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’

**Design**
- CAD
- Composite fibre steering optimization
- Topology optimization

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

**Virtual testing**
- Reduce risk and number of tests
- Evaluate spectrum for hybrid structures
- Test boundary conditions
- Actual structure as-built, thickness, fibre angles
- Test correlation with DIC and strain monitoring

**Virtual certification**
- Manufacturing constraints
- Test conditions
- Certification requirements

**Composites**
- Design
- Virtual manufacturing
- Virtual testing
- Virtual certification

**Metals**
- Design
- Virtual manufacturing
- Virtual testing
- Virtual certification

Validation

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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

**Automated using tools**
Virtual testing @ NLR

- Experience on virtual structural testing using finite element simulation

<table>
<thead>
<tr>
<th>Components</th>
<th>Aim of virtual testing</th>
</tr>
</thead>
</table>
| 1. Horizontal stabilizer | - aerodynamic load distribution  
- risk reduction |
| 2. Fuselage design and testing | - load definition  
- risk reduction |
| 3. Stiffened panel buckling | - buckling stability  
- sensitivity analyses |
| 4. Composite laminate damage simulation | - physics understanding  
- replace physical testing (partly) |

- Large component level
- Subcomponent level, more generic
- 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

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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

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<th>Comments</th>
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Towards virtual certification

• A thorough 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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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 certification of bonded repairs
3. Frangible design of Instrument Landing System Glide Slope towers: Design for certification

- Experimental testing
- Finite Element Analysis

Increasing costs and complexity
Increasing number of tests

Level 5
NLR lead
NLR witness

Level 4
Pole level

Level 3
Structural component level

Level 2
Tube level

Level 1
Specimen level

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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
Fully engaged
Netherlands Aerospace Centre

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