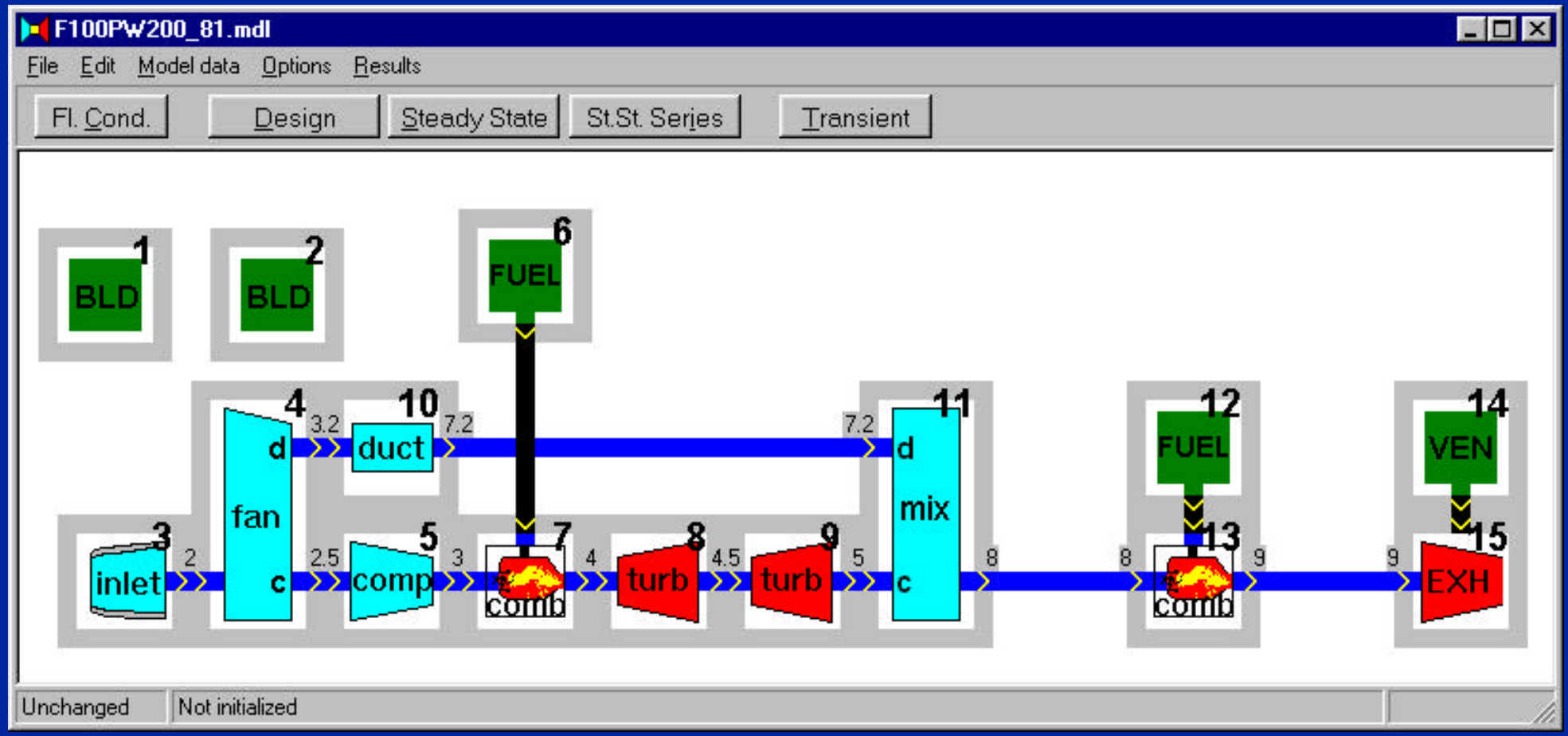
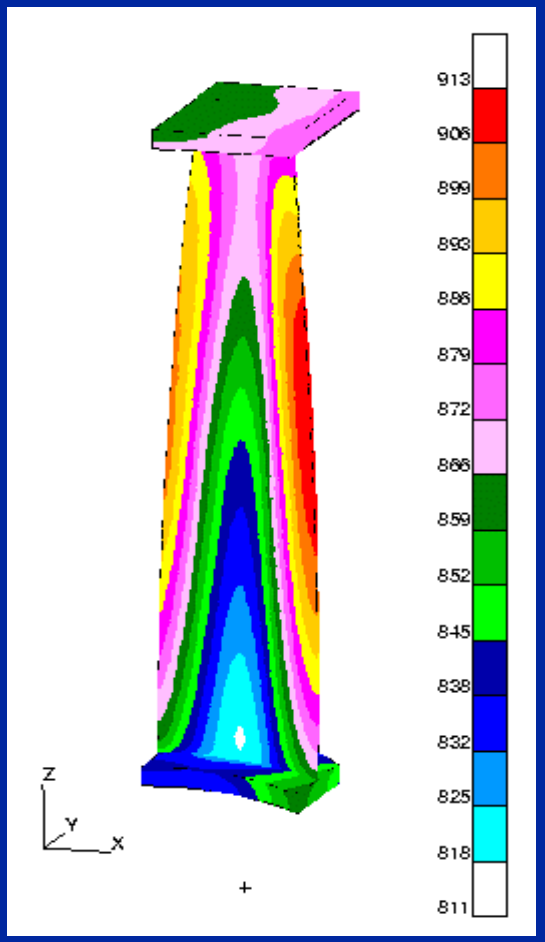
Gas Turbine Simulation Program



