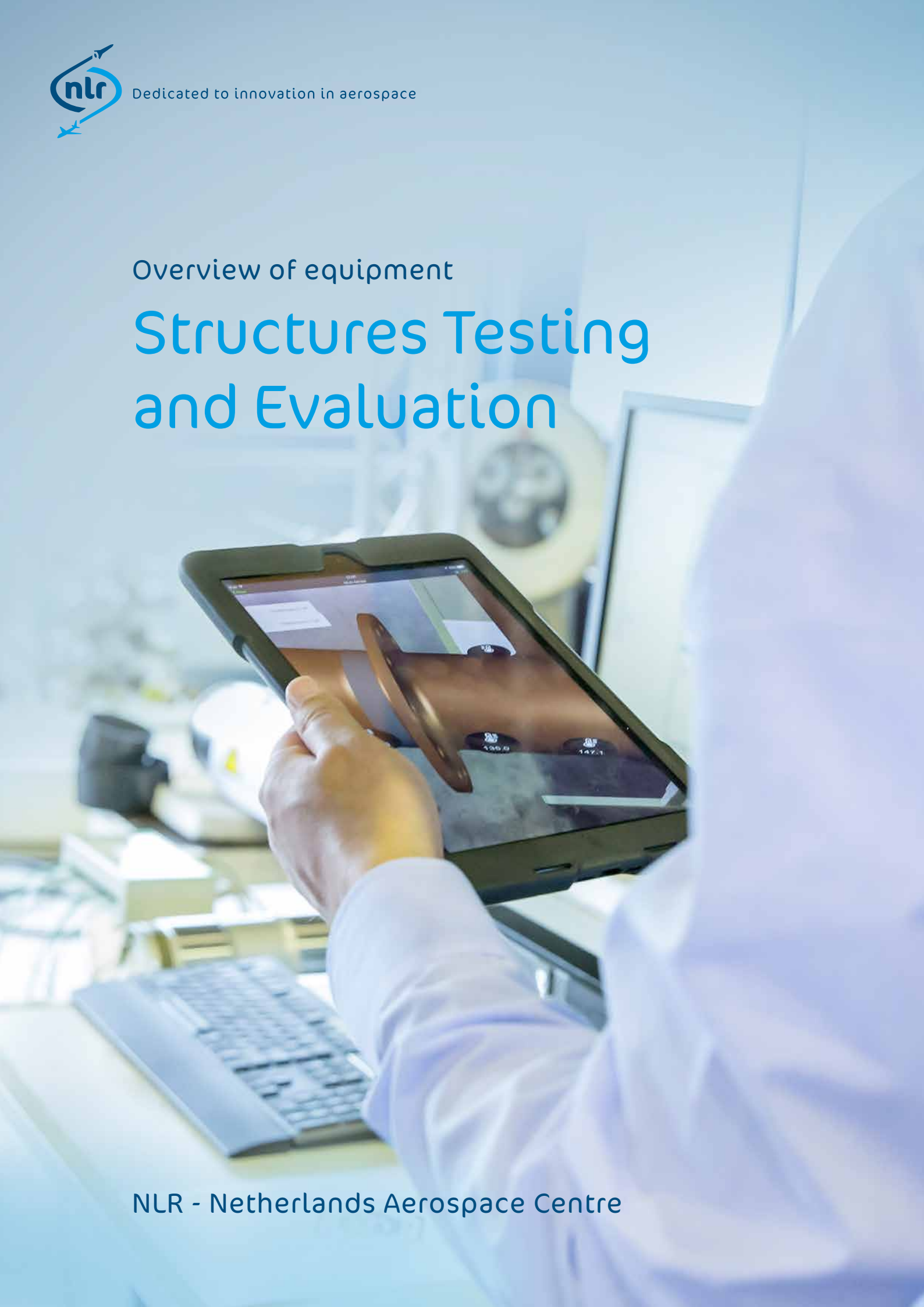
Dedicated to innovation in aerospace

Overview of equipment

Structures Testing and Evaluation



NLR - Netherlands Aerospace Centre

Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Its mission is to make air transport safer, more efficient, more effective and more sustainable. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and comprehensive solutions to the complex challenges of the aerospace sector.

NLR's activities span the full spectrum of Research, Development, Testing & Evaluation (RDT & E). Given NLR's specialist knowledge and state-of-the-art facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. They also turn to NLR because of its deep engagement with the challenges facing our clients. In this way, NLR bridges the gap between research and practical applications, while working for both government and industry at home and abroad.

NLR stands for practical and innovative solutions, technical expertise and a long-term design vision, regarding their fixed wing aircraft, helicopter, drones and space exploration projects. This allows NLR's cutting-edge technology to find its way also into successful aerospace programmes of OEMs like Airbus, Boeing and Embraer and SME's like GKN-Fokker and Airborne.

Founded in 1919, and employing some 650 people, NLR achieved a turnover of 76 million euros in 2017, of which 81% derived from contract research, and the remaining from government funds.

For more information visit: **www.nlr.org**

Table of contents

ACTIVITY AREAS

MECHANICAL TESTING

Coupon and materials testing

Static, fatigue and damage tolerance testing according to international standards or customer specifications. Materials testing, evaluation and qualification programs. Ambient, cryogenic or elevated temperatures; dry, wet or chemically enhanced.

Panel and component testing

Large complex component testing, shear / compression buckling, fatigue and damage tolerance testing, curved fuselage panel testing. Ambient, cryogenic or elevated temperatures; dry or wet.

Full scale testing, certification or research

Load spectrum generation, rig design, testing and inspections of aircraft parts like moveables up to full wings or tails. Ambient, cryogenic or elevated temperatures; dry or wet.

ENVIRONMENTAL TESTING

Testing of materials and systems under various environmental conditions. High/low temperature, humidity, salt spray, decompression, altitude and waterproofness testing. Additionally, vibration, shock, acceleration, electric and acoustic environmental tests can be performed at NLR.

MATERIAL EVALUATION

Failure analysis

Materials failure and corrosion analysis, metallurgical services and forensic engineering.

Non destructive inspection

Fully automated C-scan, Eddy current, ultrasound, dye penetrant, thermographic and magnetic inspection.

MEASURING, CONTROL AND CALIBRATION

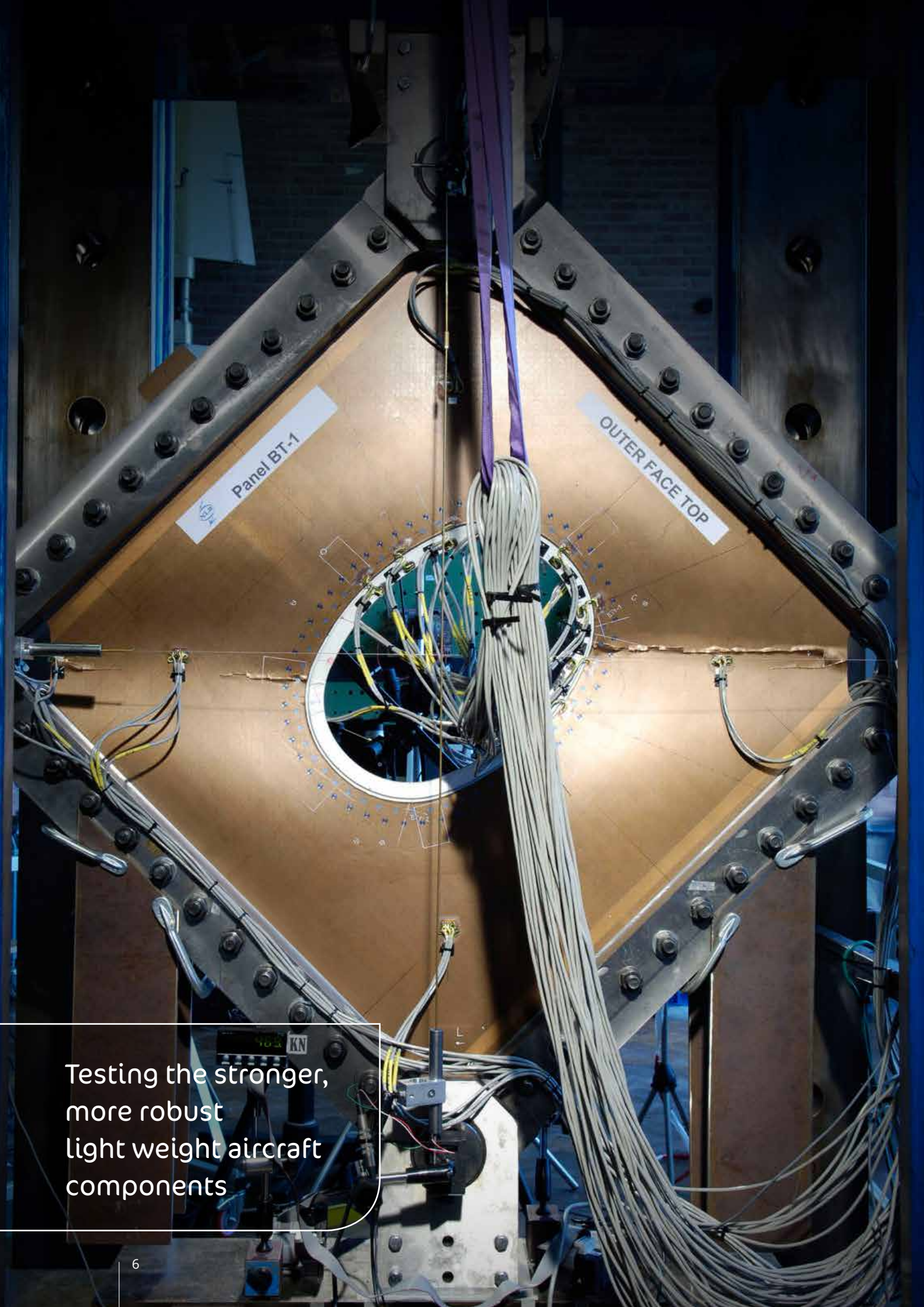
Calibration of test machines or equipment, measuring and control technology.

