



Dedicated to innovation in aerospace

Overview of equipment

# Structures Testing and Evaluation



Royal NLR - Netherlands Aerospace Centre

## Royal NLR - Netherlands Aerospace Centre

NLR operates as an objective and independent research centre, working with its partners towards a better world tomorrow. As part of that, NLR offers innovative solutions and technical expertise, creating a strong competitive position for the commercial sector.

NLR has been a centre of expertise for over a century now, with a deep-seated desire to keep innovating. It is an organisation that works to achieve sustainable, safe, efficient and effective aerospace operations.

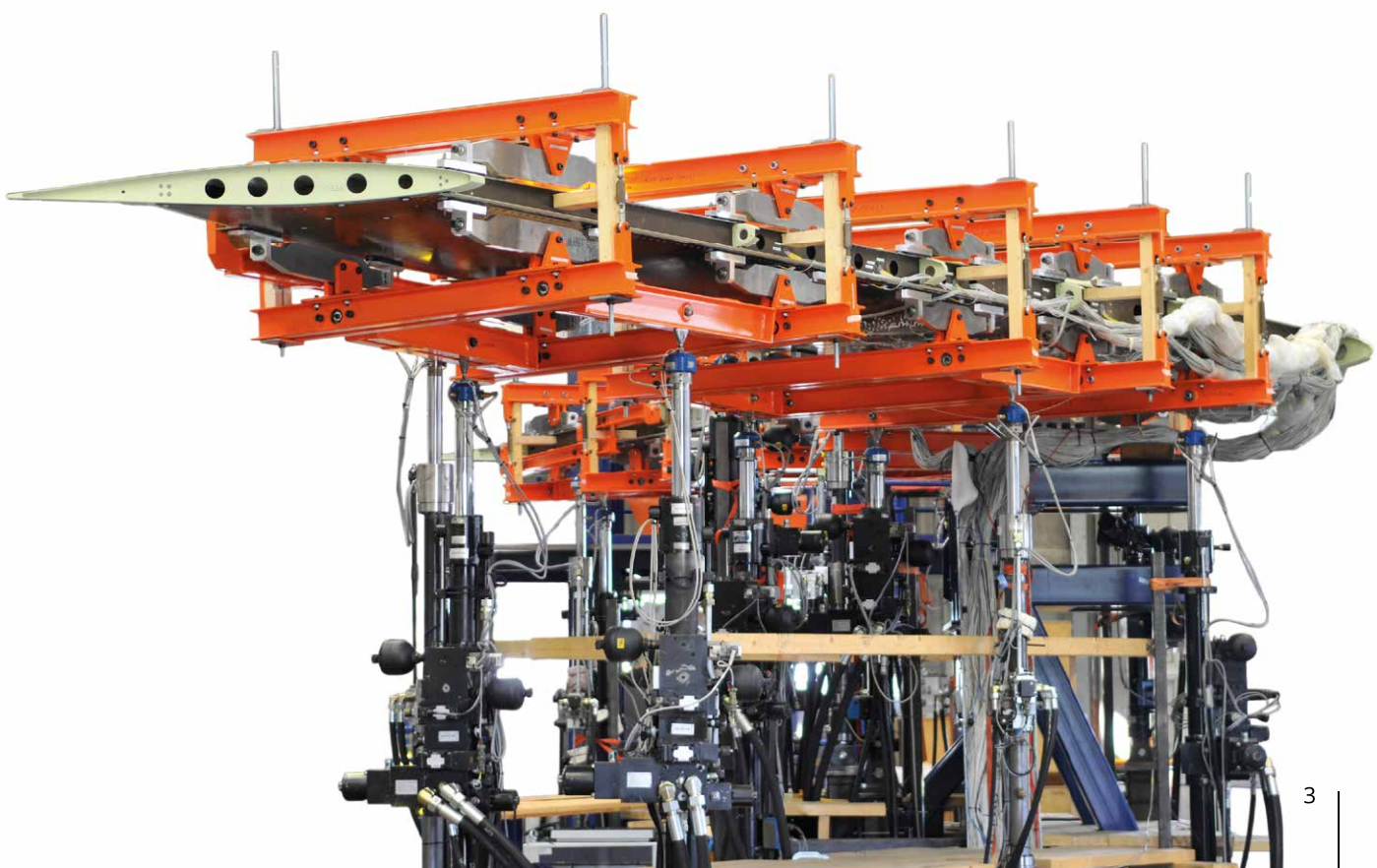
The combination of in-depth insights into customers' needs, multidisciplinary expertise and state-of-the-art research facilities makes rapid innovation possible. Both domestically and abroad, NLR plays a pivotal role between science, the commercial sector and governmental authorities, bridging the gap between fundamental research and practical applications. Additionally, NLR is one of the large technological institutes (GTIs) that have been collaborating over a decade in the Netherlands on applied research united in the TO2 federation.

