Correlation of static test and FEM analysis using the example of the H145 composite tail unit structure

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HELICOPTERS

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Outline

Targets of the presentation

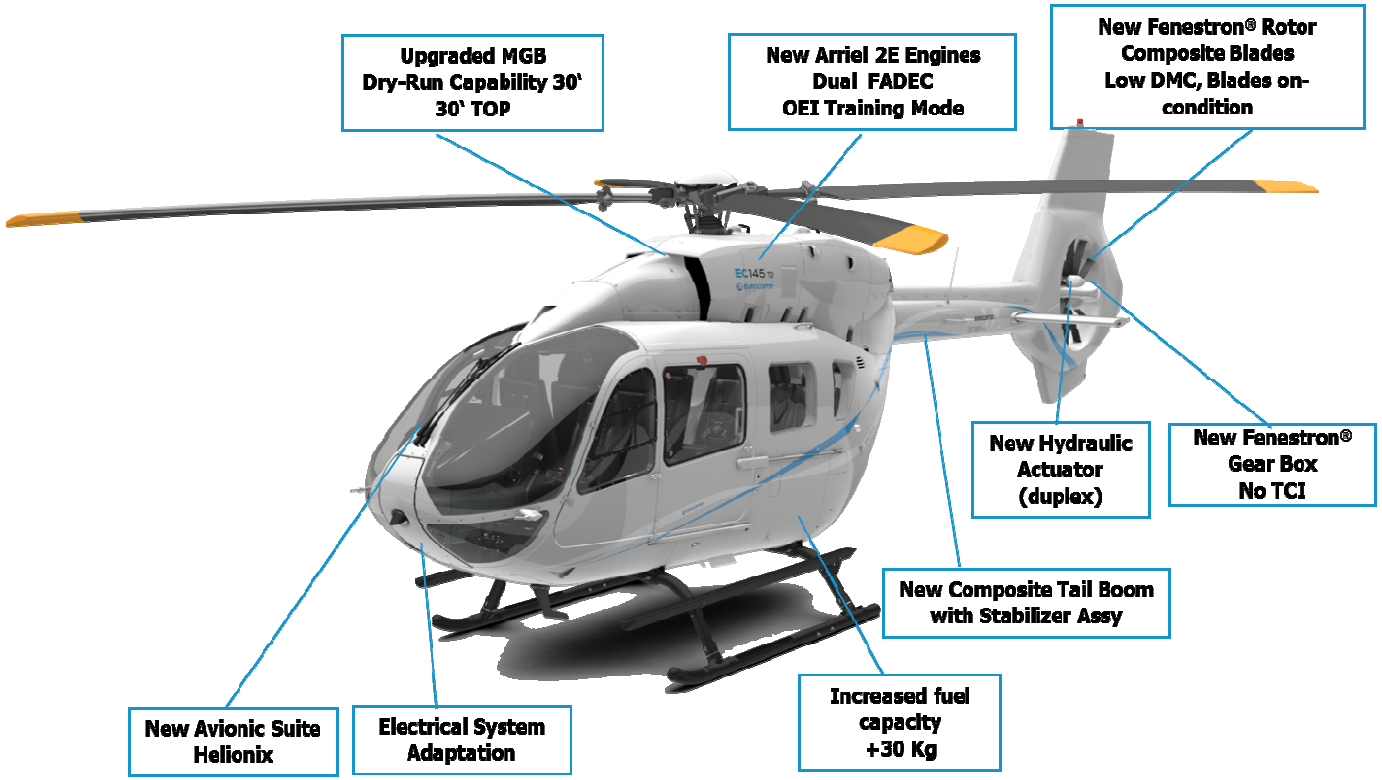
- To recap the substantiation principle “analysis supported by test”
- To share a real life example of industry best practice for FE-model validation

Content

- Introduction to the H145
- Tail unit structure design description
- Substantiation principle: Analysis supported by test
- FE-Model description
- Test setup
- FE-Model verification
- Conclusion

H145 – The multi-purpose EC145's high-and-hot evolution

- Type: MBB-BK117
  – Model: D-2
- Changes from C-2 to D-2
  – See picture ➔
- Missions
  – