Dedicated to innovation in aerospace

Virtual manufacturing and testing for novel structures and materials

Aerospace Vehicles – Computational Mechanics I **Wouter van den Brink,**

May 2016

Contents

- Introduction NLR
- Virtual testing in Aerospace and at NLR
- Virtual certification
- Virtual manufacturing
- Future development
  - Multifunctional materials
- Discussion

Virtual activities at NLR - 'first-time-right'

Manufacturing constraints

Test conditions

Certification requirements

Design

- CAD

Composites

- Composite fibre steering optimization

Metals

- Topology optimization

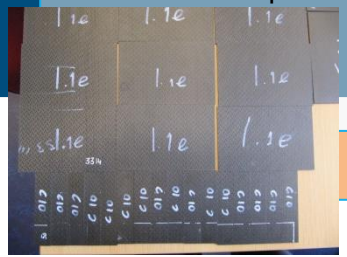
Virtual manufacturing

Composites

- Residual stress / Distortion / Overheating
  - Spring in angle
- Fibre orientation during manufacturing
- Predict AFP gap/overlap and waviness effects

Metals

- Residual stress 3D-print metal component



Virtual testing

Composites

- Reduce risk and number of tests
- Evaluate spectrum for hybrid structures
- Test boundary conditions
- Actual structure as-built, thickness, fibre angles

Metals

- Test correlation with DIC and strain monitoring

Virtual certification

Composites

Metals

Validation

Virtual testing in Aerospace

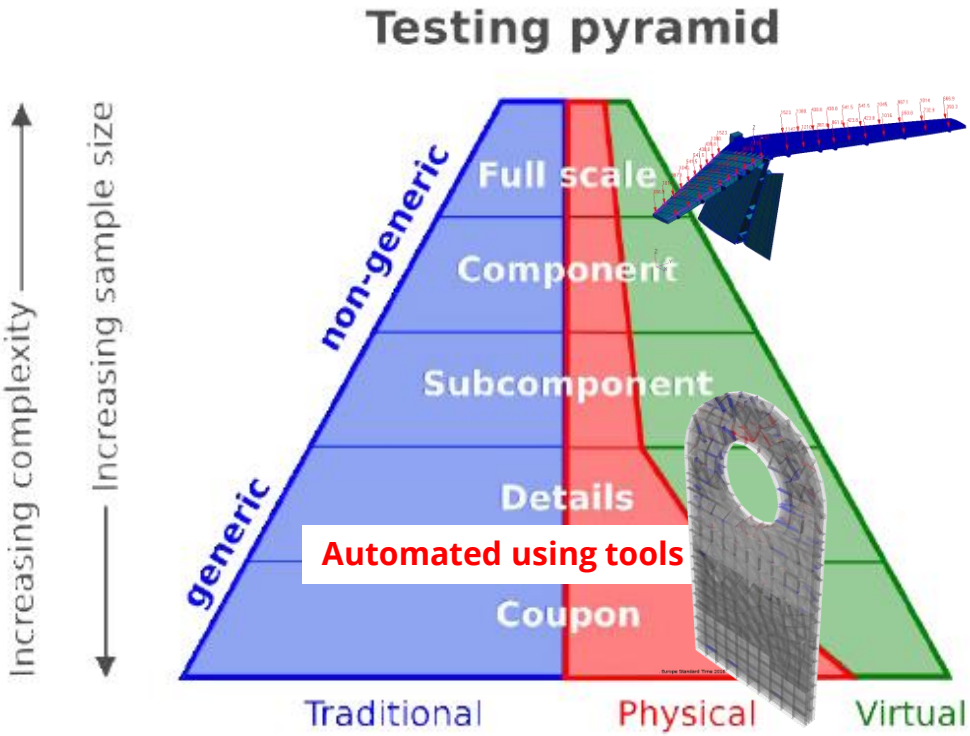
Building block approach, usage of simulation instead of physical test

→ **Approximation of reality**

Use of Virtual Testing:

1. Support the physical test by numerical simulation in order to reduce the risks and costs
2. Reduce the amount of physical tests needed for development and certification

The type of activities depend on the target level in the testing pyramid



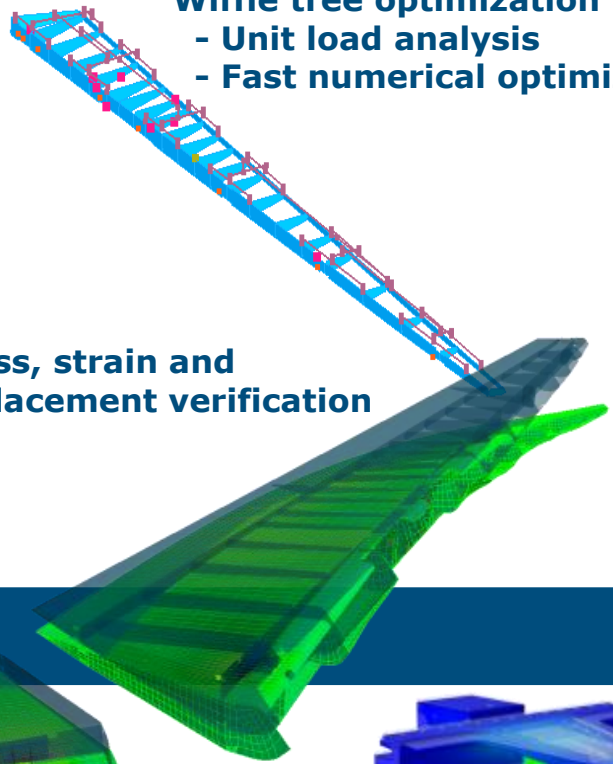
Virtual testing @ NLR

- Experience on virtual structural testing using finite element simulation

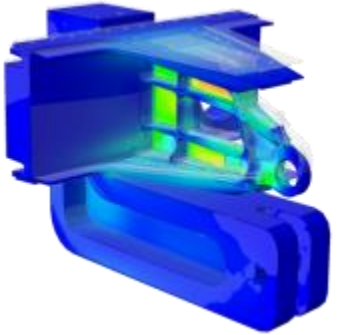
Components	Aim of virtual testing	
1. Horizontal stabilizer	-aeroload distribution -risk reduction	Large component level
2. Fuselage design and testing	-load definition -risk reduction	
3. Stiffened panel buckling	-buckling stability -sensitivity analyses	Subcomponent level, more generic
4. Composite laminate damage simulation	-physics understanding -replace physical testing (partly)	Coupon level, generic