From its main offices in Amsterdam and Marknesse plus two satellite offices, NLR helps to create a safe and sustainable society. It works with partners on numerous programmes in both civil aviation and defence, including work on complex composite structures for commercial aircraft and on goal-oriented use of the F-35 fighter. Additionally, NLR helps to achieve both Dutch and European goals and climate objectives in line with the Luchtvaartnota (Aviation Policy Document), the European Green Deal and Flightpath 2050, and by participating in programs such as Clean Sky and SESAR.

For more information visit: [www.nlr.org](http://www.nlr.org)

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## 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, (deep-) cryogenic or elevated temperatures; dry, wet or chemically enhanced. Chemically enhanced ranges from (toxic) oil and gas related substances to (liquid) hydrogen.

#### 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. Material failure analysis is performed mostly both post-mortem but also in-situ.

#### Non destructive inspection

Fully automated C-scans, submerged and squirter mode, single beam and phased array, Eddy current, ultrasound, dye penetrant, thermographic, shearographic, 3D structured light and magnetic inspection.

### MEASURING, CONTROL AND CALIBRATION

Calibration according to ISO 17025 of test machines or equipment, measuring and control technology.

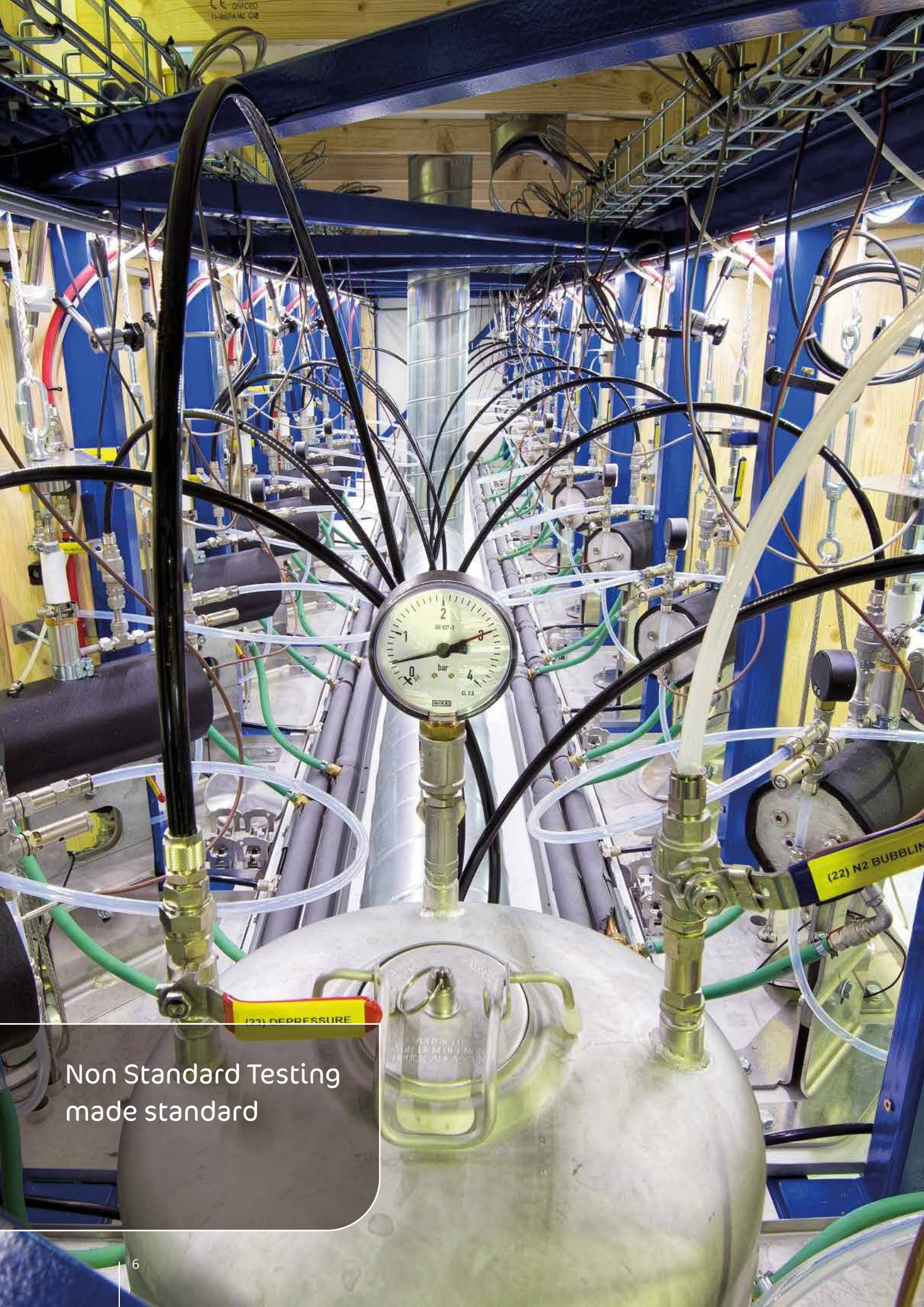
# INTRODUCTION

NLR acts as a one-stop-shop for “Non-Standard” 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.





Non Standard Testing  
made standard

# 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 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

Both Instron machines are equipped with 5900 controller, combined with Blue Hill 3, 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

## Static test machines > 600 kN

### Avery

Force range	: 2000 kN compression 1500 kN tension (special tooling needed) 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)

Controlled by Instron ISRS 5500 controller, combined with Partner software, featuring:

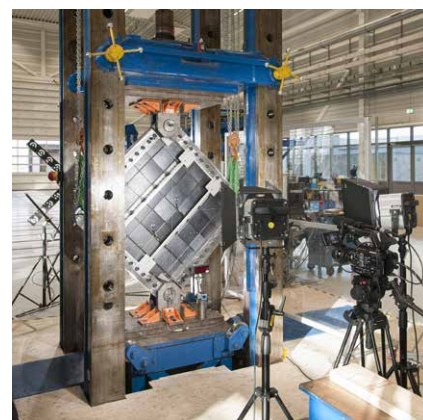
- 2 channel data acquisition system for data logging of load and ram displacement



Instron 5882



Instron 5989



Avery with rectangular shear frame, video, online monitoring, DIC,

## Dynamic test machines

The dynamic test machines below are equipped with Instron 8800 controller, combined with WaveMatrix 2 software, 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.

### 20 kN (ElectroPuls E20000)

Full electric test bench

Max. specimen size : length: 850 mm excluding grips  
width: 25 (standard pneumatic grips)

Horizontal spacing between guides: 515 mm

Other gripping options on request

### 20 kN (Minima)

Max. specimen size : length: 750 mm excluding grips  
width: 25 (standard hydraulic grips)

Horizontal spacing between guides: 355 mm

Other gripping options on request

### 3 x 100 kN (MTS, Maxima and Schenck)

Load and displacement control

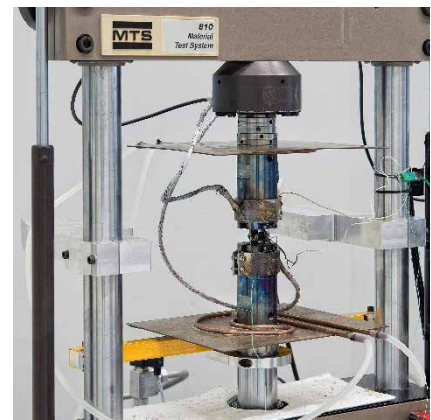
Max. specimen size : length: 600 mm  
width 85 mm (standard hydraulic grips)  
width 110/160 mm plate specimen mechanical grips

Temperature ranges : -80°C, RT, till +1300 °C

Horizontal spacing between guides: 700 mm



*Instron E20000 All Electric dynamic test machine*



*MTS, dynamic testing of coupons with heating and cooling devices*





### 1 x 900 kN (WolpertAMSsler)

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

### 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 : 1000 x 1000 mm  
available 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

### Mechanical testing with enhanced chemical environments

Dynamic testing can be performed, not only hot-wet or cold-dry, but also in combination with special (toxic, explosive) environments and/or saturations. For the energy industry material testing of composites saturated in Norsok has been performed, leading to the first certified DNV-GL F119 compliant material.

Temperatures up to 93°C, hence above boiling points, hence in pressurized contained autoclaves. Preparations are ongoing to enable testing with hydrogen and carbon-dioxides. Higher temperatures up to 120°C are under development.



*Amsler, crack growth sample, see below*



*Fully automated crack growth monitoring*



*MTS 500*



*Electric and hydraulic dynamic test machines with enhanced chemical environments*

## Creep testing

NLR can carry out creep tests on several material types, e.g. high temperature engine materials or materials for energy industry (Fossil and Sustainable). A number of individual frames in a controlled room can be used for creep testing. Specific creep test setups, combined within a controlled environmental cabinet, are used for large creep test programmes, including low and elevated temperature possibly combined with toxic environments (e.g. NORSOK). Preparations for hydrogen or carbon-dioxide environments are on-going..

Tests in the setups within the environmental cabinets 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

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.

For the individual test frames, 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



*Creep frames combined within an controlled environmental cabinet*



*Series of creep frames within a controlled room.*



*Creep test with coil heating, strain measuring and grip cooling*

## Special mechanical test tooling

Special extensions 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.

### 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 especially the master-slave steering makes this solution unique and innovative.