INTRODUCTION

NLR acts as a one-stop-shop for testing and certification of aircraft parts, structures and materials.

We have the capability to offer you inspection, testing, characterization and failure analysis. We can do that on material level, coupon level, component level or full-scale level. We can perform standardized tests, material qualification, certification tests, or tests made fit for your purposes. The tests can be of mechanical or environmental nature. The test articles can be made of ceramic, composite or metal, and can be small up to full scale. We can assist you in manufacturing and machining your test articles and help you to set up a test plan. Our simulation, engineering, manufacturing and machining capabilities enable us to provide you with the best tooling and test setup structures.

If you want, we can help you to use the results to improve your product, using NLR's design, manufacturing and maintenance skills and operational knowledge. This document gives an overview of available testing equipment, including its specifications.



Testing the stronger, more robust light weight aircraft components

MECHANICAL TESTING EQUIPMENT

Static test machines < 600 kN

Instron model 5882

Force range	:	100 N – 100 kN
Temperature range	:	-196 °C to +1200 °C
Humidity	:	70-95% RH / 50-90 °C
Testing speed	:	0.00005 to 500 mm/min
Horizontal test space	:	575 mm
Vertical test space	:	1235 mm

Instron 5882

Instron model 5989

Force range	:	600 N – 600 kN
Temperature range	:	-196 °C to +1200 °C
Humidity	:	70-95% RH / 50-90 °C
Testing speed	:	0.00005 to 508 mm/min
Horizontal test space	:	763 mm
Vertical test space	:	1790 mm

Instron 5989

Both Instron machines are equipped with 5900 controller, combined with Blue Hill III, featuring:

- 2.5 kHz data acquisition (high sample rate for brittle specimen)
- 16 channel data acquisition system for external data logging of temperatures, pressure etc.
- 2.5 kHz control loop update
- LabVIEW programmable interface

Creep testing

NLR can carry out creep tests on several materials, e.g. high temperature engine materials or materials for the Oil & Gas industry. A dozen generic test machines can be used for creep testing. Modular, low cost, specific creep test setups are used for large creep test programmes, including low and elevated temperature possibly combined with toxic environments (e.g. NORSOK).

Modular creep testing setup

Tests can be performed on the following samples:

- Cylindrical ASTM samples, M8, M6 and M4 interfaces are available.
- 3 mm flat plate samples according ASTM
- Specials on request (temperature, humidity, flammable, toxic environment etc)

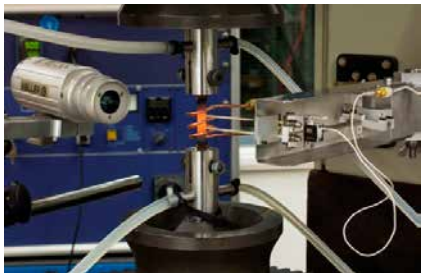
Maximum specimen length = 550 mm and width = 160 mm

Ovens are available for testing at the following temperatures:

- Two induction ovens for temperatures up to 1600 °C
- Three resistance ovens up to 1100 °C
- One resistance oven up to 1200 °C
- Induction coils for heating and simultaneous strain measuring

Loads are applied by dead weight and a low friction hinged lever. Forces up to 100 kN can be applied on the test sample.

Samples can be manufactured by NLR out of bare material or extracted from a specific part according ASTM requirements.



Creep test with coil heating, strain measuring and grip cooling

Static test machines > 600 kN

Avery

Force range	:	1000 kN tension 2000 kN compression Force and displacement controlled
Temperature range	:	-55 °C to +120 °C (+specials)
Rel. Humidity	:	controllable
Horizontal spacing	:	1040 mm between guides
Shear frames available	:	1000 x 1000 mm 800 x 800 mm
Max. specimen length	:	Compression without support: 630 – 3680mm Compression with support: 0 – 3680 mm Tension: 2470 mm (centre to centre)

Avery with video, DIC, high speed camera

Avery with rectangular shear frame, video, online monitoring, DIC, high speed camera

Dynamic test machines

The dynamic test machines below are equipped with Instron 8800 controller, combined with WaveMatrix softwareI, featuring:

- Up to 5 kHz data acquisition
- 5 kHz control loop update
- LabVIEW programmable interface

Complete software package including Matelect®
Direct Current Potential Drop (DCPD).
KIC & CTOD fracture toughness / J-Integral / Flight spectrum loading. Low Cycle Fatigue testing, strain controlled, high temperature.

Avery with environmental cabinet (80°C), video, DIC and high speed camera

2 x 100 kN (MTS and Schenck)

Load and displacement control

Max. specimen size	:	length: 600 mm width 85 mm (standard hydraulic grips) width 110 / 160 mm plate specimen mechanical grips
Temperature ranges	:	-80°C, RT, till +1300 °C

Horizontal spacing between guides: 700 mm

MTS

1 x 900 kN (Wolpert)

Load and displacement control

Force range	:	600 kN tension (100, 250, 500 and 1000 kN) 800 kN compression @ 210 bar (standard) pressure 1000 kN compression @ 280 bar pressure
Max. specimen size	:	Compression: Ø 190 mm x 1620 mm (max. load 500 kN) Beam: 600 x 180 mm, max 1220 mm Plate: 600 x 920 mm Plate: 600 x 1500 mm (< 250 kN)
Temperature ranges	:	-80°C, RT, till +1300 °C

Horizontal spacing between guides: 700 mm

24/7 full spectrum fatigue testing at -55 °C

2 x 200 kN (Amsler)

Load and displacement control

Max. specimen size : length: 1350 mm (max. 650 with hydraulic grips)
width: 50 and 160 mm (standard hydraulic grips)
width: 110 / 160 mm plate specimen
(mechanical grips)

Temperature ranges : -80°C, RT, till +1300 °C
Horizontal spacing between guides: 600 mm

1x x500 kN (MTS 500)

This dynamic test machine is controlled by a MOOG SmarTEST control system.

Force range : 500 kN tension
500 kN compression
Force and displacement controlled

Temperature range : -55 °C to +120 °C (+specials)
Rel. Humidity : controllable
Horizontal spacing : no limit (4 columns)

Shear frames available : 1000 x 1000 mm
800 x 800 mm

Max. specimen size :
- standard 500kN hydraulic grips length 1500mm, width 75
- standard 250kN hydraulic grips length 1600mm, width 160
- Wider specimens possible using non-standard mechanical grips

RR-Moore

High-speed rotating beam fatigue machines can induce fatigue cycles on a very high rate using a bending moment combined with a high rotating speed.

The RR-Moore machines have:
- a bending moment capacity of 2.5 to 23 Nm.
- rotating speed is 500 to 10,000 RPM (8Hz -170 Hz fatigue)

Several collets for various diameter straight shank specimens are available Upon request the machines can be fitted with a system to apply salt water conditions onto the specimens.

Amsler, crack growth sample, see below

Fully automated crack growth monitoring

MTS 500

RR Moore

Special mechanical test tooling

Special extentions of the standard test machines is one of the ways NLR tries to improve its possibilities

DCB-UBM

The standard double cantilever beam tooling has been replaced by uneven bending moment capabilities. The device is capable to test GI ,GII and mixed mode fracture toughness properties. Currently only static loads can be applied. An update to enable dynamic loading is under preparation. On top of the constant moment loading on the crack tip, this moment is also measured using an calibrated strain gauge instrumented load introduction device.

DCB-UBM

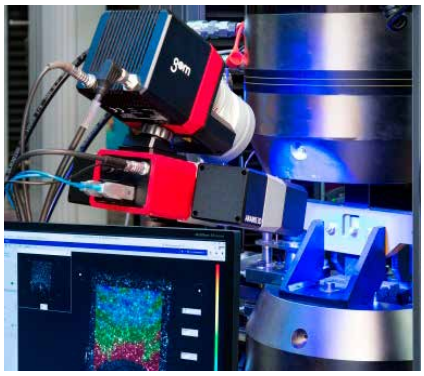
Bearing By-pass

In order to load the bolt/rivet in a loaded joint, with variable loading ratios, both in tension and compression, a bearing bypass extension on a standard Instron machine has been developed. Besides the hardware the master-slave steering makes this solution unique and usable.

Bearing By-pass

Automated 3D strain measurement

In several standard testing procedures the strain needs to be measured. This is traditionally done using strain gauges or clips. Alternatively NLR uses DIC optics, fully integrated into the Instron testing environment. After an initial calibration each strain measurement is just a simple click of the camera. Given the 3D optics also the strain (field) at the back end can be derived bases upon fronts train (fiels) and curvature (fields). For OHC testing this setup is very price competitive, since it makes 4 strain gauge per coupon obsolete.



Automated 3D strain measurement

Thermo-Electro-Mechanical testing

A special purpose testing machine has been developed within the EU-funded project DiDi. It enables testing of diode dies. It can dynamically test the diode, while a current (1600A) has been generated in one direction or a voltage (2000V) has been applied in the opposite direction. The whole testing is performed in a cyclic temperature regime (-55°C up to 150°C).

Thermo-Electro-Mechanical testing

Mechanical testing with toxic environments

Static, dynamic and creep testing can be performed, not only hot-wet or cold-dry, but also in combination with toxic environments and/or saturations. For the oil and gas industry material testing of composites saturated in Norsok is being performed. Temperatures up to 93°C, hence above boiling points, hence in pressuruzed contained autoclaves.

Mechanical testing with toxic environments

Multi-axial or full-scale testing

For full scale components, special test set-ups can be developed in close cooperation with the customer to meet international required standards. A wide variety of equipment is standard available from control and measurement systems to loading actuators and sensors to measure your parameters.

The NLR Structures Testing & Evaluation department works closely together with the NLR department Engineering and Technical services, and NLR Structures Technology department. This enables NLR to design and manufacture customized special test rigs and produce samples from metal and composite materials (using conventional autoclave cure, Resin Transfer Moulding, fibre placement or related technologies)

NLR can take care of every step in aircraft /aerospace full scale and component testing. The AVTH department is equipped with a wide range of testing, inspection and calibration facilities, enabling the performance of tests and meeting all necessary regulations.

