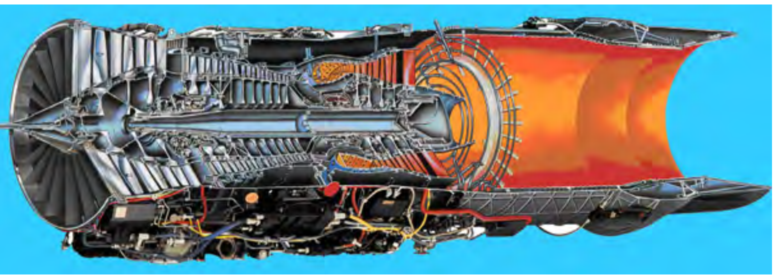
Life of Gas Turbine Components



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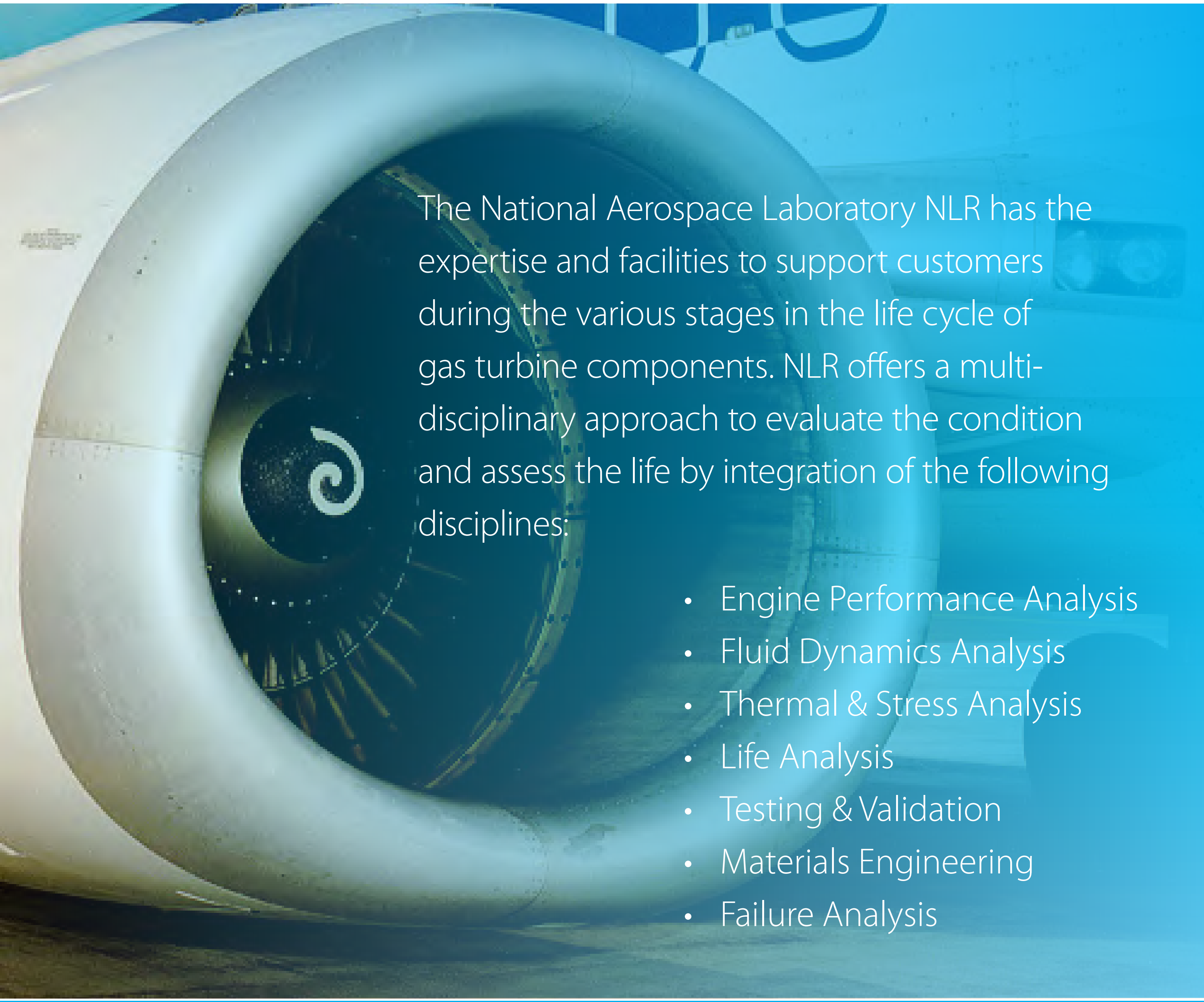

The National Aerospace Laboratory NLR has the expertise and facilities to support customers during the various stages in the life cycle of gas turbine components. NLR offers a multi-disciplinary approach to evaluate the condition and assess the life by integration of the following disciplines:

- Engine Performance Analysis
- Fluid Dynamics Analysis
- Thermal & Stress Analysis
- Life Analysis
- Testing & Validation
- Materials Engineering
- Failure Analysis

Engine System Performance

The Gas turbine Simulation Program GSP is NLR's primary tool for gas turbine engine performance analysis. GSP's flexible object-oriented architecture allows steady-state and transient simulation of any gas turbine configuration.