### Automated 3D strain measurement

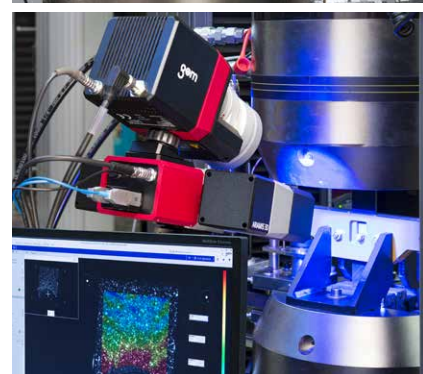
In several standard testing procedures the strain needs to be measured. This is traditionally done using strain gauges or clips. Alternatively NLR uses DIC optics, fully integrated into the Instron testing environment. After an initial calibration each strain measurement is just a simple click of the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

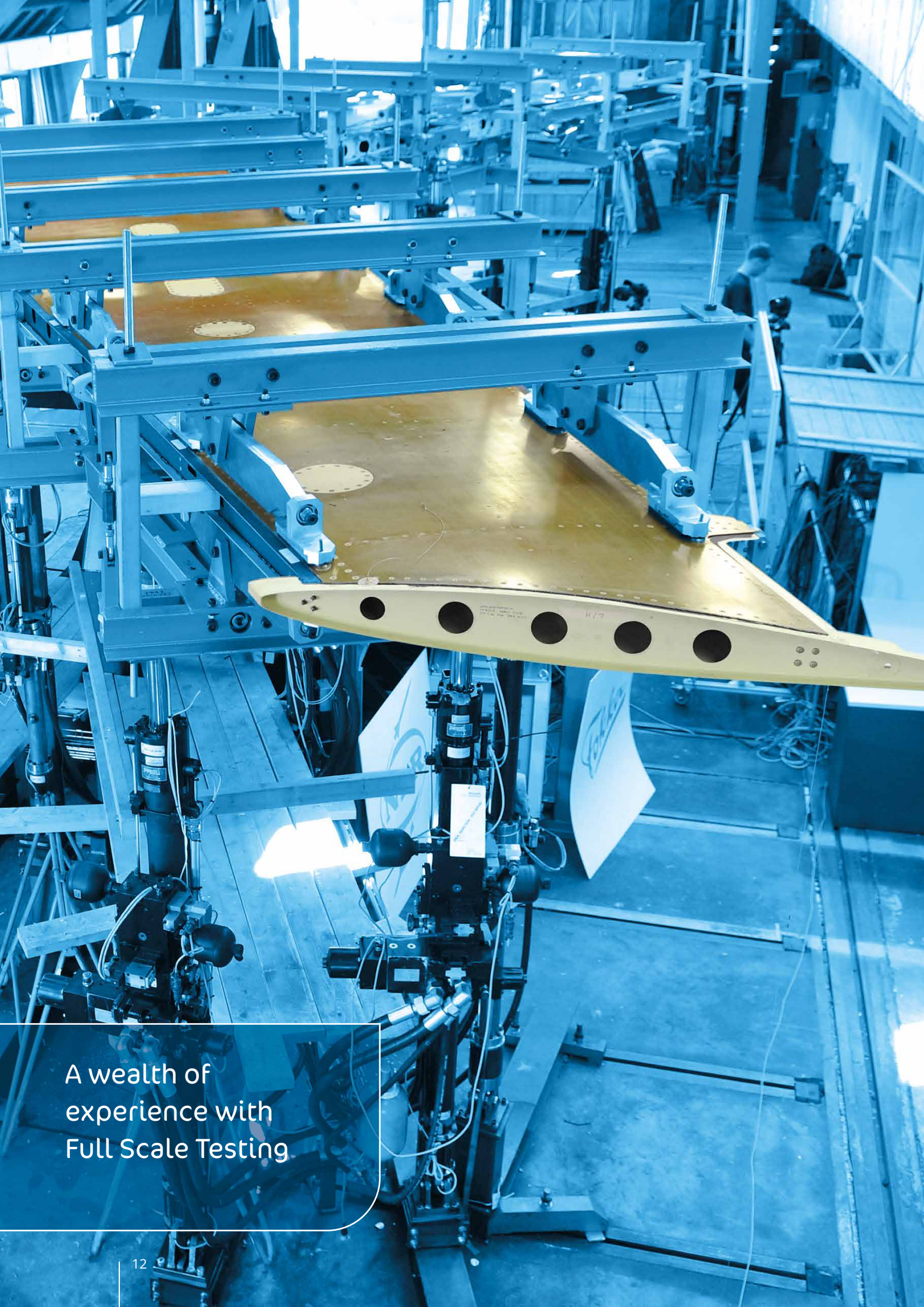
### Thermo-Electro-Mechanical testing

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).

### Coupon testing in dedicated autoclaves

For static, dynamic and creep testing in special (toxic) environments a autoclave solution is created. This enables in-situ testing within the (fluid/gas) environment at controlled pressures and temperatures.





