Fatigue Analysis Using ANSYS® Fatigue Module and ANSYS® nCode DesignLife™
OUTLINE

• Importance and Motivation
• What is Fatigue?
• ANSYS Fatigue Module
• ANSYS nCode Design Life
• Conclusions
PRODUCT DURABILITY

- Product Durability
  - Failure of components
  - Down time

- Complexity
- Uncertainty

- Manufacturing Costs
- Time to Market
- Legal Exposure
- Warranty Costs
- Skilled Labor

- Competition
- Product Lifecycle
- Product Innovation
- Customer Expectations

- Margin for Error
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
DE HAVILLAND COMET

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

Fatigue failure due to cyclic pressurization, major damage
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
FATIGUE DAMAGE OF PIPELINES
• 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 instead of product revisions
• Redesign, if needed, is expedited with simulation
• Provides informed choices to ensure product durability
Failure under repeated or otherwise varying load which never reaches a level sufficient to cause failure in a single application.
Factors that influence fatigue failure

- Geometry
- Loading
- Manufacturing
- Material
ANSYS FATIGUE SIMULATION

- Total Life approaches
  - High Cycle Fatigue (S-N)
  - Low Cycle Fatigue (E-N)

- Using ANSYS, Fatigue can be post-processed with
  - ANSYS Fatigue Module
  - ANSYS nCode Design Life
ANNYS FATIGUE MODULE : S-N LOADING

Constant Amplitude, Proportional Loading
Constant Amplitude, Non-Proportional Loading

- Alternating between two distinct load cases (bending and torsional)
- Applying an alternating load superimposed on a static load
- Scenario’s involving non-linear contact, compression-only surfaces and bolt loads
Non-Constant Amplitude, Proportional Loading
\[
\frac{\sigma_{\text{Alternating}}}{S_{\text{Endurance Limit}}} + \frac{\sigma_{\text{Mean}}}{S_{\text{Yield Strength}}} = 1
\]
Soderberg Equation

ANSYS FATIGUE MODULE : S-N MEAN STRESS CORRECTION
ANSYS FATIGUE MODULE : S-N MEAN STRESS CORRECTION

\[
\frac{\sigma_{\text{Alternating}}}{S_{\text{Endurance Limit}}} + \frac{\sigma_{\text{Mean}}}{S_{\text{Ultimate Strength}}} = 1 \quad \text{Goodman Equation}
\]
ANSYS FATIGUE MODULE : S-N MEAN STRESS CORRECTION

\[
\frac{\sigma_{\text{Alternating}}}{S_{\text{Endurance\_Limit}}} + \left(\frac{\sigma_{\text{Mean}}}{S_{\text{Ultimate\_Strength}}}\right)^2 = 1
\]

Gerber Equation
Most Experimental results fall between Goodman and Gerber corrections.

Goodman and Soderberg corrections are conservative with Soderberg being overly conservative.

Goodman is a good choice for brittle materials and Gerber for ductile materials.
ANSYS FATIGUE MODULE : S-N MEAN STRESS CORRECTION DATA

Alternating Stress

Number of Cycles

R = -1 : Fully Reversed

Increasing R

R : Load Ratio
ANSYS FATIGUE MODULE : E-N

Fatigue Analysis Type
- Strain Life

Loading Type
- Constant amplitude, proportional loading
- Constant Amplitude, non-proportional loading
- Non-constant amplitude, proportional loading
- Non-constant amplitude, non-proportional loading

Mean Stress Effects
- Morrow
- Smith-Watson-Topper (SWT)
- None

Multiaxial Stress Correction
- Component X
- Component Y
- Component Z
- Component XY
- Component YZ
- Component XZ
- von Mises
- Signed von Mises
- Maximum Shear
- Maximum Principal
- Abs Maximum Principal

Fatigue Modifications
- Value of Infinite Life
- Fatigue Strength Factor
- Load Scale Factor
\[ \frac{\Delta \varepsilon}{2} = \frac{\sigma}{E} (2N_f)^b + \varepsilon_f (2N_f)^c \]
\[ \frac{\Delta \varepsilon}{2} = \frac{\sigma_{\text{failure}} - \sigma_{\text{Mean}}}{E} \left( 2N_{\text{failure}} \right)^b + \varepsilon'_{\text{failure}} \left( 2N_{\text{failure}} \right)^c \]
\[ \sigma_{\text{Maximum}} \frac{\Delta \varepsilon}{2} = \left( \frac{\sigma_{\text{failure}}}{E} \right)^2 \left( 2N_{\text{failure}} \right)^b + \sigma'_{\text{failure}} \varepsilon'_{\text{failure}} \left( 2N_{\text{failure}} \right)^{p+c} \]
ANSYS FATIGUE MODULE: RESULTS

- Fatigue Life
- Fatigue damage at a specified design life
- Fatigue factor of safety at a specified design life
- Stress biaxiality
- Fatigue sensitivity chart
- Rainflow matrix output
- Damage matrix output
ANSYS NCODE DESIGN LIFE

- Additional loading options
- More material models and analysis types
- Easy to capture fatigue design intent with ANSYS nCode Design Life glyphs
ANSYS NCODE DESIGN LIFE: LOADING

• Time series
• Constant amplitude
• Time step
• Vibration
• Temperature
• Duty cycle – including aero spectra
• Hybrid
ANSYS NCODE DESIGN LIFE: ANALYSIS TYPES

- Standard Dang Van analysis engine
- Spot Weld analysis engine
- Seam Weld analysis engine
Use the FE results (shock.rst) for 3 load cases and load time series (shock_loads.s3t) to compute the damage of the spot welded structure.
ANSYS NCODE DESIGN LIFE: EXAMPLE : SPOT WELD ANALYSIS
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• **Start to End** automation
  – CAD to FEA to life prediction
• Comprehensive fatigue analysis
• Design optimization
Start to End Automation & Optimization

Easily repeatable fatigue analysis process
Comprehensive Fatigue Analysis Process
DesignLife Captures the Fatigue Process

Standardize your fatigue evaluation process within ANSYS Workbench based on ANSYS nCode DesignLife glyphs
ANSYS nCode DesignLife: Summary

- **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
Industries using fatigue simulation

- Aerospace
- Aeropsace
- Bio-medical equipment
- Wind energy
- Defense
- Heavy Truck
- Automotive
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.
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.
SUMMARY

• 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