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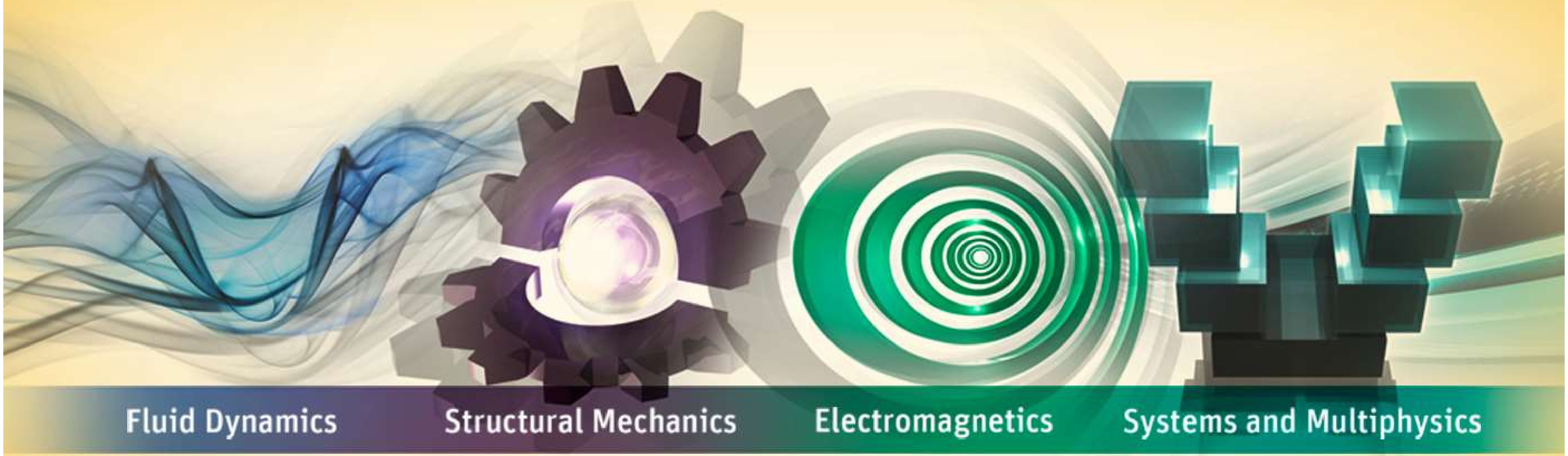
Realize Your Product Promise™

Fatigue Simulation Using ANSYS® nCode DesignLife™



Ray Browell, Dan Shaw, Bence Gerber

Outline

Introduction to fatigue and durability

Why is fatigue simulation important

The ANSYS nCode DesignLife fatigue process

Example uses of fatigue simulation

Questions and answers

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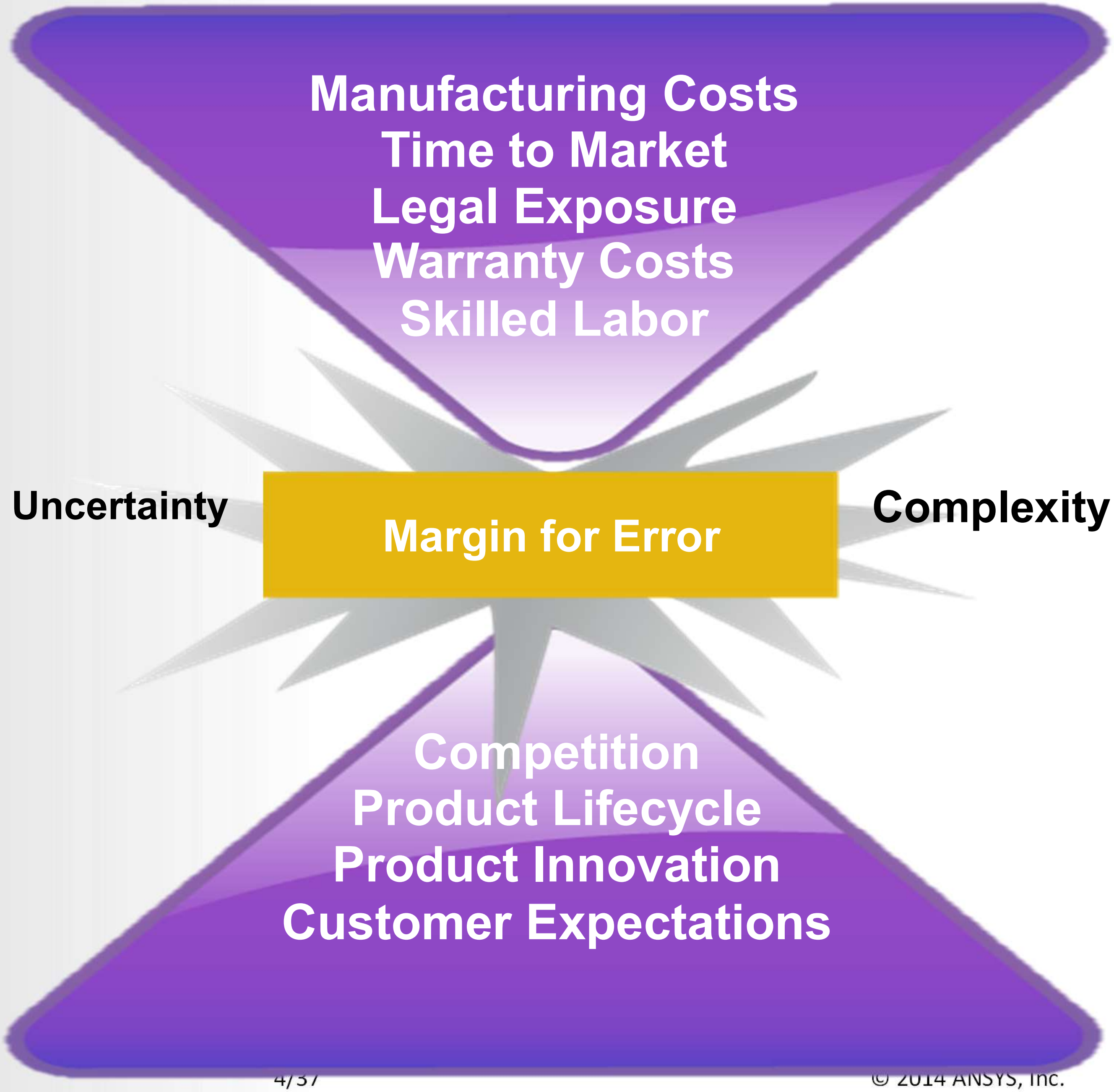
Increasing Demand for Product Durability

Products fail in use

Most frequent failure is from fatigue

Fatigue failure can be prevented with the help of simulation



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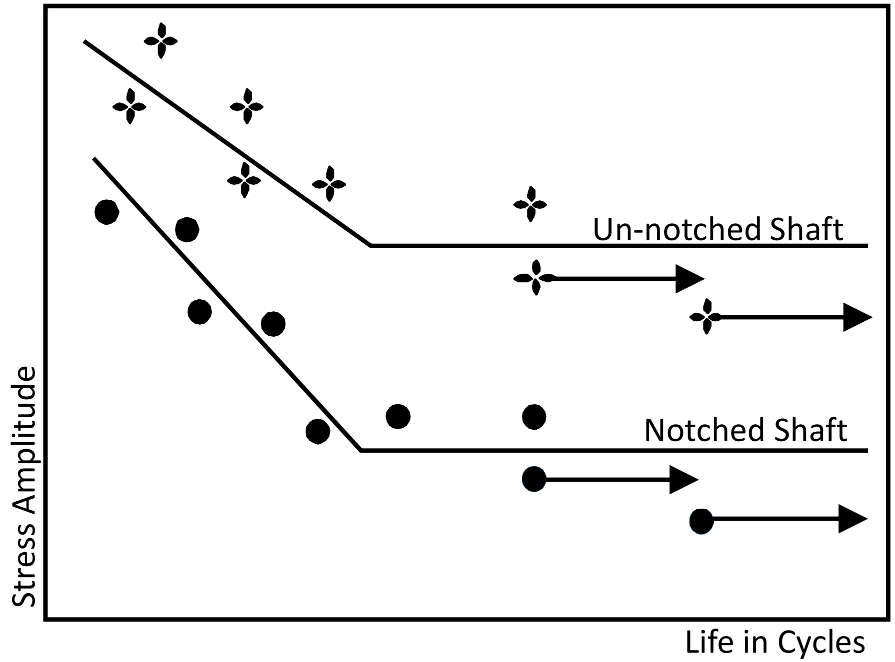
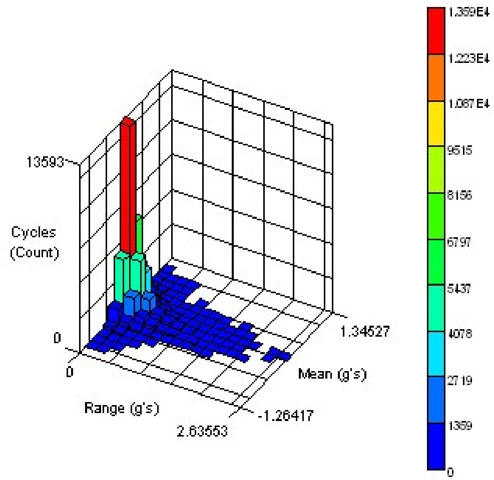
Timeline of Key Events in Fatigue Analysis

- **1837** — **Wilhelm Albert publishes the first article on fatigue**
- **1860** — **August Woehler devises a test for fatigue**
- **1910** — **O.H. Basquin proposes a log-log relationship for SN curves**
- **1945** — **A.M. Miner introduces a linear damage hypothesis (Miner's Rule)**
- **1954** — **Fatigue crack growth is explained in terms of plastic strain**
- **1968** — **Tatsuo Endo introduces rainflow cycle count algorithm**



$$\sum_{i=1}^{k} \frac{n_i}{N_i} = C$$



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Different Approaches to Fatigue Failure

Safe Life

- Evaluate expected life
- Design part to survive its expected service
- Carry out full scale tests
- Use a factor of safety
- Ideal for non-critical components with poor in-service inspections

Fail Safe

- Uses careful structural design to achieve fail safety
- Provides redundant load paths for main members
- Ideal for critical components
- Designed to fail into a safe condition and then survive until repair

Damage Tolerant

- Assumes flaws & cracks do exist – just design to live with them
- Uses fracture resistant materials and manufacturing processes
- Requires regular inspections to ensure cracks do not grow to failure
- Often used in conjunction with fail safe method

