Fatigue Life Prediction of Steam Turbine Blades during Start-up Operation Using Probabilistic Concepts

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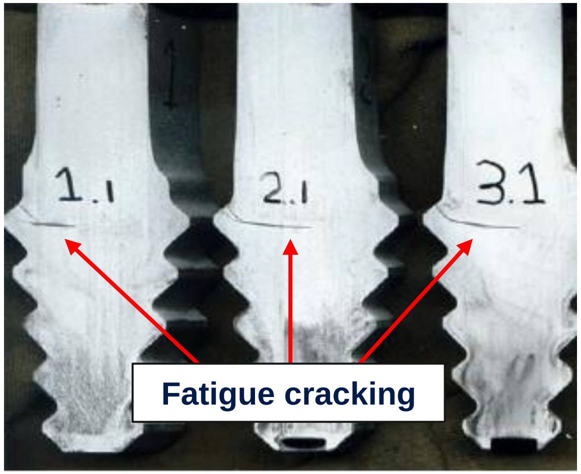
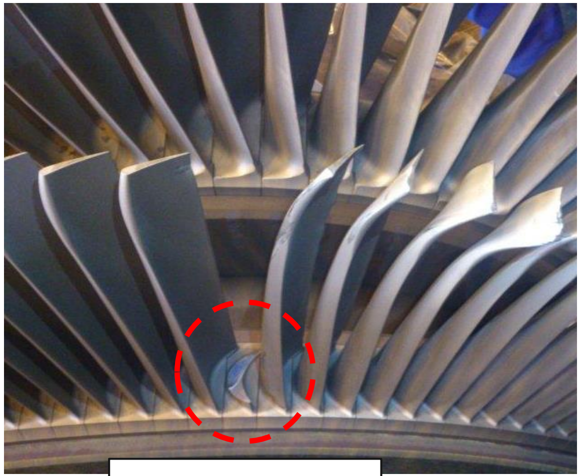
Outline

- Problem statement
- Fatigue life modelling flow chart
- Experimental material characterisation
- Finite element modelling and analysis
- Probabilistic fatigue life modelling
- Conclusion
- Acknowledgements

