DEVELOPMENT OF LIFE PREDICTIVE METHODS ON NOVALT16 COMBUSTOR WITH SIMPLIFIED PHYSICS BASED MODELS

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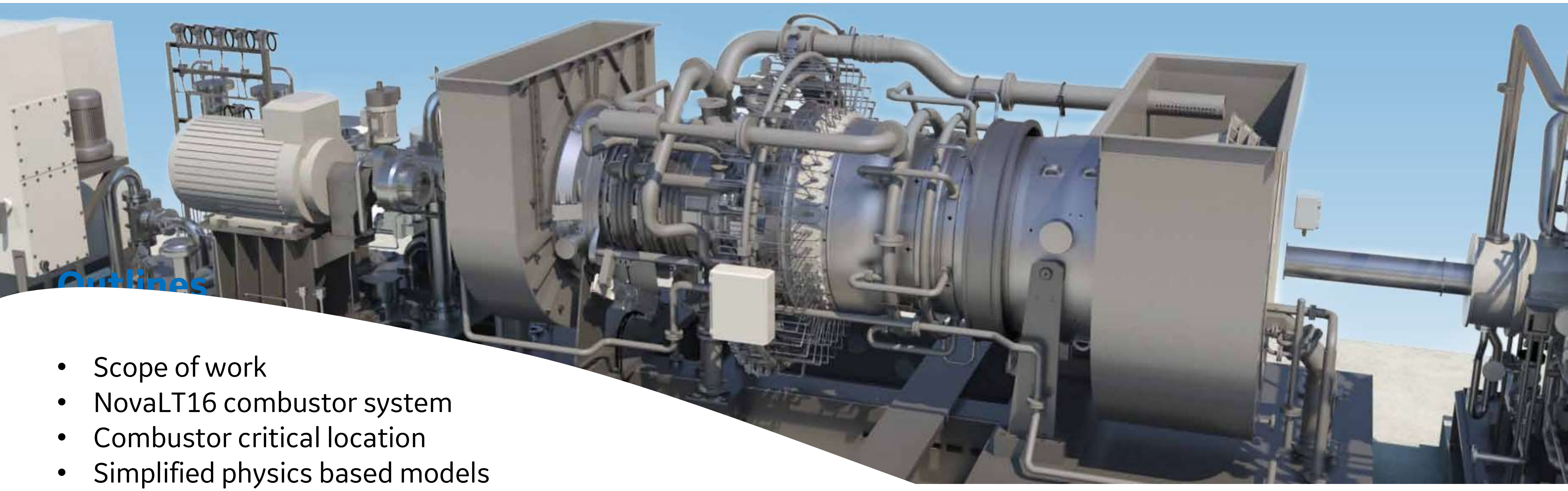

Outlines

- Scope of work
- NovaLT16 combustor system
- Combustor critical location
- Simplified physics based models
- Test results
- Thermal model
- Durability models
- Conclusions

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Scope of work

- To develop a set of simplified physics based models to predict the **durability** of NovaLT16 combustor as a function of **machine operating conditions**
- Use the models to **speed up** product **development phases** (conceptual design, product testing, off design conditions evaluation, GT introductory stage) and/or **RCA's resolution**

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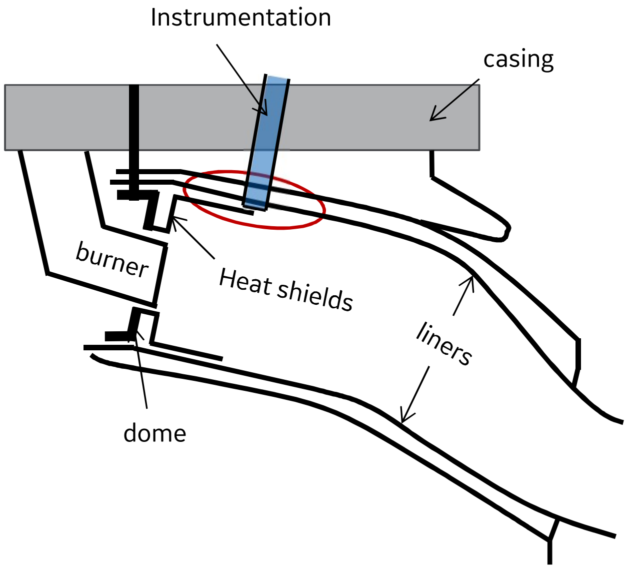
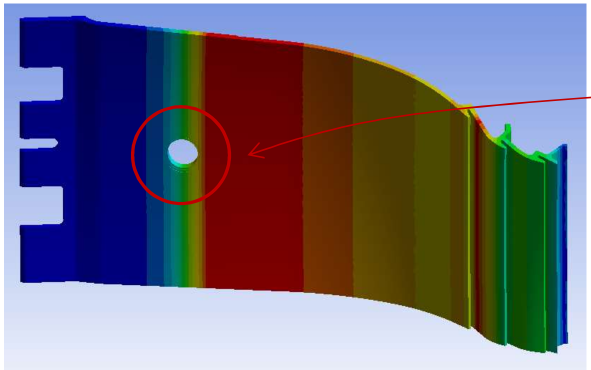
NovaLT16 Combustor system

LT16 combustion chamber

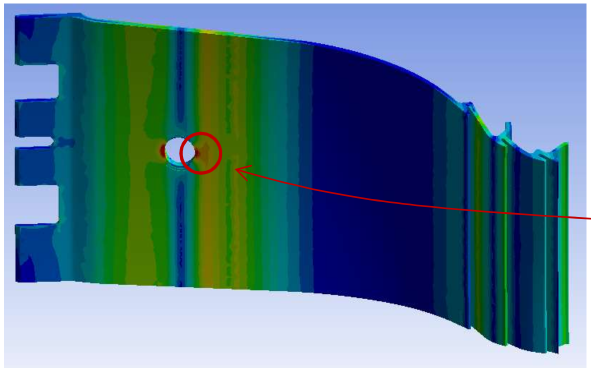


Typical Temperature distribution on Outer liner



High temperature gradient

Typical stress distribution on Outer liner



Outer liner instrumentation hole has minimum life by simulation

How is the durability of the outer liner impacted by the operating conditions of the machine?