GSP is primarily based on 0D-modelling of the thermodynamic cycle of the gas turbine. The flow properties are averaged over the flow cross section areas at the interface surfaces of the component models. GSP utilizes component model stacking to create the thermodynamic cycle of the engine of interest.

GSP is a powerful tool for analysis of effects of ambient and flight conditions, installation losses, deterioration and malfunctions of control- and other subsystems on performance. GSP has been used for a variety of applications of both aircraft and industrial gas turbines:

- Gas path analysis
- Cycle optimization
- Steady state & transient performance analysis
- Parameter sensitivity analysis

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Fluid Dynamics Analysis

NLR has vast experience with aerodynamic analysis and design of turbomachinery components, using both Computational Fluid Dynamics (CFD) and throughflow methods. CFD delivers the full 3D flow field giving insight into performance deficiencies. CFD also provides high-resolution pressure and temperature distributions for use in thermal and stress analysis. For flow analysis, NLR uses ENFLOW (in-house developed CFD code for aerodynamic, aeroelastic and aeroacoustic simulations) or commercial software. For design optimization, NLR applies CFD-based adjoint and multistage inverse methods.

Examples of projects performed by NLR:

- Axial compressor analysis and redesign
- Centrifugal compressor redesign (impeller and diffuser)
- High Pressure Turbine optimization
- Influence of turbine vane repair on engine performance
- Seal analysis and design
- Influence of seal performance on stage and engine performance.

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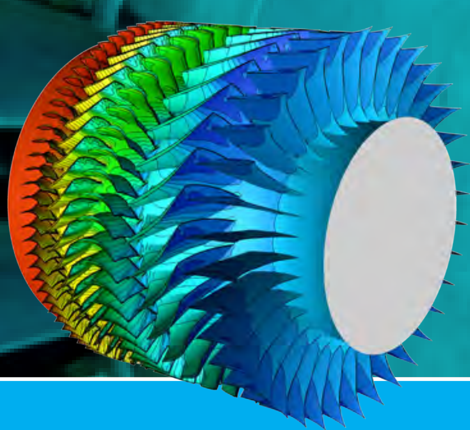
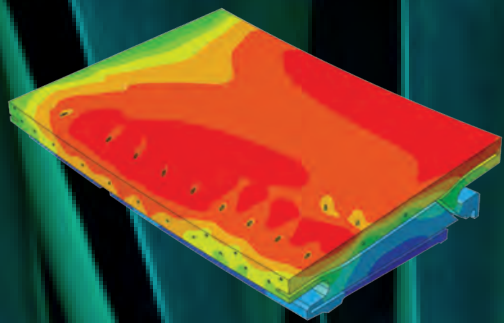


Thermal & Stress Analysis



Within NLR, extensive experience exists in prediction of temperatures and stresses in high temperature components, primarily using the finite element code Abaqus. The boundary conditions are derived using either engineering methods or CFD analysis. High fidelity transient analyses are applied and results are compared with data such as field failures and metallography.

Previously performed projects include:

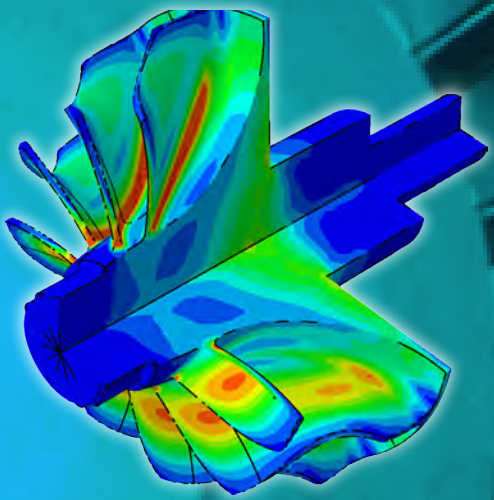
- Transient stress analysis of directionally solidified turbine blades
- Radial turbines
- Redesign of highly cooled single crystal solid shrouds
- Advanced single crystal and directionally solidified material modelling
- Combustion chamber flow, heat transfer and stress analysis

Life Analysis

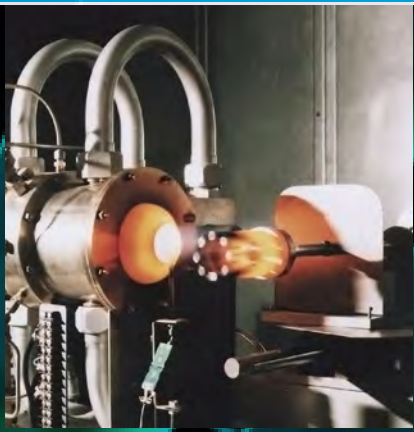
One of the main questions from customers to NLR is to predict the life of high temperature components. NLR has experience in life prediction based on diverse degradation mechanisms such as creep, low and high cycle fatigue, fatigue crack growth, oxidation, TBC spallation and wear. Empirical life prediction methods are combined with high fidelity (transient) finite element analysis to obtain a balance between life prediction accuracy and costs.