Problem statement

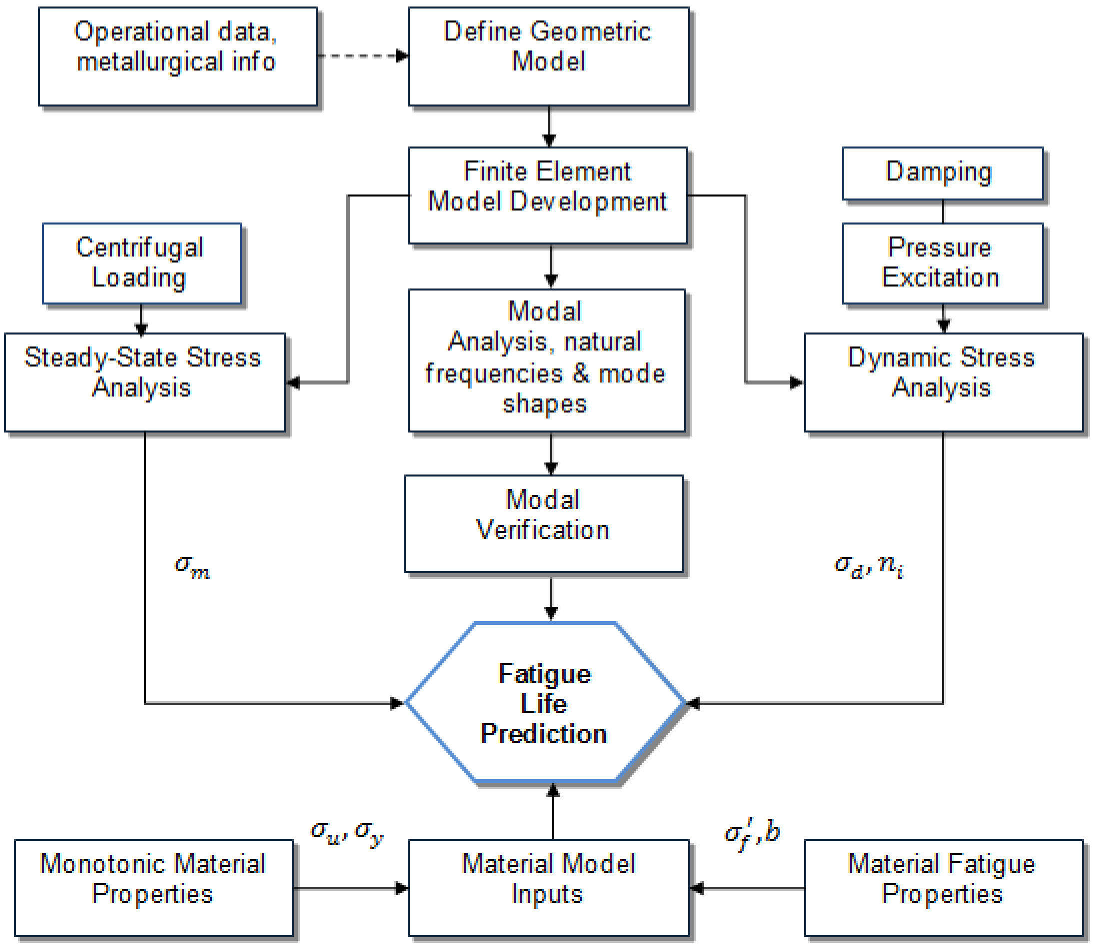
- Fatigue in LP turbine blades has been recognised to be one of the primary causes of steam turbine blade failures worldwide
- During start-up operation, blades experience vibration and resonances at critical speeds which produce high dynamics stresses resulting in high cycle fatigue damage.
- Life assessment and prevention of fatigue failures requires the development of a fatigue life model
- Probabilistic model eliminates overly conservative assumptions and allows for uncertainty in key variables to be accounted





Fatigue failure

Fatigue life modelling flow chart



Finite element modelling and analysis

Telemetry testing

Fatigue life analysis

Experimental material characterisation

Experimental materials characterisation

- Material properties required as inputs for the finite element and fatigue life prediction models
- 12% chromium martensitic stainless steel X22CrMoV12-1
- Prior to fatigue testing, tensile testing to determine monotonic properties
- Load controlled uniaxial fatigue testing
- Fatigue cycles tested were fully reversed tension-compression and tension-tension with a mean stress