1. Horizontal stabilizer business jet

Wiffle tree optimization
- **Unit load analysis**
- **Fast numerical optimization**



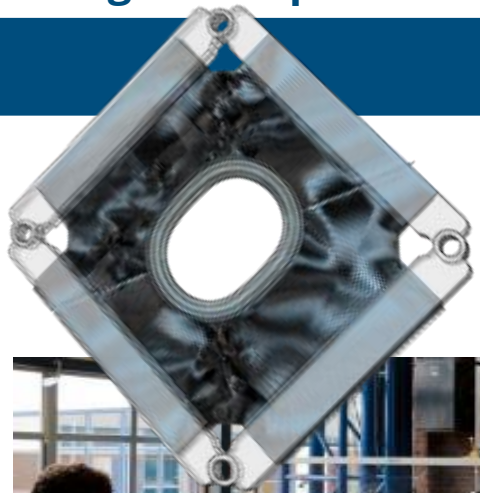
Stress, strain and displacement verification



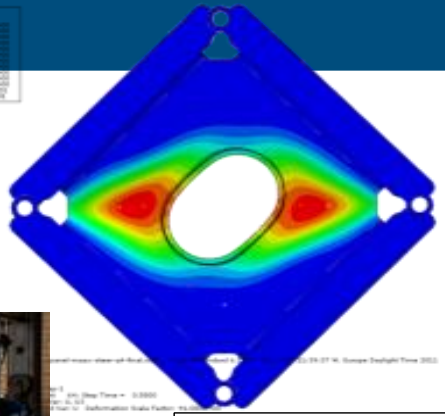
Verify and optimize load introduction (stiffness, strain level)