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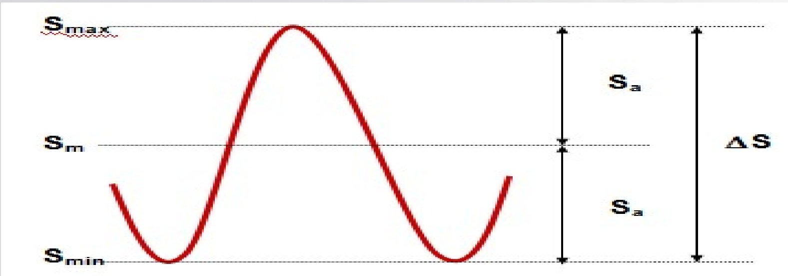
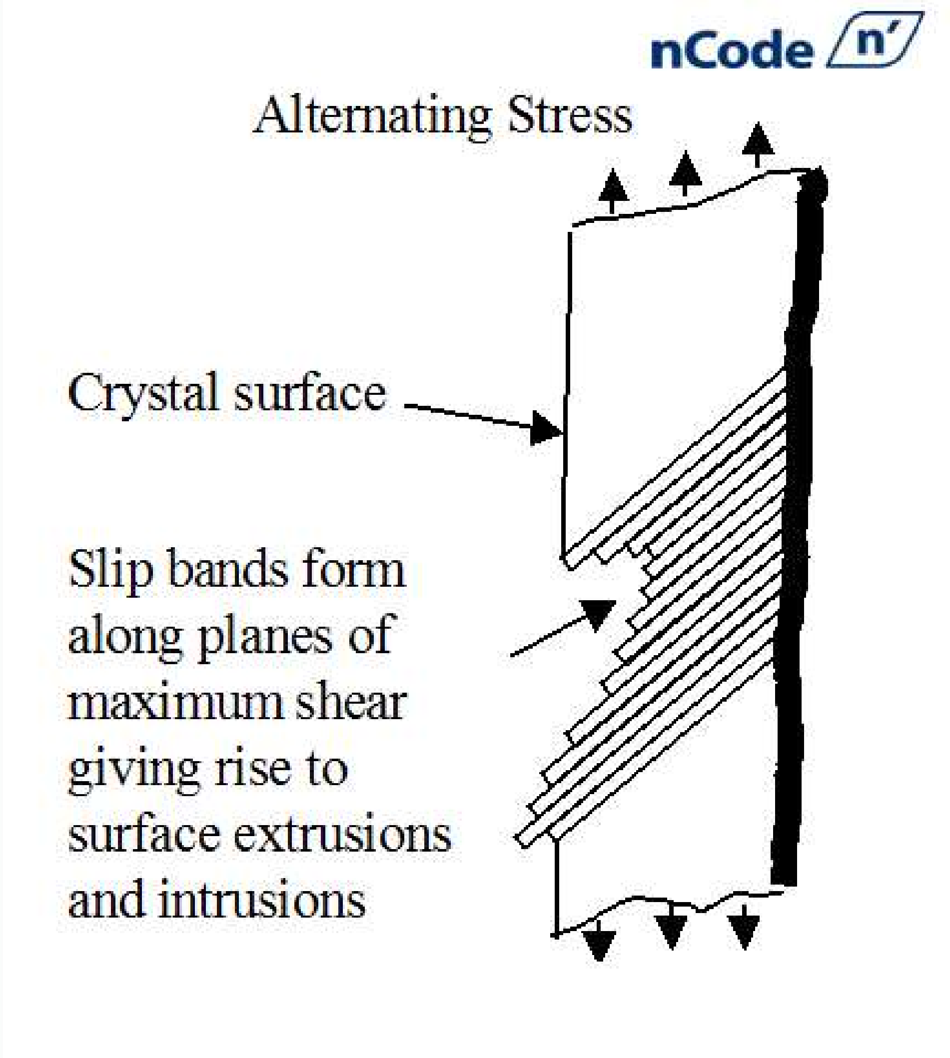
What is Fatigue

Failure under repeated or otherwise varying load which never reaches a level sufficient to cause failure in a single application.



Simple loading history



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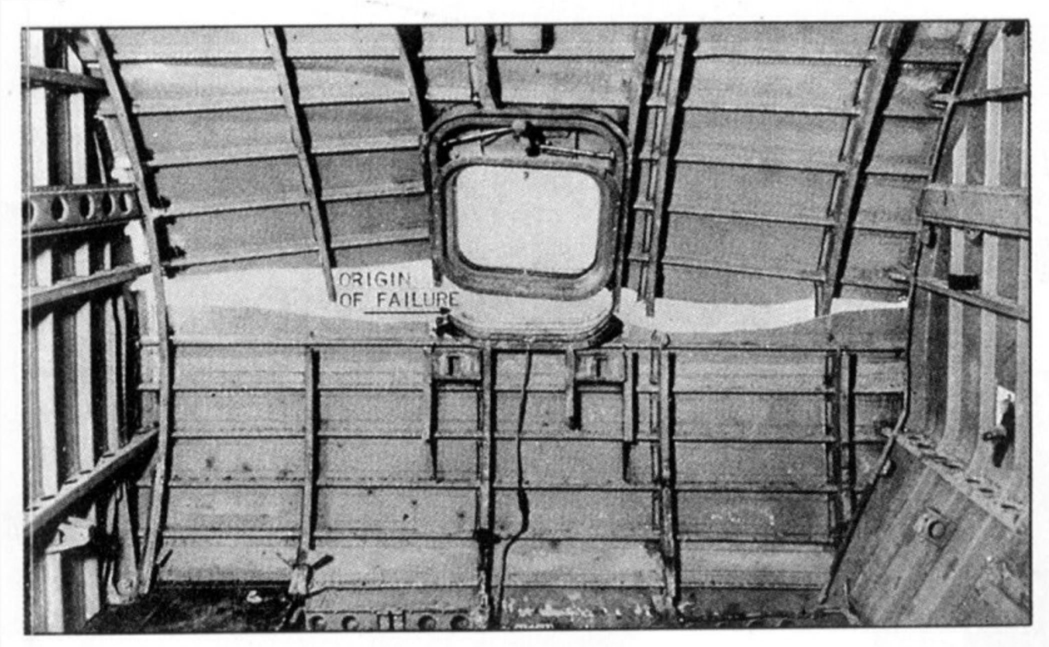
Fatigue Failure Example: de Havilland Comet

- de Havilland Comet, 1954
- Cracks initiated at sharp corners caused failure of fuselage



Fatigue failure due to cyclic pressurization, major damage

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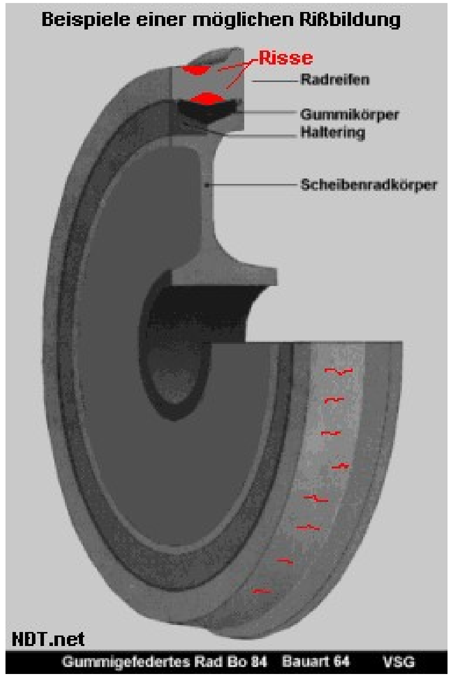
Fatigue Failure Example: ICE train derailed

- Train derailed, 1998 Eschede, Germany
  - Failure: crack in a wheel
  - Wheel vibration (original design)
  - Redesign based on streetcar wheel
  - Dynamic, repetitive forces not considered
  - Design lacked an adequate margin of safety



Inexpensive, part, major damage

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Fatigue Failure Example: Ignition Switch

NHTSA Campaign ID number : 03V423000 (2003)

Summary:

...the ignition switch may wear excessively and prevent proper interlock operation...

Consequence:

... if the vehicle operator does not shift to "park" before removing the key and fails to engage the parking brake, the vehicle could roll and crash ...

Inexpensive, simple, minor part, major potential damage, expensive repair campaign, damage to brand

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The Cost of Fatigue Failure

Gear failure from fatigue

- "...Between 80 - 90% of all structural failures occur through a fatigue mechanism..." *NBS report*
  - *Estimated cost > $600B/year*
- The cost of failure is high:
  - Legal Liability
  - Maintenance costs
  - Redesign Costs
  - Repair Costs
  - Damaged PR and Brand
  - Loss of future business

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Why Is Fatigue Simulation Important

Informed choices to insure product integrity by designing for durability

Fatigue simulation with ANSYS nCode DesignLife

- **Facilitates Product Integrity for an "expected life"**
- **Informed design decision about parameters used**
  - **Conservative designs: too expensive**
  - **Not conservative enough: exposure to high costs**
- **Optimize with simulation not product revisions**
- **Redesign, when needed expedited with simulation**
- **Unique, comprehensive fatigue process**
  - **Set up by expert, used by designers**

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Simulation Compared With Testing

Fatigue testing

- requires multiple physical prototypes
- realistic tests are difficult sometimes impossible to achieve
- slow and expensive
- fails to deal with over-design
- difficult to handle late changes and design variations
- test results may differ significantly
  - requiring statistical interpretation

Fatigue Simulation

- Predict fatigue damage in a virtual environment
- Optimize design rather than fail/no fail determination
- Insight into fatigue failure for each design
- Captured re-usable fatigue process

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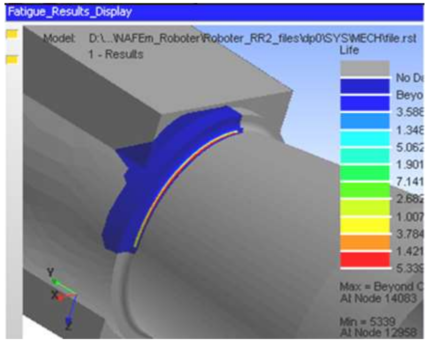
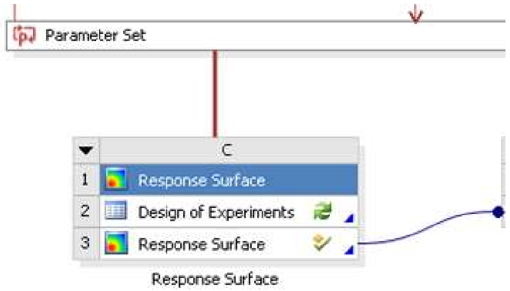
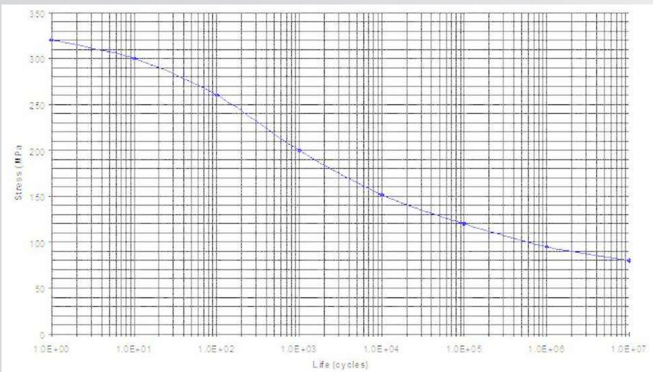
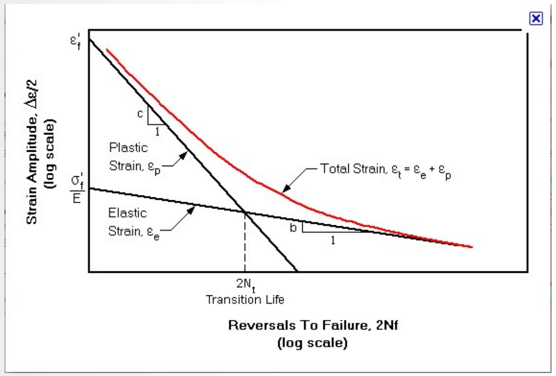
ANSYS nCode DesignLife Fatigue Process

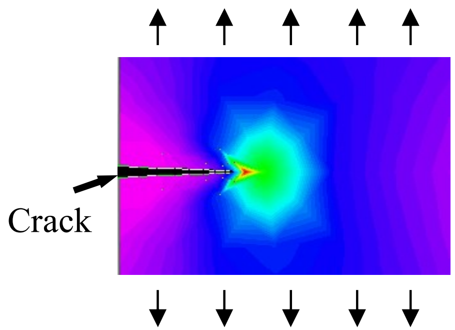
- *Start to End* automation
  - CAD to FEA to life prediction
- Comprehensive fatigue analysis
- Design optimization