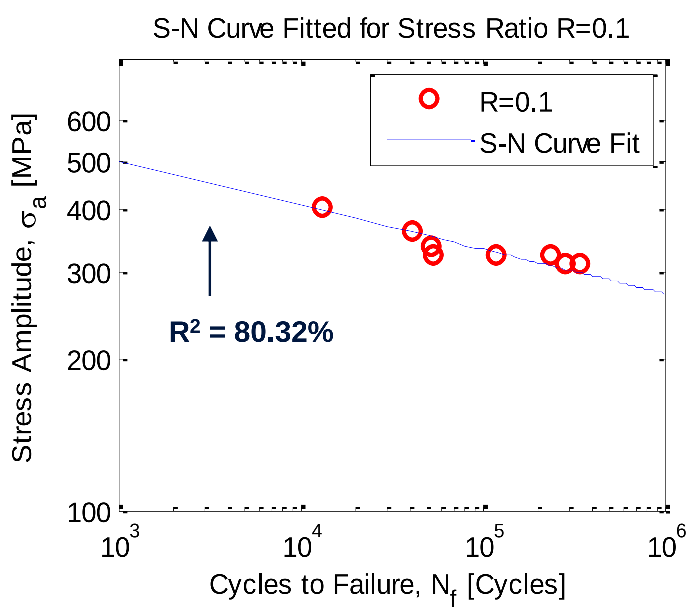
Tensile test specimen

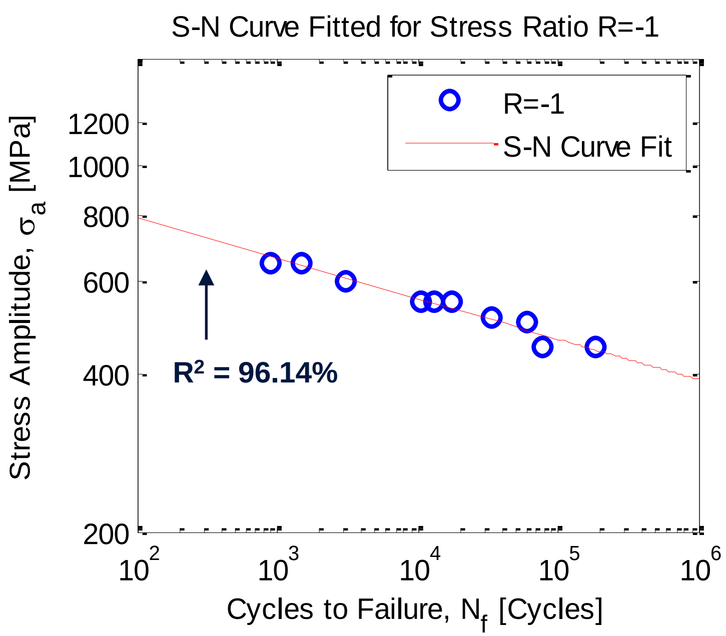
Fatigue specimen

MTS fatigue test equipment

Experimental materials characterisation

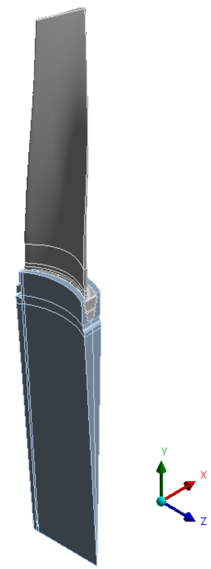
- Statistical modelling using linear regression analysis
- Goodness of fit revealed high coefficient of determination, R^2
- Sample run-outs not considered

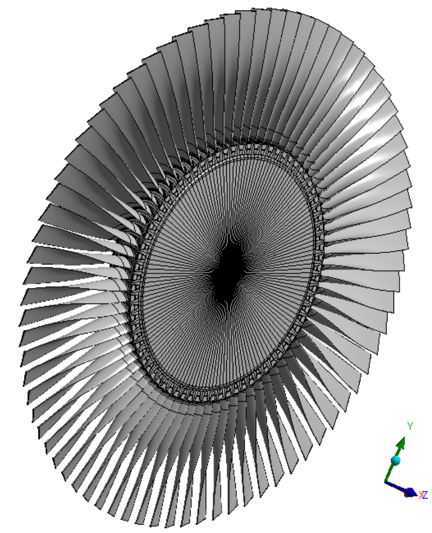


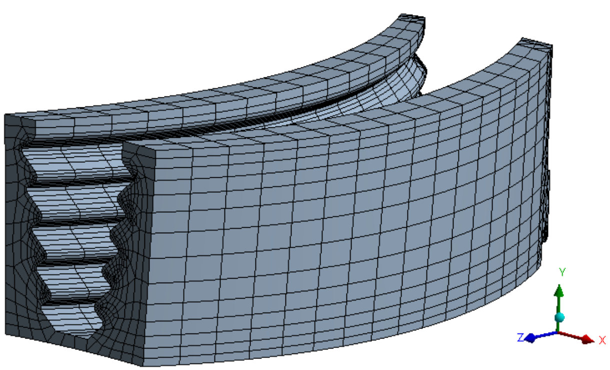


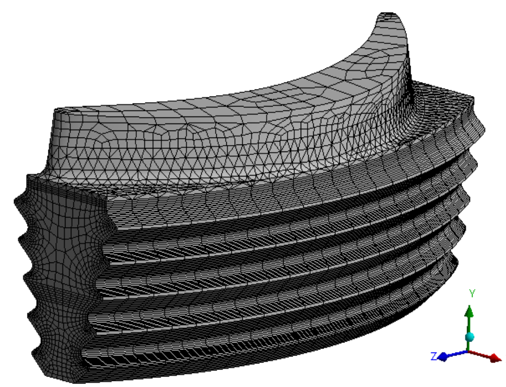
Finite element modelling and analysis

- Geometrical scanning to determine the blade topology
- Free-standing last stage LP blade
- Cyclic symmetric model based on principal of sub-structuring
- Higher order 3D 20-node solid elements
- 225009 nodes and 74891 elements
- Surface-to-surface contact