www.nlr.nl/gsp

Finite Element Model

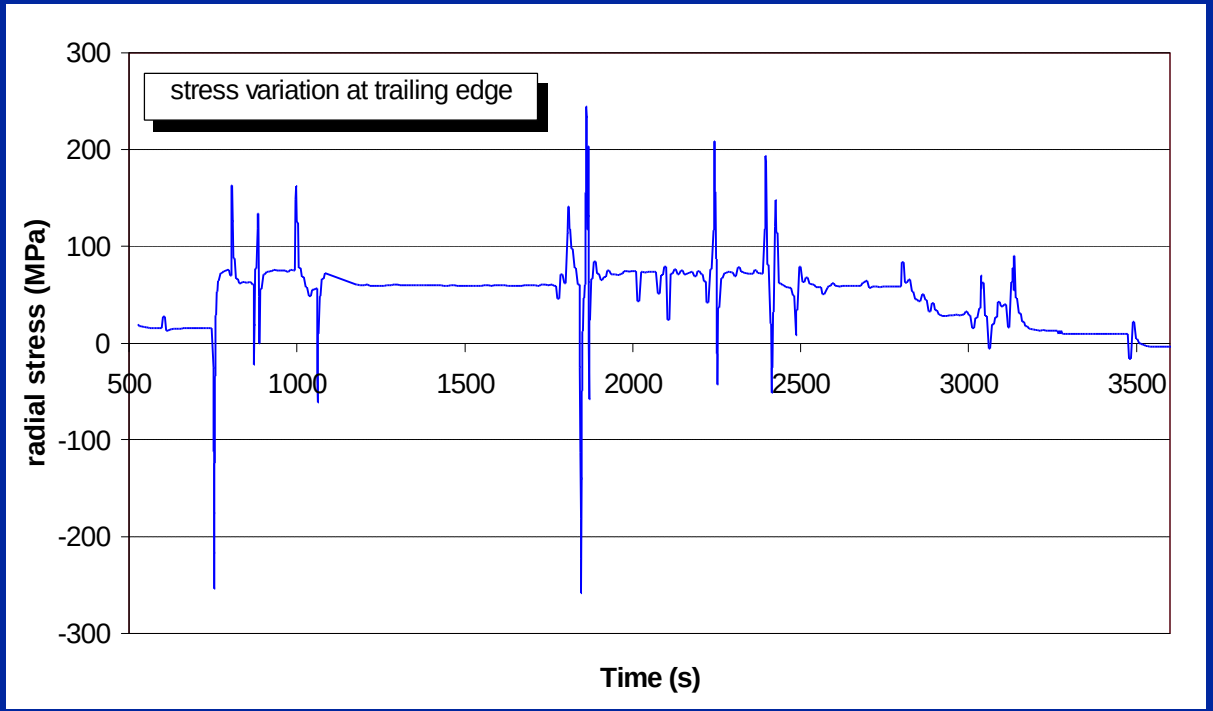
- ***Thermal model includes:***
  - Variation of heat transfer coefficient h across blade surface (CFD)
  - Variation of gas temperature in time (GSP)
  - Internal / film cooling effects
- ***Result:***
  - temperature distribution and variation in time