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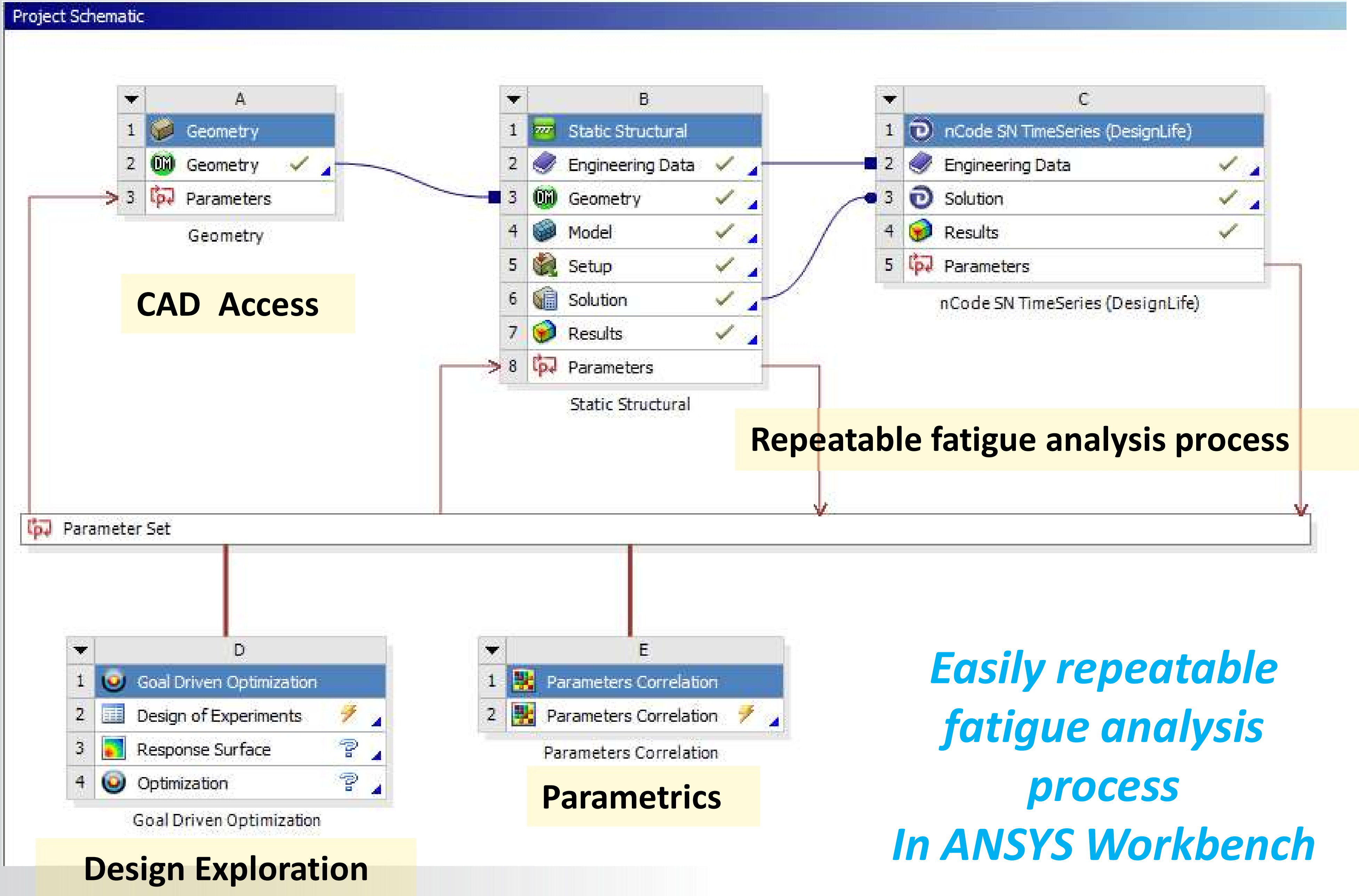
Start to End Automation & Optimization



Easily repeatable fatigue analysis process In ANSYS Workbench

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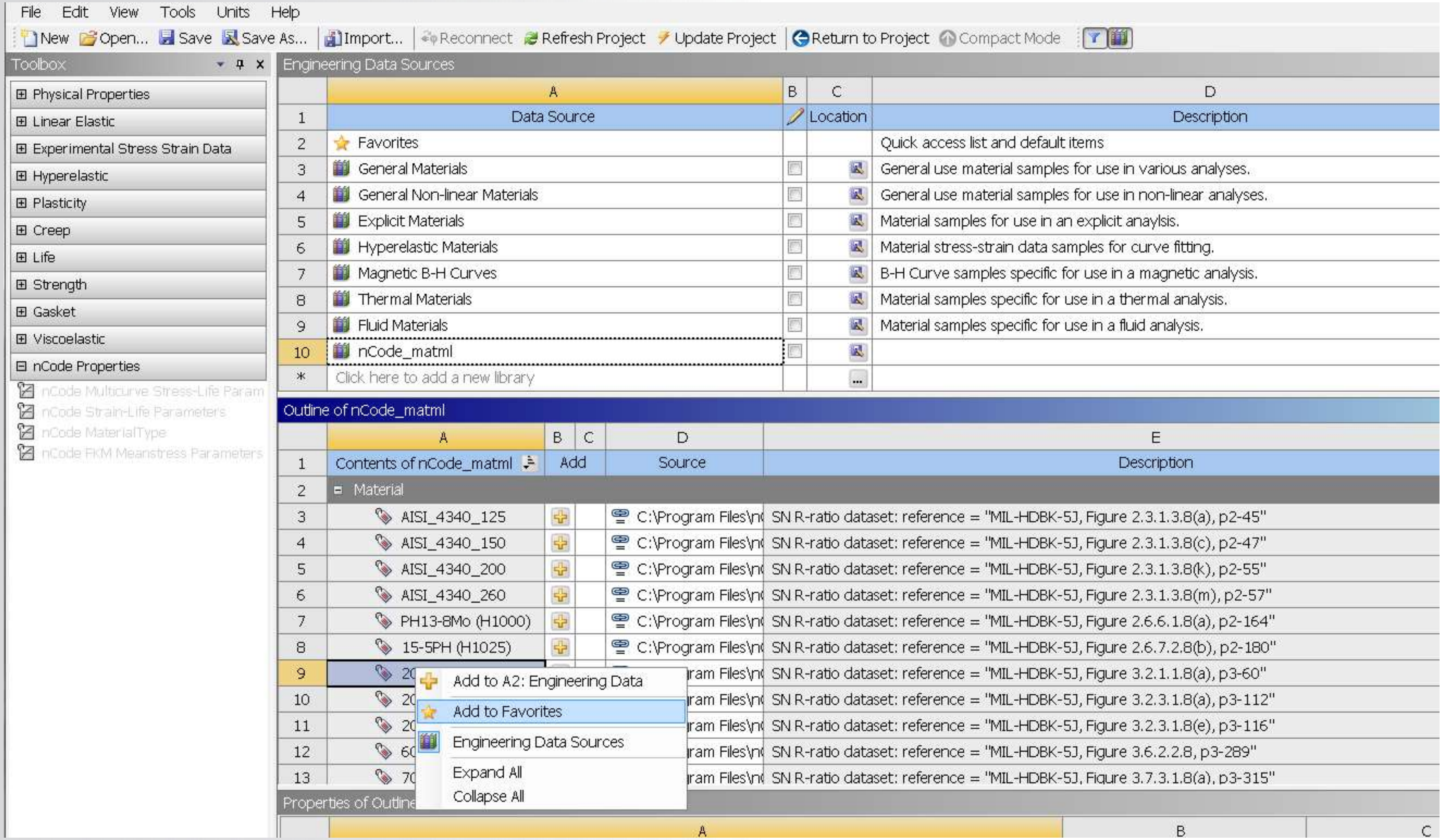
Fatigue Materials in Engineering Data



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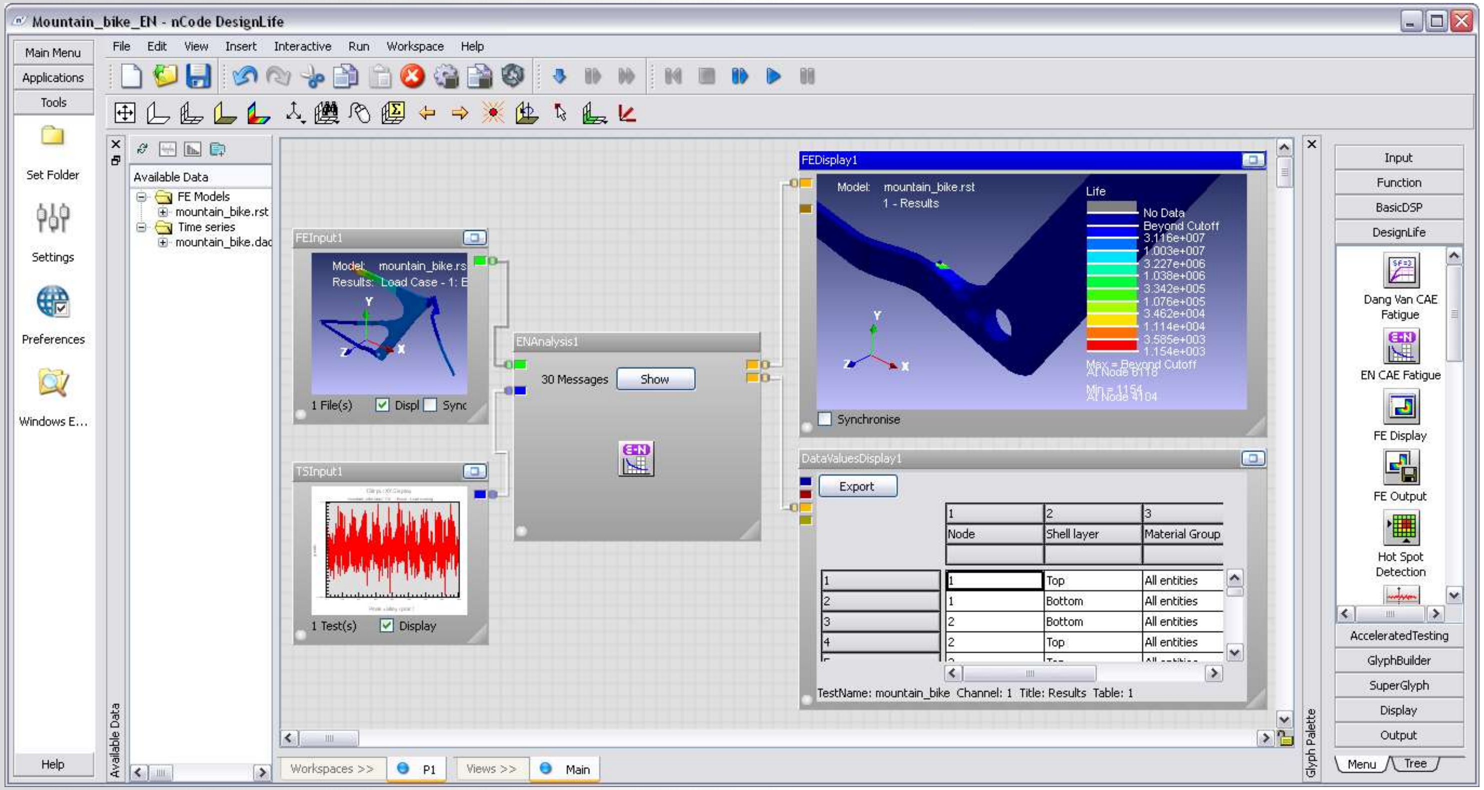
DesignLife Flo

DesignLife workflow is defined by group of connected actions

Predefined *ANSYS nCode DesignLife* systems automatically create data flows that can be used as is or modified