2 Fuselage panel design with fibre steering

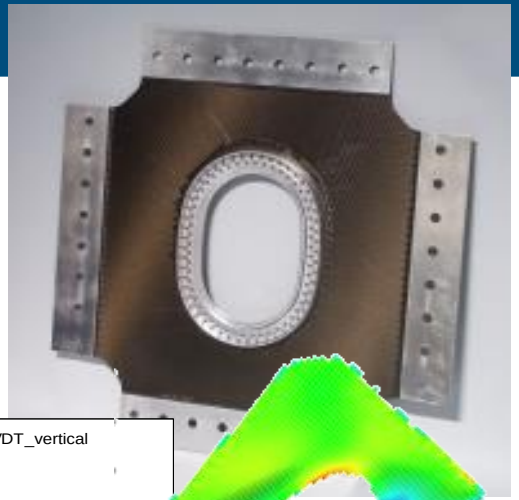
Design and optimization



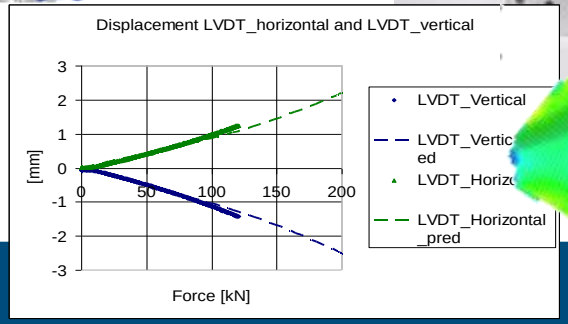
Virtual testing

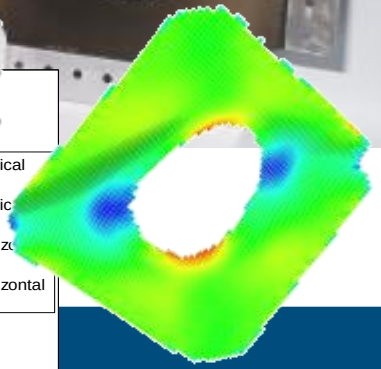


Manufacturing



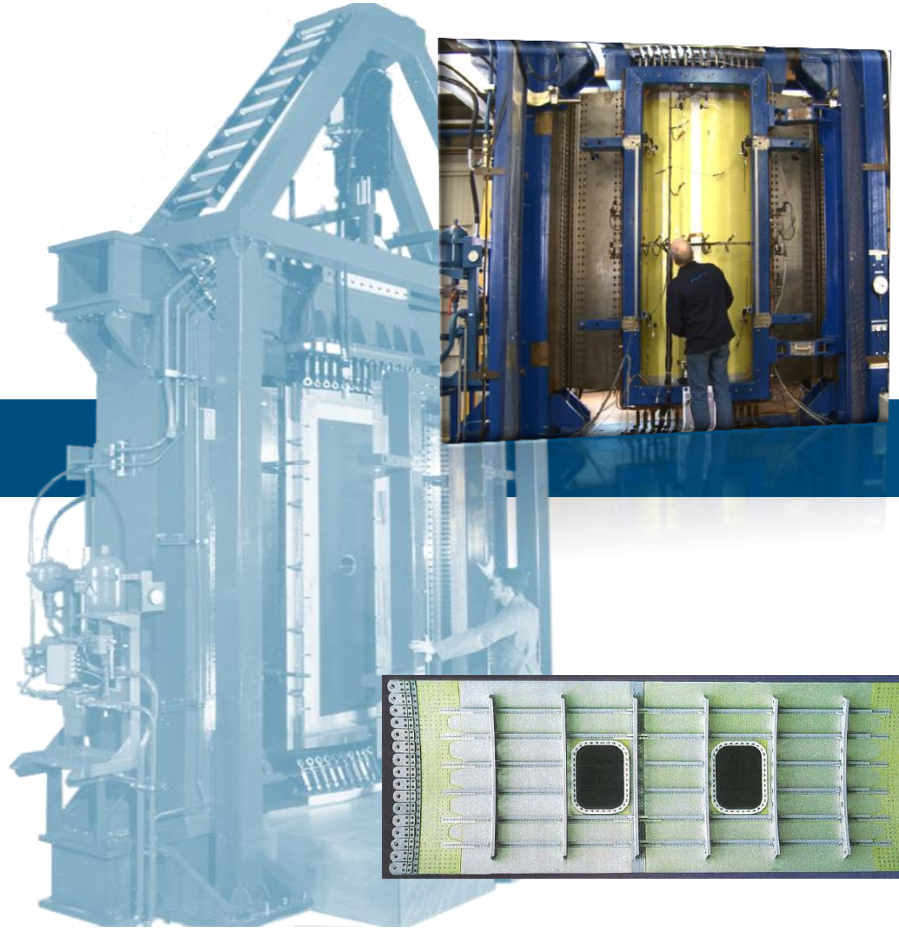
Physical testing

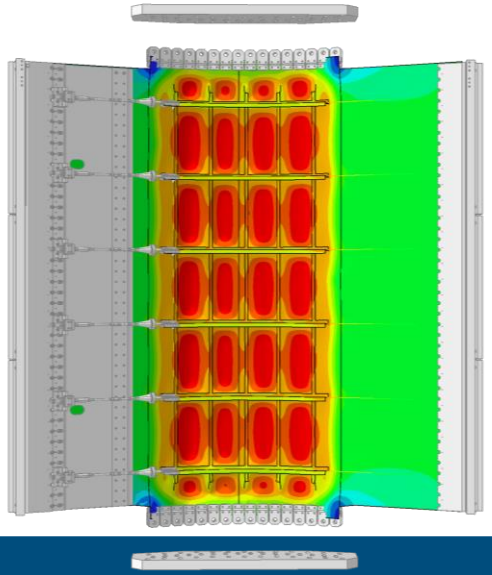


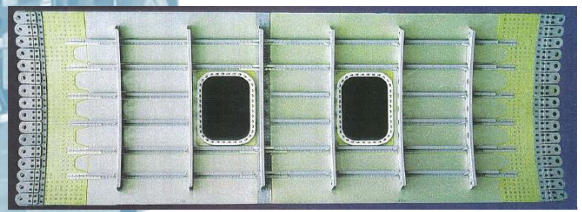


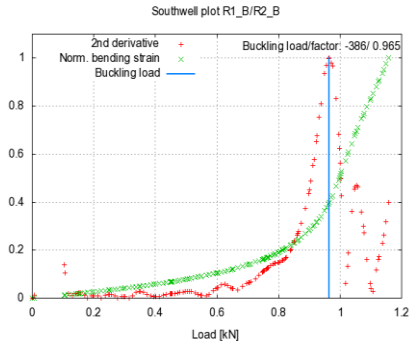
Data analysis and simulation correlation

