SIMULIA

Authorized fe-safe® Reseller

fe-safe®

Durability Analysis Software for Finite Element Models

Overview

Safe Technology is the technical leader in the design and development of durability analysis software and is dedicated to meeting its customers' most demanding applications. It develops and sells fe-safe®, the leading fatigue analysis software suite for Finite Element models.

As a privately owned company, its independence and focus enables Safe Technology to continually bring the most accurate and advanced fatigue analysis technology to real-world, industrial applications.

fe-safe® is used by leading companies in automotive, heavy truck, off-highway, marine, defense, offshore, power generation, wind energy, medical engineering and many other industries.

fe-safe® has been developed continuously since the early 1990's in collaboration with industry to ensure that it continues to set the benchmark for fatigue analysis software.

fe-safe® was the first commercially available fatigue analysis software to focus on modern multiaxial strain based fatigue methods.

fe-safe® provides unique capabilities for thermo-mechanical fatigue and creep-fatigue, the fatigue analysis of composite materials and the Verity® Structural Stress Method for welded joints.

fe-safe® is renowned for its accuracy, speed, comprehensive capabilities and ease of use.

Regardless of the complexity of your fatigue analysis, fe-safe® fits smoothly into your design process, enabling you to develop products that are designed for durability.

Introduction

Industry is putting increasing pressure on manufacturers to use less material to deliver lightweight but stronger components, lower warranty and recall costs and all in less time.

Modern technologies are available to meet these tough demands.

Many companies use advanced Finite Element Analysis to calculate design stresses, but the fatigue analysis is often still done by manually picking stress points for spread-sheet analysis. This is time-consuming and unreliable because it is easy to miss failure locations.

Component validation by fatigue testing a prototype design in the test lab is time-consuming. If the prototype fails prematurely, a costly, open-ended cycle of design-test-redesign may be required. Project time-scales slip and delivery is late.

Key benefits

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

- optimise designs to use less material
- reduce product recalls and warranty costs
- optimise and validate design and test programmes
- improve correlation between test and analysis within a single user interface
- reduce prototype test times
- speed up analysis times, thereby reducing man-time hours
- increase confidence that your product designs pass their test schedules as "right first time"

Key questions

fe-safe® helps you answer these questions:

What is the fatigue life of this component?

fe-safe® uses advanced critical plane multiaxial fatigue with in-built plasticity modelling to post-process results from an elastic FEA. Results can be displayed as contour plots showing crack locations and fatigue lives.

Will cracks propagate?

fe-safe® uses critical distance methods to check whether cracks will propagate. Allowing cracks to initiate but not propagate to failure may allow higher working stresses and lighter and more efficient designs.

Where can material be saved? Where must extra material be added?

fe-safe® calculates the allowable stresses or loads to achieve a specified service life. This is the factor of strength (FOS).

fe-safe® fully accounts for any changes in plasticity that may be caused by changes to loads or stresses.

fe-safe® shows how much the design is over-strength or under-strength at each node. Results are displayed as contour plots.

How reliable is this design?

The 'warranty claim' calculation combines variability in material strength and variability in loading to estimate the proportion of components un-cracked after any period of time in service. This can be used to achieve uniform reliability over different parts of an assembly.

Factor of Strength (FOS) and Probability of Survival calculations can be combined with the initial fatigue life calculation in a single run. Together they show the interaction between design stress margins and component reliability.

Which loads are causing fatigue damage?

fe-safe® performs a load sensitivity analysis to show the effect of each applied load. This can be used to refine the design and to design and validate an accelerated fatigue test.

Once the critical and non-critical loads have been identified, test programmes can be optimised and validated by removing unrepresentative tests.

What is causing fatigue cracking?

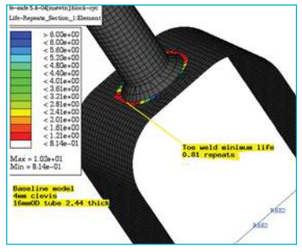
fe-safe® can provide detailed results for hot-spot areas or individual elements or nodes, time histories of calculated stresses and strains, fatigue cycle and damage histograms, Haigh and Smith plots and many other graphs to explain why the fatigue life is what it is.