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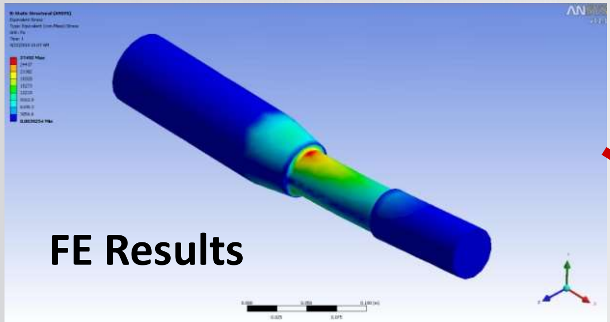
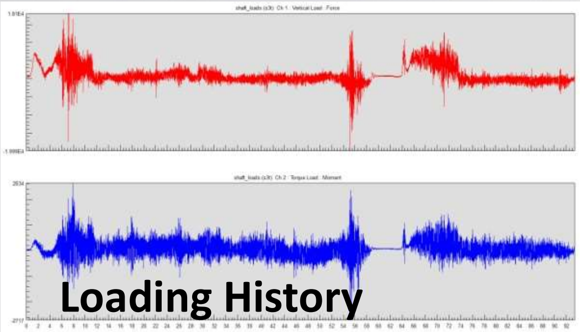
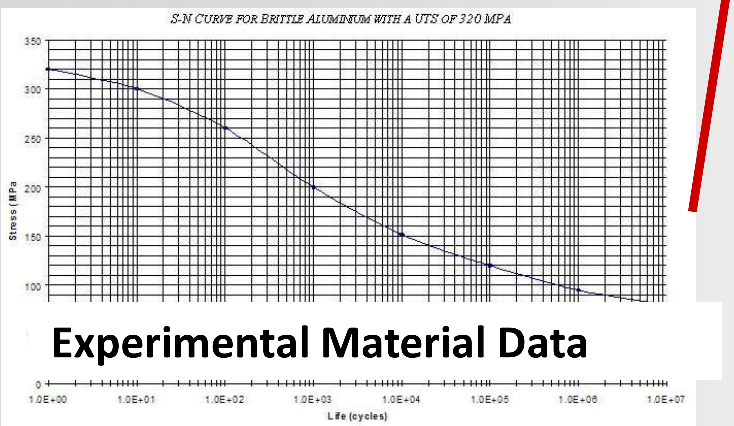
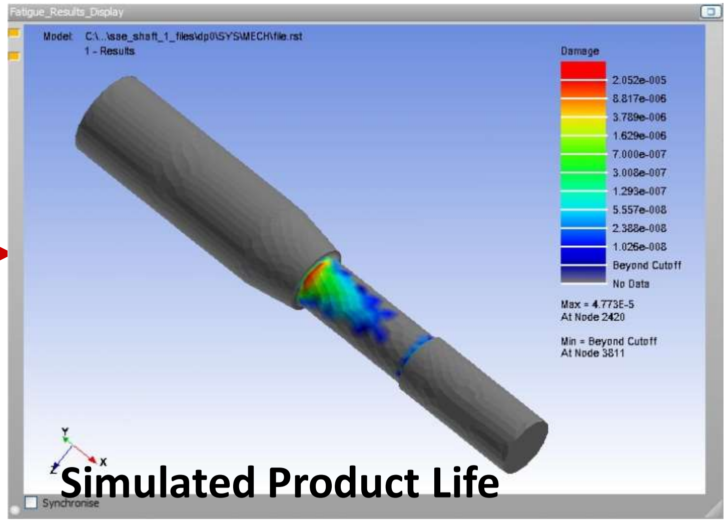
How Does ANSYS nCode DesignLife Work







ANSYS nCode DesignLife



- **Combines:**
  - **FE Results, Load History, Material Data**
- **Predicts time to fatigue failure**
- **Integrated in Workbench**
- **Intuitive, Easy GUI**
- **Integrated reporting**
- **Process encapsulation**
- **Fast solution, Efficient in parallel**
- **Accurate Results**

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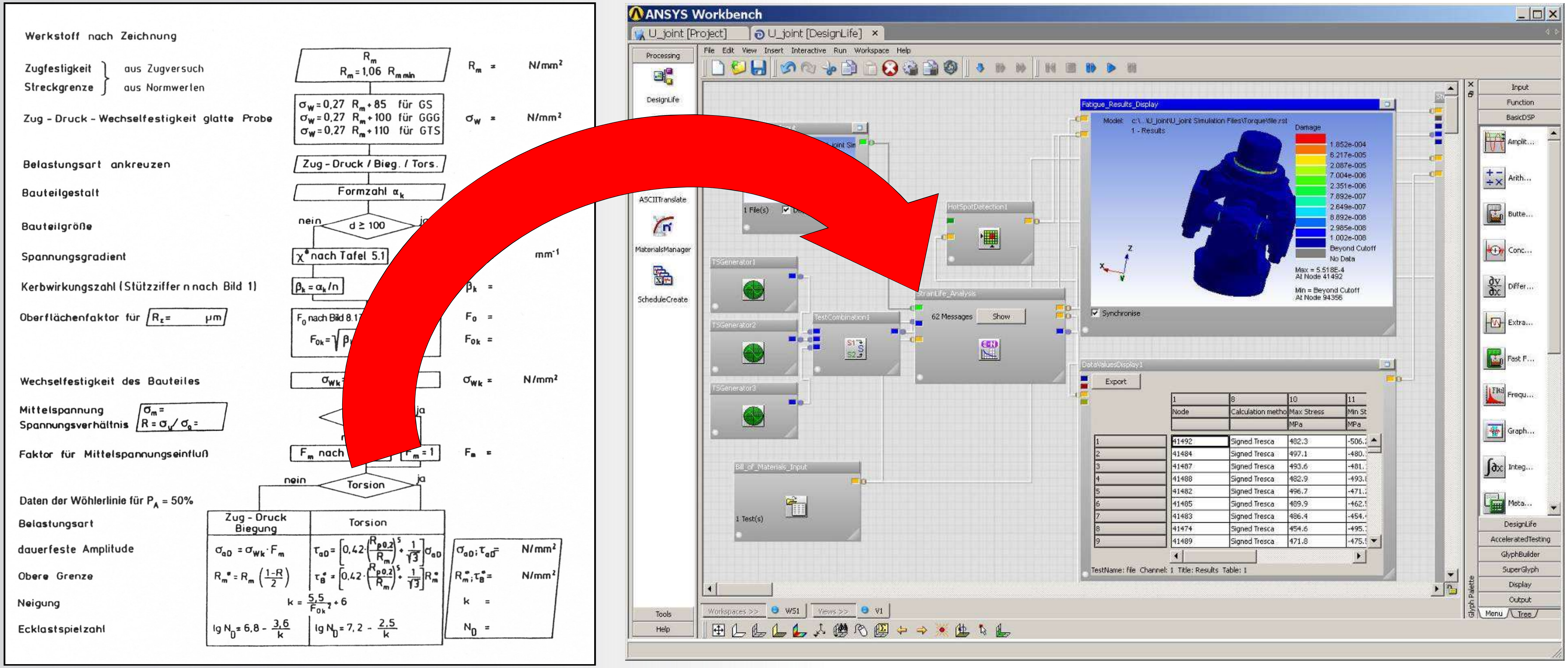
DesignLife Captures the Fatigue Process



Standardize the fatigue evaluation process within ANSYS Workbench with ANSYS nCode DesignLife

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nCode DesignLife Fatigue Methods

Stress-life (SN) method uses calculated stresses and stress vs. cycle fatigue curves (Wohler S-N curves)

- elastically calculated stresses drive fatigue
- only applicable to high cycle fatigue
  - greater than 100,000 cycles for metals

Strain-life (EN) method uses calculated strains and Strain Life Relationship Equation

- elastic-plastic local strains drive fatigue
  - either directly calculated or predicted from elastically calculated strains
- applicable to low and high cycle fatigue

Safety Factor for the damage can be calculate when using complex loadings

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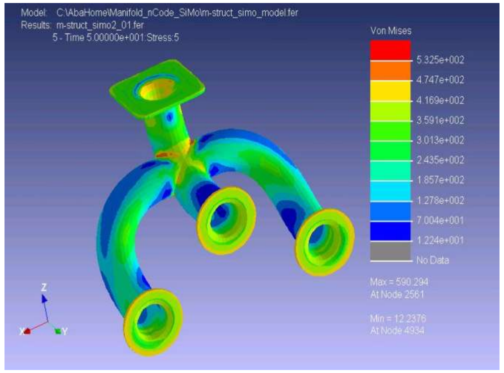
Additional Fatigue Methods for DesignLife

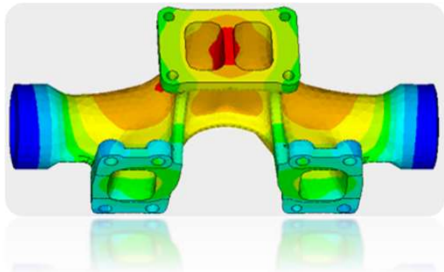
Thermo-Mechanical Fatigue (TMF)

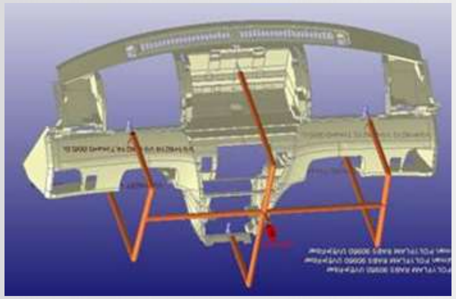
- Provides solvers for elevated temperature fatigue and creep by using stress and temperature results from finite element simulations

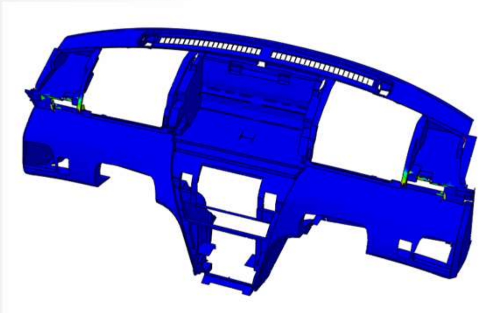


Short Fiber Composite

- stress-life fatigue calculations for anisotropic materials such as glass fiber filled thermoplastics







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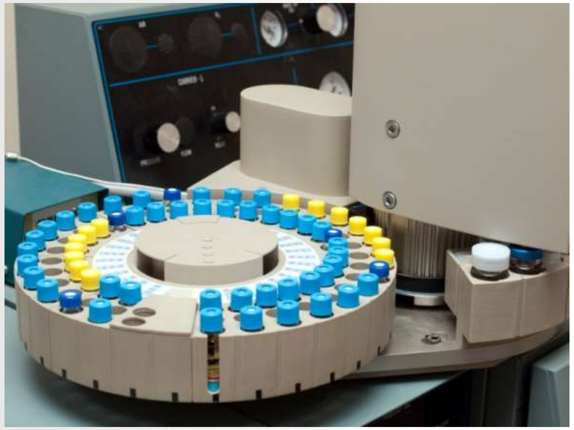
Industries Using Fatigue Simulation