Current airworthiness regulations require demonstration of adequate fatigue life and damage tolerance by means of full scale tests. Within the NLR organization the total process of testing can be carried out, starting from load generation techniques with realistic flight data, relevant testing techniques for static, fatigue and damage tolerance testing.

This certification and testing process can be sustained with certified inspectors. In close cooperation with the customer, special rigs can be designed for testing of aircraft parts. Specialists are available for implementation and controlling complex loading spectra. Specimens can range from simple component tests to full scale sized aircraft structure tests.

Besides full scale testing at ambient circumstances, hot/wet or cold testing can be performed. Several weeks (24/7) of full scale fatigue testing at -55°C have been done. Full scale testing encompasses both elastic deformation testing as kinematic system testing.

If desired, experts at NLR can advise on how to set up the tests, choose the correct test standard and specimen and carry out the tests.

- Realistic load spectra generation
- Test article development, (production) and modification
- Test setup and tooling design and manufacturing
- Non-destructive inspection, In-house calibration facilities and accreditations
- Measurement and control technology
- Crack growth and failure mode analysis and prediction
- Engineering results report generation
- Certification to authorities

G650 stabilizer

G650 Elevator

Dassault F7X spoiler

Bombardier C-series flap track testing at -55°C (24/7)

Testing stabilizers and elevators poses the dilemma what degree of realism the test environment should reach. A dedicated elevator test setup and a dedicated stabilizer setup is one possibility (see G650). Another is a combined setup. Loading both stabilizer and elevator at varying angels of deployment is a step dealt with in a cost effective manner.

Another cost driver for testing is the tooling. For full scale test and component test a extensive set of modular setup building elements is available:

- 'Meccano' beams of different length from 1m to 3m
- 'Meccano' bracketry and shear rods
- Whiffle tree:
  - Pads and pad brackets
  - Joints (with appropriate kinematic freedoms)
  - C-bars
  - Bleds

Research and quality assurance can go hand in hand. The 'Hands On Experience Centre' (HOEC) is a fixed setup, not project driven, used as a development platform for both research topics and quality assurance topics:

Current research topics:

- Time synchronous measurements and control
- On-line data monitoring
- Data base driven data storage
- On-line 3D data processing
- Rig-Less testing, moveables tested without test rig. Compare the amount of steel in the G650 Elevator test rig and the HOEC.
- Optical measurement systems validation

Current quality assurance topics:

- Training platform for operators and programmers
- Examining platform for continuous quality assurance
- Embedded software debugging platform
- Procedures testing platform

Dassault F5X Stabilizer and elevator loading with variable elevator deployment

Torsion test using modular setup building elements

Hands On Experience Centre (HOEC)

Special test machines

Fuselage panel test rig (Rotop)

Fuselage panels can be subjected to multi-axial loading conditions at room temperature, combining internal pressure with longitudinal load introduction (through lugs bolted to the skin at each end) and lateral load reaction at the frame ends and in the skin through a bonded interface. This bonded interface is a unique feature, providing a highly uniform hoop load, unmatched by any discrete bolted/riveted connection.

The design loads for the fuselage test facility were derived directly from the fatigue and static design loads of typical fuselage sections. This resulted in the following design loads for the test facility (the run- ning loads per mm panel width or panel length are given between parentheses:

Static	:	axial load	:	950 kN	(700 N/mm)
		ΔP / tangential skin load	:	140 kPa	(340N/mm)
Fatigue	:	axial load	:	450 kN	(334 N/mm)
		ΔP / tangential skin load	:	110 kPa	(340N/mm)

A range of different fuselage panels with different curvatures has been tested in the fuselage panel test rig. In the table below some typical examples of tested panels are given.

Aircraft	Fuselage diameter [mm]	Type of test	Type of loading	Goal
JAXA investigation	2880	Static + Fatigue	Constant amplitude	Natural crack growth in lap-joint
Airbus 380	5640	Static + Fatigue	Constant amplitude	Investigation of orbital joint and longitudinal joint at stringer
ANSA	3950	Fatigue + Damage tolerance	Flight simulation spectrum	Fatigue crack growth + demonstrate bonded repair patch
Shots Global Express	2693	Fatigue + Damage tolerance + Residual strenght	Flight simulation spectrum	Demonstrate technological feasibility of GLARE side-wall fuselage panels
Alenia ATR 42	2865	Residual strenght	Static + Constant amplitude	Verification of residual strenght models with and without multi-side damage (MSD)
Airbus A300	5640	Residual strenght	Static	Verification of residual strenght models with and without multi-side damage (MSD)
Fokker 100	3300	Static + Fatigue	Flight simulation spectrum	Demonstrate feasibility of GLARE and glare stringers and evaluate structural health monitoring systems

Bi-axial Test frame (Biax)

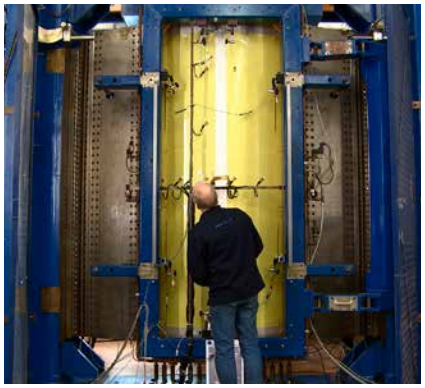
Static and dynamic testing in all four quadrants
Tension-Tension Tension-Compression
Compression-Tension Compression-Compression
Vertical load up to 500 kN, horizontal load up to 200 kN.
Dynamic testing performed up to 5Hz for common specimen.

Biaxial test frame (Atlas)

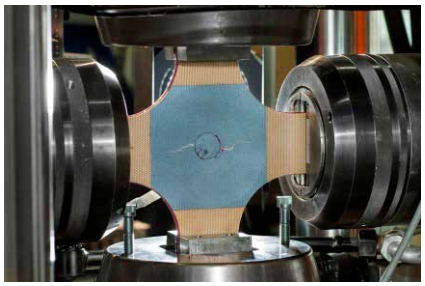
Force range # 1 1600 kN tension Force range # 2 200 kN tension
Force range # 2 500 kN tension Force range # 2 100 kN tension

Panel test rig

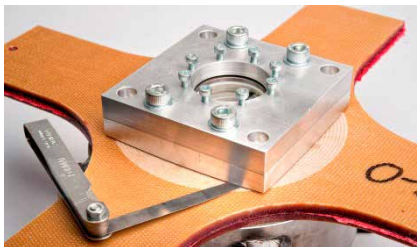
Horizontal test space 1400 mm ; Vertical test space 3000 mm
Force range 2300 kN tension ; 2300 kN compression



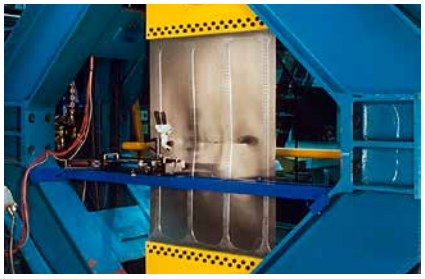
Rotop



Biax



Transparent Anti Buckling Guide for Biax



Atlas

Panel test rig

Portable impact system at work

Generic dynamic panel /sensor testing facility

A generic 2 axis dynamic test setup has been developed in which instrumented panels can be tested. Shakers can be used as well

- Development of Autonomous Wireless Sensors for loads & usage monitoring of military aircraft
- Bi-axial dynamic test under -30ºC temp.
- Combination of hi/lo frequency actuators provide unique test conditions
- Development of strain-based damage indicators for Structural Health Monitoring

Generic panel setup

Impact testing

Instrumented impact facilities are available for high and low speed impact testing. Mass and velocity are measured using calibrated instruments. Energy prediction and measurement is embedded in software system. Digital and hard copy output with all relevant impact data.

Mobile impacter

Handy low speed device, instrumented, mobile impactor up to 150 Joule using elongated tube, including catching device.

Mobile Impactor

Drop tower

7 mtr height with 10 kg weight. Incl. velocity sensor and load sensor. High speed DIC instrumentation possible.

Droptower

High velocity impact gun

Ice or metal projectiles up to 2 inches. Speed up to 210 m/s

Droptower with High Speed DIC instrumentation

High Velocity Impact Gun

NLR Environmental test facilities

- **Climatic**
  - Temperature
  - Humidity
  - Salt Spray
  - UV Light
  - Fluid Susceptibility
  - Altitude, Decompression & Overpressure
  - Waterproofness
  - Icing
  - Tear Down
  - Thermal Vacuum
  - Fungus
  - Sand & Dust
- **Mechanical**
  - Vibration
  - Shock
  - Acceleration
  - Static Load
  - Bending Resistibility
  - Pull Force
- **Electric**
  - EMI/EMC
  - ESD
  - HIRF
  - Lightning
- **Radiation**
  - Total Dose
  - Proton
  - Heavy Ion
  - Californium Cf-252
- **Acoustics**
  - Acoustic Noise
  - Transmission Loss

Tests performed externally under NLR responsibility

ENVIRONMENTAL TESTING EQUIPMENT

High/low temperature & humidity testing

The Testhouse of the Structures Testing & Evaluating Department operates four Climate Test Chambers for executing heat-cold tests in air conditions ranging from very dry to extremely humid.

Tests according to:
- RTCA DO-160
- MIL-STD-810
- IEC60068 Part 2-1, 2-2, 2-38, and 2-78

Specifications of climate chambers:
- Dimensions: 2000 × 3000 x 2000 mm (w x d x h)
  -10 to 80 °C and 20-90
- Dimensions up to: 910 × 1160 x 1110 mm
  -70 °C to +150 °C and 15-95%RH (between 10 °C and 95 °C).
  Maximum cooling rate is 3 °C/min.

Suitable for operational tests of electronic equipment. A complete range of power supplies can be used. Cable ports are available with diameters up to 100. In addition to testing of electronic components, NLR has a solid experience in testing composites and in accelerated corrosion testing.