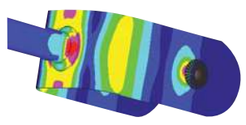
Case Study

Weld fatigue analysis of a prototype rear trailing arm link

Test results to crack initiation: 0.83 repeats of block cycle test
fe-safe® fatigue life prediction to crack initiation: 0.81 repeats

Ford Motor Company





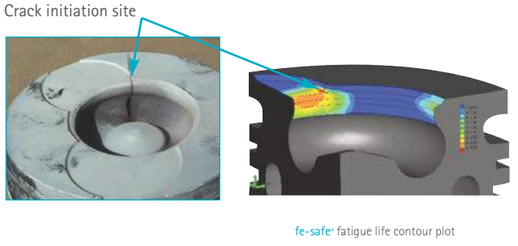
fe-safe® fatigue life contour plots

Case Study

Fatigue cracking of a diesel piston

"fe-safe® accurately predicted the location and time to crack initiation"

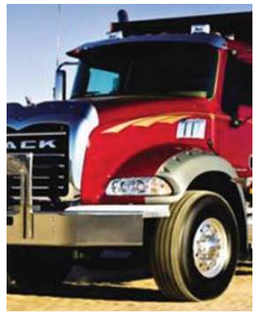
Federal Mogul Technology, USA



fe-safe® fatigue life contour plot

Durability by design - advanced multiaxial algorithms are the core of fe-safe®

Different parts of an assembly may need different design stress margins to achieve the same level of reliability



fe-safe Durability Analysis Software for Finite Element Models

Workflow

Loadings

fe-safe® can predict fatigue lives from a range of loading types:

- Single load time history applied to a linear elastic Finite Element model
- Multiple time histories of loading superimposed in fe-safe® (more than 4000 load histories can be applied)
- Sequence of FEA stresses (elastic or elastic-plastic, linear or non-linear)
- Superimposition of steady state modal solutions
- Superimposition of transient dynamic modal solutions
- PSD loading, block loading test programmes, rainflow cycle matrices
- Effects of forming or assembly stresses can be included

fe-safe® includes a powerful, simple-to-use batch command system, with on-line parametric variation for 'sensitivity' studies.

Standard analyses can be set up and saved for re-use.

Analysis methods

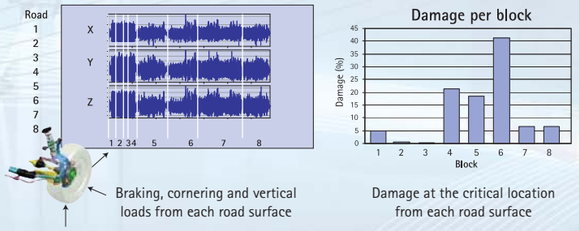
fe-safe® includes a wide range of analysis methods, all of which are included in the standard package:

- Strain-based multiaxial fatigue algorithms - axial strain, shear strain, Brown-Miller with a multiaxial Neuber's rule and cyclic plasticity model
- S-N curve analysis including multiaxial fatigue using axial stress or a new Brown-Miller analysis formulated for use with S-N curves
- Dang Van multiaxial fatigue for high cycle design
- Plots of material data including the effect of temperature, strain rate etc.
- Advanced analysis methods for fatigue of cast irons
- Analysis of welded joints
- High temperature fatigue
- Analysis from elastic and elastic-plastic FEA stresses, linear and non-linear analysis
- Automatic detection of surfaces
- Automatic detection of fatigue hot-spots
- Comprehensive element/node group management
- Stress gradient corrections
- Critical distance algorithms

Output

fe-safe® outputs a wide range of results, in a single run:

- Contours of fatigue life show crack initiation site
- Contours of stress-based factors of strength for a specified design life – to show how much the stresses must be changed to prevent failure or to reduce material
- Probability of survival for specified lives (the 'warranty curve')
- Which loads need to be included in a test programme
- Contour plots of maximum stress during loading
- Detailed results – time histories of stresses and strain, Haigh and Smith diagrams, Dang Van plots and many more in order to explain the rationale behind the life prediction
- Damage at the critical location from each loading block – for example each road surface on a test track
- Vector plots identifying critical damage planes

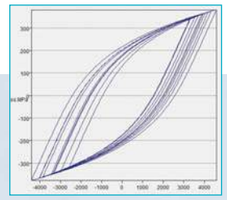


Braking, cornering and vertical loads from each road surface

Damage at the critical location from each road surface

Material database

- Comprehensive material database of strain-life and S-N curve properties – may be extended by the user
- Material approximation algorithm
- AFS database of strain-life fatigue properties for cast iron
- Materials data support services