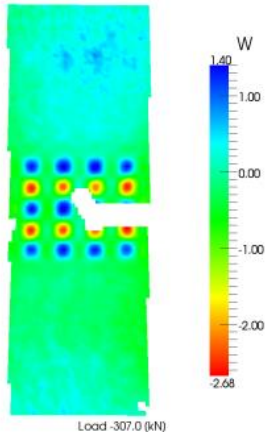
3. Stiffened panel buckling



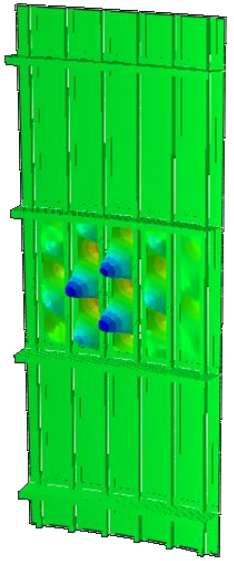




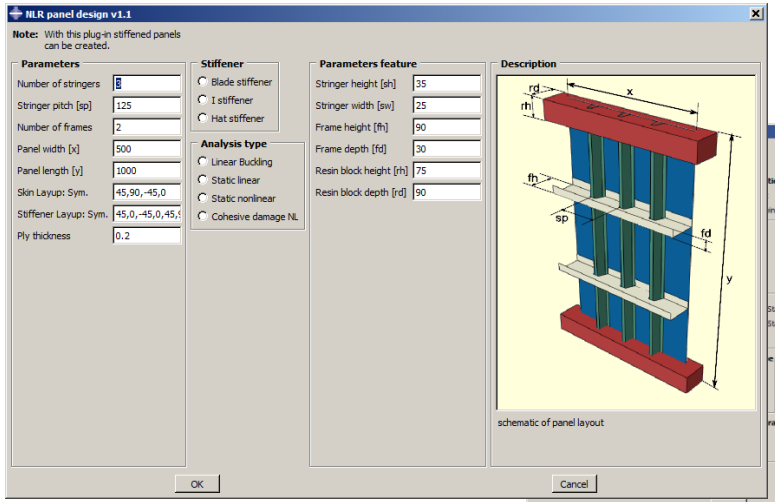


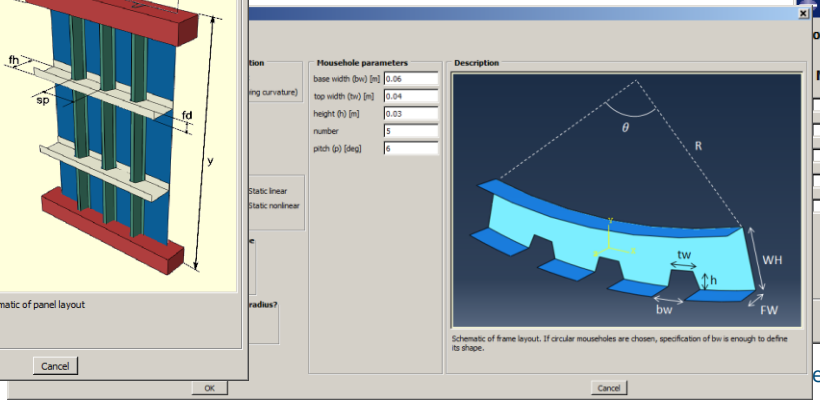


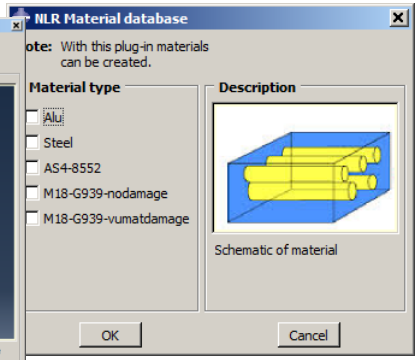
3b Stiffened panel virtual test database



- To support virtual testing
  - Rapid creation of generic stiffened panel models
  - Composite material tool
  - Included in the Abaqus Environment as plug-in with GUI





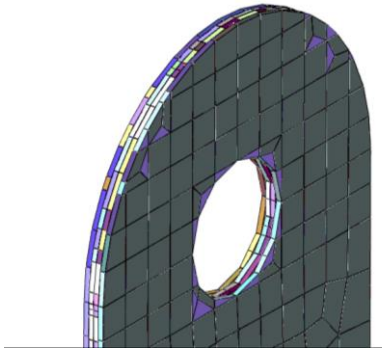


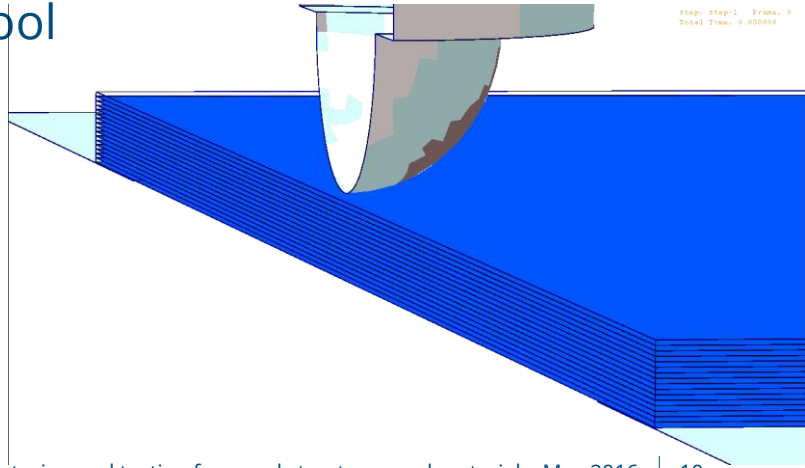
4. Coupon level - composite laminate damage simulation

- Low level in pyramid using generic models and more material physics involved
- Focus on advanced damage simulations
- Ply-by-ply composite laminate models
- Rapid dynamic effect during impact and failure
- Challenge to validate and use as design tool

Tensile strength

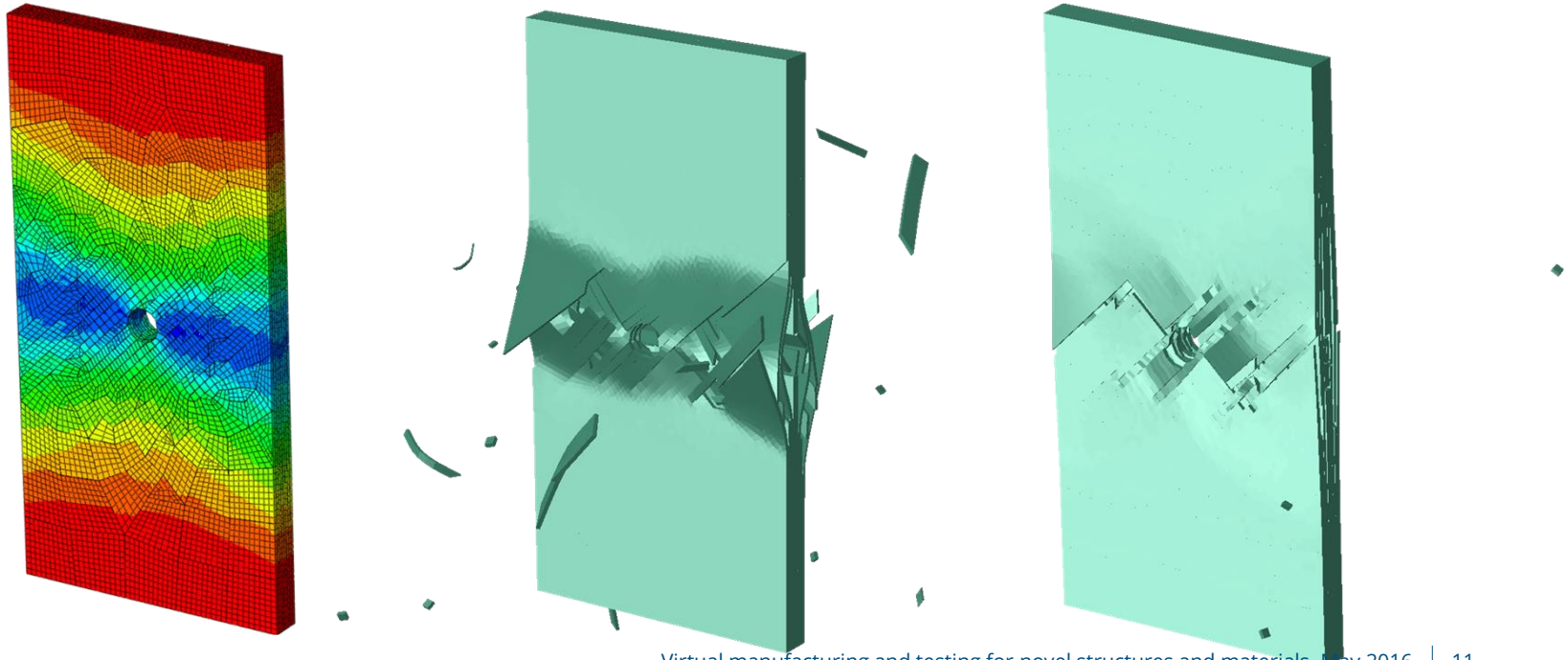
Shear





4b Composite failure using fracture mechanics

- Extended cohesive use to capture all failure modes, fibre failure, matrix distributes cracks and local delamination