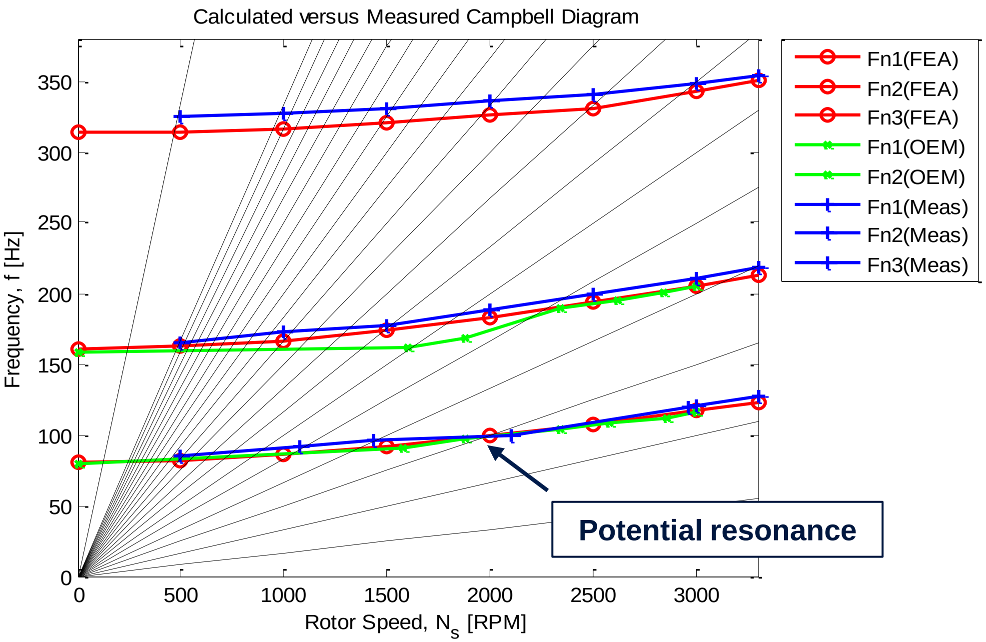




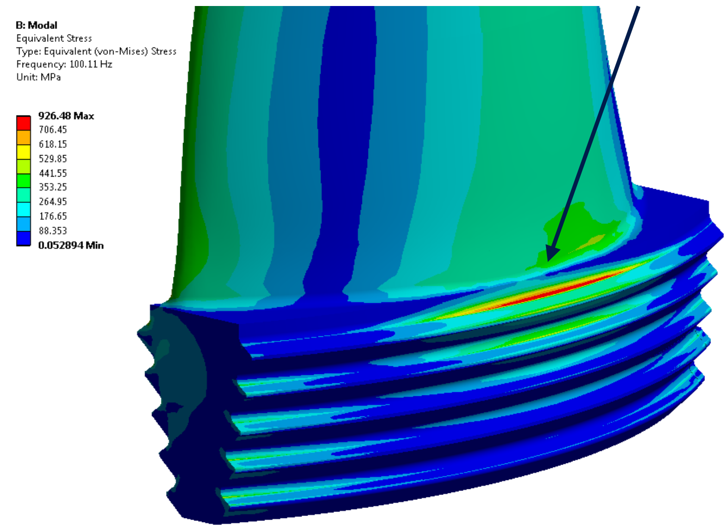


Finite element modelling and analysis

- Modal analysis to characterise blade natural frequencies and mode shapes
- Pre-stressed mode
- Campbell diagram identified potential resonance
- FEM validated against full scale spin test data on LP rotor and OEM results