Testing services

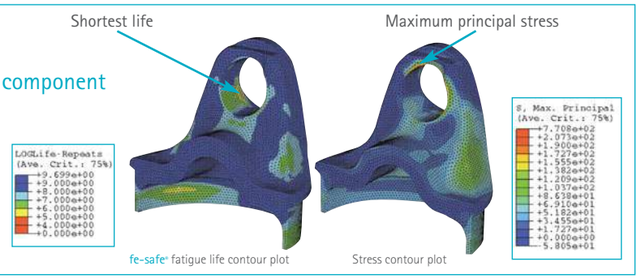
Safe Technology supports its software - multiaxial fatigue, thermo-mechanical and creep-fatigue, welded joints and composites - with a wide range of testing services. Material testing includes both S-N and strain-life tests under different loading and temperature regimes. Test results are analysed and provided in reports and in formats that allow users to add material data to the fe-safe® material database.

Case Study

Fatigue analysis of a tube yoke suspension component

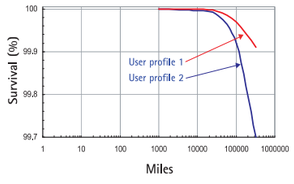
"fe-safe® results were confirmed by lab tests on actual loaded specimens"

Dana Automotive Systems Group, LLC



fe-safe® fatigue life contour plot

Stress contour plot



Estimated 'warranty curve' for two user profiles, combines material variability and load variability

Vector plot identifying the orientation of critical damage planes

"fe-safe® results were confirmed by lab tests"
Raufoss Technology

fe-safe® fatigue life contour plot

Cracks may not occur at the locations of maximum stress

Critical plane multiaxial stress-life & strain-life methods are included as standard

fe-safe® Durability Analysis Software for Finite Element Models

Key features

- Calculates fatigue lives at every point on a model, producing contour plots to reveal fatigue lives and crack sites. Critical locations will not be missed
- Determines how much the stresses must be changed in order to achieve a target design life, showing clearly where the component is under strength or where material and weight can be saved
- Estimates warranty claim curves based on probabilities of failure
- Identifies which parts of a duty cycle are most damaging. In prototype testing this could mean shorter tests with fewer actuators
- Manufacturing effects such as residual stresses from a stamped or formed part, or the material variation effects in castings and forgings can be included
- Automatic detection of contact using contact fatigue algorithms
- No special meshing is required. fe-safe® works from a standard free tet mesh. Solid and shell elements can be combined on the same model
- Unique calculation of the fatigue life of welded joints using the Verity® Structural Stress Method
- Unique calculation of composite materials using the physics-based Multi-Continuum Technology (MCT) methods available in fe-safe/Composites®

FAST

- Assemblies of different parts, surface finishes and materials can be analysed in a single run - fe-safe® automatically changes the method of analysis as it moves from one material to another. Contour plots showing the fatigue life at each node, the factor of strength, and probabilities of survival can all be calculated in the same run
- Highly efficient coding plus parallel and distributed processing allow fe-safe® to analyse large FE models and report results quickly

ACCURATE

- Advanced multiaxial algorithms are the core of fe-safe®
- Unique nodal elimination methods ensure no trade-off between speed and accuracy
- Users consistently report excellent correlation with test results. Continuous development ensures fe-safe® maintains its position as the technology leader

EASY TO USE

- fe-safe® has many default settings and automatically selects the most appropriate algorithm based on the selected material
- Standard analyses can be saved making it ideal for the non-specialist fatigue analyst
- fe-safe® is highly configurable for the advanced user
- Direct interfaces to leading FEA suites such as Abaqus, ANSYS, I-deas, Nastran (MSC, NEi, NX) and Pro/Mechanica are driven from an intuitive, single screen, Windows-based GUI

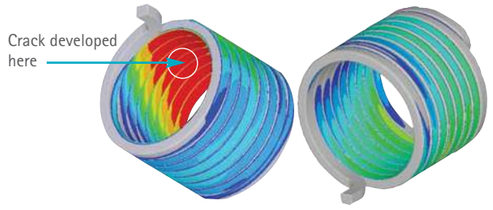
Case Study

Fatigue analysis of a supercharger torsion isolator spring

Test results to crack initiation: 60,000 cycles
fe-safe® fatigue life prediction to crack initiation: 67,500 cycles

