



3DEXPERIENCE®

# **fe-safe /TURBOLife™**

HIGH TEMPERATURE AND CREEP FATIGUE  
DURABILITY ANALYSIS SOFTWARE FOR  
FINITE ELEMENT MODELS



## INDUSTRY CHALLENGES

Finite Element analysis is used for stress analysis, but this does not answer the most important questions: How long will the component last in service? What design changes are needed to provide optimum durability? How does elevated temperature service reduce durability? What is the cause of failure: creep, fatigue, or creep-fatigue interaction?

## SOLUTION

fe-safe/TURBOLife™, from the SIMULIA brand of Dassault Systèmes, provides the answers. It is a powerful, unique and comprehensive suite of creep-fatigue analysis software. fe-safe/TURBOLife is available as an add-on module to fe-safe, the world's leading technology for durability analysis. It directly interfaces to leading suites of FEA software and is supplied with a material database to which users can add their own material.

fe-safe/TURBOLife creep-fatigue methodologies are based on the Ductility Exhaustion concepts and Strain Range Partitioning which have been developed over the past 30 years in the United Kingdom and the United States. These methods are used extensively throughout the nuclear and fossil fuel power generation industries and are used for new designs and for continuous monitoring applications on power station boilers and gas turbines.

fe-safe/TURBOLife creep-fatigue algorithms have been successfully applied to nuclear power plant components, power station boilers, gas turbine blades and steam turbine components.

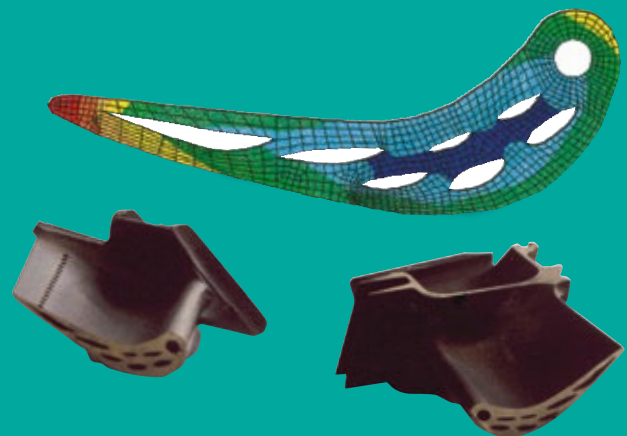
fe-safe/TURBOLife is used increasingly in the powertrain industry where creep and creep fatigue interaction is prevalent, in automotive exhaust components and turbocharger impellers.



# Unique, advanced fatigue analysis solution for creep and creep-fatigue interactions

## Case Study: Gas Turbine Blade

- Complex design including internal cooling channels to limit the maximum operating temperature
- Very conservative design rules are typically used to assess gas turbine blades leading to overdesign and excess use of materials
- Use of actual operating cycles and fe-safe/TURBOLife enabled the user to predict very realistic life, thereby allowing considerable design optimization and life extension



## TECHNOLOGY OVERVIEW

fe-safe/TURBOLife calculates:

- Where fatigue cracks will occur
- When fatigue cracks will occur
- How creep mechanisms will influence fatigue life
- The factors of safety on working stresses - for rapid optimization
- The endurance of components in high temperature environments where fatigue damage mechanisms and creep damage mechanisms interact to significantly reduce component life

fe-safe/TURBOLife identifies whether fatigue and/or creep are the dominant damaging mechanisms, thus allowing re-design to focus on the relevant damage mechanisms and significantly reduce pre-service component testing.

fe-safe/TURBOLife works from elastic Finite Element analysis and easily available material data to construct complex, stress-strain hysteresis loops including stress relaxation due to creep. In this way, component specific operating histories and the order of cycling are comprehensively accounted for.



## KEY BENEFITS

- Easy to learn and easy to use
- Uses easily available material data
- Supported by highly experienced fatigue and assessment engineers and extensive material testing laboratories at Amec Foster Wheeler

With fe-safe/TURBOLife as an integrated part of your design process, you have the ability to:

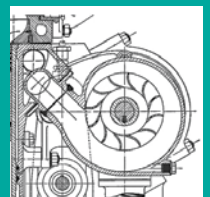
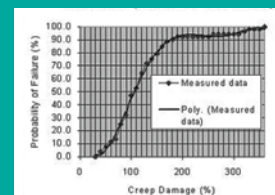
- Optimize designs to use less material
- Reduce product recalls and warranty costs
- Optimize and validate design and test programs
- Improve correlation between test and analysis within a single user interface
- Reduce prototype test times
- Speed up analysis times, thereby reducing man-time
- Increase confidence that your product designs pass their test schedules as "right first time"
- Reduce reliance on physical testing



**Determines whether fatigue and/or creep are the dominant damage mechanisms, allowing re-design to focus on the most relevant mechanism**