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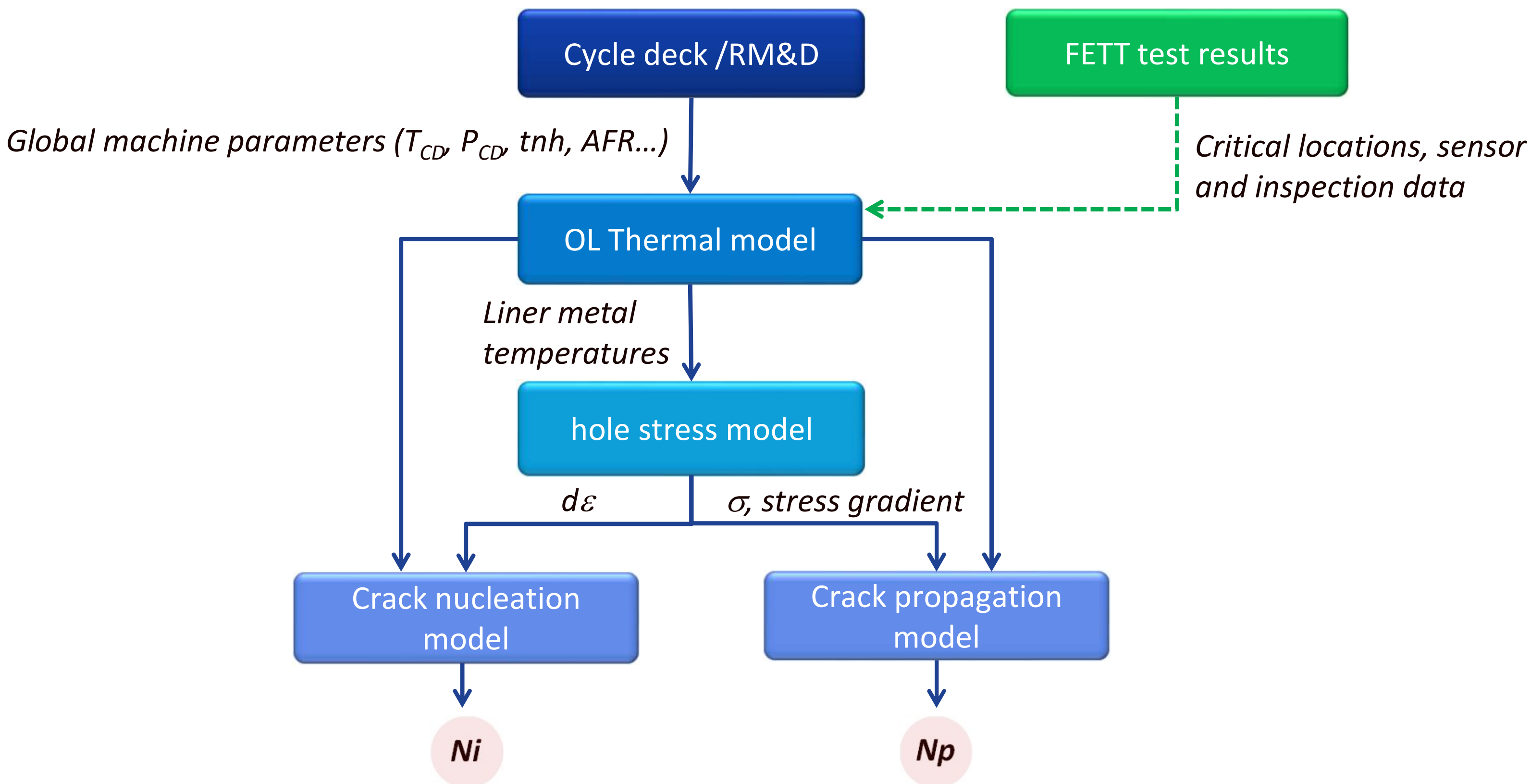
Simplified durability models of outer liner hole

Flow diagram



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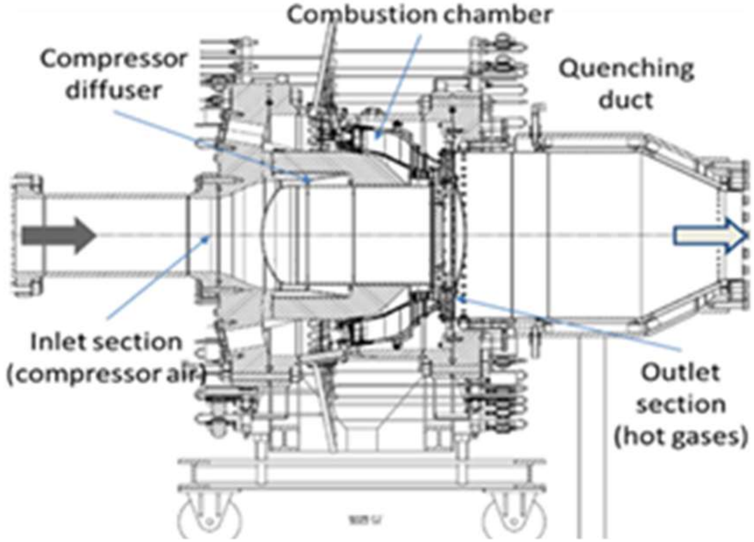
NovaLT16 Test rigs

Extensive test campaigns executed on NovaLT16

- **FAR Test**→ emissions, blow out, flashback



- **Full Engine Test** → mechanical assessment
- **Endurance test** (8000h) → durability assessment

2200 direct measurement points, covering flange-to-flange, package and auxiliaries