"fe-safe® - invaluable and indispensable for predictive fatigue analysis"

Eaton Corporation, Vehicle Group, USA



fe-safe® fatigue life contour plots

Users consistently report that fe-safe® gives accurate, reliable fatigue life predictions that correlate well with test data



Industry sector applications

Automotive, ground vehicle & off highway

Powertrain & Engines
fe-safe® is used widely for powertrain applications. It can use FE models of the rotation of crankshafts and the movement of pistons and con-rods. It can account for rapid temperature variations, can map the material property changes through the engine cycle and can handle complex loading conditions, intermittent contact and complex duty cycles. High frequency mechanical cycles can be superimposed on low frequency thermal cycles. Specific algorithms for cast metals are provided.

fe-safe® includes high-temperature fatigue as standard. For higher temperatures, the thermo-mechanical module fe-safe/TMF® also allows for the effects of strain-rate dependency, oxidation, bulk stress relaxation and strain ageing.

Suspension, Chassis & Cab
fe-safe® can handle complex multiaxial road load data. The damage contribution from each road surface can be calculated and displayed in a single run. This means that fatigue tests can be shortened by only including the damaging parts of the duty cycle.

fe-safe® uses PSDs, steady state modal and random transient dynamic analyses to calculate the effects of complex vibration fatigue. FE models of large flexible components and structures are analysed efficiently.

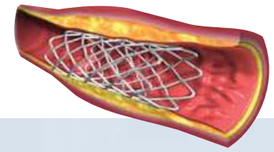
Exhausts
fe-safe/TURBOlife® is used to predict the fatigue life of exhaust components. fe-safe/TURBOlife® enables structural and thermal loading variations and creep and creep-fatigue interaction effects to be accounted for.

Marine

fe-safe® is being used by several companies for marine engine and power plant design. It can map the material property changes through the engine cycle and can analyse complex loading conditions and duty cycles. For ship hulls and structures, the Verity® module provides fatigue analysis of welded joints using FE models with coarse meshes.

Medical

Safe Technology has been working with medical companies for many years. The fatigue behaviour of vehicle-mounted medical equipment as it interacts with the suspension dynamics of the vehicle and the road load input has been investigated using fe-safe®. The fatigue properties of medical implants have also been assessed using fe-safe®.



Wind energy

fe-safe® can analyse the effects of many of the complex conditions seen in wind turbines such as vibration, the effects of rotating components, complex loading conditions, and duty cycles consisting of different wind states. Weld fatigue and the effect of high temperatures and can be included in the analysis.

For the fatigue analysis of composite turbine blades, fe-safe/Composites® offers an unparalleled technical solution.

Oil & gas pressure vessels

Verity® in fe-safe® is the original, patented Structural Stress Method for the fatigue analysis of welded joints, offering a mesh insensitive approach that removes the subjectivity from welded joint fatigue analysis and provides new levels of accuracy. The Verity® method is an approved method of analysis in the ASME Section VIII Div 2 design code.

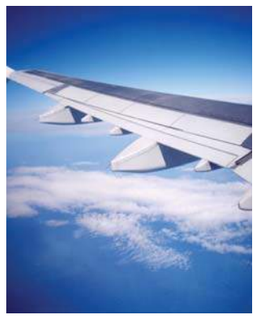
Rail

Axles, bogies, wheels, rail track, and welded steel and aluminium structures have all been analysed successfully by fe-safe® customers. Vehicle dynamics, rolling contact, residual stresses and the effects of manufacturing processes can all be included.

Aerospace

Loading spectra can be specified and the damage contribution from each block can be separately identified. The interaction between loading blocks and sequence effects are included. fe-safe® allows higher frequency loads to be superimposed over a ground-air-ground cycle very efficiently with the minimum of FE solutions. fe-safe® has been used for the analysis of aircraft engine components and can include thermo-mechanical and creep-fatigue interactions.

fe-safe/Composites® is ideal for the analysis of helicopter rotor blades. Steel rotor hubs and composite blades can be analysed in a single operation.