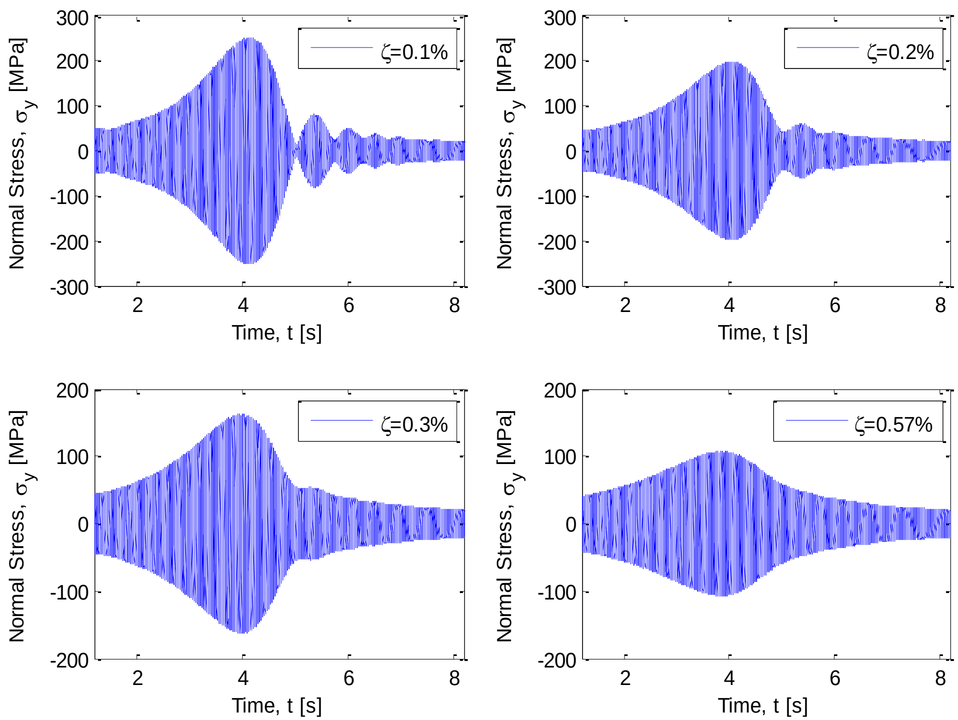
Peak stress location



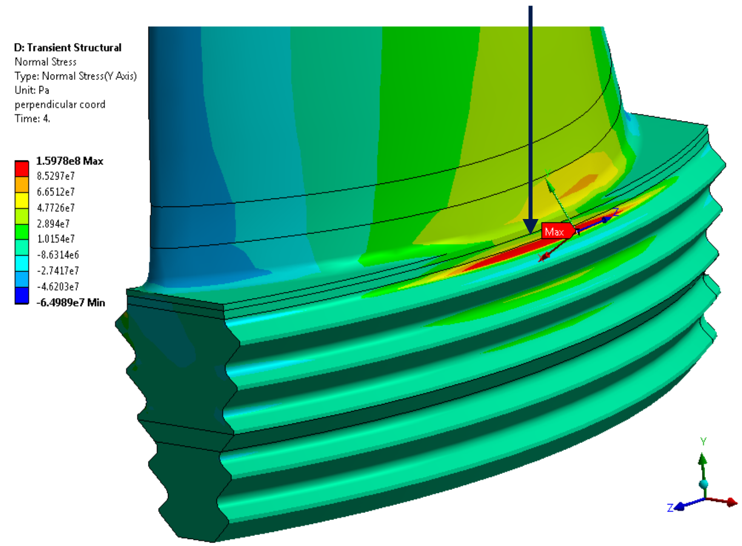
1^{st} Mode stress distribution

Finite element modelling and analysis

- Transient stress response assessed at resonance for twenty-four variations in blade damping
- A pressure excitation was formulated through approximations from the static steam forces during a turbine start-up