## Case Study: Compressor Wheel

- Aluminum alloy compressor wheels often fail by casing rubbing due to creep dilation at elevated temperatures, or by cracking due to the accumulation of cyclic creep-fatigue damage
- The ultimate failure mechanism was determined by destructive testing under variable load creep conditions
- Analysis of the test conditions using fe-safe/TURBOLife established that the probability of creep-fatigue failure was very low, and that the calculated creep dilation correlated well with measurements
- Creep dilation rather than creep-fatigue cycling was confirmed as the cause of failure by fe-safe/TURBOLife, allowing the designer to focus on the most effective method of extending the life of the compressor wheel



Cumulative probability of failure determined from stress data for a compressor wheel aluminum alloy



## KEY FEATURES

- Calculates the endurance of components in high temperature environments where fatigue damage mechanisms and creep damage mechanisms interact to significantly reduce component life
- Works from elastic Finite Element analysis and easily available material data to construct complex, stress-strain hysteresis loops including stress relaxation due to creep. In this way, component specific operating histories and the order of cycling are comprehensively accounted for
- Identifies whether fatigue and/or creep are the dominant damaging mechanisms, thus allowing re-design to focus on the relevant damage mechanisms and significantly reduce pre-service component testing
- Provides comprehensive graphical output in terms of life contours and stress safety factors enabling critical areas to be easily identified
- Includes comprehensive on-line help and information on material data preparation
- Direct interfaces to leading FEA suites such as Abaqus, ANSYS, I-deas and Nastran (MSC, NEi, NX) are driven from an intuitive, single screen, Windows®-based GUI

### Component loading

- Time histories of stresses and temperatures calculated in an elastic FE analysis

### Stress-strain modeling

- Transition from monotonic to cyclic behavior
- Multiaxial plastic relaxation rules to estimate the actual stress and strain from the elastic stress
- Creep material data enhanced using the Larson-Miller parameter for interpolation and logarithmic extrapolation

### Damage calculation

- Thermo-mechanical fatigue damage, creep damage through Ductility Exhaustion, and fatigue-creep interaction
- Thermo-mechanical fatigue damage and fatigue-creep damage interaction based on Strain Range Partitioning
- Inelastic Strain Range Partitioning of the strain cycle and computation of plastic-plastic (PP), creep-plastic (CP), plastic-creep (PC), and creep-creep (CC) damage
- Damage for each individual cycle, including damage for uncompleted cycles
- Advanced treatment of multiaxial stresses

### Output

- Fatigue life and creep life contour plots for the component
- Contours of PP, CP, PC or CC type damage
- Creep damage and fatigue damage for the entire loading history is cross-plotted as a damage trajectory on the creep-fatigue damage envelope to indicate creep-fatigue interaction effects
- Stress ranges and strain ranges of complete cycles and part-cycles for selected locations
- Cumulative creep damage, cumulative fatigue damage, cumulative creep strain, instantaneous stress, instantaneous strain, instantaneous creep strain rate, plotted as a function of time for selected locations

**“fe-safe/TURBOLife helps to reduce overall development costs and timescales”**

## Case Study: Exhaust Manifold

- Jaguar has implemented a Virtual Design Validation (VDV) system using fe-safe/TURBOLife to enable rapid development and deployment of high temperature components
- fe-safe/TURBOLife plays a key role in accurately determining performance at the design stage, minimizing both component and material testing iterations
- fe-safe/TURBOLife helps to reduce overall development costs and timescales as well as providing insight into identifying lower cost materials for production



Typical exhaust manifold thermocouple positioning



Temperature prediction correlation at thermocouple locations

–Jaguar Land Rover

## CAPABILITIES OVERVIEW

### Assessment point

- Calculations are performed for a single assessment point on a component or for the whole model

### Material data

- For a range of temperatures: Young's modulus, Poisson's ratio, monotonic stress-strain curve and cyclic stress-strain curve
- The damage required to progress fully from the monotonic stress-strain curve to the cyclic stress-strain curve is specified as a percentage of damage
- For a range of temperatures: creep deformation behavior in terms of creep strain, time and temperature

#### Ductility Exhaustion:

- For a range of temperatures: the fatigue endurance in terms of strain-range
- A range of temperatures: creep rupture ductility versus creep strain rate including the two values of the upper and lower creep ductility plateaus
- The creep-fatigue damage envelope in terms of the creep damage: fatigue damage coordinates which define the onset of cracking

#### Strain Range Partitioning:

- Endurance curves under PP, CP, PC and CC loadings

### Material data processing

- Young's modulus, Poisson's ratio, monotonic stress-strain curve, cyclic stress-strain curve and creep ductility are linearly interpolated between data sets supplied at different temperatures to obtain the data for the assessment temperature
- Creep data is enhanced to cover the problem range using the Larson-Miller parameter for interpolation and logarithmic extrapolation

### Plastic relaxation

- The monotonic and cyclic stress-plastic strain data are fitted to equations of the Ramberg-Osgood form and these equations are used for plasticity calculations
- Plastic relaxation rules (Neuber, Glinka or  $-E'$ ) are employed to estimate the actual stress and strain from the elastic stress and strain