Climate test chamber

Salt spray testing

The Testhouse of the Structures Testing & Evaluating Department operates two Salt spray cabinets for corrosion testing.
Standard and customized tests can be executed on avionics, coated and non-coated materials and structures. Solutions can be acidified or Sulphur dioxide can be injected periodically to simulate acid rain.

Test according to:
- DIN 50017
- ASTM B117-07
- ASTM G85-02 Annex A1, Annex A2, A3, A4
  (and Annex 5 (Salt/SO2) for cabinet 1 only)
- RTCA DO-160
- MIL-STD-810
- IEC 60068
- Other specific requirements

Temperature range between room temperature and +55 °C.
Maximum dimensions of Salt spray chamber 1:
- 1300 × 980 x 1320 mm (w × d x h)

Maximum dimensions of Salt spray chamber 2:
- 1010 × 640 x 1140 mm (w × d x h)

Cyclic tests can be executed with freely programmable spray, purge and soak periods.

Salt spray cabinet1

Salt spray cabinet 2

Fluid susceptibility testing

To perform fluid contamination tests on materials and equipment.
Tests according to:

- RTCA DO-160, MIL-STD-810
- Spray and Immersion tests
- Contamination with pasta like substances possible

Spray test facility specifications:

- Dimensions testbox: 750 × 700 × 500 mm (w × d × h)
- Fluid temperatures up to 80 °C (depending on flashpoint)
- Temperature controlled testbox
- Programmable spray intervals

Immersion test facility specifications:

- Dimensions testbox: on request

Fluid susceptibility cabinet

Icing test

Tests according to RTCA DO-160 Category C.
Tests according to RTCA DO-160 Category B on agreement.
Controlled with a climate chamber and cooled spray bottle.

Icing test

Waterproofness testing

Various test facilities for executing Condensing water proof test, drip proof test, spray proof test and continuous stream proof test.
Tests according to:

- RTCA DO-160
- MIL-STD-810

Waterproofness test and UV Tester

UV-testing

Tests according to:

- ASTM D4329, D4587, D4799, D5208, G151, G154 (Cycle 1-6)
- DIN EN 12224, 1297, 13523-10
- DIN EN ISO 4892-1
- SAE J2020

Fluorescent UV lamps:

- UVB 313; UVA 340; UVA 351

Specimen holder dimensions:

- 3 x 6 inch 4 x 6 inch Other dimensions on request

Climate cabinet with UV Tester

Decompression testing

As part of the NLR's 'One-stop shop' for Environmental test facilities, the NLR operates a Rapid Decompression test facility. This facility is developed to test the performance characteristics of avionics or materials during and after decompression. The main components of the Rapid Decompression Facility are two vacuum vessels, the decompression vessel (blue) can be evacuated to cabin pressures equivalent to 6000 to 8000ft. The big vacuum buffer (green) can be evacuated to pressures well below operation altitude. After opening a valve between both vessels, complete decompression of the small vessel can take place in 2 or 15 seconds to a maximum flight height of 52.000ft.

Determined during decompression tests are: leakage, deformation, rupture or explosion of (gasket sealed) containers, or a change in physical properties of low density materials.

In the past NLR has tested Avionics, Night-vision cameras, an AED, Pantry equipment like Bun warmers, Convection- and Steam-ovens, and all types of iPad's used as Electronic Flight Bag (EFB).

Decompression test specifications:

- Decompression test can be performed according:
  - RTCA DO-160G section 4
  - MIL-STD-810G Procedure III
  - Customized test-profiles upon request
  - Min. decompression time: 2 seconds
- Altitude testing
  - Altitudes up to 15.800 meters (52,000 feet)
- Overpressure testing:
  - Can be performed in our autoclave up to 200kPa
- Test Article dimensions 700x700x700mm
- Data acquisition (up to 20hz)
- Signal feed troughs for:
  - Power supply (3phase, Neutral & ground)
  - 9 thermocouples channels for K- or T-type
  - Video system
  - 19 Pins connector for test article data
  - Cooling water
  - 3 x USB

Rapid decompression test facility

iPad used as Electronic Flight Bag

Brazing and heat treatment

NLR is equipped with several high temperature furnaces for the brazing, heat treatment and the testing of materials.

Torvac Vacuum Furnace

In the full metal vacuum furnace, specimens with a maximum diameter of 280 mm and a height of 350 mm can be heat treated and/or brazed at a temperature up to 1250 °C. The furnace is automatically controlled and operates in vacuum mode or in a protective gas mode.

Torvac Vacuum Furnace

Air circulation furnaces

For the standard annealing and tempering of materials up to 750 °C with a maximum dimension of 350 x 350 x 350 mm.

Heat treatment furnaces

For the high temperature applications up to 1400 °C with a maximum dimension of 320 x 320 x 320 mm these furnaces are used for heat treatment and/or testing materials. Two furnaces are specially equipped with an installation to simulate a shock effect on the material and/or coatings.

Together with the 'Avionics Technology' department (ASAQ) an extensive set of environmental test capabilities is available.

Furnace #2 and #3

High-temperature materials and coatings fulfil the extreme requirements

Hot gas turbine parts testing

Turbine inlet temperatures in aircraft engines and land-based gas turbines are still increasing for improved performance and efficiency. High-temperature materials and coatings fulfil the extreme requirements. To improve component life and life cycle costs, special super alloys, coatings and repair schemes are being developed, which have to be tested.

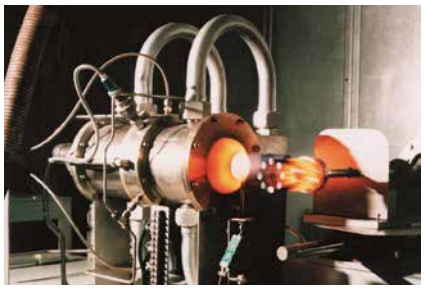
Because of the high cost of testing complete engines NLR operates two facilities for testing parts of gas turbines (blades, vanes) in high-temperature gas flows. With these facilities comparative tests can be carried out under simulated service conditions including pollutants, erodents and thermal shocks.
This way, coatings, materials and repair methods are evaluated for several customers which operate, manufacture and repair gas turbines, including Pratt and Whitney, the Royal Netherlands Air Force and KLM.

Burner Rig

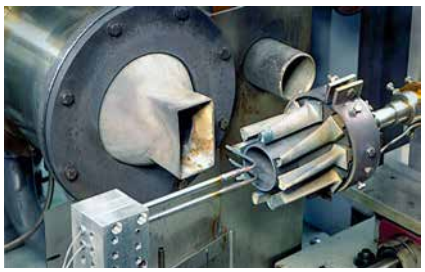
In the high-temperature Burner Rig, small specimens are studied in a test area of 50 mm diameter in which flight-by-flight temperature profiles can be simulated with temperatures up to 1650 °C. The maximum velocity of the gas flow in the test area is Mach 0.8. The high temperature Burner Rig offers the use of alternative fuels and features also pollutant and erodent injection. Specimen holders for testing specimens with internal cooling are available. Temperatures can be monitored accurately by thermo-couples and dual-wavelength pyrometry.

Compressor Test Rig and thermal fatigue

NLR's Compressor Test Rig has a test zone of 200 mm x 50 mm, with block temperature control. The air flow has a maximum temperature of 700 °C and a maximum velocity of Mach 0.6. This test rig is capable of injecting both pollutants and erodents. In addition, it features a facility for testing for thermal fatigue by cycling between the hot test zone and cold air or even water.



Burner rig



Burner rig test set-up with a specimen holder with turbine blades Leading edges

Specimen holders with internally cooled flat and cylindrical specimens

Microturbine

Microturbines are becoming widespread for Combined Heat and Power (CHP) applications. NLR operates a microturbine, as part of the development of a 3 kW recuperated microturbine by MTT for micro CHP applications. The turbomachinery is based on off-the-shelf automotive turbocharger technology. The primary objective of the test-rig at NLR is to select the appropriate turbine material by determining the creep behaviour under specified operating conditions. Secondary objectives are to validate software tools, like GSP (Gas turbine Simulation Program) and FE models, and to test alternative fuels.

Triple 3D

3D-scan, 3D-(re)design and 3D-print of a turbine disc.

Microturbine test rig and turbine disc after thermal paint test

Triple 3D re-engineered turbine disc

Where questions about materials are answered

FAILURE ANALYSIS EQUIPMENT

Scanning Electron Microscope

The Netherlands Aerospace Centre NLR of the Netherlands has a wide experience in the area of failure analysis and forensic engineering.

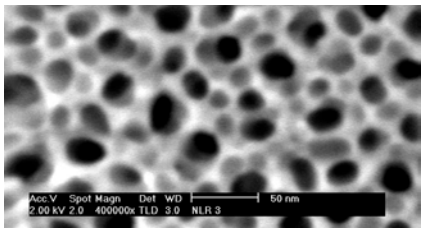
In the past 40 years, more than 400 service failure related investigations were performed under contract to industry and aircraft operators, in the following application fields:

- Aerospace
- Aircraft power plants and structures
- Energy supply (gas turbines and wind turbines)
- Mechanical, chemical and industrial engineering
- Manufacturing processes
- Offshore structures
- Automotive
- Shipping

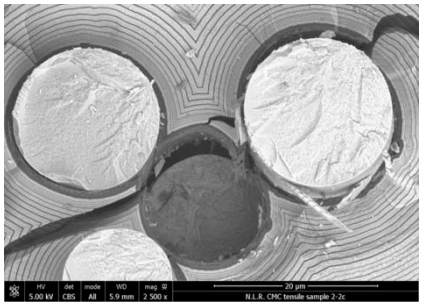
For failure analysis the NLR uses standard and advanced equipment, including;