A wealth of  
experience with  
Full Scale Testing

## Multi-axial or Full-Scale Testing (FST)

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*



*Algesmo Nose Landing Gear*



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



*F16 Damage Enhancement Test*

## Special test machines

### Fuselage panel test facility (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 running loads per mm panel width or panel length are given between parentheses):

Static : axial load : 950 kN (700 N/mm)  
 $\Delta P$  / tangential skin load : 140 kPa (340N/mm)  
 Fatigue : axial load : 450 kN (334 N/mm)  
 $\Delta P$  / 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 # 1 500 kN tension Force range # 2 100 kN tension

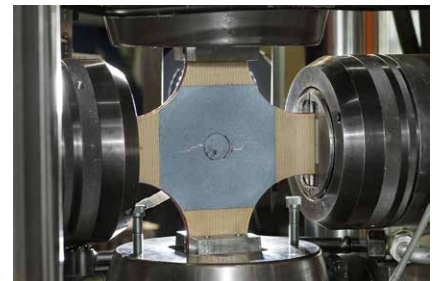
### Panel test rig

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

### 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 -30°C 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 impactor

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





# 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 × 2400 × 2400 mm (w × d × h)  
-10 to 80 °C and 20-90
- Dimensions up to: 910 × 1160 × 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/SO<sub>2</sub>) 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 × 1320 mm (w × d × h)

Maximum dimensions of Salt spray chamber 2:

- 1010 × 640 × 1140 mm (w × d × h)

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



*Salt spray cabinet 1*



*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

## 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.



Fluid susceptibility cabinet



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

## 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



Waterproofness test and 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.



Climate cabinet with UV Tester

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

## 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.

### 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.



*Rapid decompression test facility*



*Torvac Vacuum Furnace*



*Furnace #2 and #3*



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:

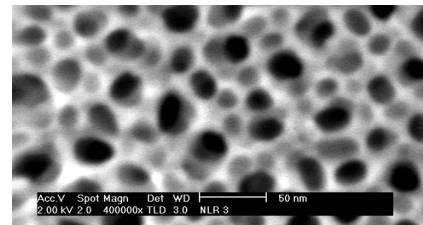
- Aerospace
- Aircraft power plants and structures
- Energy supply (gas turbines and wind turbines)
- Mechanical, chemical and industrial engineering
- Manufacturing processes
- Offshore structures
- Automotive
- Shipping
- 

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

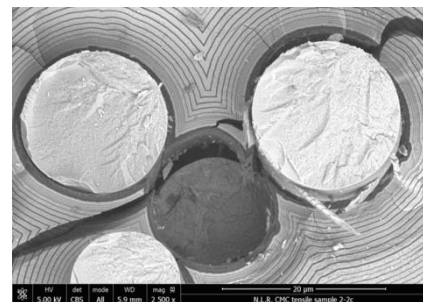
- Optical microscopes, magnification up to 1000×, including high definition image capturing and image analysis
- Digital Binocular, magnification up to 1000×, including 3D reconstruction
- Scanning Electron Microscope FEI NovaNanoSEM450, magnification up to 500.000×. The microscope operates at high and 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



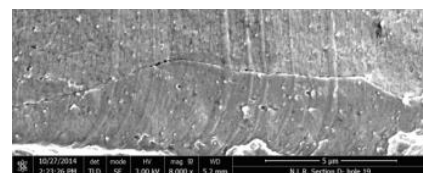
Anodised aluminium surface (400.000x)



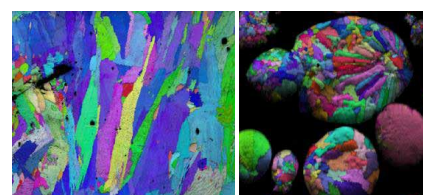
CMC investigation SiC/Si



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:

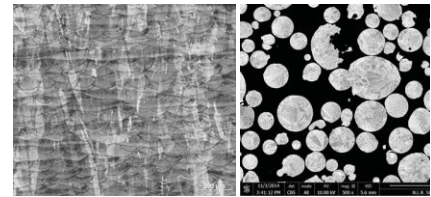
- Aerospace
- Mechanical and industrial engineering
- Manufacturing processes
- Product development

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 and 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



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



*Micro mechanical test setup*



*Digital binocular for visualisation*

Eminence  
in finding  
small details



Controlling  
Full Scale depends  
on many details



# 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

## Data-acquisition systems

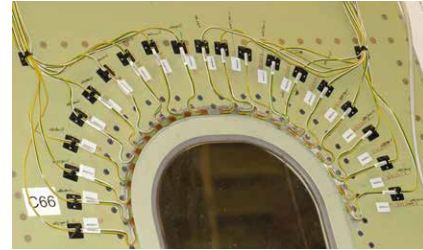
- Dedicated (strain gauge) multi-amplifier Peekel Instruments systems (up to 2500 strain gauge channels; 7 x dynamic 1kS/s, 3 x multiplexer 10 S/s, 4 x seq. scanner systems)
- 3 x 250 KS/s multiplexer NI PXI systems
- 6 x 200 KS/s multiplexer IOtech systems
- Dedicated (strain gauge) multi-amplifier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