Finite Element Model

- **Mechanical model includes:**
  - Variation of blade temperature with location and time (FE-thermal)
  - Variation of rotational speed (centrifugal loading) (GSP)
- **Result:**

  stress / strain distribution and variation in time

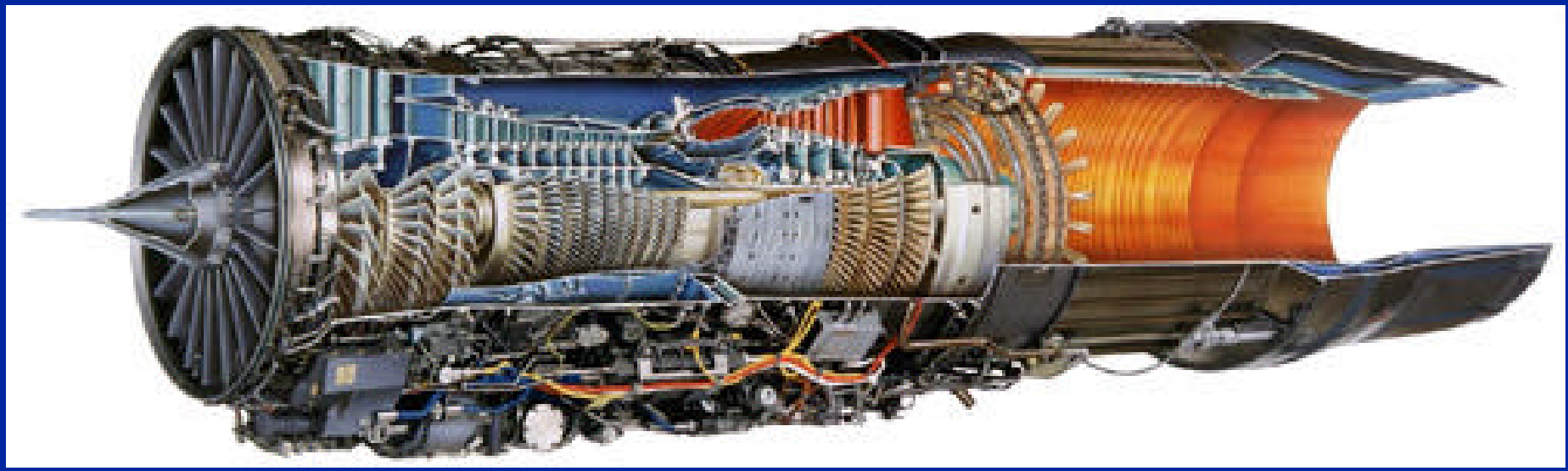


Life prediction Model

- ***Translates the variation in stress and temperature to life consumption***
- ***Several mechanisms:***
  - low cycle fatigue
  - creep
  - oxidation
  - fatigue crack growth

Applications

- 1. Effect of HPT deterioration on creep life consumption of 3rd stage turbine blade
- 2. Crack growth life of 2nd stage fandisc hub