Capabilities

Fatigue of welded joints
fe-safe® includes the BS7608 analysis as standard. Other S-N curves can be added. fe-safe® also has an exclusive license to the Verity® Structural Stress Method developed by Battelle. Developed under a Joint Industry Panel and validated against more than 3500 fatigue tests, Verity® is bringing new levels of accuracy to the analysis of structural welds, seam welds and spot welds.

Vibration fatigue
fe-safe® includes powerful features for the analysis of flexible components and structures that have dynamic responses to applied loading. Steady state modal analysis, random transient analysis and PSDs are among the analysis methods included.

Test programme validation
fe-safe® allows the user to create accelerated test fatigue programmes. These can be validated in fe-safe® to ensure that the fatigue-critical areas are the same as those obtained from the full service loading. Fatigue lives and fatigue damage distributions can also be correlated.

Critical distance – will cracks propagate?
Critical distance methods use subsurface stresses from the FEA to allow for the effects of stress gradient. The data is read from the FE model by fe-safe®, and the methods can be applied to single nodes, fatigue hot-spots or any other chosen areas, including the whole model.

Property mapping
Results from casting or forging simulations can be used to vary the fatigue properties at each FE node. Each node will then be analysed with different material data. Temperature variations in service, multiaxial stress states and other effects such as residual stresses can also be included.

Vector plots
Vector plots show the direction of the critical plane at each node in a hot-spot, or for the whole model. The length and colour of each vector indicates the fatigue damage.

Warranty curve
fe-safe® combines variations in material fatigue strengths and variability in loading to calculate the probability of survival over a range of service lives. The effect of design variables on product reliability can be explored easily from a single user interface.

Damage per block
Complex loading histories can be created from multiple blocks of measured or simulated load-time histories, dynamic response analyses, block loading programmes and design load spectra. Repeat counts for each block can be specified. fe-safe® also exports the fatigue damage for each 'block' of loading (for example, from each road surface on a vehicle proving ground, or for each wind state on a wind turbine). This shows clearly which parts of the duty cycle are contributing the most fatigue damage. Re-design can focus on this duty cycle, and accelerated fatigue test programmes can be generated and validated.

Material database
A material database is supplied with fe-safe®. Users can add their own material data and create new databases. Material data can be plotted and tabulated. Effects of temperature, strain rate etc can be seen graphically.

Automatic hot-spot formation
fe-safe® automatically forms fatigue hot-spots based on user-defined or default criteria. Hot-spots can be used for rapid design change studies and design sensitivity analysis.

Manufacturing effects
Results from an elastic-plastic FEA of a forming or assembly process or from surface treatments such as cold rolling or shot peening can be read into fe-safe® and the effects included in the fatigue analysis. Estimated residual stresses can also be defined for areas of a model for a rapid 'sensitivity' analysis.

Surface detection
fe-safe® automatically detects the surfaces of components. The user can select to analyse only the surface, or the whole model. Subsurface crack initiation can be detected and the effects of surface treatments allowed for.

Surface contact
Surface contact is automatically detected. Special algorithms analyse the effects of contact stresses. This capability has been used for bearing design and for the analysis of railway wheel/rail contact.

Virtual strain gauges
Virtual strain gauges (single gauges and rosettes) can be specified in fe-safe® to correlate with measured data. fe-safe® exports the calculated time history of strains for the applied loading. FE models can be validated by comparison with measured data.

Parallel processing
Parallel processing functionality is included as standard – no extra licences are required.

Distributed processing
Distributed processing over a network or cluster is available, offering linear scalability. Mixed networks of Windows, Linux and Unix applications are supported. Fail-safe methods if nodes go offline and auto load balancing are included.

Signal processing
Signal processing, load history manipulation, fatigue from strain gauges, and generation of accelerated testing signals are among the many features included as standard.

Structural optimisation
fe-safe® integrates seamlessly into Isight from SIMULIA, ANSYS Workbench, TOSCA from FE-Design and Optistruct from Altair to allow the full fe-safe® capabilities to form an integral part of a design optimisation process.

fe-safe® Custom Module Framework®
fe-safe® Custom Module Framework® allows users to create and modify fatigue analysis methods. Confidential algorithms can be created and modified (in Python, FORTRAN, C++ and other languages). fe-safe® uses its own powerful fatigue loading capabilities to assemble the tensor time history, and this is passed to the Custom Fatigue Algorithm: Stress, strain and temperature variations and node-by-node material property variations are supported. User-defined results and other information are returned to fe-safe®. New user-defined material properties can be added to the material database. An initialisation call can generate a user interface to read text from the screen or batch file. Batch and distributed processing are also supported. By using the Custom Module Framework®, the users own algorithms can be added to those supplied with fe-safe® to operate seamlessly within the fe-safe® environment.