Virtual manufacturing

1. Additive manufacturing process optimization
2. Additive manufacturing residual stress predictions
3. Composite curing simulation for prediction of residual and distortion

1. Additive manufacturing of aircraft parts

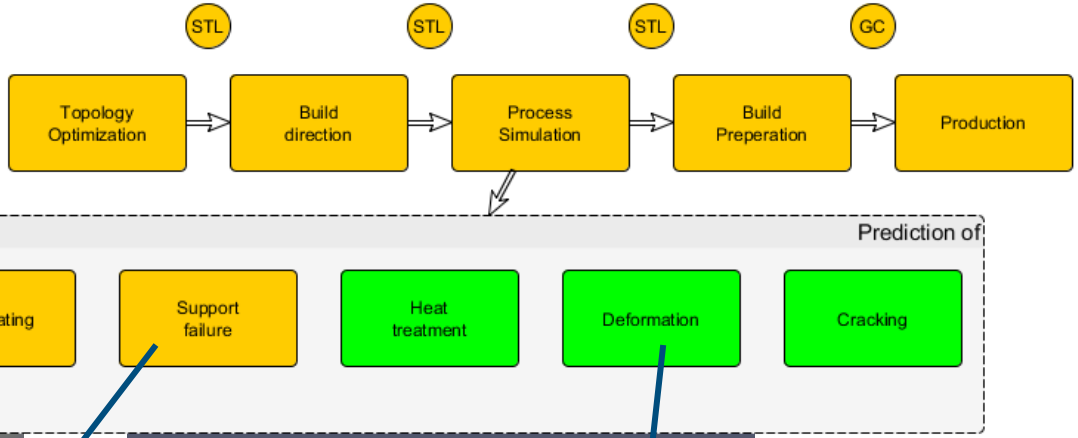
Manufacturing process optimization using a machine learning approach

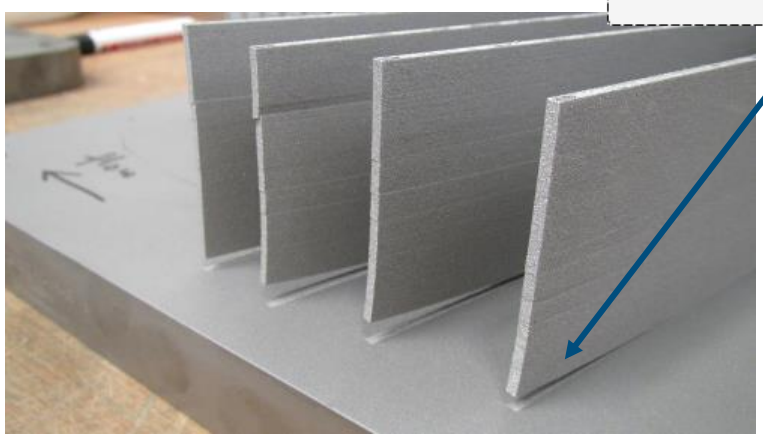
- **Selective Laser Manufacturing (SLM)**: Producing complex parts layer-by-layer by melting fine metal powders with a high-power laser beam

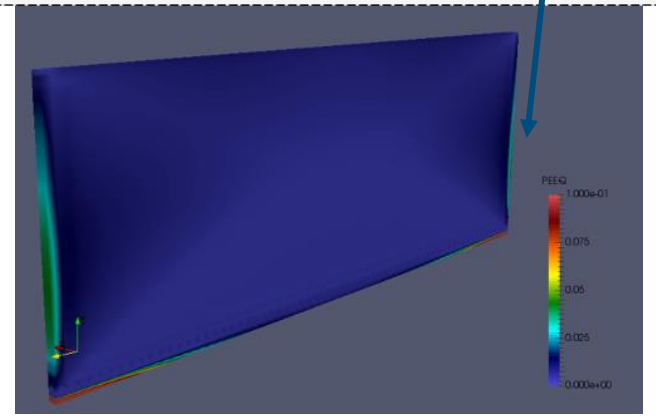
- **Challenge**: Variability in finished products' properties
- Manufacturing process optimization is an important step to obtain qualified and airworthy aircraft components and requires advanced data analytics methods
- NLR applies a machine learning approach in order to:
  - Support decision making capabilities of quality control engineers by predicting and triaging defects in finished products by the means of automatic analysis of collected process parameters
  - Control process parameters online to timely correct deviation from optimum, potentially saving hours of machine time