- Optical microscopes, magnification up to 1000×, including high definition image capturing and image analysis
- Digital Binocular, magnification up to 1000×, including 3D
- reconstruction
- Scanning Electron Microscope FEI NovaNanoSEM450, magnification up to 500.000×. The microscope operates at high and low vacuum and has a large chamber for samples up to 150 × 150 × 150 mm. Conductive and non-conductive materials can be analyzed in the SEM. This SEM is equipped with EDAX Trident analysis system (EDX, WDX and EBSD).
- Energy Dispersive X-ray analysis (EDX) for the general analysis and X-ray mapping. This analysis method is used for qualification up to boron and quantification up to sodium
- Wavelength Dispersive X-ray analysis system (WDX) for the analysis of ultralight elements (up to boron) and trace elements present at 0,05 weight % or lower.
- Electron BackScatter Diffraction analysis system (EBSD) for crystallographic information, the determination of the local deformation near a crack tip and/or the influence of a mechanical/chemical process on the structure from a cross-section of a material. The analysis method can be used in combined with the information of the EDX analysis system.
- Digital analysis system for the quantification of micro-structural
- Features such as grain sizes, pores in anodised layers or particle
- distribution.
- 3-D analysis, 3-D quantification and reconstruction and/or characterisation of areal surface texture roughness
- Various non-destructive testing techniques
- Component analysis by FEM

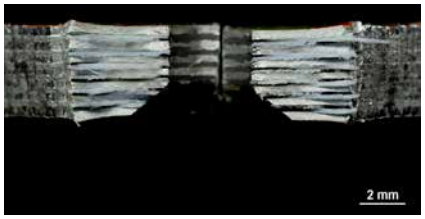
Scanning Electron Microscope



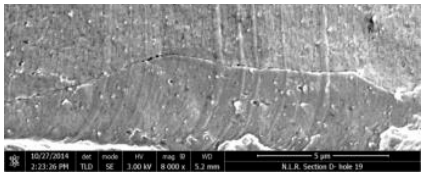
Anodised aluminium surface (400.000x)



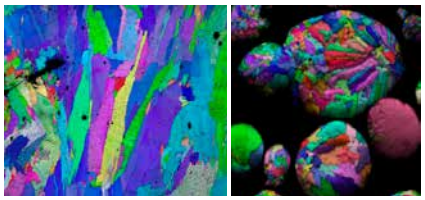
CMC investigation SiC/SiC



Fracture surface of glare skin



Severe flights on glare fracture surface



EBSD image of SLM part and powder particles

Material characterization

NLR offers a multi–level approach in material science for the essential feedback to design, manufacturing, material/failure analysis and maintenance.

For the material characterization the NLR uses a fully equipped material testing and investigation laboratory:

- Cutting machinery for rough and precision cutting of components
- Grinding and polishing machinery for the preparation of cross section for metal, coating, composite material, etc.
- Metallographic imaging equipment for microstructural examination and material characterization, magnification up to 1000x, including high definition image capturing and image analysis
- Portable microscope and replication kit for filed investigations, magnification up to 1000x, including 3D reconstruction
- Advanced photo equipment, including high speed camera and video
- Scanning Electron Microscope (SEM) for fractographic and metallographic analysis equipped with a material analysis system.
  - Bulk and micro hardness capability
  - Environmental testing equipment
  - High temperature environmental testing equipment

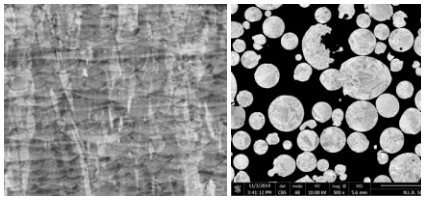
Cutting and Grinding/polishing machinery

Light microscope for material characterization

Micro-mechanical testing

For testing small test items or for the validation of FEM models the Netherlands Aerospace Centre NLR has 30 years of experience in the area of micro-mechanical testing, in the following application fields:

- Aerospace
- Mechanical and industrial engineering
- Manufacturing processes
- Product development



LM image of SLM part (welds and grains) and SLM powder particles

Advantages of the micro-mechanical test modules are:

- Flexible specimen geometry and sample design possible
- Flexible in use under binocular, light microscope, in the Scanning Electron Microscope (SEM) and/or as standalone system.

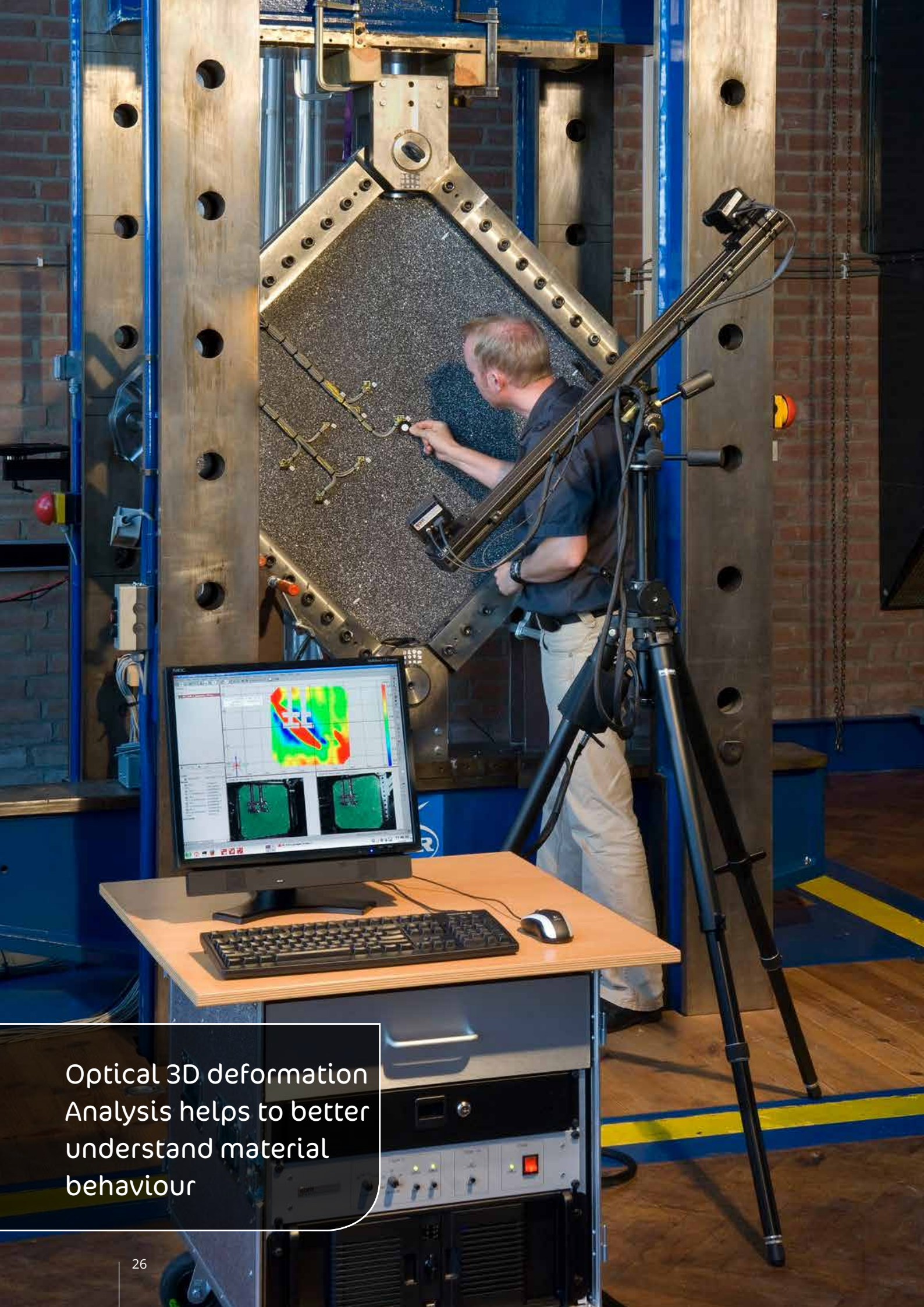
For the micro-mechanical testing the NLR uses standard and advanced equipment, including;

- Tensile and compression module, for tensile, compression, horizontal three and four point bending and DSB tests, load up to 5 kN
- Three and four point bending module, for vertical three and four point bending tests, load up to 2 kN
- Digital Binocular, for the visualisation at low magnification and/or samples that require a better depth of field
- Optical microscopes, for the visualisation of defects and/or crack at a magnification up to 500 x.
- Scanning Electron Microscope (SEM) NovaNanoSEM450, for the visualisation fine details and/or cracks at higher magnification
- Digital analysis system, for processing en analysing the data.
- Digital Image Correlation for processing and analysing the data
- Various non-destructive testing techniques, for combining the visualization techniques with the micro-mechanical testing and the non-destructive testing

Micro mechanical test setup

Digital binocular for visualisation

Eminence in finding small details



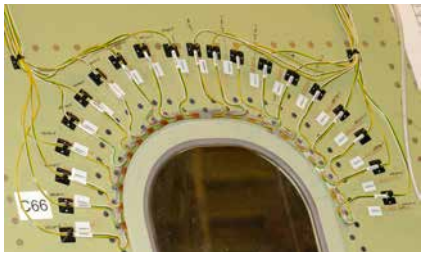
Optical 3D deformation Analysis helps to better understand material behaviour

MEASUREMENT AND CONTROL EQUIPMENT

Measurement techniques

A broad range of transducers types is available:

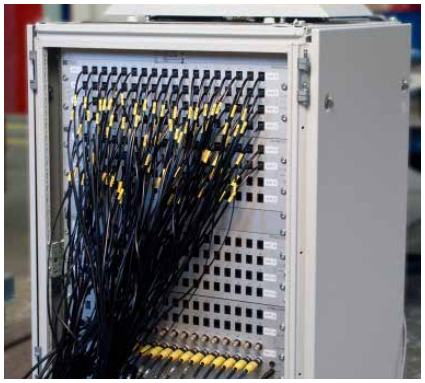
- Strain transducers (strain gauges, extensometers, DIC, lasers, fibre optic)
- Displacement transducers (LVDT, linear encoders, SPR, lasers, capacitive, draw wire, etc)
- Temperature (pyrometry, thermography IR camera, thermal paint, PT100, thermocouples)
- CMOD clip gauges (displacement of the crack mouth opening
- Loadcell's from 0 up to 2500 kN
- Pressure, acceleration, flow