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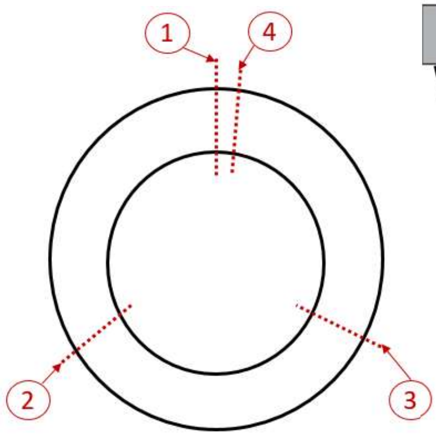
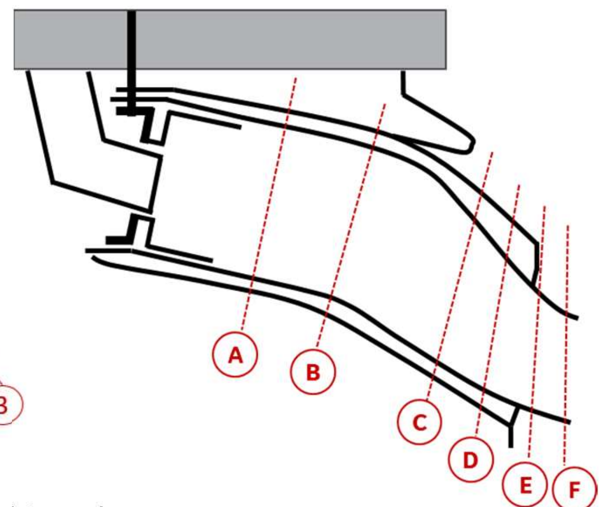
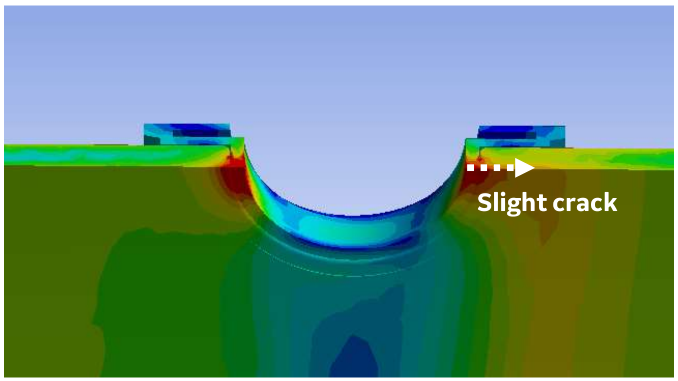
NovaLT16 Test rigs

Combustion chamber instrumentation

- Both inner and outer liner instrumented with 24 thermocouples each
- Thermocouples are installed in 6 axial and 4 circumferential locations and measure metal temperatures of external surfaces







- Robust model validation achieved
- Slight crack occurred in liner instrumentation hole for off design conditions

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Thermal model

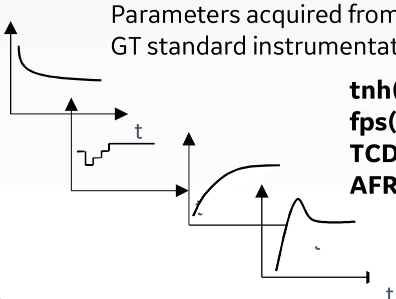
Semi empirical approach – external metal temperature

Model Input

GT on field

Operating Data Acquisition

Parameters acquired from GT standard instrumentation



Model definition

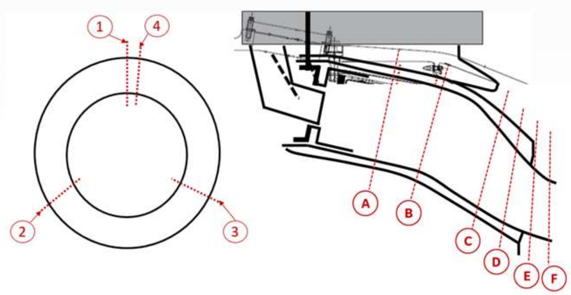
- Axisymmetric model
- Temperature prediction under transient conditions

$$\boldsymbol{Tm_i(t) = k_i \cdot f_1(tnh(t)) \cdot f_2\,(f_{ps}(t)) \cdot \frac{T_{CD}(t)}{T^*_{CD}} \cdot \frac{AFR^*}{AFR(t)}}$$

Where:

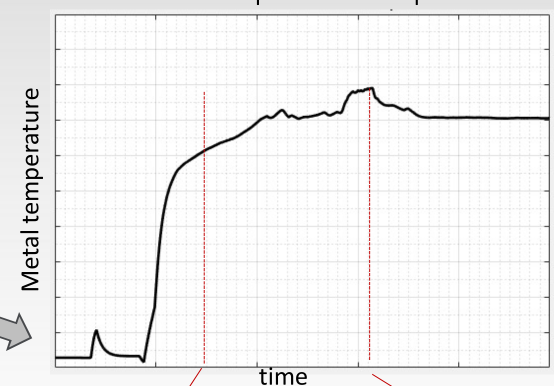
- $f_1\big(tnh(t)\big) = a_i \cdot e^{b_i \cdot (tnh(t) - tnh^*)}$
- $f_2\left(f_{ps}(t)\right) = c_i \cdot (f_{ps}(t) - f_{ps}{}^*) + d_i$
- k_i, a_i, b_i, c_i, d_i: tuning constants for axial location ‘i’

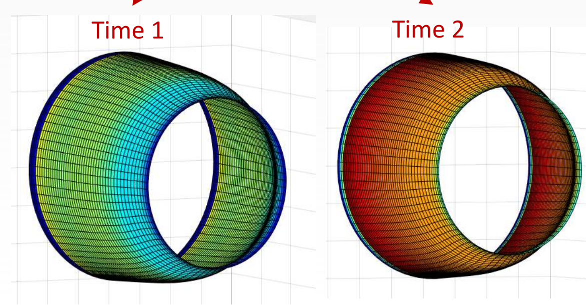
- Computes liner metal temperature in a generic axial location ‘i’ and at the instant ‘t’
- Temperature distribution on liners obtained by cubic interpolation



