Correlating Virtual Fatigue Results with Test Failures

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Correlating fatigue lives

• How does predicted fatigue life compare with actual life?
• Can analytical results be trusted?

**Prediction**

Life = 610.2 repeats

**Real World**

Life = 274 repeats

**ANSWER!**

**ANSWER!**
What makes fatigue life correlation difficult?

1. Statistics
   • Deterministic vs. probabilistic
   • Does my analytical result correlate to a distribution?

2. Analysis assumptions
   • Does what I analyze match what I test?
   • Does how I analyze match how I test?
What makes fatigue life correlation difficult?

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   - Does *what* I analyze match what I test?
   - Does *how* I analyze match how I test?
A roadmap for fatigue analysis

Loading ➔ Geometry ➔ Fatigue analysis ➔ Fatigue results

Materials ➔ Fatigue analysis
Deterministic fatigue

- Loading distribution
  - PDF

- Geometry variability
  - PDF

- Material variability
  - PDF

Fatigue analysis

Distribution of results
  - PDF
Deterministic correlation

- Is predicted life the same as actual life?
- Or using a 2x rule of thumb, is the life within a 2x scatter band?

**Prediction**

\[ \text{Life} = 610.2 \text{ repeats} \]

**Real World**

\[ \text{Sample 1 Life} = 274 \text{ repeats} \]

\[ \text{Sample 2 Life} = 974 \text{ repeats} \]

**ANSWER!**

\[ \text{Life} = 610.2 \text{ repeats} \neq \text{Sample 1 Life} = 274 \text{ repeats} \]

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Probabilistic fatigue

- Loading distribution
- Geometry variability
- Material variability

Fatigue analysis

Distribution of results
Statistical correlation

- Also known as **Weibull analysis** or **life data analysis**
- What can life distributions tell us?

**Prediction**

**Real World**

**ANSWER!**

Life = 610.2 repeats

**ANSWER!**

Sample 1 Life = 274 repeats
Sample 2 Life = 974 repeats
Weibull analysis

The attempt to make predictions about the life of all products in a population by fitting a statistical distribution to life data from a representative sample of units

1. Gather life data from field or test lab
2. Select a distribution that will properly model life of the part
3. Estimate parameters that will fit the distribution to the data
4. Estimate life characteristics (e.g. reliability or mean life)

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Estimating life characteristics

Median Life = 600
Understanding confidence bounds

- The confidence bounds are estimates of the likelihood that a sample will fall within a set of values.
- The sample size has a large influence on these confidence bounds.
Number of samples and confidence bounds

- As the sample population increase, the confidence bounds move closer together
Is correlation achieved?

- Yes, if the simulated life result falls within the confidence bounds.
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Modelling assumptions vs. test conditions

Loading and test conditions
- Nominal vs. worst case
- Are test fixtures infinitely stiff?
Modelling assumptions vs. test conditions

Are test fixtures infinitely stiff?
Modelling assumptions vs. test conditions

Geometry

- Is my FE model based on design geometry or as-manufactured?
  - Draft, radii, extra holes, etc. to make it manufacturable
- Worst case vs. nominal geometry?
  - Assembly stackup
- Where did the test samples come from?
  - Prototype, best from the production line, randomly chosen, etc.?
Modelling assumptions vs. test conditions

Material strength

- Is life predicted with the mean SN curve, R95, B10,...?
Modelling assumptions vs. test conditions

- What is the definition of failure?
  - Analysis = crack initiation
  - Test = fracture

1st crack initiates here

But 2nd crack here leads to fracture
Is correlation achieved?

- If modelling with worst case, expect the predictions to fall to the left side of the life distribution, not in the middle
Recommendations for improving fatigue life correlation

1. Use statistical techniques to quantify bounds on fatigue life
2. Recognize interaction between sample size and confidence bounds
3. Review assumptions in FE analysis vs. test conditions
4. Don’t expect analysis results to match mean life if analysis is done with worst case