### Creep relaxation

- The creep deformation data is fitted to polynomial equations and these equations are used for the creep calculations
- Forward creep, creep relaxation or any creep behavior between these two extremes is accommodated through the use of the elastic follow-up factor  $Z$ , the value of which is specified by the user
- The creep strain and creep strain rate for all time increments are calculated by the software

### Cycle recognition

- From the elastic stress history and the nominated plastic relaxation rule, the elastic-plastic stress history is derived
- Creep strain effects are added to the elastic-plastic stress history to produce the stress and total strain histories
- The individual stress-strain hysteresis loops are identified as fatigue cycles

- Complete cycles and unmatched half cycles are individually identified
- Cycle identification is performed as the stress and total strain histories are derived - no post processing of the histories is required

### Damage calculation

#### Ductility Exhaustion:

- The fatigue damage is calculated for each individual cycle on the basis of the total strain range for that cycle
- Fatigue damage for unmatched half cycles is calculated as half the damage of the equivalent complete cycle
- The creep ductility data is fitted to polynomial equations - these equations are used in the creep damage calculations
- Creep damage for each time increment is calculated as the creep strain increment divided by the creep ductility as a function of creep strain rate

#### Strain Range Partitioning:

- Each individual cycle is partitioned into four possible types of strain (PP, CP, PC or CC)
- Damage from each strain increment is calculated based on the corresponding strain-life curve
- Total damage is the summation of the individual damage components

### Output

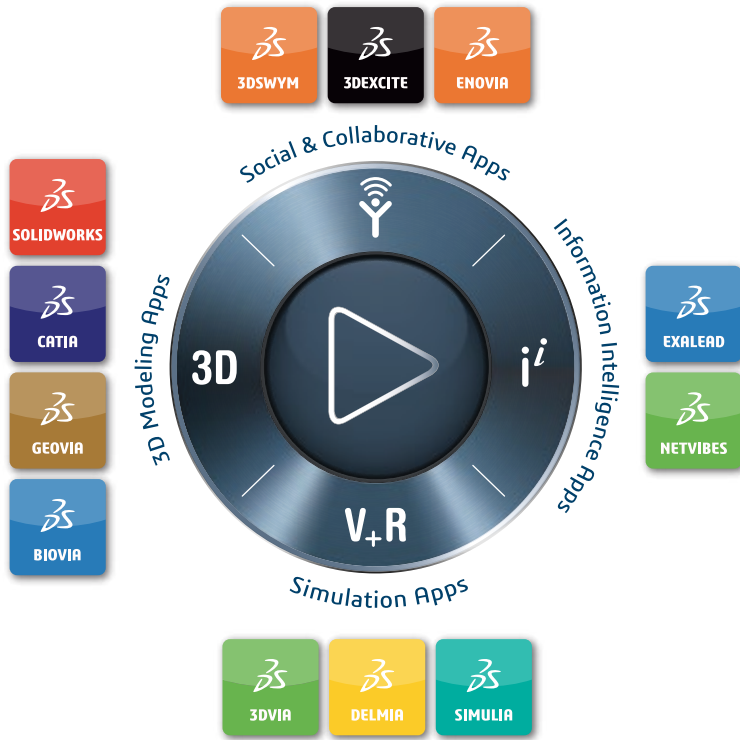
- Fatigue lives at each node or element (3D contour plot)
- Contours of PP, CP, PC or CC type damage
- Stress safety factor at each node or element to achieve the design life (3D contour plot)
- Probability of failure or survival at specified lives (3D contour plot)
- Load sensitivity shows the effect of each load history on the total fatigue damage
- Stress histories, cycle histograms, biaxiality, critical plane orientation, Haigh diagrams, fatigue reliability factors etc, for the whole model or selected elements
- A list of the most damaged elements is saved - re-analysis can concentrate on these elements if required
- A text file of user inputs, analysis type and a results summary is produced for QA trace-back

### Conventional fatigue analysis

fe-safe/TURBOLife also includes all the standard fe-safe features for conventional fatigue analysis, including:

- Advanced multiaxial fatigue analysis with automatic algorithm selection
- Analysis of complex assemblies in a single operation
- Analysis of complex multi-directional loading
- Probability of failure and warranty claim curves
- Stress-based factors of strength for a specified design life
- Comprehensive signal processing for measured loading histories
- Easy-to-use Windows® style GUI
- Macro recording and batch processing
- Parallel and distributed processing

*This is not a complete list of features in fe-safe/TURBOLife.*



**Our 3DEXPERIENCE® platform powers our brand applications, serving 12 industries, and provides a rich portfolio of industry solution experiences.**

Dassault Systèmes, the 3DEXPERIENCE® Company, provides business and people with virtual universes to imagine sustainable innovations. Its world-leading solutions transform the way products are designed, produced, and supported. Dassault Systèmes' collaborative solutions foster social innovation, expanding possibilities for the virtual world to improve the real world. The group brings value to over 190,000 customers of all sizes in all industries in more than 140 countries. For more information, visit [www.3ds.com](http://www.3ds.com).

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