## Multi-Axis Control systems

- 6 MOOG Aerospace test systems, up to 500 channels
  - 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
- 1 "Next Generation" MOOG Aero Test Controller equipped with:
  - 10 Control channels and upgradable to 32 channels
  - Interface to 16 bridge type analogue sensors
  - Loop update rate up to 5kHz
  - Real time modular control system for static, dynamic or endurance testing
  - Wide range of transducer inputs and control outputs
  - Modular design allows easier upgrades
  - Capable of integrating and combining with the older MOOG systems into a test. "Add-on repair module"
  - Using the same, well known, Aerotest software as the older MOOG systems
- 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 acquisition systems

## Single Axis Control systems

- Three custom made (Perdok/NLR) single axis actuator control systems
  - Control system for static, dynamic or endurance testing
  - Loop update rate 250 Hz
  - Position or load controllable
  - Linkable for multi axis testing
  - Modbus data system



*Strain gauges on window panel*



*Data Acquisition System (288 channels)*



*Typical Moog Control system*



*MOOG Next Generation control system*



*Typical Perdok Control system*

## 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

## 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  $\mu\text{m}$
- scanspeed 200 Hz

## 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.

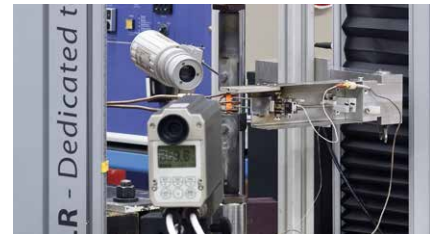
## Residual stress measurements (hole drilling method)

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



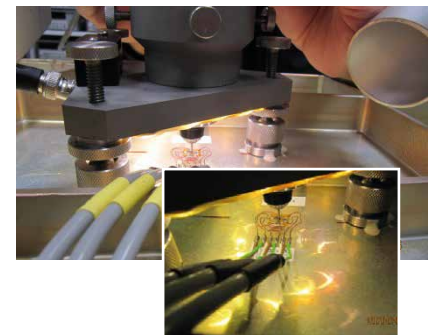
Pyrometry



Laser extensometer



Potential drop



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

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)

Embedding techniques (Smart Structures)

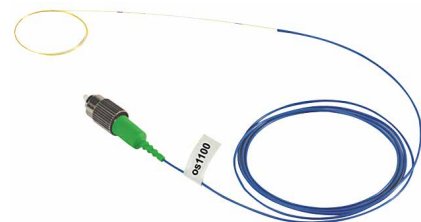
NLR has developed potential manufacturing techniques for the integration of optical FBG sensors in composites, optimized to avoid the problem with emerged fibres from the laminates during manufacturing:

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

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



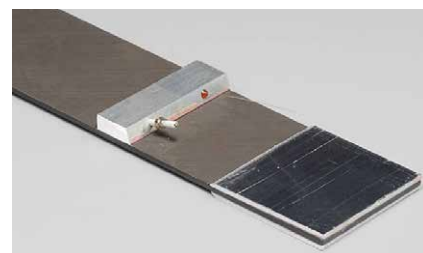
*Demonstration of the feasibility of specific SHM systems on a representative structure (Glare fuselage panel with bonded and riveted repair patches)*



*Fibre optic strain sensor*



*Interrogator*



*Embedded FBG sensor*



Effective NDI solution for composite components and other lightweight aircraft structures

# NON-DESTRUCTIVE INSPECTION EQUIPMENT

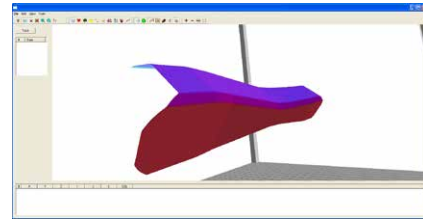
The Non-Destructive Inspection (NDI) group carries out a complete range of NDI services. Assistance is provided to airlines, air forces and aircraft component manufacturers. Activities of the NLR include:

- NDI R&D studies (EU and Defense programmes)
- Development and Evaluation of new NDI techniques
- NDI of composite, metals and FML materials
- In-service inspections
- Teardown inspections
- Investigating the reliability of NDI
- Structural Health Monitoring (SHM)
- Failure analysis

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

## Visual

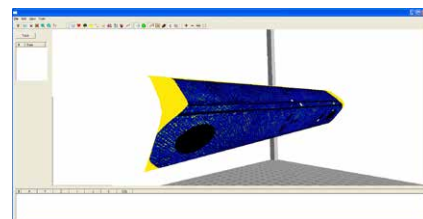
Visual inspection is the oldest, most economical and widely used inspection technique. Difficult accessible areas can be visually inspected with state-of-the-art video inspection systems and large surfaces inspected with e.g. 3D optical structured light scanning. 3D test results of the asset can be stored on location and sent directly to the customer for evaluation.