Max stress at first serration coincident with crack origin

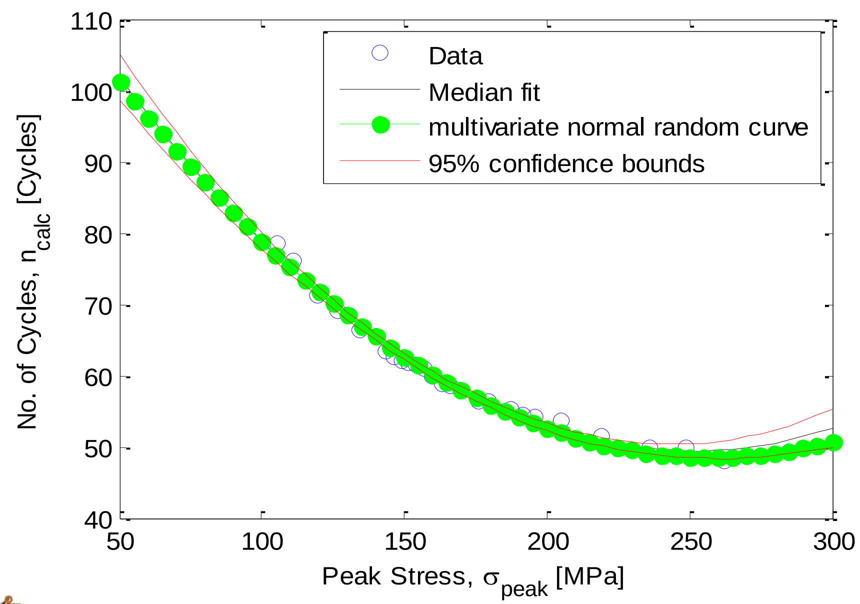


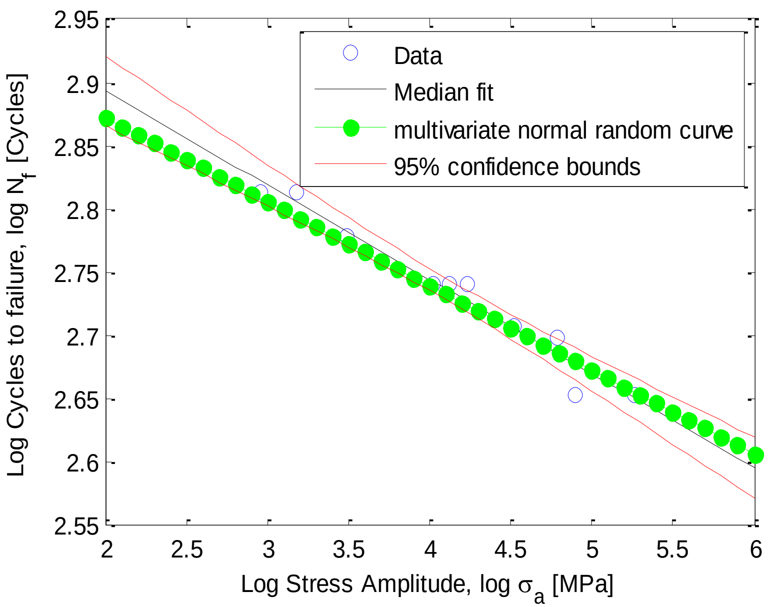
Probabilistic fatigue life modelling

- Uncertainty and variability in the material fatigue strength parameters and the stochastic nature of the transient stress in the blade root due to variability in blade damping is investigated by random variable simulations using a statistical analysis algorithm written in MATLAB.

- Random curve fitting routines were used to ensure the selection of the random variables used in fatigue life calculations is stochastic in nature