2. Additive manufacturing residual stress prediction

- 3D print metal SLM
- Titanium plates for tests
- PEEQ>10% → fail at edge

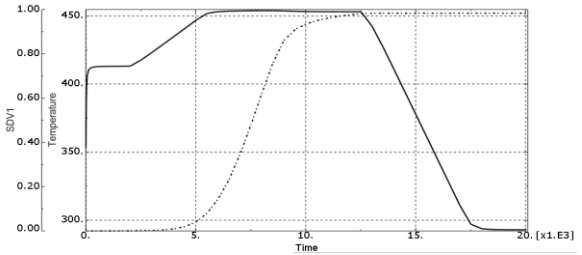


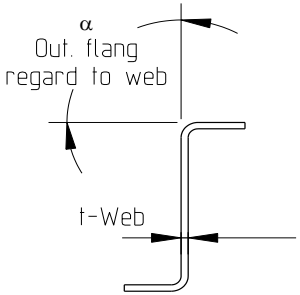


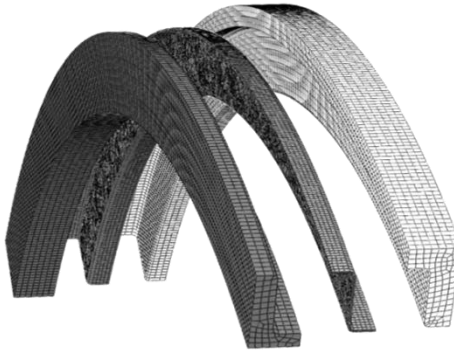


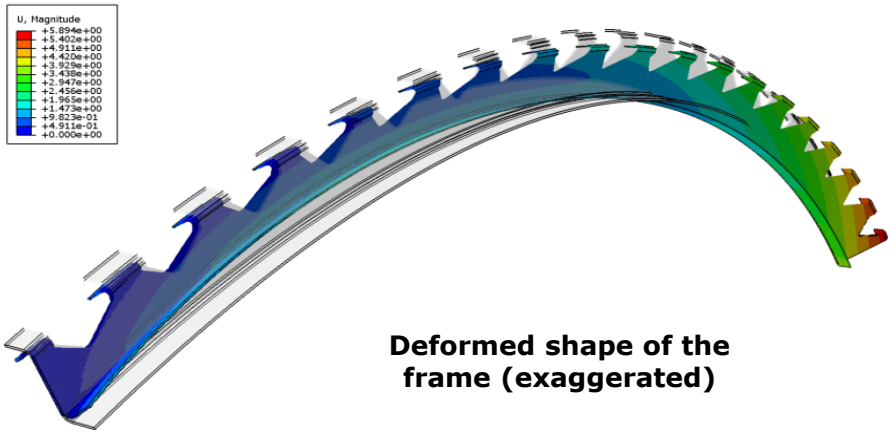
3. Composite curing prediction – RTM frame deformation

- Validation case on aircraft frame (TANGO project)
- Moulds are included in the simulation
- Spring-in effect observed for this component in both flanges of 1.2 degree









Deformed shape of the frame (exaggerated)

ID	Dwell2 temp	angle α	Comments
Reference	Thermal expansion	90.519	
TANGO1	180C	89.562	
TANGO2	170C	89.423	Not fully cured (0.90)
TANGO3	160C	89.344	Not fully cured (0.72)

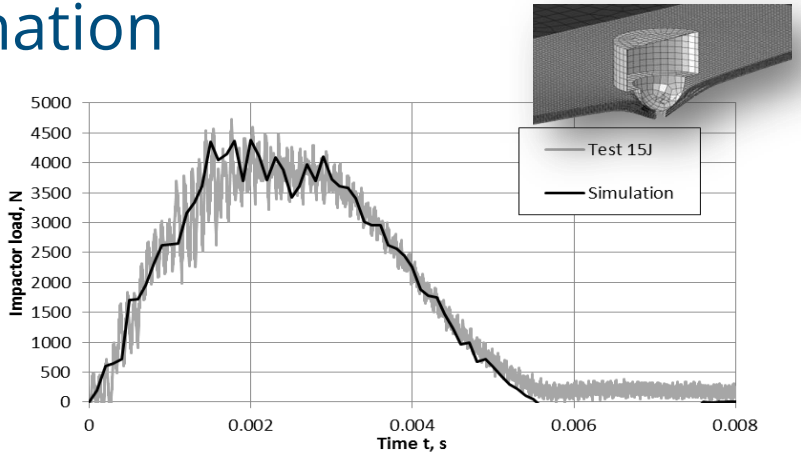
Towards virtual certification

- A thourough understanding of the material and structure behaviour is needed
- Validated model that can be used to certify modifications

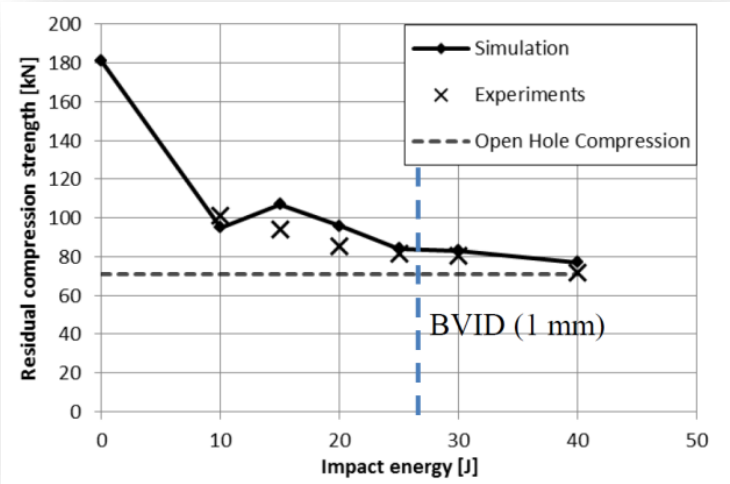
1. Compression after impact prediction for allowables
2. Repair of composite structures – bonded
3. Certification of airport structures - frangibility

1. Composite Allowable determination

- Numerical method compared to test results for load and delamination size
- Load is mainly determined by boundary conditions and laminate stiffness



Impact load over time for simulation and test



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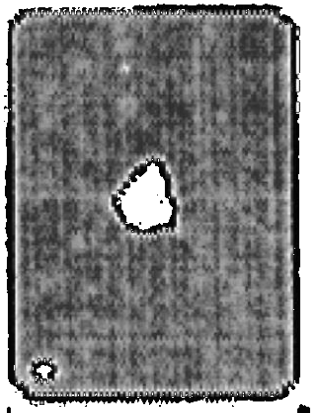
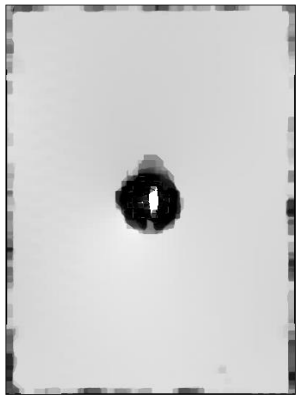