Model results

Transient metal temperature in a specific axial section





Temperature distribution at specific time instants

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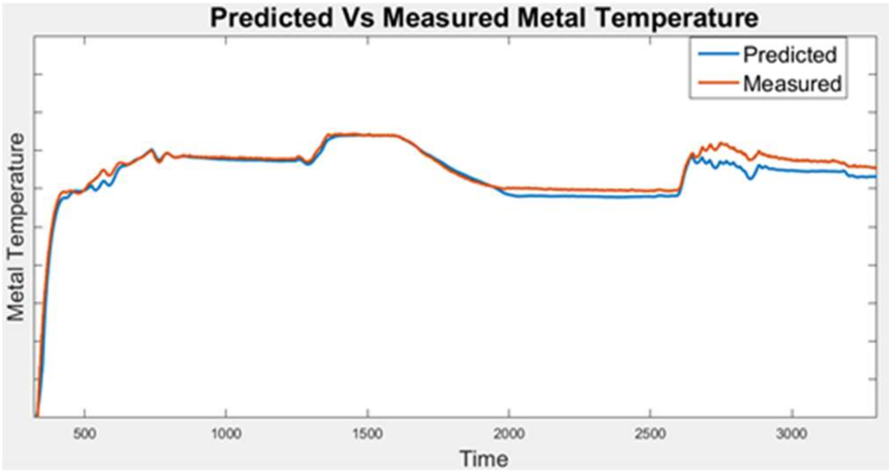
Thermal model

Semi empirical approach – tuning and validation

- Tuning and validation based on combustion chamber metal temperature measurements from engine test performed on FETT in Florence Facility (8000 operating hours accrued)

- Several transient and steady state conditions simulated from engine start-up to full load including:
  - Loading and fast loading
  - Unloading
  - Normal shut down and trip
  - Load steps and load rejections

- Accuracy
  - ± 35°C during transient conditions
  - ± 20°C at steady state conditions



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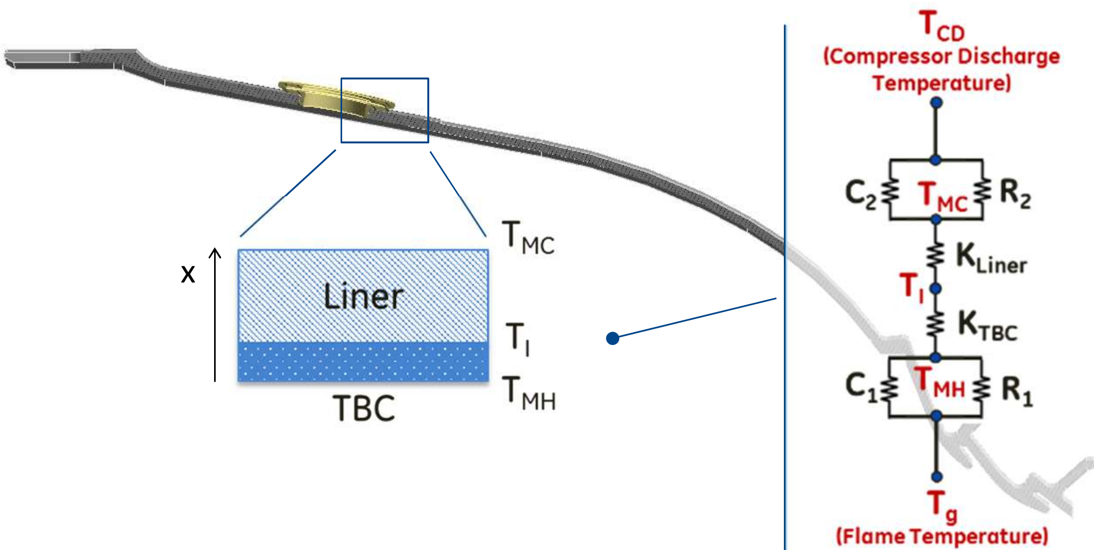
Thermal model

Through thickness conduction – internal metal temperature



- C_1: convection Gas → Liner
- R_1: radiation Gas → Liner
- C_2: convection Liner → Baffle
- R_2: radiation Liner → Baffle
- K_{TBC}: conductivity of TBC
- K_{Liner}: conductivity of liner
- Tg: temperature of hot gas
- T_{CD}: gas temperature of compressor discharge

$$-\frac{\partial}{\partial x} k \frac{\partial T(x,t)}{\partial x} = \rho c \frac{\partial T(x,t)}{\partial t} \rightarrow T_I(t)$$

(ρ = density, k = conductivity, c = specific heat capacity)

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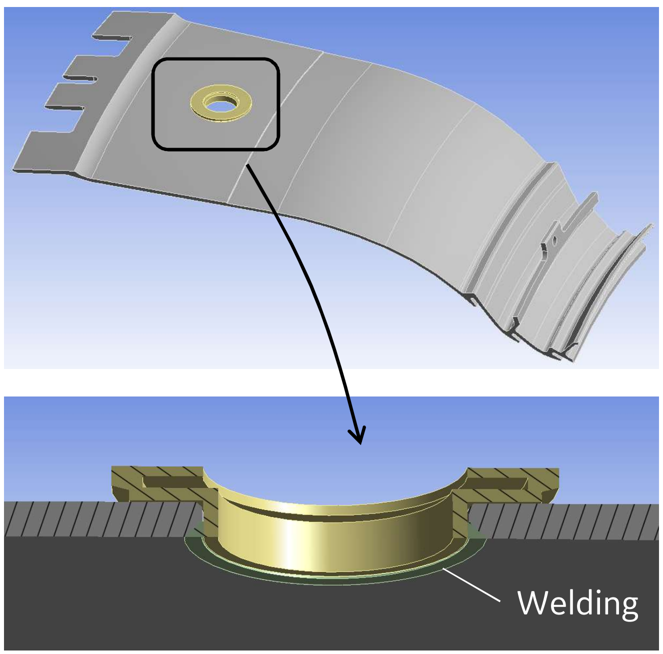
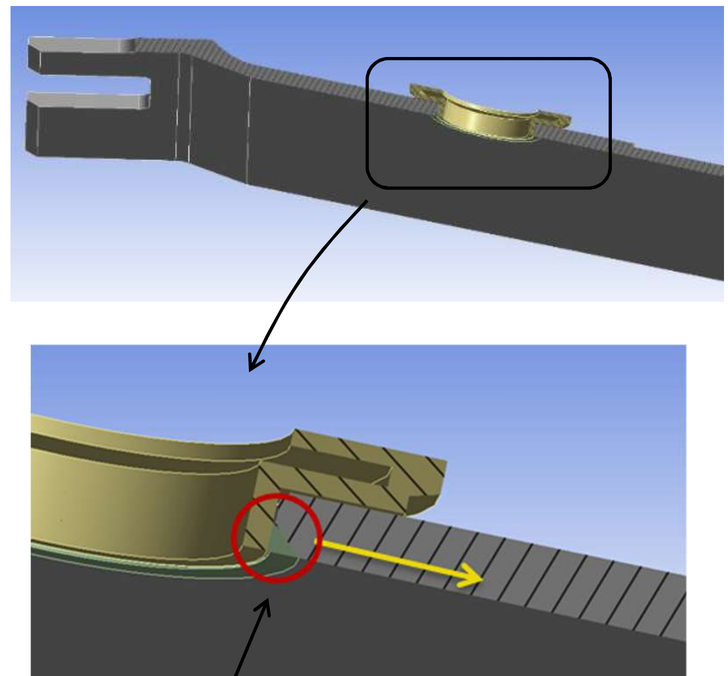
Durability models