Completed life prediction projects include:

- LCF and creep life of axial turbine blades using detailed transient creep and stress analysis
- LCF life of radial turbines under transient operating conditions
- TBC life prediction model development
- Advanced life prediction models for single crystal materials
- Tip curl analysis of an LPT blade



Testing & Validation



NLR operates several facilities for high-temperature testing in near gas turbine engine environments. The NLR burner-rig is capable of evaluating the material and coating performance (life) under simulated service conditions, like:

- temperatures up to 1650 °C
- gas flows up to Mach 0.8
- injection of pollutants and erosive particles

The NLR advanced seal test rig is capable of evaluating the flow performance of dynamic seals (i.e. labyrinth, brush and new seal concepts) under simulated service conditions, like:

- Gas temperatures from RT to 760°C
- Pressures up to 24 bar
- surface speeds up to 365 m/s
- Active clearance control

NLR has several testing facilities to evaluate the material behaviour at high temperatures, like:

- Stress-strain behaviour
- Low and high cycle fatigue
- Creep
- Creep-fatigue interaction
- Corrosion / Oxidation
- Erosion

Materials & Process Engineering

Currently used materials in gas turbine engines exhibit a well balanced set of material properties. These advantageous material characteristics include high strength, high stiffness, creep & fatigue resistance coupled with good oxidation and corrosion resistance.

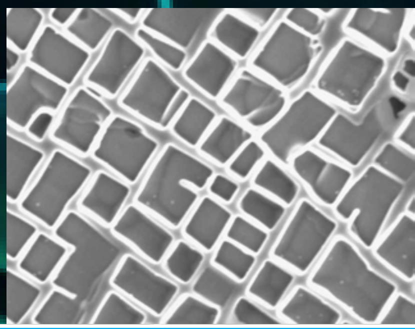
For more than 40 years NLR has investigated the material condition of gas turbine components made of advanced Nickel and Cobalt based superalloys by making use of inspection techniques like:

- Electron Microscopy (SEM)
- Chemical analysis (EDS/WDS)
- Crystallographic analysis (EBSD)
- Hardness testing

Materials for combustors, shrouds, turbine blades and vanes have been investigated for various stages in the life cycle of gas turbine components, as part of life, remaining life and failure analysis.

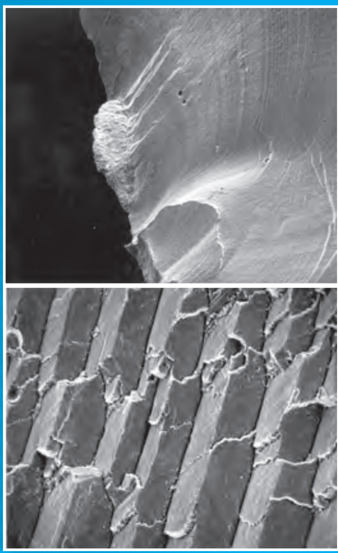
Customers in the gas turbine industry are supported with technologies for manufacturing and repair of gas turbine components. NLR has expertise in:

- Heat treatments
- Vacuum brazing and welding
- Laser additive manufacturing
- Microstructural stability and degradation



Failure analysis

The NLR has a long history in failure analysis, covering more than 350 cases over the last forty years. Most of the failure analyses have been done on aircraft and aero engine components. In addition to the aerospace cases many non-aerospace cases have been investigated. NLR provides small and medium enterprises as well as large (multi-national) companies a broad portfolio of failure and root cause analyses. These services range from detailed fatigue crack analyses to complete system chain of event analyses. NLR has been strongly involved in aerospace / aero engines but has successfully broadened their working area into other industries.



Multi-disciplinary framework for life prediction model

WHAT IS NLR?

The National Aerospace Laboratory (NLR) is the key centre of expertise for aerospace technology in the Netherlands.

NLR's facilities include wind tunnels (for development and testing of new aircraft produced by Airbus, Boeing, Lockheed Martin and others), simulators (for testing and training the safety of new flight procedures), and laboratory aircraft.

NLR employs around 700 people. NLR's revenue adds up to €75 million a year, with contracts accounting for €55 million (2011).

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