Strain gauges on window panel

Data-acquisition systems

- Dedicated (strain gauge) multi-amplifier Peekel Instruments systems (up to 2500 strain gauge channels; 7 x dynamic 1kS/s, 3 x multiplexer 10 S/s, 4 x seq. scanner systems)
- 3 x 250 KS/s multiplexer NI PXI systems
- 6 x 200 KS/s multiplexer IOtech systems
- Dedicated (strain gauge) multi-amplifier HBM systems
- Wireless MicroStrain systems for strain, temperature, DC and acceleration
- High speed and/or high accuracy



Data Acquisition System (288 channels)

Control systems

- 6 MOOG Aerospace test systems, up to 500 channels
- Wide variety of hydraulic actuators
- Support of electric, pneumatic and hydraulic test systems
- RvA calibrated controllers, load cells and data acquisition systems
- Fully integrated with Peekel data acquisition systems
- Loop update rate 2.5kHz
- Centralized data base to access all tests and test data
- Pseudo channels, special functions, mixed force modes etc. to meet the most challenging test requirements

Typical Moog Control system

Photo-elasticity measurement techniques

Photo-elastic Stress Analysis (PSA) produces a full-field stress map of static or dynamic loaded objects with the help of polarized light

Key points about photo-elasticity:

- Result: Full field image of the difference of the main stresses ($\sigma 1$-$\sigma 2$)
- Thin plastic coating
- In-plane shear strains
- Directions of principal strains
- Simple static loads including assembly stresses
- Should view normal to surface
- Can measure residual stress in glass and plastic

Applications

- Verifying numerical and analytical models and calculations

Photo-elasticity setup

Passive Thermography

FLIR Thermovision A40 camera

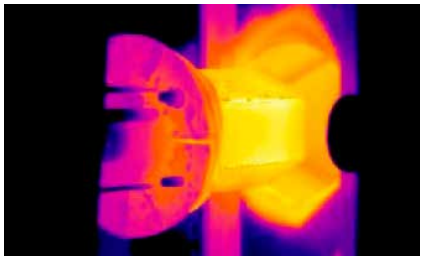
- 76.800 pixels resolution
- Spectral range 7.5 to 13 µm
- Thermal sensitivity @50/60Hz 0.08 °C at 30 °C
- Accuracy (% of reading) ± 2 °C or ± 2%

FLIR Thermovision camera

FLIR Thermovision A35 camera

Thermo-elastic stress analysis (TSA) is a technique that gives the stress field of dynamically loaded component of structure. TSA utilizes an infra-red sensitive (thermal) camera and the thermo-elastic effect, which describes a small reversible change in the temperature of an object as it undergoes an elastic deformation. TSA is ideal for:

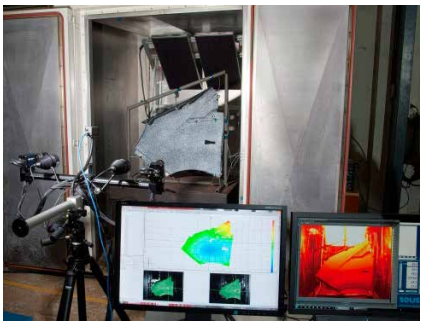
- Easy and fast evaluation of hot spots in components
- Crack detection
- Verification and iteration of Finite Element Models



IR camera result

Specifications:

- 86.016 pixel resolution (336x256)
- Spectral range 7.5 to 13 µm
- Thermal sensitivity @60 Hz 0.05°C at 30 °C
- MITE software

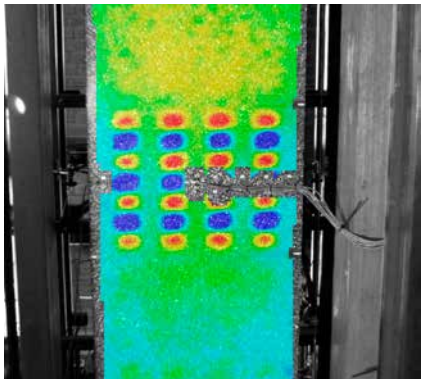


Thermo-elastic stress analysis combined with 12M DIC

Digital Image Correlation (DIC)

Optical 3D deformation field analysis for static or dynamically loaded components and structures is an effective, full-field, non-contact and material independent measurement solution; featuring:

- Visualization of strain gradients and hot spots
- Visualization of crack growth, crack tip opening and local/global strain fields/distribution
- Measurement of in-plane strains and 3D out-of-plane displacements
- Verification and iteration of Finite Element Models
- Verification of failure behaviour
- Investigation of fracture mechanics
- Design tool validation
- Tracking damage in (composite) materials



12M DIC displays a buckling pattern

GOM ARAMIS 12M

Specifications:

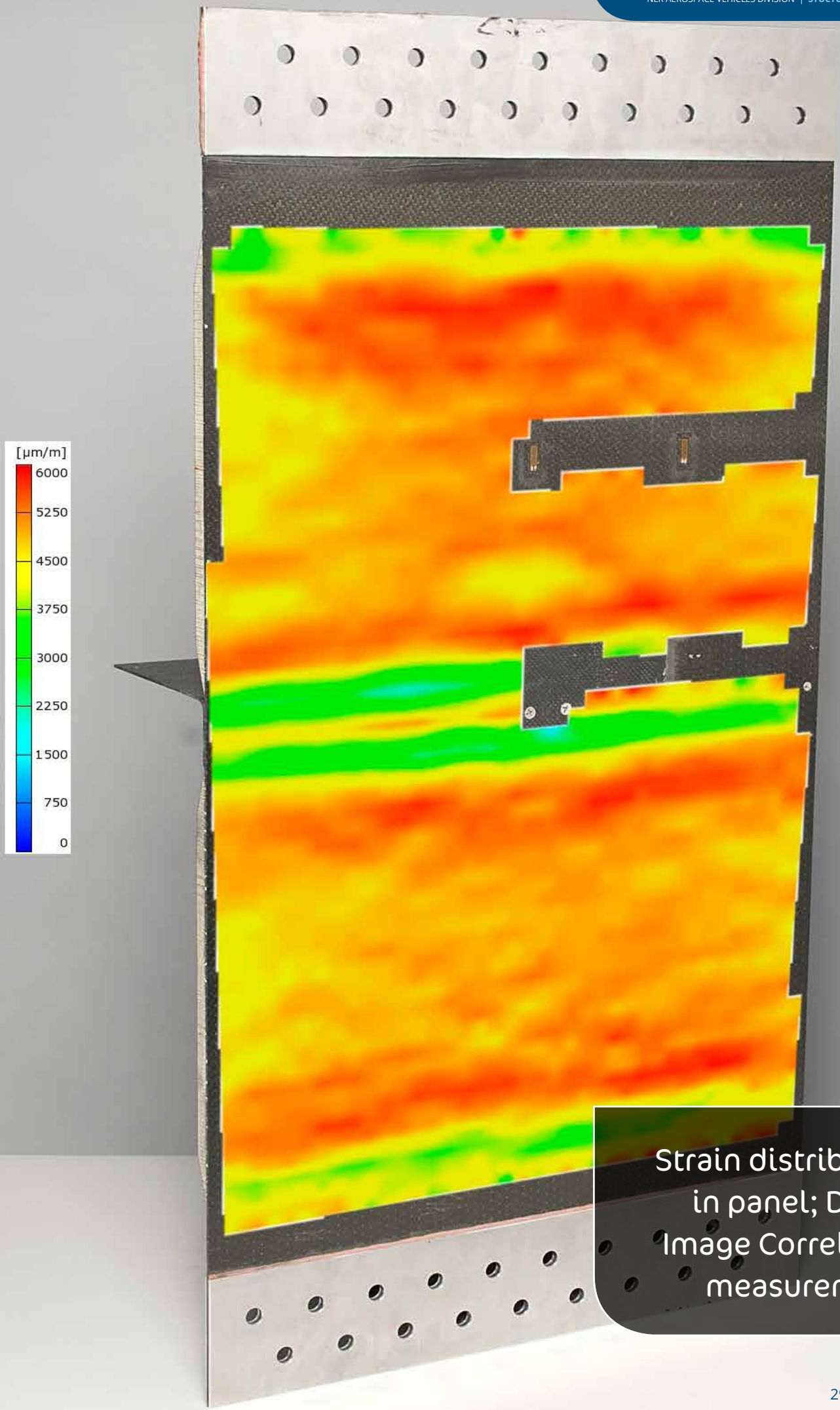
- Full-field analysis of small and large components
- 4000x3000 pixels camera resolution
- 58 images/sec
- High speed option with 2 high speed camera's (up to 7000 fps at 1024x1024 pixels resolution)
- 3D point/marker target tracking function (PONTOS)

GOM ARAMIS 6M

Specifications:

- Camera frame with integrated cabling
- Camera frame length: 300 mm
- Light Projector (Blue Light Technology,Light shaping, Revolver optics)
- 2x 6M pixel cameras, resolution 2750 x 2200
- Frame rate: 25 Hz (44 Hz with reduced resolution)

DIC measurement using 6M camera



Strain distribution in panel; Digital Image Correlation measurements

Stereo Pattern Recognition (SPR)
GOM PONTOS

The 3D point target tracking function PONTOS is based on the recognition and tracking of visible reflective markers on the object surface using stereo metric camera's and is based on Stereo Pattern Recognition (SPR) or more general on Digital Image Correlation (DIC) technology. Positions and movements of complex parts which cannot be measured directly (e.g. concealed components, etc.), are measured by means of adapters. With the use of high-speed cameras, the system is also suitable for measuring fast processes and motion sequences, e.g. for impact testing.