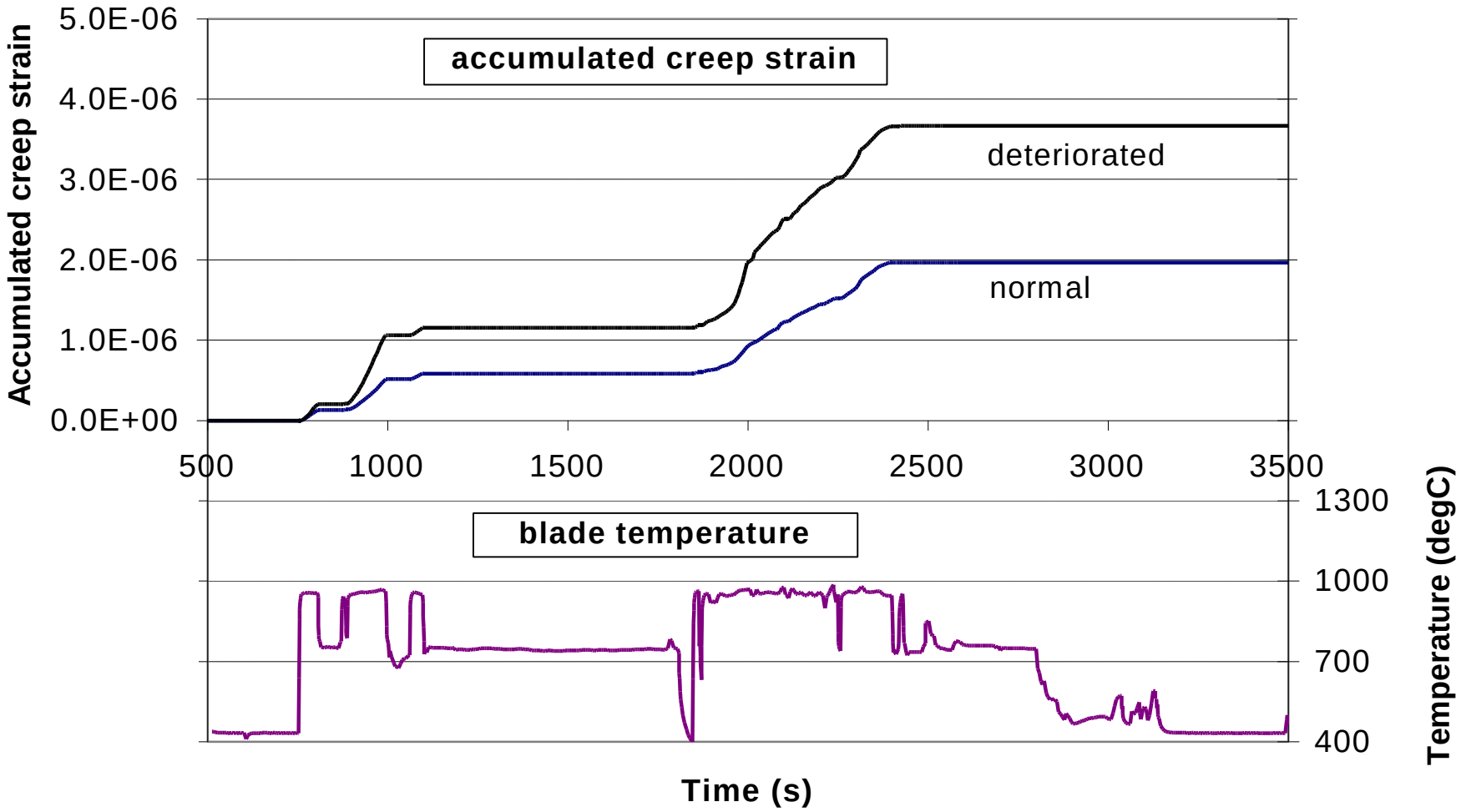
Third stage turbine blade

- ***Component:*** **3rd stage turbine blade F100-PW-220**
  - solid and uncooled blade
  - creep is life-limiting damage mechanism
- ***Mission:*** ***randomly chosen RNLAF mission***
- ***Lifing model:*** ***creep strain accumulation***
- ***Effect to study:*** ***HPT deterioration***

HPT deterioration

- High Pressure Turbine (HPT) deterioration is modeled by decreasing HPT efficiency in GSP
- Engine control system maintains fan rotor speed by increasing fuel flow
- Resulting higher gas temperature causes higher component temperature

Effect of HPT deterioration

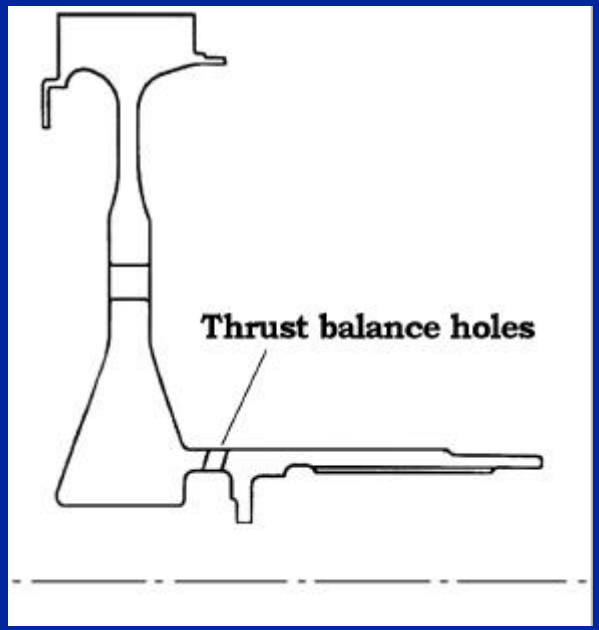


Second stage fan disc

- ***Component:*** **hub of 2nd stage fan disc F100-PW-220**
  - cracks occur at thrust balance holes
  - occurrence of critical crack is life-limiting damage