*CATIA model*



*Complex 3D component*



*C-scan result projected on CAD model*

## Ultrasonic C-scan facilities

Automated 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.

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



*3D C-scan facility*



*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

## 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. Sound beams can be steered, scanned, swept and focused electronically.

## 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.

## 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.

## Resonance Testing

This technique 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 FML-materials. Material defects can be detected by a shift in the dominant resonance frequency. Both Olympus bond testing C-scan and Fokker Bondtester are available.

## Smart portable equipment

New generation of smart portable NDI equipment, tablet based, with multi-methods (UT, ET, resonance) in a single equipment. The equipment is equipped with 4G/Wi-Fi connectivity which enables "job cracking" which means remote assistance and therefore avoiding delays. The tool to manage the NDI staff capacity.

## Penetrants

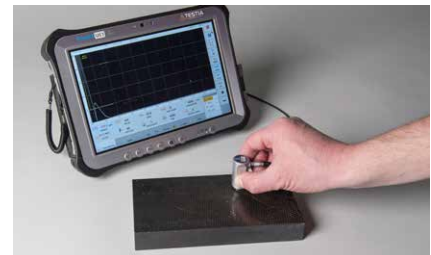
Liquid penetrant inspection (PT) is used to detect small cracks or discontinuities open to the surface which may not be revealed by normal visual inspection. Penetrant inspection can be used on most airframe parts. The inspection is performed by applying a special liquid to the surface. This liquid has 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.



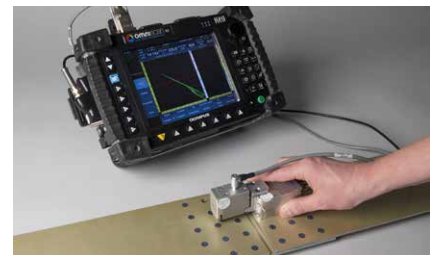
2D LSA C-scan facility



Curved and roller probe



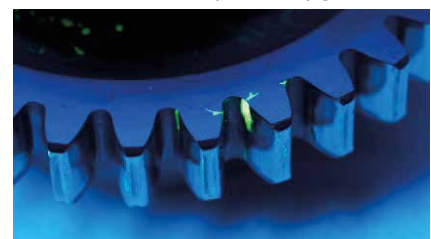
PT inspection of gear wheel



PT inspection of gear wheel



PT inspection of gear wheel



PT inspection of gear wheel

## 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 pattern 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 (1m<sup>2</sup>) and well established for the characterization of carbon fiber reinforced plastics after manufacturing and under in-service conditions.



*Thermography on wing flap*

## Shearography

Shearography is a non-contact NDI method that can determine gradient of the out of plane deformation of a subject under load by use of light interference. Excitation of the subject is done optically, using high power halogen lamps, causing a temperature increase and therewith expansion of the subject. Area's containing defects that change the stiffness of the material can be detected in this way, making the technique ideally suited to detect skin-to-core disbonds.



*Shearography on wing flap*

## Computer Tomography

No NLR CT-scan hardware is available yet, but AVIZO software is available in order to perform analyses on externally scanned components.

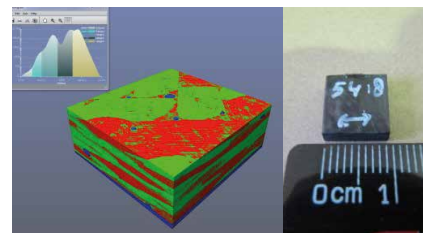
## Modelling/simulation of NDI methods

CIVA is a software platform developed to simulate NDT imaging and signal processing. The platform consists multiple modules, the following are available at NLR:

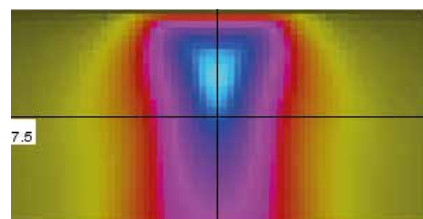
- Ultrasonic Testing (UT)
- Electromagnetic Testing (ET)
- Infra-Red Thermography (IRT)

## Multi Domain Scanning

By combining NDI techniques with optical scanning a complete 3D representation of an object including the NDI-data can be made. Using this process, location information can be easily added to the NDI data allowing for easy comparison between different techniques and better differentiation of defects. Additionally, all data is stored on the surface mesh in a single file opening the possibilities of a Digital Twin.



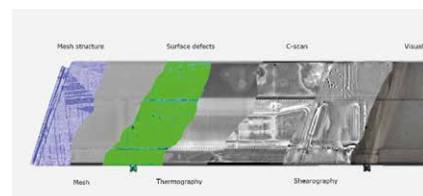
*Fiber (green/red) and void (blue)  
CT-image of woven composite specimen*



*Simulated Ultrasonic beam profiles in CFRP*

## Augmented Reality used in NDI

Augmented Reality is used to display NDI-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.