SPR is ideal for:

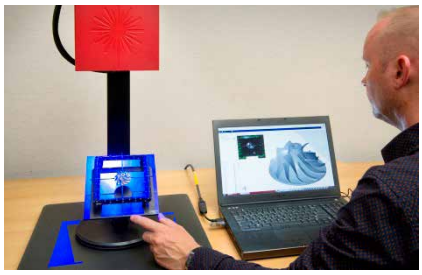
- Full field Structural Monitoring
- Complex motion tracking and analysis
- Component deformation analysis
- Mode shapes
- Relative motion
- Gap size changes

SPR system

Reflective markers on the elevator surface, recorded by SPR cameras for SPR processing of 3D displacements

Optical 3D measurements
GOM ATOS 200

- Measuring area: 200 mm x 150 mm
- Working distance: 250 mm
- Point spacing: 0.08 mm
- Sensor dimensions: ca. 206 mm x 205 mm x 64 mm
- Calibration object for this sensor with certificate



Optical 3D geometry measurement

Optical 3D Photogrammetry
GOM Tritop

Optical 3d coordinate measuring system

- Measuring volume 1 x 0.5 x 0.5 m^3: 0.015mm accuracy
- Measuring volume 10 x 5 x 5 m^3: 0.2mm accuracy

Optical 3D coordinate measurement

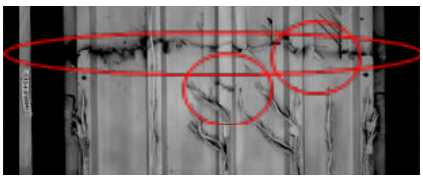
High Speed Video
Photron FASTCAM SA5

- Monochrome sensor
- Synchronization with integrated DAQ units
- Recording memory capacity:16 GB (1.5 sec. with max. resolution)
- Multiple camera synchronization: possibility for performing ARAMIS optical 3D deformation (DIC) high speed measurements

Performance examples:

- 1,024 x 1,024 pixels @ 7,000 fps
- 1,024 x 744 pixels @ 10,000 fps
- 512 x 512 pixels @ 25,000 fps
- 256 x 256 pixels @ 87,500 fps
- 128 x 128 pixels @ 262,500 fps
- 128 x 24 pixels @ 775,000 fps

High speed video



High speed video enabling the detection of the sequence of event:

Pyrometry

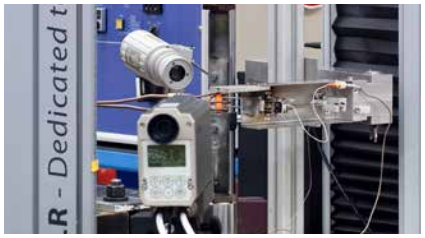
A pyrometer is a non-contacting device that intercepts and measures thermal radiation which can be used to determine the temperature of an object's surface

- Contactless
- Infrared radiation
- Emission coefficients

Types: Heitronics, Williamson, Keller, Optris

General specifications

- Temperature range .....-1500 °C
- Accuracy up to 0.5 °C
- Spot diameter min. 2 mm
- Optical viewfinders, display and laser aiming sight options
- Response time 5 ms – 600 sec



Pyrometry

Laser extensometer

Laser Extensometer

The laser extensometer - type parallel scanner is used for non-contact measurement of strain or compression of specimen at uniaxial load

Fiedler P-50:

- scanning range 50 mm
- working distance 100-300 mm
- accuracy class 0.2
- resolution 0.1 µm
- scanspeed 200 Hz

Potential drop

Potential Drop

Potential drop instruments for the measurement of crack initiation and propagation in metals, also in the presence of stress corrosion effects.

Potential drop techniques rely upon the basic principle that a conductive specimen that carries an electric current will exhibit a voltage drop across its surface. If the resistance of the specimen is known, the voltage drop can be calculated for any particular value of the current. Specimen resistance can be altered by the presence of a defect such as a crack. Thus, by maintaining a constant current through the specimen, it is possible to detect the initiation and propagation of a defect by monitoring the value of the potential drop.

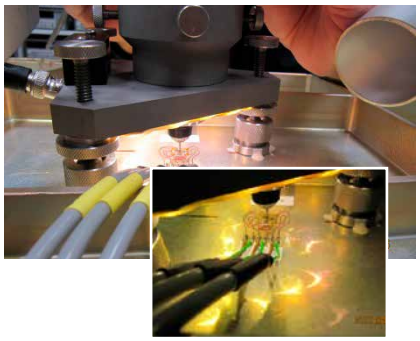
In potential drop studies, it is not usually important to know the absolute value of the resistance or voltage since it is the relative change in potential that is used to monitor crack growth.

Residual stress measurements
(hole drilling method)

The strength behaviour of components is influenced by residual stresses existing in these components without showing any visible signs.

The most widely used practical technique for determining residual stresses is the hole-drilling strain gauge method described in ASTM Standard E837. With this method, a specially configured strain gauge rosette is bonded to the surface of the test object. A small shallow hole is introduced into the structure, through the center of the gauge, with a precision drilling apparatus. Strains in the immediate vicinity of the hole are measured, and the relaxed residual stresses are computed from these measurements.

System:
- Vishay RS 200



Residual stress measurement
Courtesy: Airbus Defence & Space Netherlands

Fibre Optic Sensors

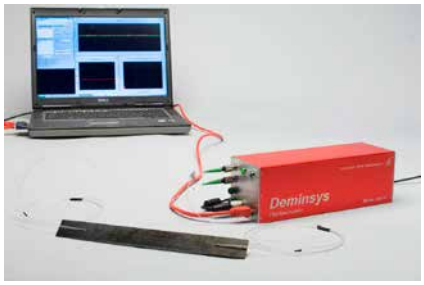
Fibre bragg gratings (FBGs) appear to offer the best prospect for large scale commercial exploitation of fibre optic sensor (FOS) technology. Main applications:

Structural Health Monitoring (SHM)/ damage detection
- environmental, accidental
- disbond/debond detection
- impact detection
- internal crack detection

Monitoring of physical parameters
- like strain/temperature/pressure/impact/vibration/flow; but also chemical parameters (gasses, humidity, corrosion,...)

Process monitoring of composite materials
- state of cure during manufacturing
- internal strain after manufacturing

General attributes
- High spatial resolution, high sensitivity, low signal loss
- Small diameter, light weight, flexible
- Immunity against, i.e. applicable in
  - Electro-magnetic fields, high voltage, lightning
  - Explosive or chemically aggressive + corrosive media
  - High and low temperatures
- Read-out unit galvanically separated from object
- Ability to measure different parameters such as strain, temperature, pressure, moisture, chemical compounds

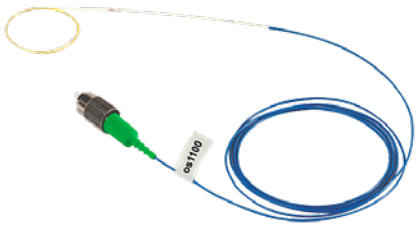


Deminsys system

Demonstration of the feasibility of specific SHM systems on a representative structure (Glare fuselage panel with bonded and riveted repair patches)

Specific Fibre Bragg Grating(FBG) attributes

- Multiplexing capability (“Sensor Networks”): 100’s of FBG sensors / fibre ! (instead of 1 electrical cable/strain gauge
- Embedding in composites/fibre-metal laminates like Glare ('Smart Structures')
- Wavelength encoded –transferable measurement, neutral to intensity drifts
- Mass producible at reasonable cost
- High and low temperatures (4 K .. 900 °C)



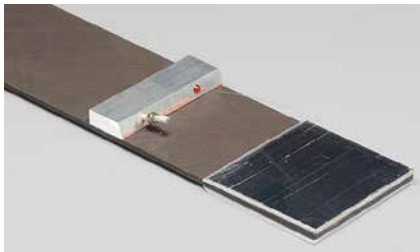
Fibre optic strain sensor

Embedding techniques (Smart Structures)
NLR has developed potential manufacturing techniques for the integration of optical FBG sensors in composites, optimized to avoid the problem with emerged fibres from the laminates during manufacturing:

- Embedding-after-manufacturing with hollow tubes method
- Embedding-during-manufacturing with integrated miniature connector

Interrogator

The currently by NLR used Deminsys interrogator is capable to scan with 20 kHz a total of 32 FBG sensors.



Embedded FBG sensor

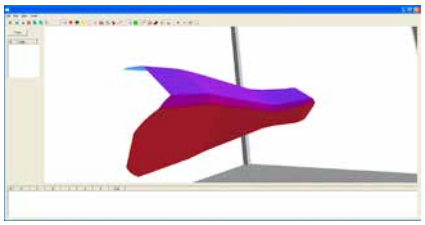
Effective NDI solution for composite components and other lightweight aircraft structures

NON-DESTRUCTIVE INSPECTION EQUIPMENT

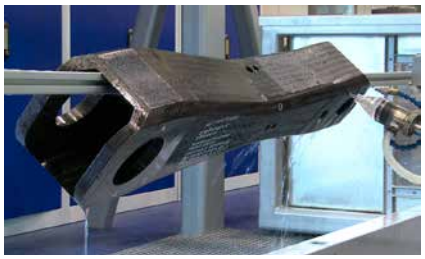
The Non-Destructive Inspection (NDI) group carries out a complete range of NDI services. Assistance is provided to airlines, air forces and aircraft component manufactures. Activities of the NLR include:

- Development and Evaluation of new NDI techniques
- NDI of composite and Glare materials
- In-service inspections
- Teardown inspections
- Investigating the reliability of NDI
- Structural Health Monitoring (SHM)
- Quality support (e.g. audits)
- Level III assistance and training/examination/certification of NDI personnel
- Failure analysis

The NDI group has specialists (NDI level 3 qualifications) and facilities enabling the development of inspection procedures in many NDI disciplines.



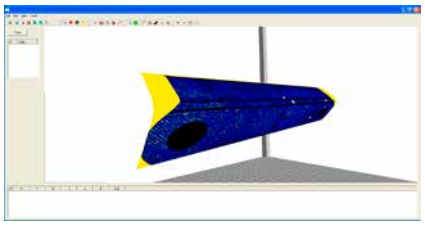
CATIA model



Complex 3D component

Visual Facilities and equipment

Visual inspection is the oldest, most economical and widely used inspection technique. Difficult accessible areas can be visually inspected with a state-of-the-art video inspection system which enables remote inspection. Test results can be stored on location and sent directly to the customer.