FE model → Stress model → LCF model → Crack propagation model



- 20° OL sector
- Ferrule ring explicitly represented
- Welding explicitly represented



Crack nucleated in this region and propagated backwards

LT16 simplified physics based models

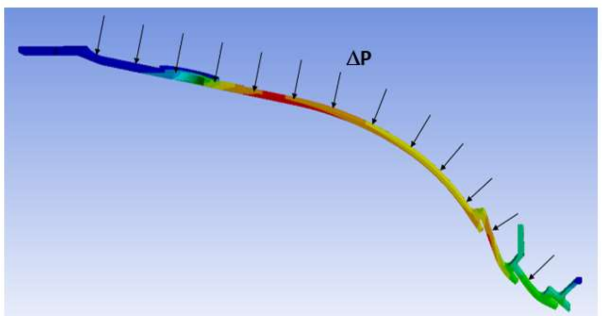
Durability models

FE model → **Stress model** → LCF model → Crack propagation model

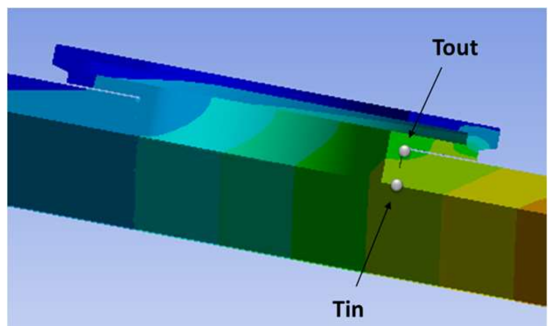
Linear elastic model

Linear elastic stress field solved for the three different external loads separately, in order to capture the effect of any single contribution

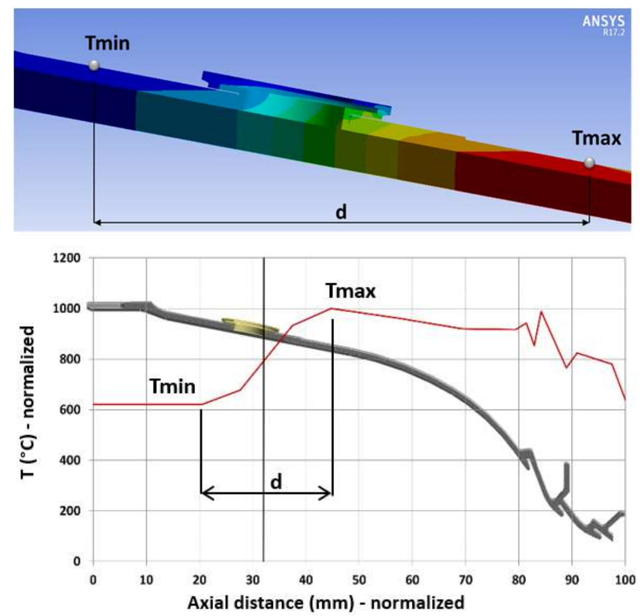
ΔP



Through thickness temperature gradient



In-plane temperature gradient



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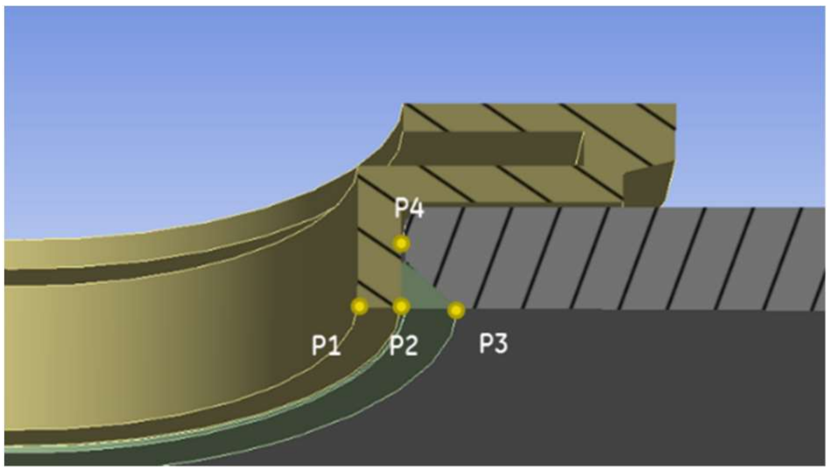
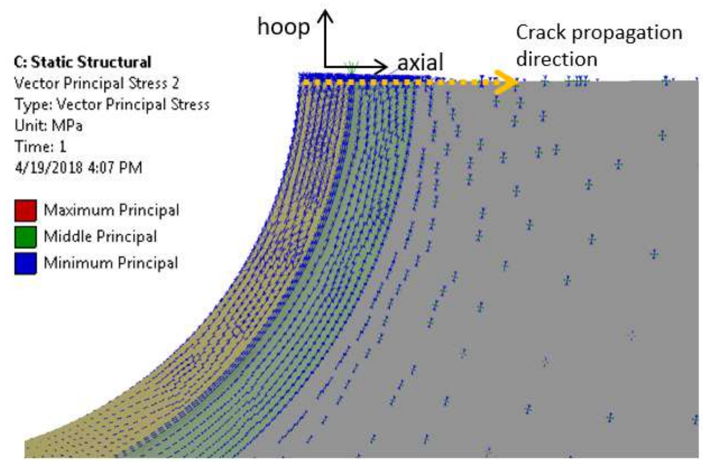
Durability models