Heavy Truck



Bio-medical equipment

Automotive

Aeropsace

Wind energy

Defense

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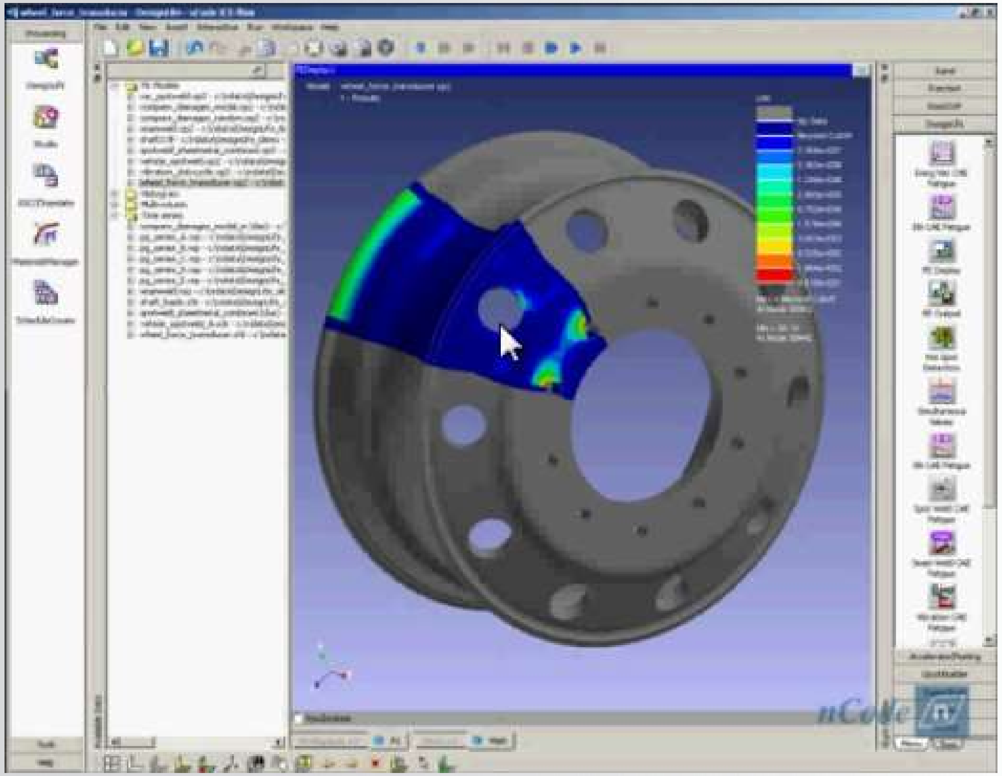
ANSYS nCode DesignLife Example Uses



Wheel Design

- *ANSYS* calculates stresses for 18 static analyses as tire loads rotate around the wheel.
- *DesignLife* produces stresses histories at every node on the wheel model, and predicts the number of revolutions of the wheel that will cause it to crack.

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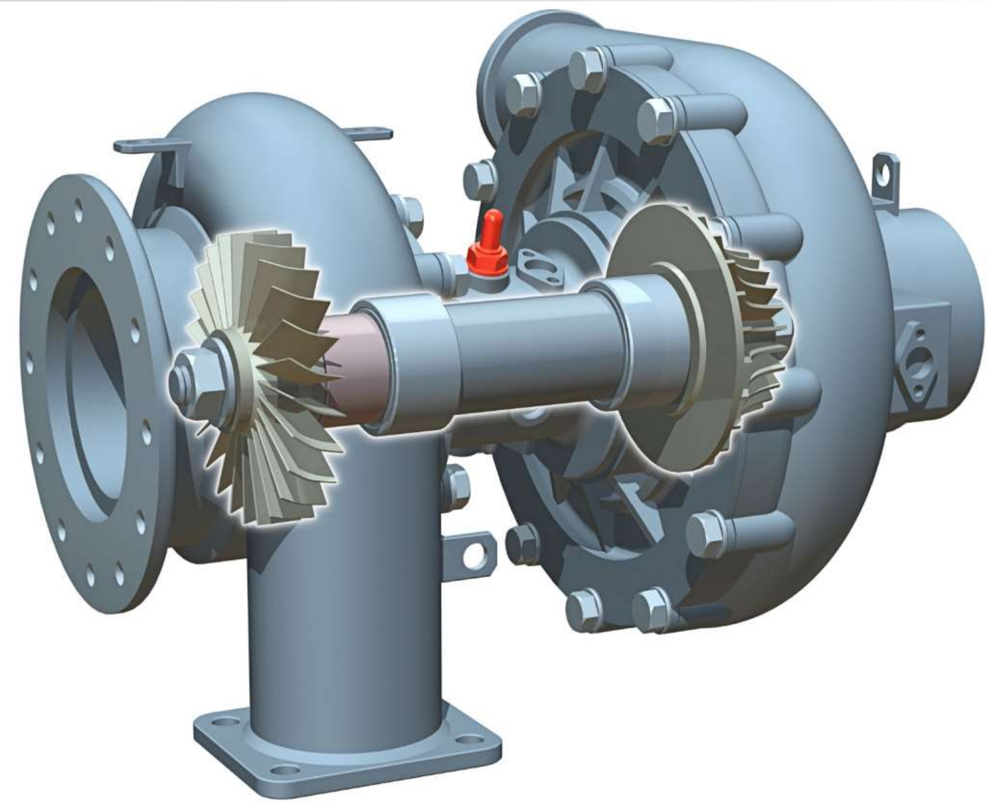
ANSYS nCode DesignLife Example Uses



Turbocharger Housing

- *ANSYS* calculates the stress history due to a 30 minute thermal cycle, and the stresses due to a 40 Hz mechanical excitation.
- *DesignLife* superimposes the thermal and mechanical stresses into a 720,000 point time history and calculates the turbocharger housing's life in hours of operation.

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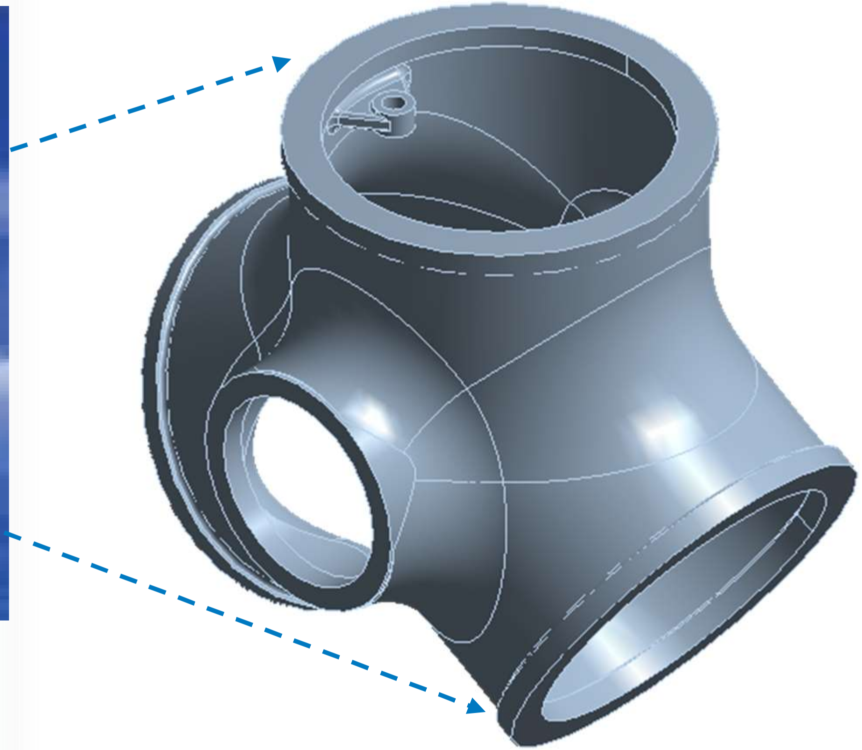
ANSYS nCode DesignLife Example Uses



Wind Turbine Hub exposed to multi-axial loading, that varies over time with wind conditions. Realistic loads (bending & shaft torque moments) are measured over a period of 7 days.

Life of the hub is predicted by ANSYS nCode DesignLife for a loading condition built based on the measurements.

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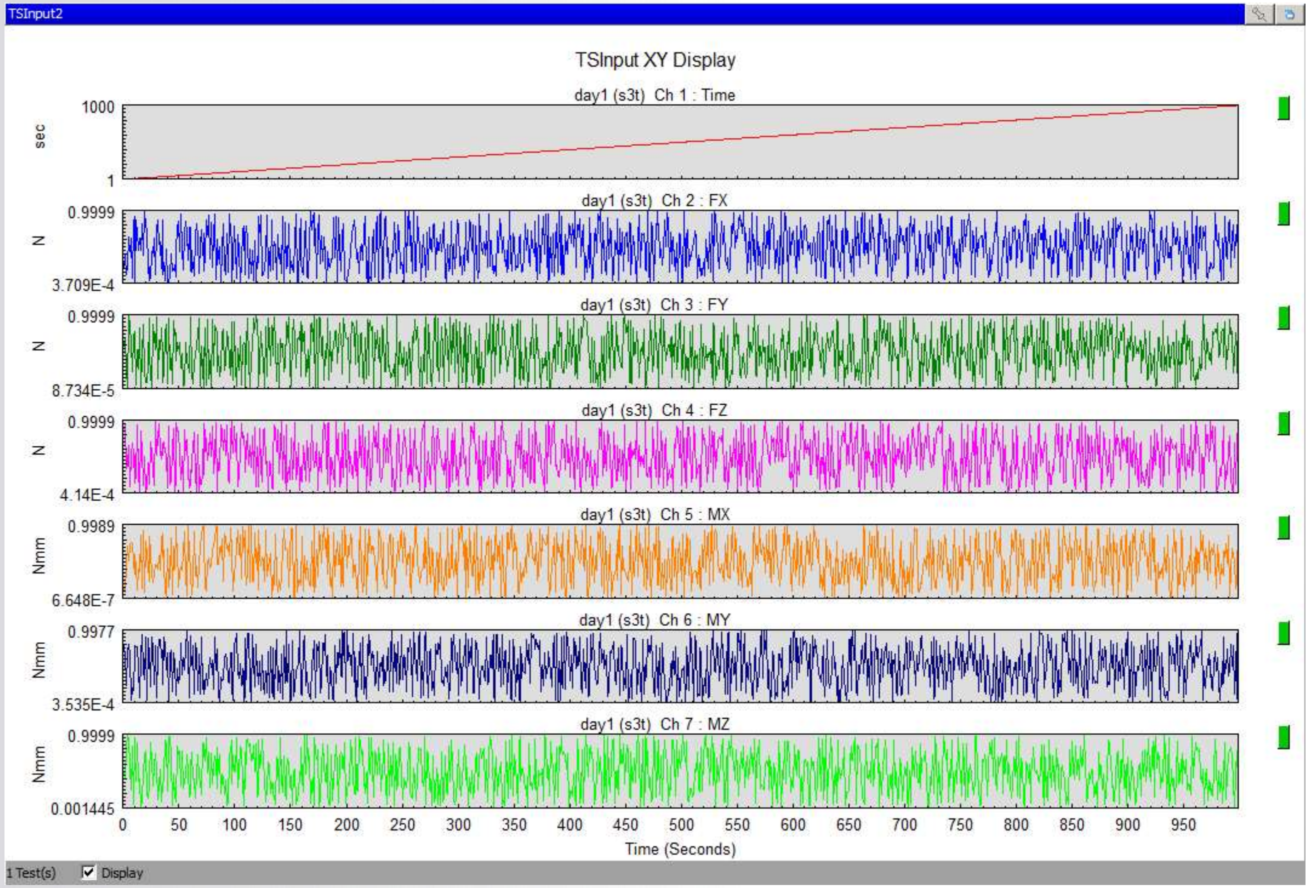
Hub Life Simulation in ANSYS Workbench



Moment and force measurements recorded in ASCII format are imported into ANSYS nCode DesignLife to build the Duty Cycle data

(single day shown)