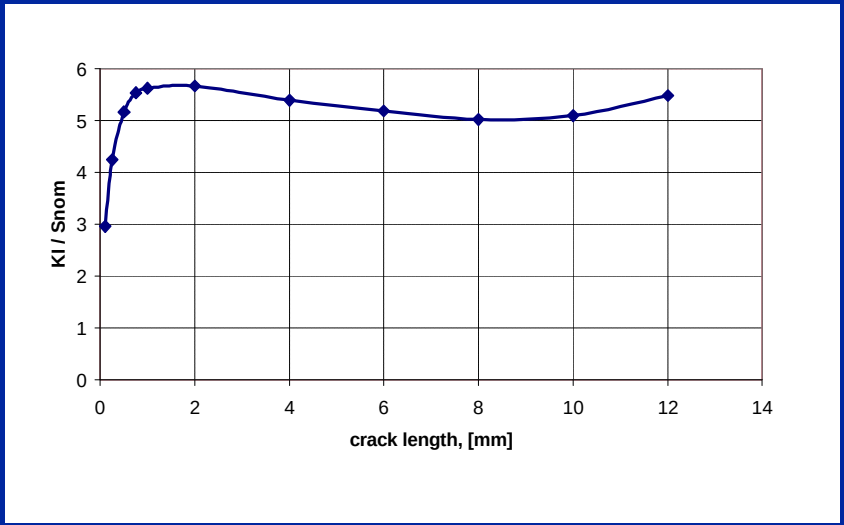
- ***Load sequence:***
  - shear stress from shaft torque
  - calculated with GSP
  - representative mission mix

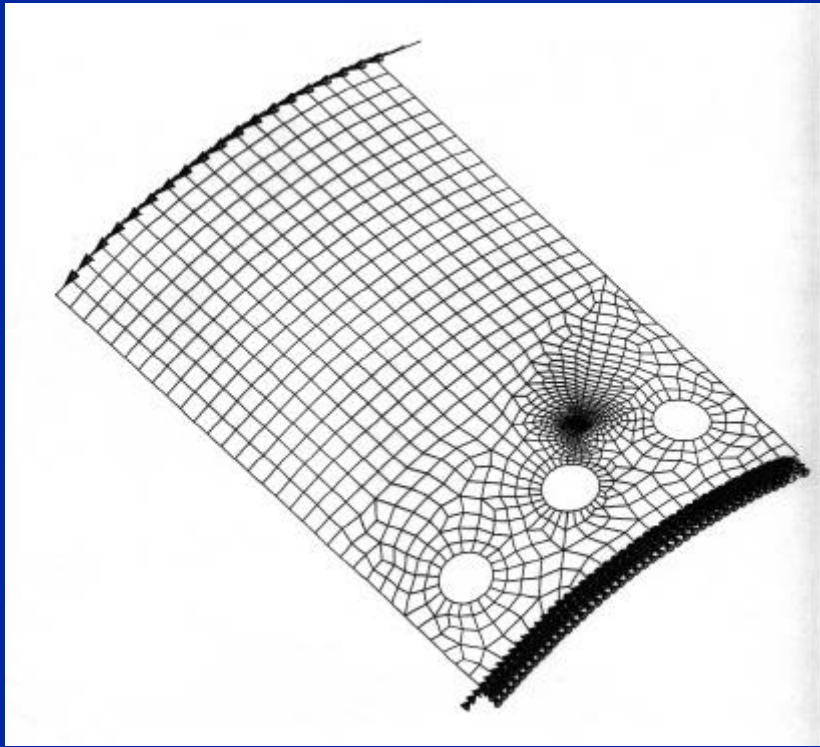
- ***Material properties:***
  - from material handbooks



Crack growth analysis

- **SIF solution:** **FE model:**





- **Initial crack length: 0.254 mm (0.01 inch)**

Conclusions

- Thermal and mechanical loads on a variety of gas turbine components can be calculated with this tool
- The loads can be used as input for (comparative) life predictions

Potential for PHM

- ***'On-condition maintenance'***
  - life consumption tracking of individual components
- ***Optimization of operational use of aircraft***
  - determination of life consumption for different maneuvers