FE model → **Stress model** → LCF model → Crack propagation model

Linear elastic model



P1 and P2 most critical from reference structural model



Uniaxial compressive state of stress on P1 and P2

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Durability models

FE model → **Stress model** → LCF model → Crack propagation model

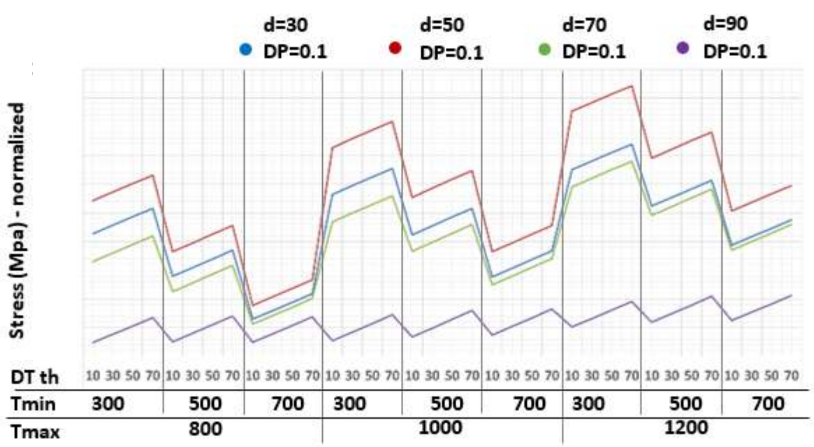
Linear elastic model

$$\sigma 3 = d0\,\Delta P + d1\,\alpha\,E\,(Tin - Tout) + f(Tmin, Tmax, d)$$

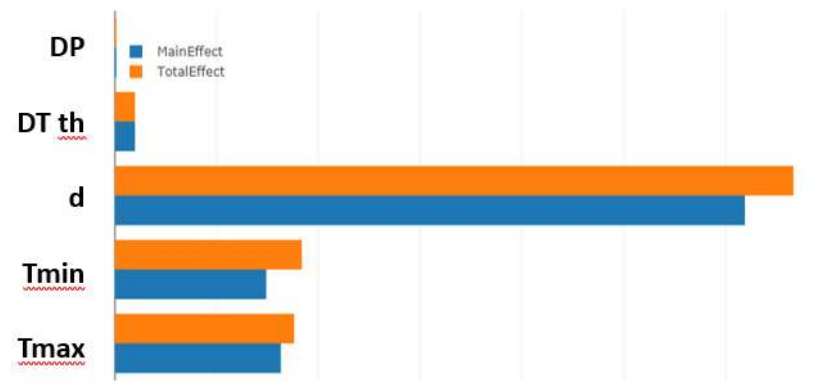
- $d0\,\Delta P$: Delta pressure
- $d1\,\alpha\,E\,(Tin - Tout)$: Through thickness temperature gradient
- $f(Tmin, Tmax, d)$: In-plane temperature gradient

In-plane TF Computed through DOE and BHM

Representation of s3 TF



Pareto of effects



Distance ‘d’ is the major contribution on stress

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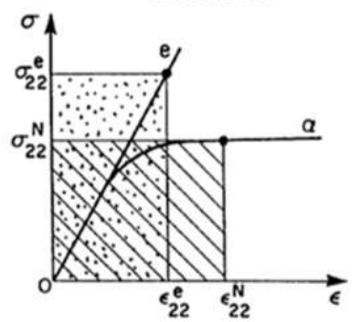
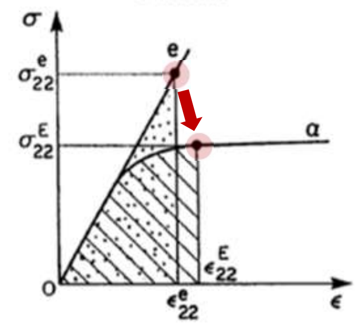
Durability models

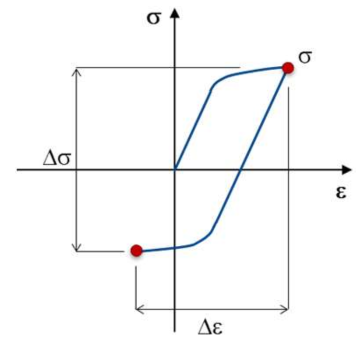
FE model → **Stress model** → LCF model → Crack propagation model

Elastic plastic model

- Elastic stresses are converted into elastic plastic stresses using Glinka method







- elastic plastic stress (σ), the stress range (Δσ) and the strain range (Δε) are computed through the formulas:
  - $\frac{\sigma^2}{E} + \frac{2\sigma}{n+1}\left(\frac{\sigma}{K}\right)^{\frac{1}{n}} = \frac{(K_f S)^2}{E}$
  - $\frac{\Delta\sigma^2}{E} + \frac{4\Delta\sigma}{n+1}\left(\frac{\Delta\sigma}{2K}\right)^{\frac{1}{n}} = \frac{(K_f \Delta S)^2}{E}$
  - $\Delta\varepsilon = \frac{\Delta\sigma}{E} + 2\left(\frac{\Delta\sigma}{2K}\right)^{\frac{1}{n}}$

K_f = fatigue notch factor, S = elastic stress, k, n = Ramberg-Osgood constants

- It has been demonstrated that dε computed with the Glinka method is well aligned with the FE results obtained with a full elastic plastic analysis