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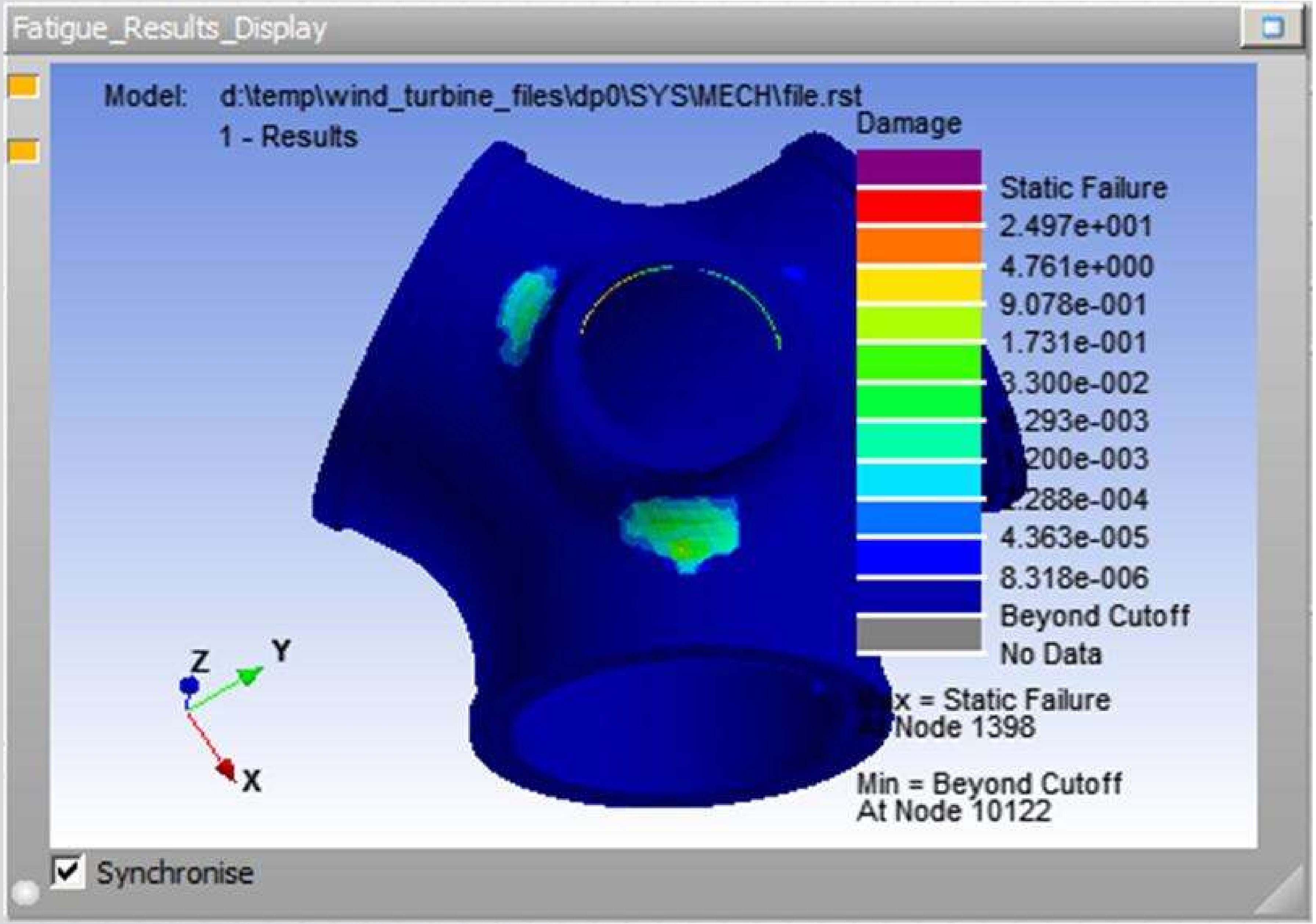
Wind-turbine Hub Multi-axial Loading



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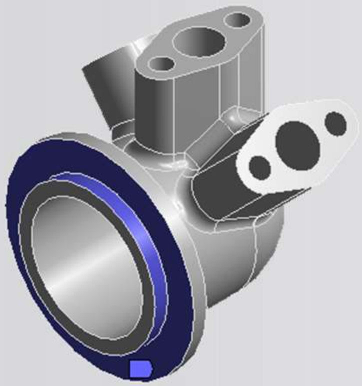
ANSYS nCode DesignLife Example Uses

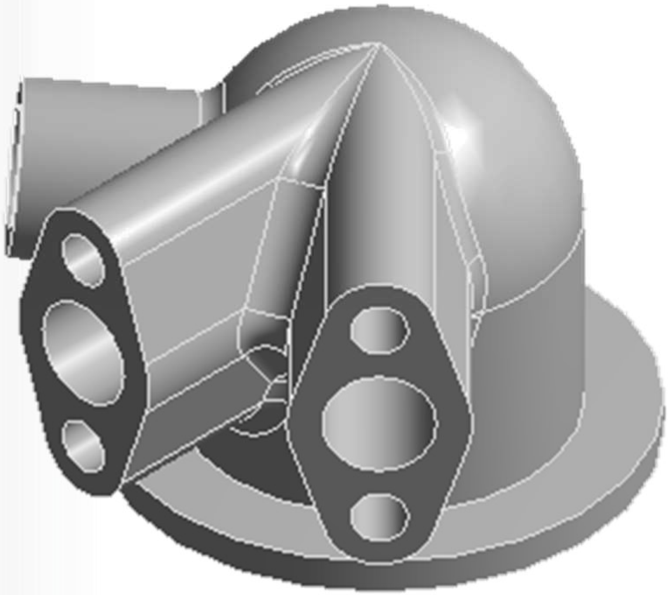
Multi-axial SN Life analysis

Pressure Manifold

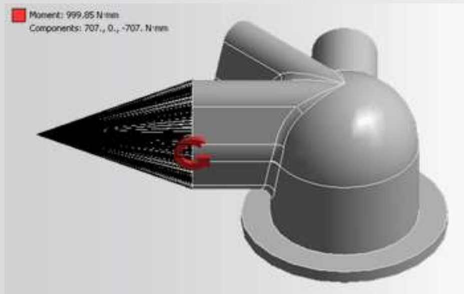
Compacted Graphite Cast Iron

1 bar on inner surfaces

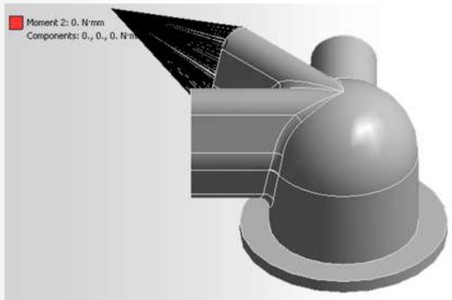




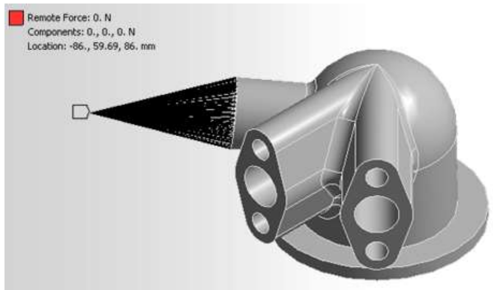
Bending moment 1



Bending moment 2



Axial force



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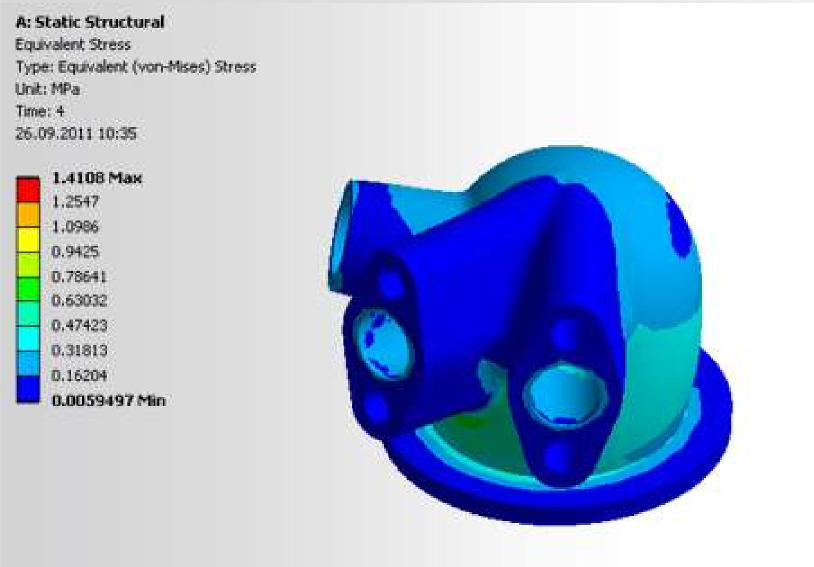
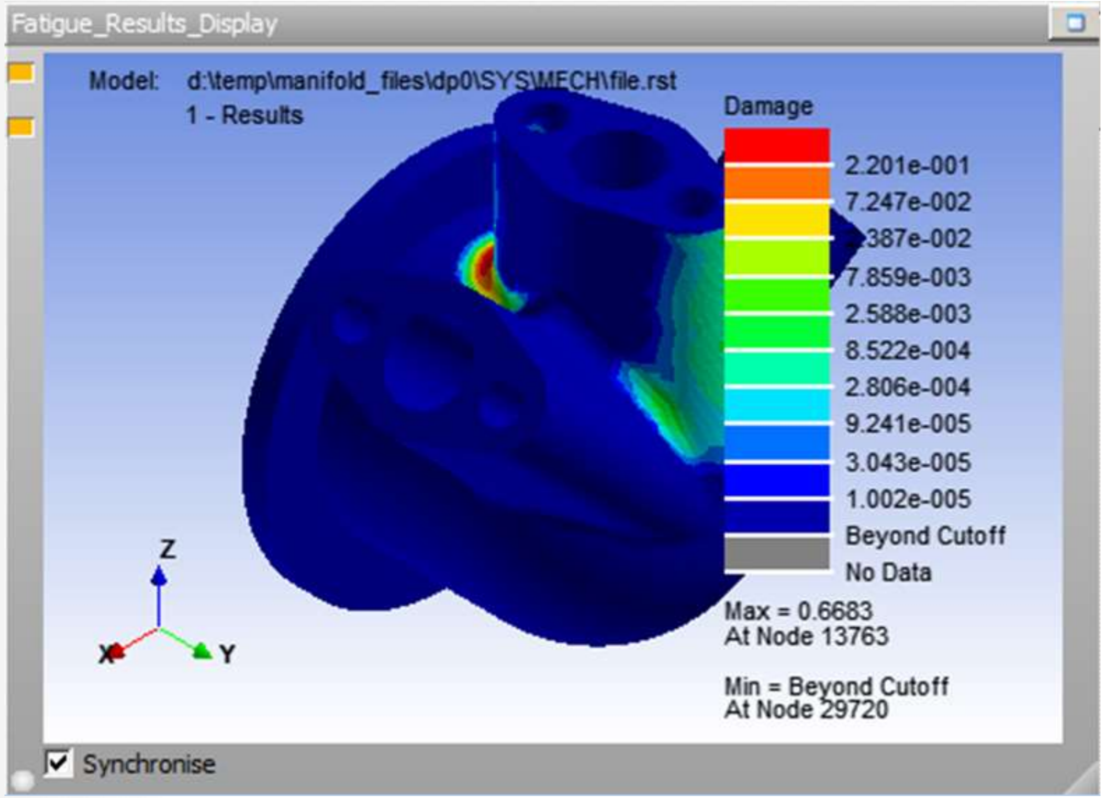
Multiaxial Strain Life Analysis: Manifold



Equivalent Stress from ANSYS Mechanical solution



Damage from Duty Cycle

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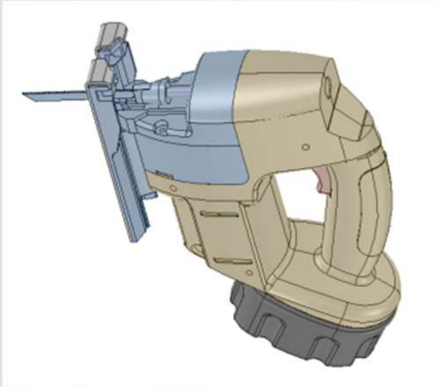
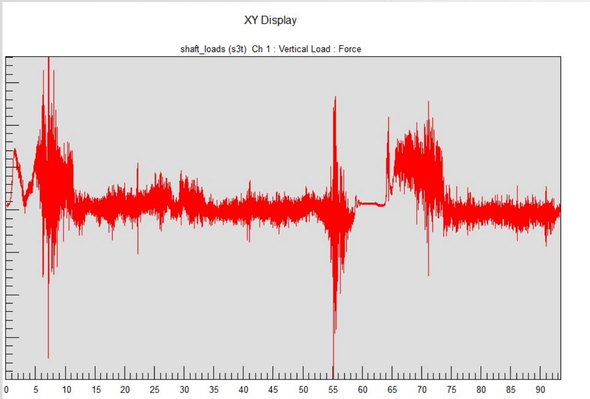
ANSYS nCode DesignLife Example Uses