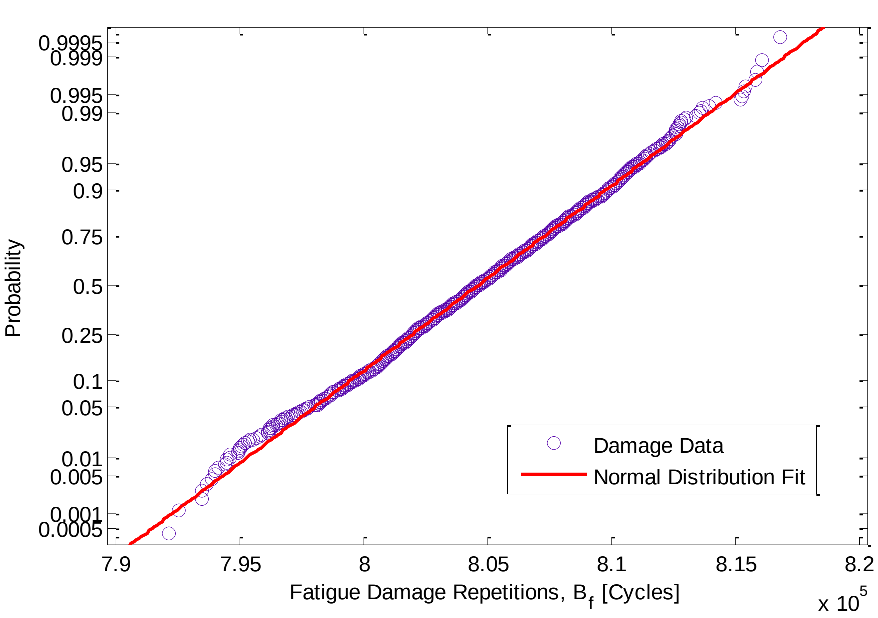
- Random vectors are then chosen from a multivariate normal distribution with mean μ and covariance Σ to create multivariate normal random curves based on the fitted data

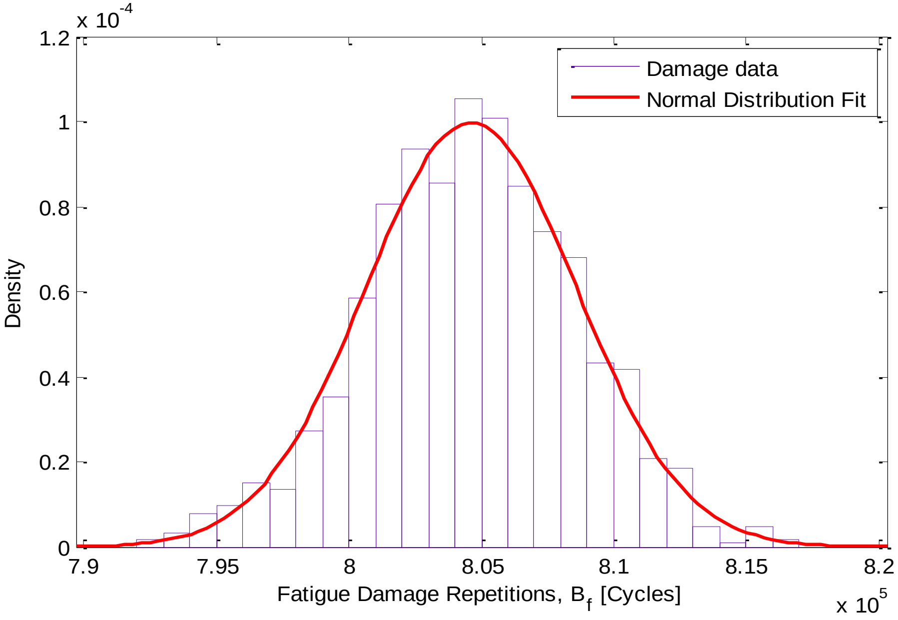




Probabilistic fatigue life modelling

- Results represent the number of repetitions, which for this case is turbine start-ups, required to initiate a fatigue crack which was defined as the failure point.
- Fatigue repetitions shown to follow a straight line indicating normality in the data.





Conclusion

- The probabilistic fatigue life model was successfully implemented to determine the fatigue life of a blade during a turbine start-up.
- The method is shown to adequately quantify variability in material strength parameters and varying root stress
- High dynamic stresses associated to low levels of damping had a low probability of occurrence however in the event they occurred they were shown to have a significant impact on the overall fatigue life
- The probabilistic results findings reinforced those of the discrete life model but showed that the discrete life solution to be more conservative in predicting the life of the blade.

Acknowledgements

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Thank you for your time!

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