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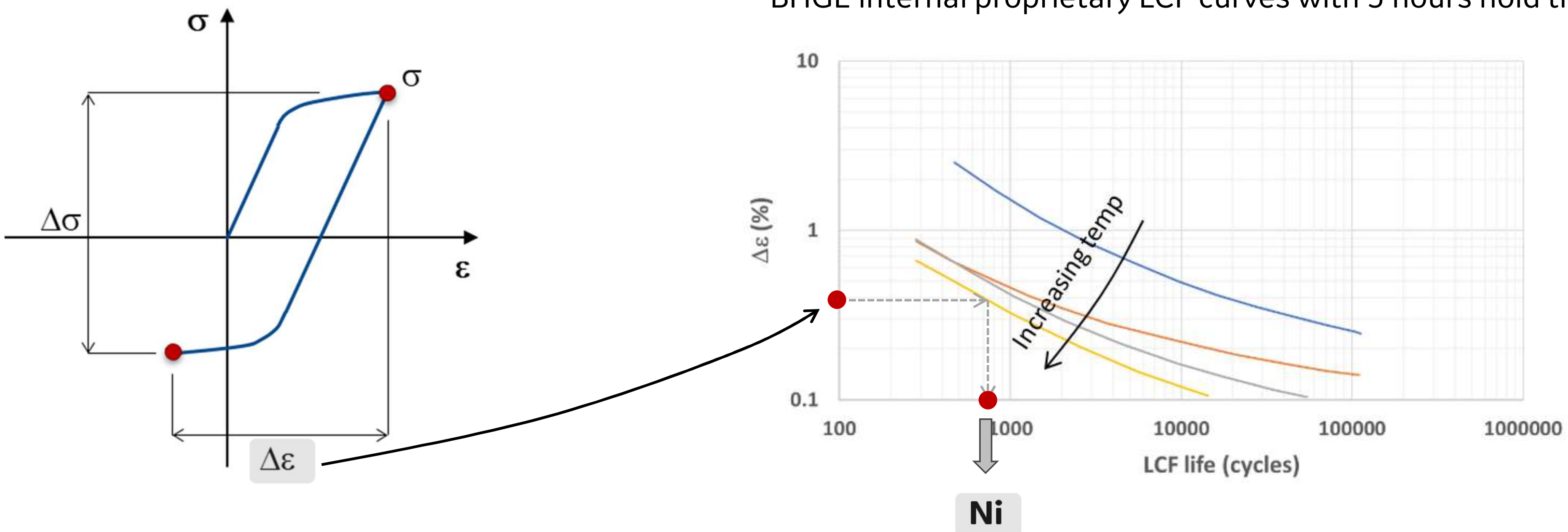
Durability models

FE model → Stress model → **LCF model** → Crack propagation model

Low Cycle Fatigue Model

BHGE internal proprietary LCF curves with 5 hours hold time



Crack initiation life well aligned with test outcomes

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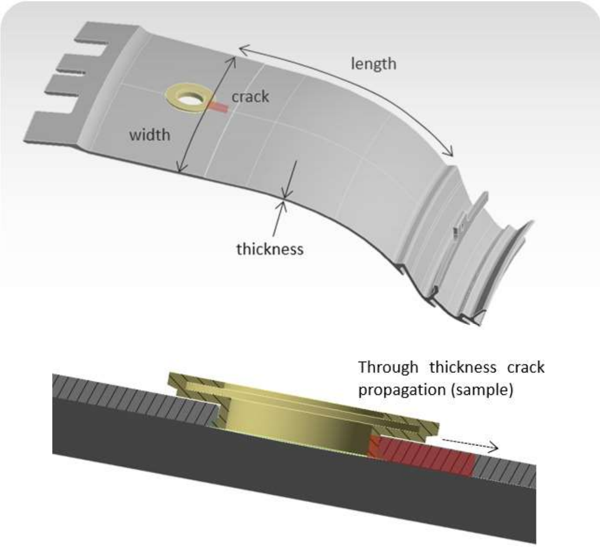
Durability models

FE model → Stress model → LCF model → **Crack propagation model**

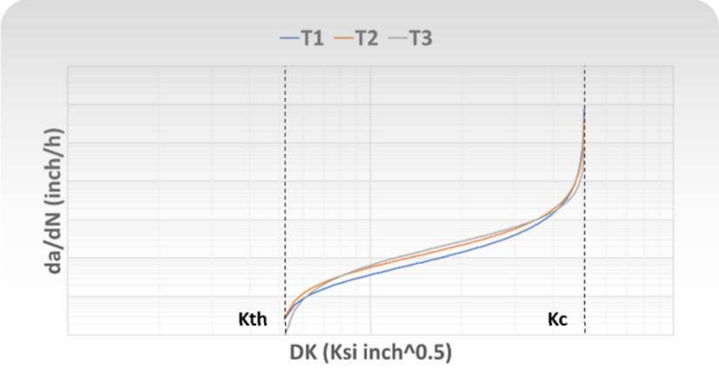
Crack growth analysis

Performed with proprietary BHGE tool → Input are: geometry, material, loading

Geometry

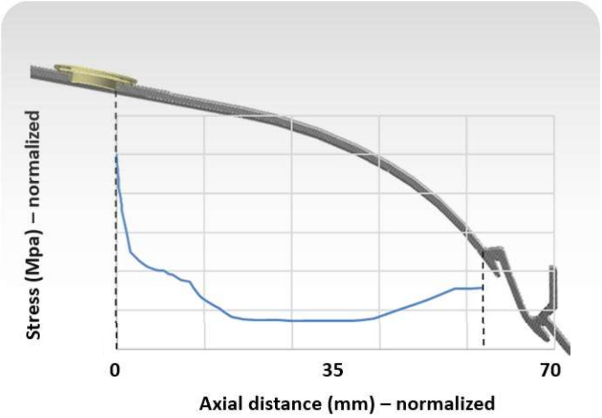


Material



- Paris curves for different temperatures
- Walker correction for mean stress $K_{eff} = \Delta K(1 - R)^{m-1}$

Loading



- Stress gradient along the crack direction
- Input stress gradient at operation and at shut down