Power Tool Vibration Analysis

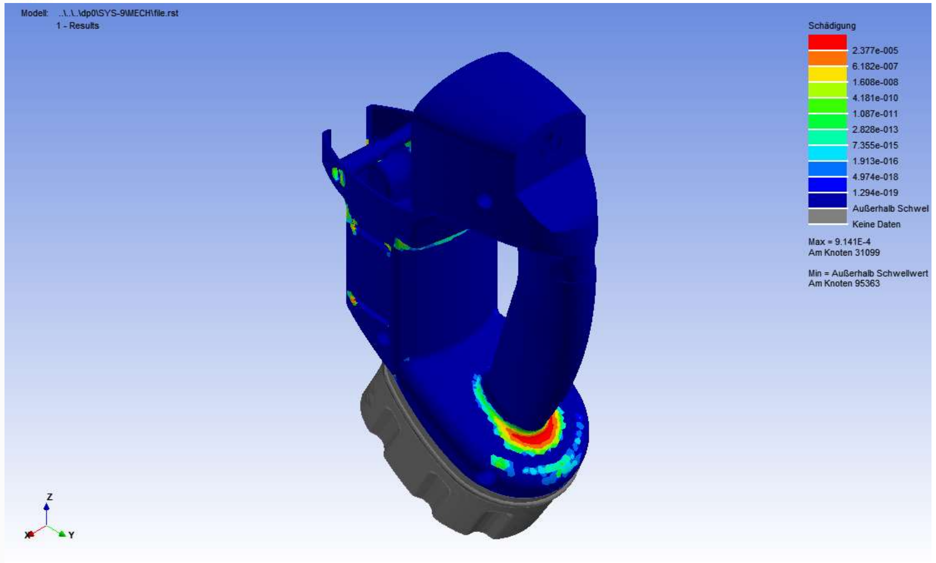
Simulate the service life of a battery-powered jigsaw.

Looking at the aluminum housing to determine how soon it might fail.





acceleration of housing.



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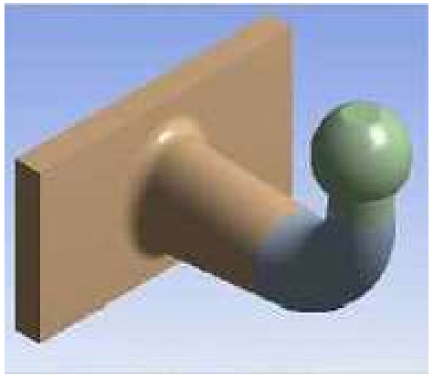
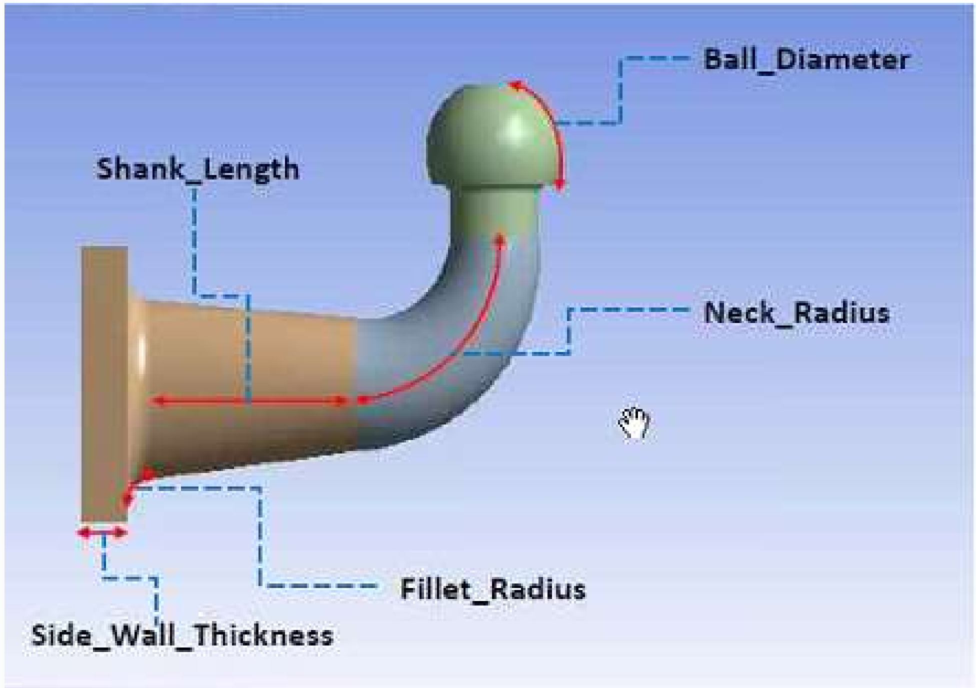
ANSYS nCode DesignLife Example Uses

Demo Optimization

Trailer hitch

- Input parameters:
  - Shank length
  - Side wall thickness
  - Fillet radius
  - Neck radius
  - Ball diameter
  - *Material used*
- Output parameters
  - Total mass
  - Maximum equiv. stress
  - Life





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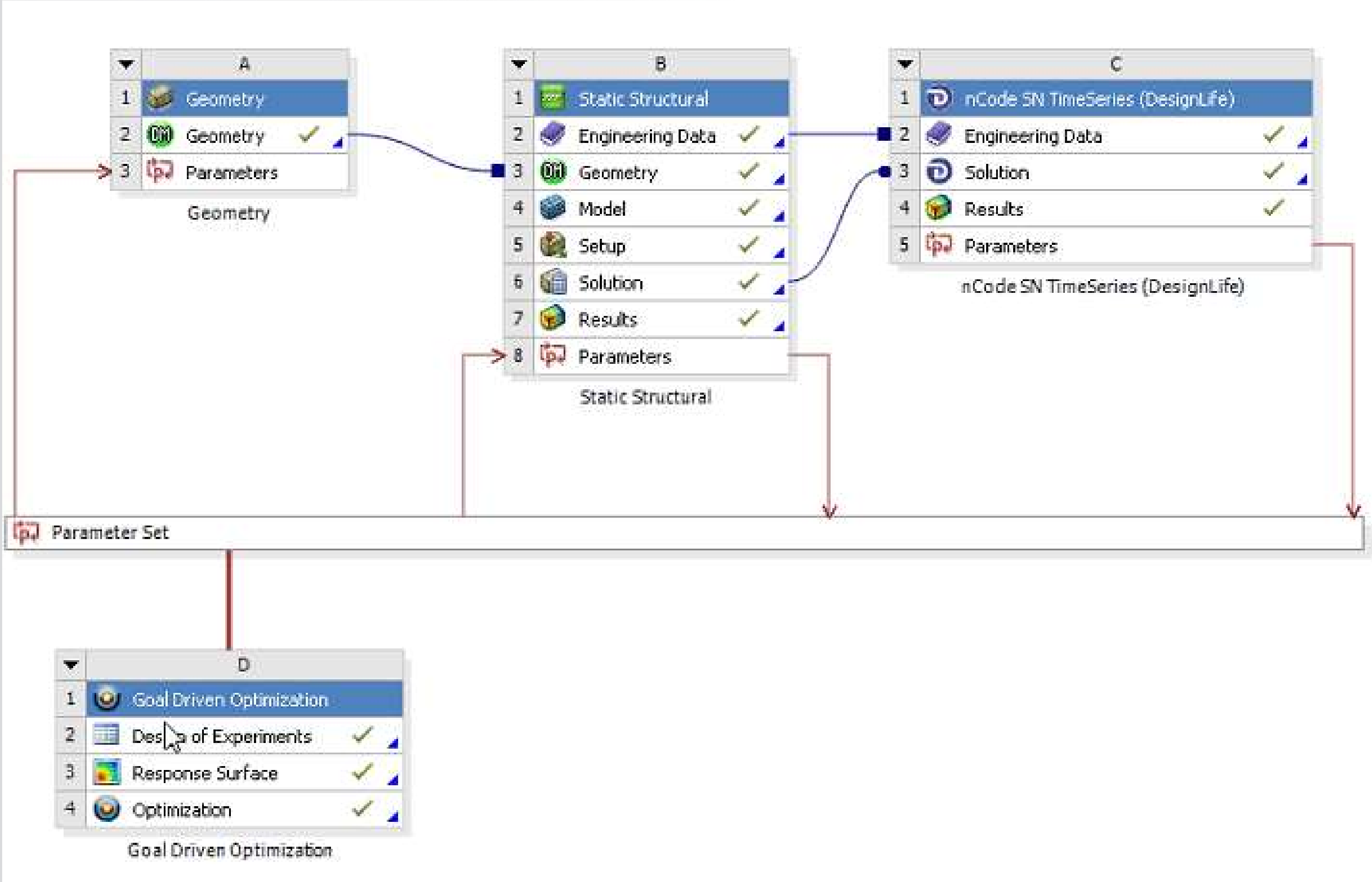
Optimization Using DesignXplorer



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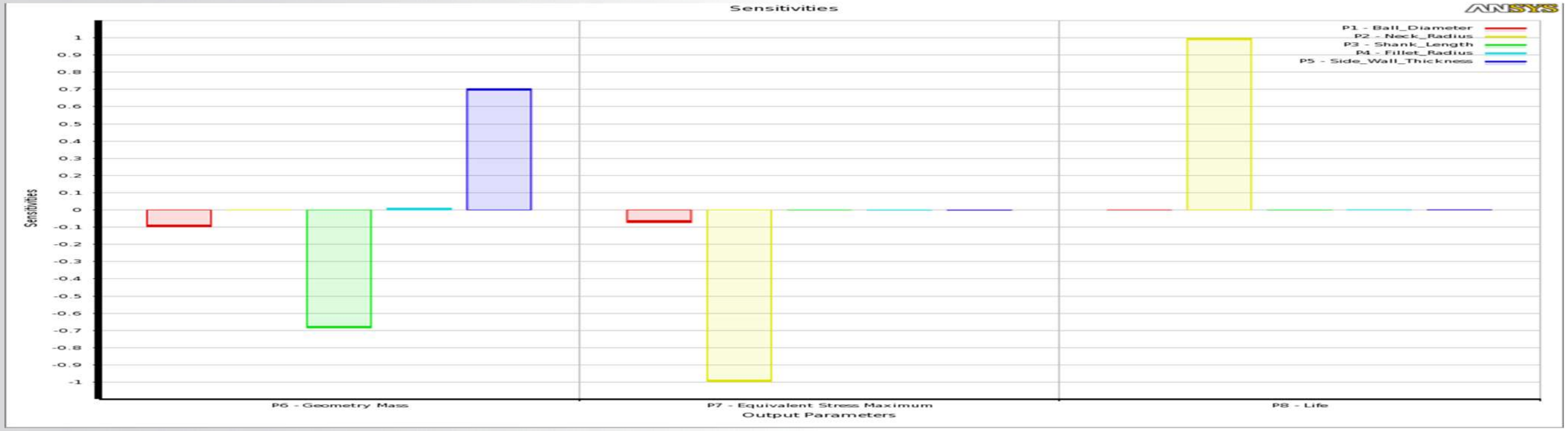
Input Parameters | **Output** | **Optimized**