C-scan delamination

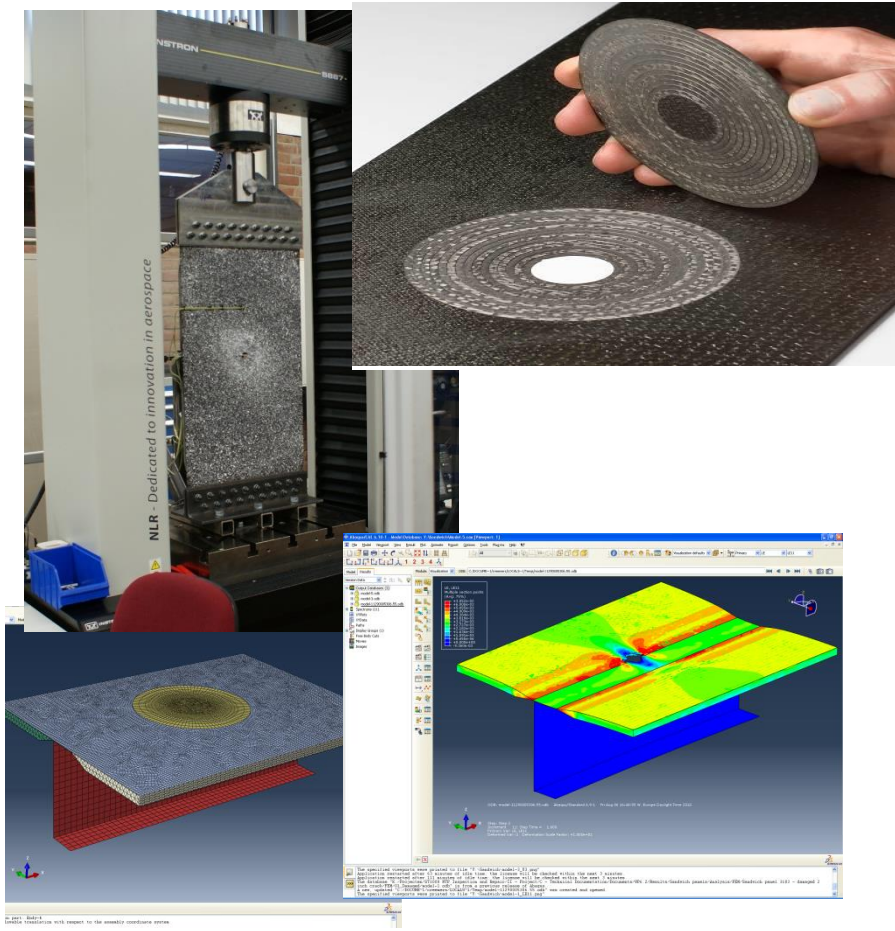


Predicted delamination

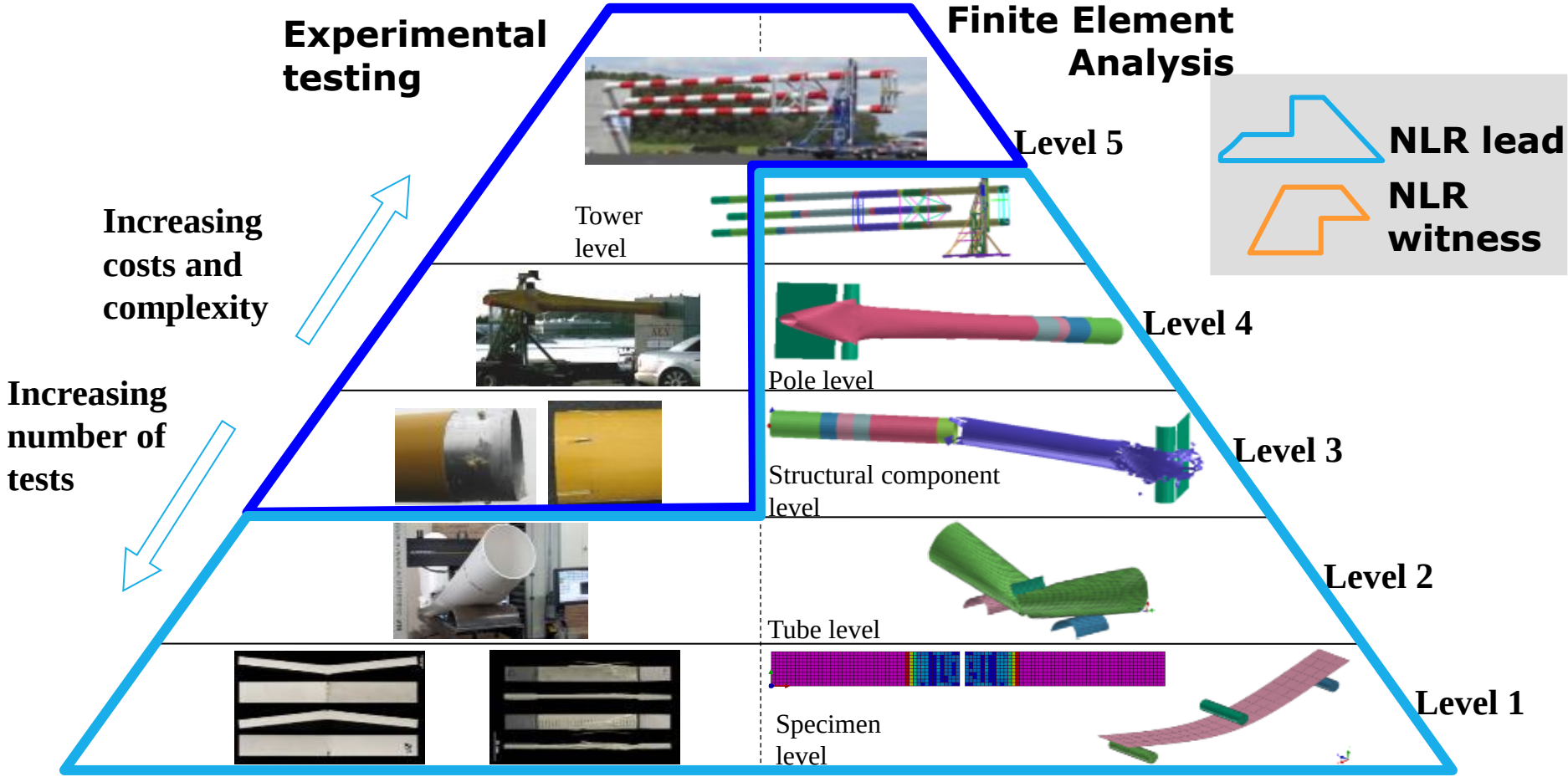
2. Repair of composites

Research and experience on repair of composites:

- Development of repair tools and guidelines (e.g. for Dutch Royal Air Force)
- Design & analysis of repairs (bolted and bonded)
- Manufacture of repair test coupons & elements
- Testing of repair test coupons & elements
- Currently in PATCHBOND project research in certfication of bonded repairs

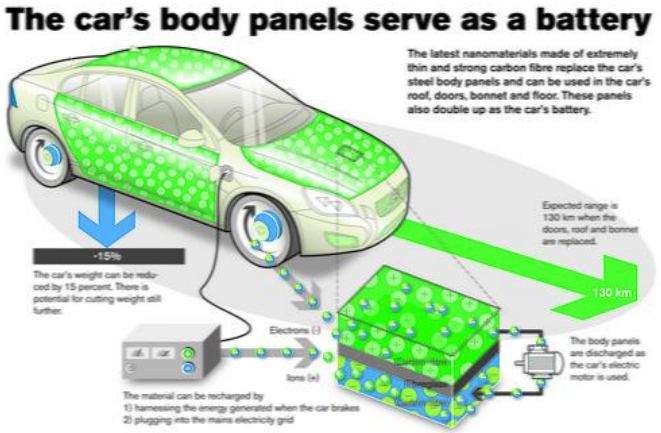


3. Frangible design of Instrument Landing System Glide Slope towers: Design for certification

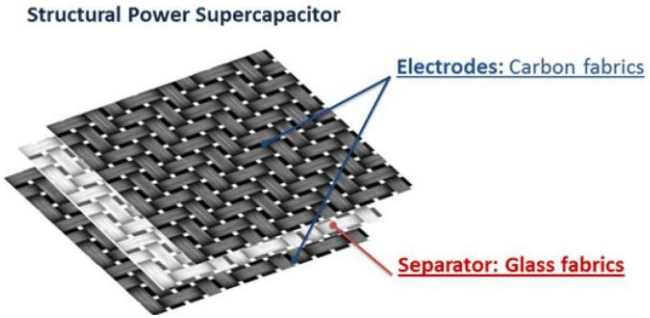


Current focus

- Multifunctional materials and constructions
  - Integration of energy storage and energy transfers in the structure.
  - Other possibilities are anti-icing and antenna integration
  - Hybrid
- Hybrid laminar flow
- High velocity impact
- Proposals for CleanSky2 on the topic of antenna integration in a composite structure have been created



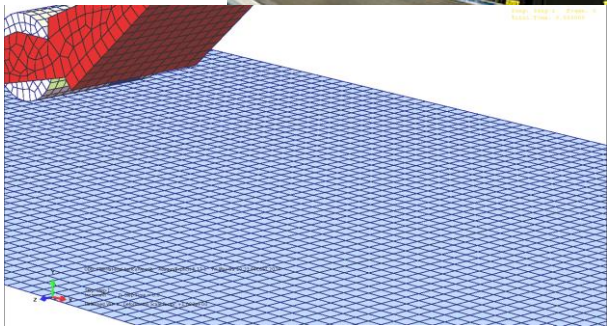
source: http://articles.sae.org/9024/

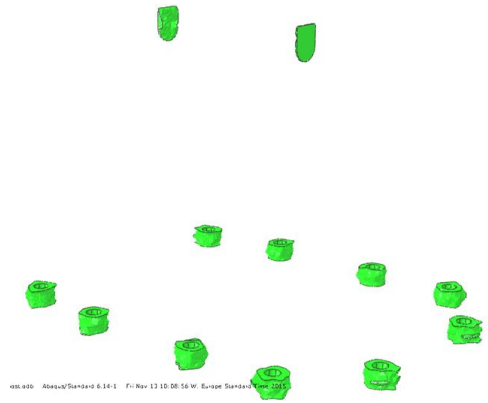


source: http://www.imperial.ac.uk/nanostructures-and-composites

Current focus 2

- Virtual manufacturing
  - Composite manufacturing with curing distortion prediction
  - 3D printing for metal components with melt pool and residual stress/distortion prediction
  - Prediction of fibre placement manufacturing
- Optimized design
  - Deviate from iterative and engineering judgement design
  - Topology optimization
  - Fibre steering optimization and 3D printed integration with carbon fibres





Discussion

- **Approximation of reality, do we trust this approximation to make real decisions? - some physical testing always needed!**
- What is the accuracy and fidelity of the numerical approach
  - Stiffness – ok
  - Buckling - ok
  - Strength up to failure – problematic especially for composites and connections
  - Fatigue endurance – very difficult especially for composites
- Continuous developments in this area in terms of capability and computing power
- Lower level virtual testing allows for automation of analyses
- Virtual certification supported by test

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Fully engaged

Netherlands Aerospace Centre

NLR Amsterdam
Anthony Fokkerweg 2
1059 CM Amsterdam

p) +31 88 511 3113 **f)** +31 88 511 3210
e) info@nlr.nl **i)** www.nlr.nl

NLR Marknesse
Voorsterweg 31
8316 PR Marknesse

p) +31 88 511 4444 **f)** +31 88 511 4210
e) info@nlr.nl **i)** www.nlr.nl