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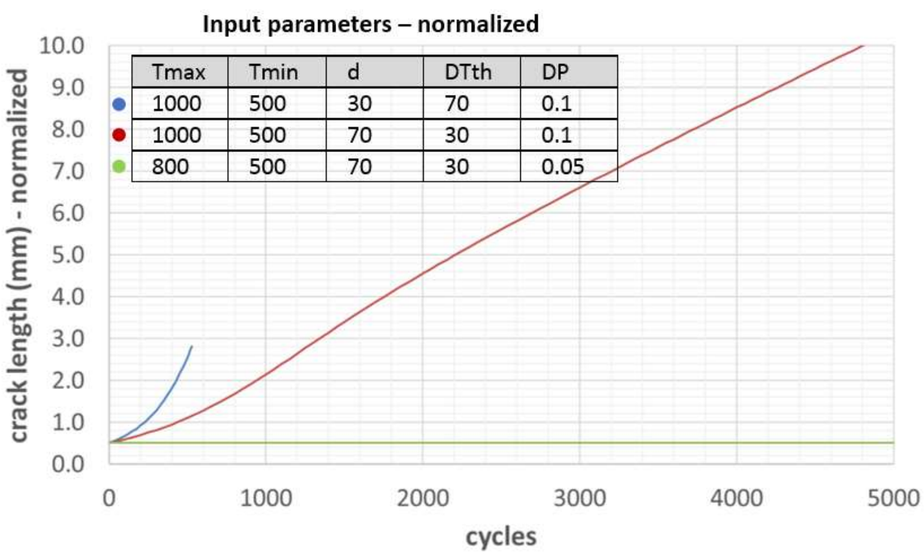
Durability models

FE model → Stress model → LCF model → **Crack propagation model**

Crack growth analysis

- Load driven Crack propagation (conservative)
- Further enhancements on going

Typical crack evolution with number of cycles for different sets of normalized input parameters



Tmax	Tmin	d	DTth	DP
1000	500	30	70	0.1
1000	500	70	30	0.1
800	500	70	30	0.05

In-plane delta temperature and distance Tmax-Tmin have a major impact in the crack propagation rate.

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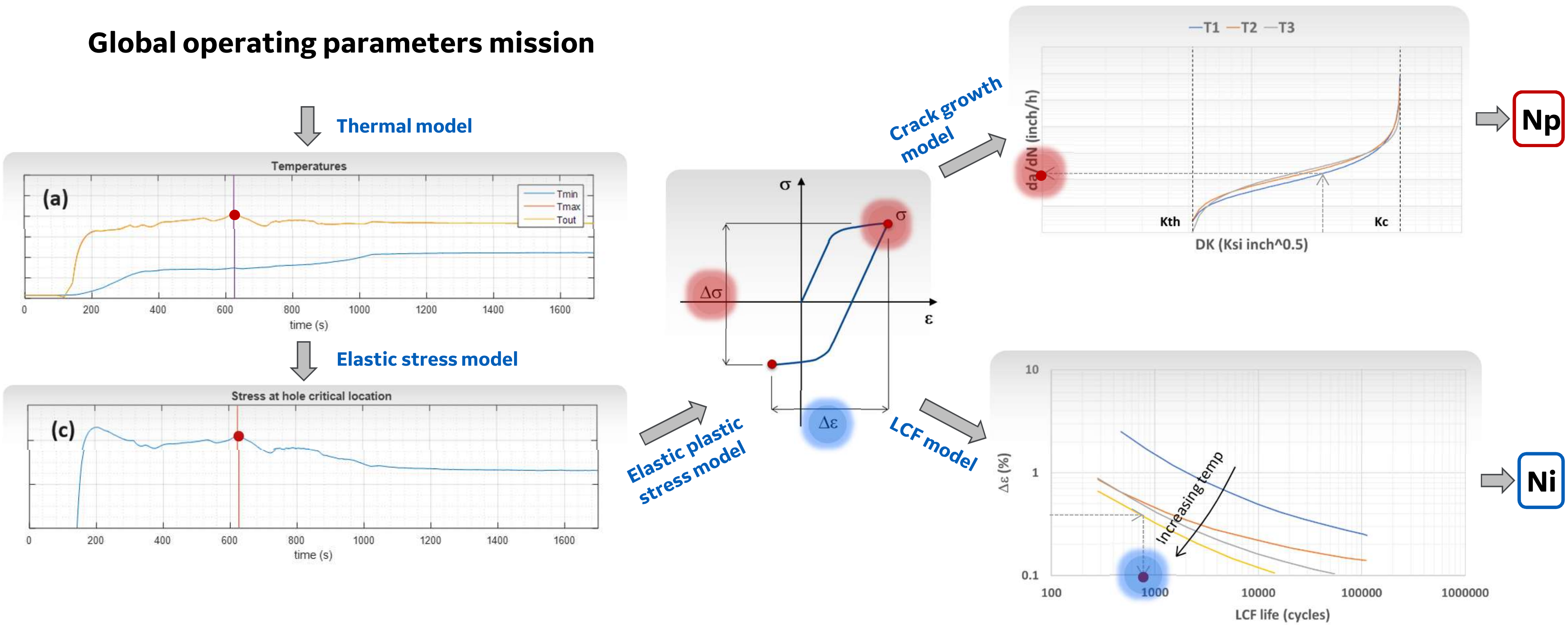
Life computation workflow



The whole life computation process has been automated in Matlab

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Conclusions

- A **simplified physics based model** of the instrumentation hole of NovaLT16 outer liner has been created,
- The model extracts the **global operating parameters** from the GT control system or remote diagnostics and uses them as input to compute the **durability** of the critical outer liner location, for any given GT mission profile,
- All the models connected together and integrated in a **software platform** developed in Matlab, capable of estimating outer liner life in **real time**, given the actual operating mission profile of the machine,
- The approach is easily exportable to other similar physical problems (**paradigm**), due to its inherent **modularity**,
- Analytical brick of NovaLT16 **digital twin**,
- Fields of applicability:
  - Strengthening design process,
  - Supporting GT introductory phase and RCA's,
  - Improving knowledge of the physical assets,
  - Performing predictive maintenance,
- Novel integrated digital framework, able to **respond more promptly** to business and market requests

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Thank you