Table of Schematic D4: Optimization

	C	D	E	F	G	H	I
1	P2 - Neck_Radius	P3 - Shank_Length	P4 - Fillet_Radius	P5 - Side_Wall_Thickness	P6 - Geometry Mass (kg)	P7 - Equivalent Stress Maximum (Pa)	P8 - Life
2							
3	40.5	-132	7.2	13.5			
4	48	-108	8.8	16.5			
5							
6	No Objective	No Objective	No Objective	No Objective	Minimize	Minimize	Maximize
7							
8					Lower	Lower	Higher
9							
10							
11	47.938	-111.63	8.5888	13.793	3.3916	2.112E+07	6.3599E+06
12	47.85	-108.47	8.3431	14.632	3.4438	2.115E+07	6.1916E+06
13	47.989	-116.81	7.659	13.713	3.465	2.1159E+07	6.1803E+06



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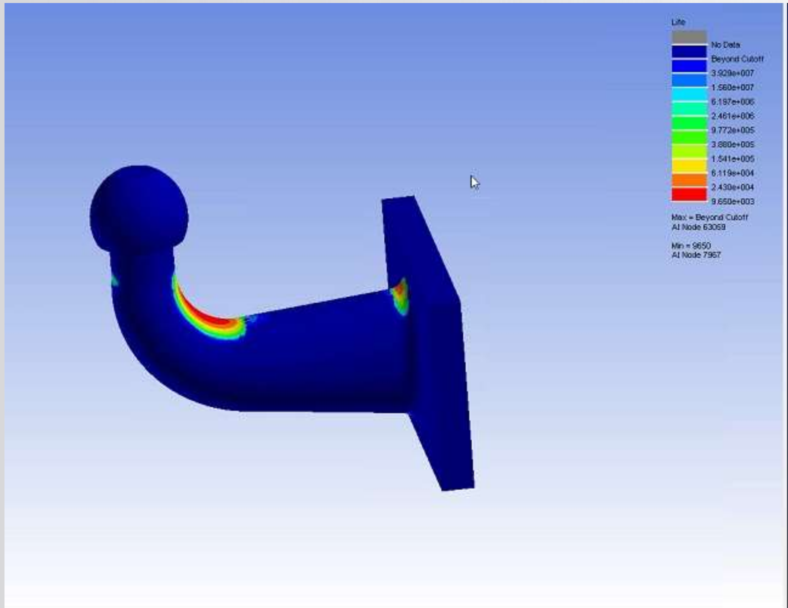
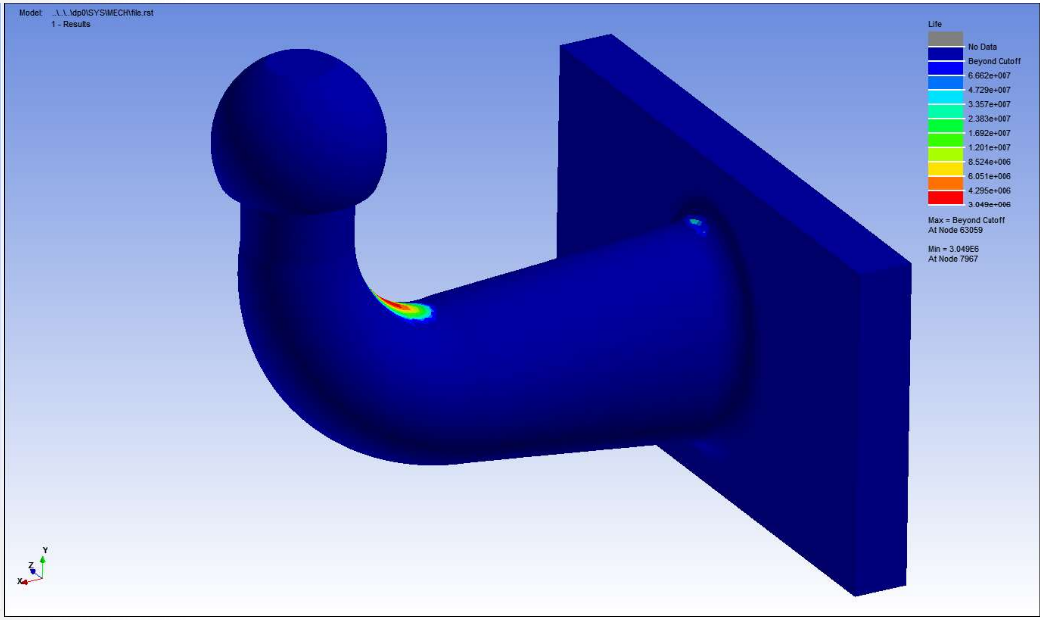
Optimized vs. Un-optimized





Un-optimized life: 9,650 **Optimized life 3,048,000**

Almost three orders of magnitude difference!

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ANSYS nCode DesignLife Delivers

- Product integrity
  - *Through informed design decisions*
- Planned & Designed durability of products
- Comprehensive reusable *fatigue process*
  - *Capturing the users process*
  - *Ability to run long time histories*
- Optimization and parametric analysis
- Right design decisions to avoid failure in an increasing competitive climate

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For More Information:

Web Page:

[ANSYS nCode DesignLife]

Blogs:

Why Use the ANSYS, Inc Version of nCode DesignLife?

What is Fatigue and Why Use CAE to Assess It?

What Fatigue Capabilities Does ANSYS Offer at Release 14.5?

Which Fatigue Methodology is Appropriate — Stress-Life or Strain-Life?

Performing Random Vibration Fatigue Using ANSYS nCode DesignLife

The Five-Box Trick in an ANSYS nCode DesignLife Fatigue Simulation

Turbomachinery, Vibration, and High-Cycle Fatigue

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Frequently asked Questions

Use the slides below if there are no questions from the audience.

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ANSYS nCode DesignLife FAQs!

Q. **What is the difference between ANSYS nCode DesignLife and the ANSYS Fatigue module?**

A. **ANSYS nCode DesignLife has a wider range of analysis and loading types to be able to capture realistic conditions.**

The ANSYS Fatigue module is limited in what it can do. Loading is limited to a single time history or a specific 2 load case option. ANSYS Fatigue cannot analyze multiple events (It has no “duty cycle” capabilities). Also, it does not support vibration, spot-weld, or seam-weld.

Example:
Fatigue Module: Failure of a bolt from repeated bending
nCode DesignLife: Failure based on real live test track accelerations at multiple sensors

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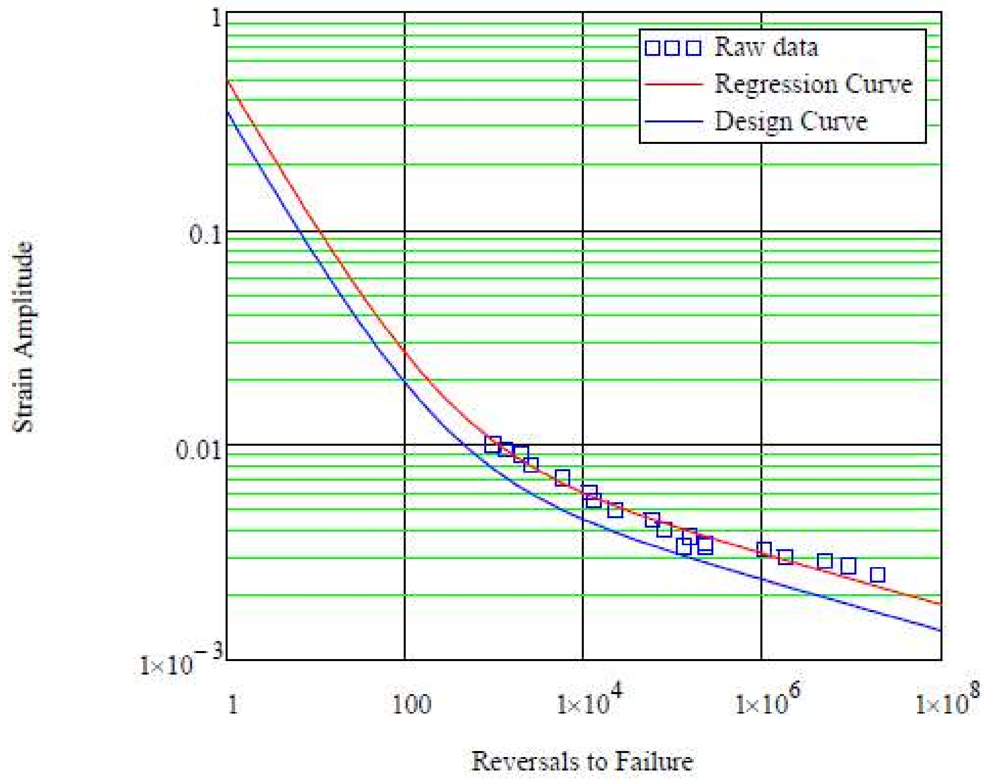
ANSYS nCode DesignLife FAQs!

Q. What if I do not have fatigue material data

A. HBM nCode has comprehensive material testing capabilities.

The HBM Lab delivers fully characterised design curves to the appropriate statistical and confidence level, for direct input into fatigue analysis



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ANSYS nCode DesignLife FAQs!

HBM nCode Material Testing Lab

Return qualified material parameters ready for use in analysis, not just test data

Advanced material analysis by PhD. metallurgists

- Statistical reliability analysis with confidence assessment – (6-sigma data)
- Parameter back-modelling capability for extracting properties from complicated components
- Materials characterization using metallography and other techniques
- Materials advice service

Advanced fatigue testing

- Strain Life (EN), Stress Life (SN)
- Axial, bending, shear and torsion testing
- Very thin specimens
- High temperature fatigue data
- Variable amplitude & random vibration fatigue data

Testing of advanced materials

- Weldments
- New high strength sheet steels
- Engineering polymers & polymer composites

In-house fabrication of tooling and fixtures

Pre-testing consultancy and advice

Expert team with >150 years fatigue testing experience

Backed by specialist nCode engineering consultants and software products

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ANSYS nCode DesignLife FAQs!

Q. **What is the difference between ANSYS nCode DesignLife Standard and nCode's standalone product?**

A. **The ANSYS product is integrated within the Workbench 2.0 framework, otherwise, they are identical. (Prior to the 12.1 release, the ANSYS version could only read ANSYS files, but now it can read all FE codes that the nCode version supports.)**

Price in the US same from nCode and ANSYS

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ANSYS nCode DesignLife FAQs!

Q. Where will customers get their fatigue properties?

A. ANSYS nCode DesignLife contains the complete nCode DesignLife Material Library integrated into Engineering Data.

Additionally, nCode has a materials testing service that customers may wish to use for unique materials or conditions.

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ANSYS nCode DesignLife FAQs!

Q. **On what platforms is ANSYS nCode DesignLife available**

A. **Windows and Linux:**

Platform	Processor	Operating System
Windows (64-bit)	x64	Windows 7 64-bit, Vista 64, XP 64
Windows (32-bit)	x86	Windows 7, Vista, XP
Linux (64-bit)	x64	Red Hat RHEL 5, Suse 10.2, 11.1

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ANSYS nCode DesignLife FAQs!

Q. Are there any add-on products to DesignLife Standard?

A. Yes

ANSYS nCode DesignLife Add-on Modules

Module	Description
ANSYS nCode DesignLife Vibration	Vibration fatigue for swept sine and PSD loadings
ANSYS nCode DesignLife Accelerated Testing	Simulate accelerated virtual and physical tests
ANSYS nCode DesignLife Welds	Fatigue evaluation of seam and spot welds
ANSYS nCode DesignLife Parallelization	Multi-thread parallel solver
ANSYS nCode DesignLife TMS	Solvers for elevated temperature fatigue
ANSYS nCode DesignLife Composite	SN fatigue for fiber filled anisotropic materials

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