This is not a complete list of features in fe-safe® To discuss your particular requirements, please contact Safe Technology Limited or your local fe-safe® representative.

"Remarkably easy to use for such a powerful suite of software"



Optional add-on modules for fe-safe®

- **Fatigue of composites**
  fe-safe/Composites®, powered by Helius:Fatigue combines the extensive capabilities of fe-safe® with leading edge composite technology from Firehole Technologies to create a unique and unparalleled commercial solution for the fatigue of composite materials. Safe Technology has exclusively licensed the Helius:Fatigue technology. Both composite and metal materials can be analysed in a single operation and displayed as a single fatigue life contour plot.

- **Fatigue of welded joints**
  Verity® in fe-safe® is a revolutionary new mesh-insensitive Structural Stress Method developed by Battelle that allows engineers to predict failure locations and calculate fatigue lives for welded joints and welded structures. Safe Technology has exclusively licensed the Verity® technology. As an add-on module to fe-safe® it enables both welded and non-welded areas to be analysed in a single operation and displayed as a single fatigue life contour plot.

- **Thermo-mechanical fatigue**
  fe-safe/TMF™ provides a full thermo-mechanical fatigue analysis using instantaneous temperature and strain rates, bulk stress relaxation and effects of strain ageing from an elastic Finite Element model. fe-safe/TMF™ has been successfully used for pistons, exhaust manifolds and cylinder heads.

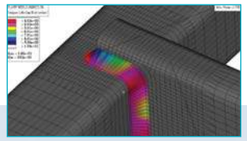
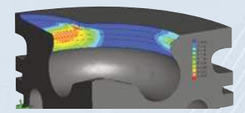
- **Creep-fatigue**
  fe-safe/TURBOlife™ has been developed in partnership with Serco Assurance to assess creep damage, fatigue damage and creep-fatigue interactions. It was developed in collaboration with the nuclear power industry using the R5 design code and has been extended to include multiaxial fatigue and complex loading histories. fe-safe/TURBOlife™ includes several methods for estimating high temperature material properties so that it can be used with sparse material data sets.

  fe-safe/TURBOlife™ creep-fatigue algorithms have been successfully applied to gas turbine blades, steam turbine components, exhaust components and turbocharger impellers.

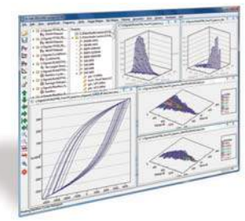
- **Fatigue using axial symmetry**
  fe-safe/Rotate™ speeds up the fatigue analysis of rotating components by taking advantage of their axial symmetry. It is ideal for wheels and bearings.

- **Fatigue of Rubber**
  fe-safe/Rubber™ developed with Endurica LLC estimates the fatigue life of a rubber component. Based on the mechanical duty cycle computed via your Finite Element Analysis, and a specification of the rubber's material properties, it computes the number of repeats of the duty cycle that are required to produce a small crack at each location within the component.

- **In-Situ Load Management**
  fe-safe/True-Load™ developed with Wolf Star Technologies brings to market a unique solution to provide strain correlated FEA load calculations. fe-safe/True-Load™ turns any structure into an n-dimensional load transducer by coupling FEA analysis with experimental strain measurement.



safe4fatigue™

Safe Technology's proven signal processing suite safe4fatigue™ is included as standard in fe-safe®. Capabilities include amplitude analysis, rainflow cycle counting, PSDs and transfer functions, signal cleaning, digital filters, uniaxial and multiaxial fatigue from strain gauges, generation of test command signals with optional cycle omission criteria, and macro recording.

For further information visit www.safetechnology.com



SIMULIA is the Dassault Systèmes brand that delivers a scalable portfolio of Realistic Simulation applications including; Abaqus for unified Finite Element Analysis and multiphysics simulation, Isight for design exploration and optimization, and SLM for managing simulation data, processes, and intellectual property. SIMULIA's realistic simulation applications are used as part of key business practices by world-leading manufacturing and research organizations to explore physical behavior, discover innovative solutions, and improve product performance.

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