*Multi Domain result*

## 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 be considered as a passive monitoring technique for the detection of dynamic defects such as crack growth and impact events.



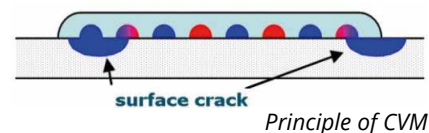
*AR using a hololens*

## Comparative vacuum monitoring

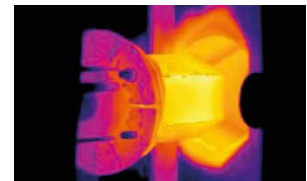
Comparative vacuum monitoring (CVM) is a relatively new technique that can be used for monitoring areas of a component where damage is expected to occur. The technique is based on the principle that a small volume maintained at a low vacuum is extremely sensitive to any ingress of air. The working principle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



Acoustic emission



Principle of CVM



IR camera result

## Passive Thermography

Thermo-elastic stress analysis (TSA) is a technique that gives the stress field of dynamically loaded component of structure. TSA utilizes an infrared 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:

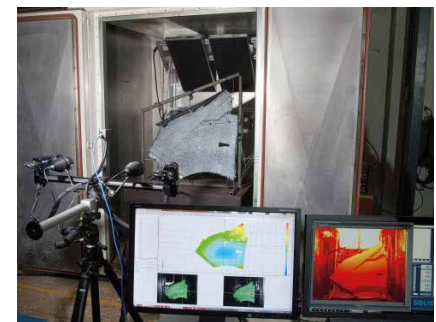
- Easy and fast evaluation of hot spots in components
- Crack detection
- Verification and iteration of Finite Element Models

Specifications:	A35	A40
Pixel resolution:	86.016 (336x256)	76.800 pixels resolution
Spectral range:	7.5 to 13 $\mu\text{m}$	7.5 to 13 $\mu\text{m}$
Thermal sensitivity:	@60 Hz 0.05°C at 30 °C MITE software	@50/60Hz 0.08 °C at 30 °C Accuracy (% of reading) $\pm 2$ °C or $\pm 2\%$

## 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

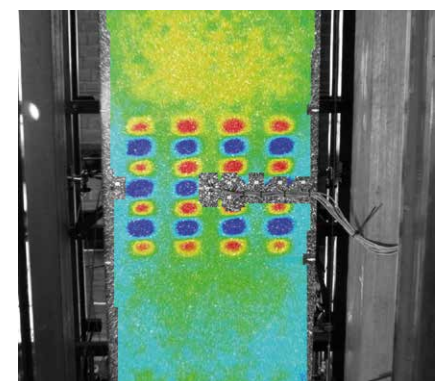


Thermo-elastic stress analysis combined with 12M DIC

## 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)



12M DIC displays a buckling pattern

## 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



## 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

## 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

### GOM ATOS 5

- Measuring area / point spacing/ max length measurement error:
  - 320 x 240 mm / 0.068 mm / -0.002 mm
  - 1000 x 750 mm / 0.236 mm / -0.049 mm
- Calibration object for this sensor with certificate

## Optical 3D Photogrammetry GOM Tritop

Optical 3d coordinate measuring system

- Measuring volume 1 x 0.5 x 0.5 m<sup>3</sup>: 0.015mm accuracy
- Measuring volume 10 x 5 x 5 m<sup>3</sup>: 0.2mm accuracy

## 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:

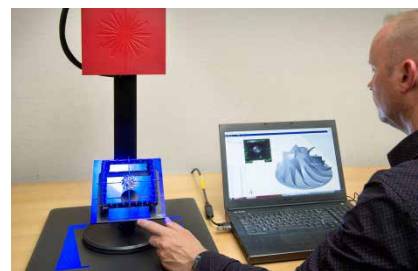
- 1,024 x 1,024 pixels @ 7,000 fps
- 1,024 x 744 pixels @ 10,000 fps
- 512 x 512 pixels @ 25,000 fps
- 256 x 256 pixels @ 87,500 fps
- 128 x 128 pixels @ 262,500 fps
- 128 x 24 pixels @ 775,000 fps



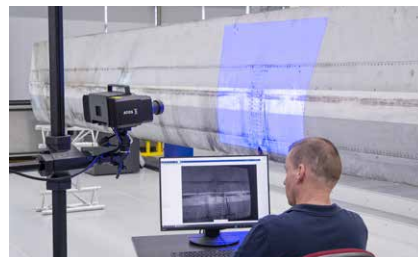
SPR system



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



Optical 3D geometry measurement



Structured 3D Light Scanning



Optical 3D coordinate measurement



High speed video



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

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