C-scan result projected on CAD model

NLR C-scan facilities

Automatic ultrasonic inspection (C-scan) is an effective NDI solution for composite components and other lightweight aircraft structures. With this C-scan inspection the quality assessment of a material or structure can be determined without impairing its further use. In the development stage of components the C-scan test results are a significant input for adjusting production parameters to improve the overall quality. Further, the C-scan inspections guarantee a consistent quality during the production stage.

3D C-scan facility

Ultis software environment enables automatic defect detection and characterization. AITM requirement representations included
Reporting automated to a large degree.
Uniform data processing over different devices.

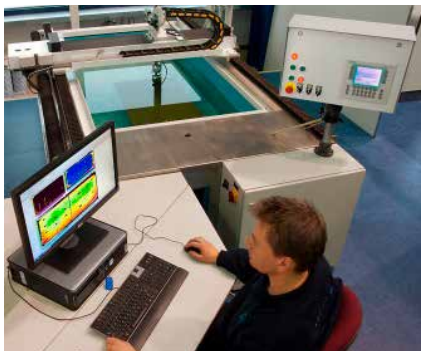
3D C-scan facility

- Scan window of X 4.0m × Y 2.5m × Z 2.5m
- Immersion and squirter inspection mode
- Scanning of complex geometry components (double curved) in
- Both pulse-echo and through transmission mode (simultaneously)
- Complex scan profiles generated from CATIA or by Teach and Learn
- Turntable to inspect 3D circular components (max. diam. 1.9 m)
- Advanced 3D data acquisition and analysis system
- Integrated ultrasonic equipment with full wave signal capture
- Linear Scanning Array (LSA), cost effective scanning of large surfaces

Squirter inspection large aircraft component

2D C-scan facility

- Scan window of X 1.8m × Y 0.9m
- Immersion inspection mode
- Scanning of flat components in pulse-echo mode
- TomoView advanced acquisition and analysis system
- TomoScan LT ultrasonic equipment with full wave signal capture
- Linear Scanning Array (LSA), effective scanning of large flat surfaces



2D LSA C-scan facility

Phased array ultrasonics

Phased array ultrasonics (PA-UT) is a very promising technique for the in-service inspection of composite structures. An important advantage of phased array technique is the possibility of real-time imaging during scanning (amplitude or time-of-flight C-scans) on location.

Portable UT equipment

- Sonic-138 flaw scope
- Krautkrämer USM25 DAC
- LeCroy LT342 digital oscilloscope
- Thickness gauges

Curved and roller probe

Additional NDI capabilities

Penetrants

Liquid penetrant inspection (PT) is used to detect small cracks or discontinuities open to the surface which may not be revealed by normal visual inspection. Penetrant inspection can be used on most airframe parts. The inspection is performed by applying a special liquid to the surface. This liquid has excellent capillary action and penetrates into very small defects. After a dwell time the excess penetrant liquid is removed. A suitable developer is applied to the inspection surface to draw back the penetrant out of the crack. A visual indication is then obtained by colour contrast or by fluorescence under black light.

In-service Phased array in action

Fokker Bondtester

The Fokker Bondtester technique (FBT) is based on the resonance impedance technique. It can be used for test the cohesion quality of adhesive bonded joints and to detect delaminations and/or disbonds e.g. in composite and Glare materials. Material defects can be detected by a shift in the dominant resonance frequency.

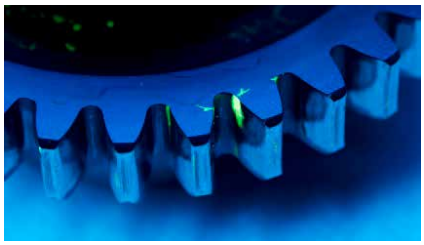
Acoustic emission

The acoustic emission technique (AE) is based on the principle that acoustic emissions are generated when defects initiate or grow in a material under stress. Acoustic emission is not a 100 % NDI method but can considered as a passive monitoring technique for the detection of dynamic defects such as crack growth and impact events.

Acoustic emission

Eddy current

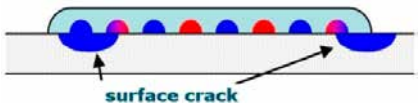
Eddy current inspection (ET) is a primary technique for the in-service inspection of metallic aircraft components. The technique is based on the response of induced currents that are caused in a conductive material when the material is subjected to an alternating electromagnetic field. The technique is capable e.g. to inspect longitudinal lap-joints and circumferential butt-joints of a fuselage, but also rapid bolt hole inspections are possible.



PT inspection of gear wheel

Eddy current array

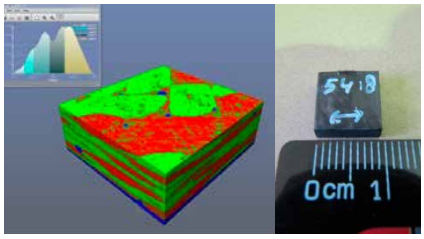
Eddy current array (ECA) inspection is a relatively new development in eddy current inspection. It implies the simultaneous use of a large number of EC coils which are integrated in a single probe. This application is typically for off-line EC inspection and allows wide-surface coverage of the inspection in a one-pass scan. Increases the scanning speed while maintaining a high resolution and allows real-time imaging (C-scan) of defects in the inspected part.



Principle of CVM

Comparative vacuum monitoring

Comparative vacuum monitoring (CVM) is a relatively new technique that can be used for monitoring areas of a component where damage is expected to occur. The technique is based on the principle that a small volume maintained at a low vacuum is extremely sensitive to any ingress of air. The working principle is illustrated in the adjoining figure, the red lines represent the vacuum lines, the blue the atmospheric lines.



Fiber (green/red) and void (blue)
CT-image of woven composite specimen

Computer Tomography

No NLR hardware is available yet, but AVISO software has been purchases in order to perform analyses on externally scanned components.

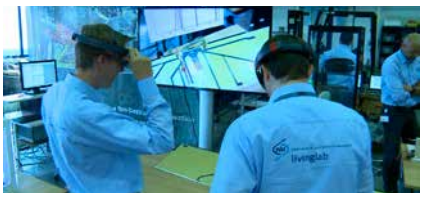
Magnetic particles

Magnetic particle inspection (MT) is capable of finding surface and subsurface detects in ferro-magnetic parts. A magnetic field is induced in the part and a powder or liquid containing iron oxide particles is applied to the surface. In case of a defect magnetic poles are formed which attract the oxide particles. This accumulation of particles will form an indication and can be obtained by colour contrast or by fluorescence under black light.

AR using a tablet

Augmented Reality used in NDI

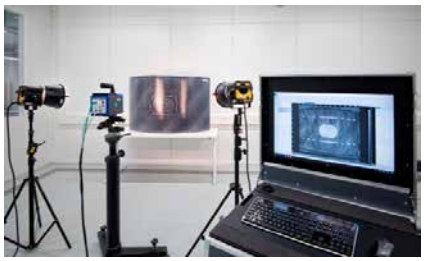
Augmented Reality is used to display NDO-images onto the hardware. Final goal is to guide the inspector towards the relevant information to be decided upon. This guidance can be computer assisted. The decisions can be discussed in a team effort.



AR using a hololens

Lock in Thermography

Optical Lock-in thermography (OLT) is a non-contact NDI method that monitors the heat radiation pattern on the surface of a test part. OLT uses a low-frequency modulated heating which is imposed on the test part using two sets of halogen lamps, differences in surface temperature are caused by internal features (discontinuities/geometry). The inspection technique is non-contact, fast and with a large field of view (1m2) and well established for the characterization of carbon fiber reinforced plastics after manufacturing and under in-service conditions.



Thermography on fuselage panels

NDI capabilities range from manufacturing quality validation towards in-service inspection

CONTACTS

Paul Arendsen
Structures Testing and Evaluation / Department Head
e) Paul.Arendsen@nlr.nl
p) +31 88 511 46 75
i) http://www.nlr.org/capabilities/structures-testing-and-evaluation

Hotze Jongstra
Coupons & Materials Testing
e) Hotze.Jongstra@nlr.nl
p) +31 88 511 46 49
i) http://www.nlr.org/capabilities/coupon-testing-materials-testing

Jan Docter
Panel Testing
e) Jan.Docter@nlr.nl
p) +31 88 511 46 57
i) http://www.nlr.org/capabilities/panel-testing/

Rens Ubels
Full Scale Testing
e) Rens.Ubels@nlr.nl
p) +31 88 511 49 70
i) http://www.nlr.org/capabilities/full-scale-testing-certification-testing

Bernard Bosma
Environmental Testing: Materials
e) Bernard.Bosma@nlr.nl
p) +31 88 511 46 54
i) http://www.nlr.org/capabilities/environmental-testing

Guus Vos
Environmental Testing: Equipment
e) Guus.Vos@nlr.nl
p) +31 88 511 47 43
i) http://www.nlr.org/capabilities/environmental-testing

Emiel Amsterdam
Failure Analysis
e) Emiel.Amsterdam@nlr.nl
p) +31 88 511 42 84
i) http://www.nlr.org/capabilities/failure-analysis

Marcel van der Kroeg
Failure Analysis; Operations
e) Marcel.van.der.Kroeg@nlr.nl
p) +31 88 511 47 41
i) http://www.nlr.org/capabilities/failure-analysis

Jacco Platenkamp
Non Destructive Testing
e) Jacco.Platenkamp@nlr.nl
p) +31 88 511 42 17
i) http://www.nlr.org/capabilities/non-destructive-inspection

Dedicated to innovation in aerospace

NLR'S CUTTING EDGE TECHNOLOGY FINDS ITS WAY TO AEROSPACE PROGRAMS IN CIVIL AND MILITARY SECTORS.

- Requirements & Specification
- Concept development
- Design & Analysis
- Prototyping & Manufacturing
- Testing, Verification & Validation
- Qualification & Certification

http://www.nlr.org/industry/

NLR Amsterdam
Anthony Fokkerweg 2
1059 CM Amsterdam
p) +31 88 511 31 13
e) info@nlr.nl i) www.nlr.org

NLR Marknesse
Voorsterweg 31
8316 PR Marknesse
p) +31 88 511 44 44
e) info@nlr.nl i) www.nlr.org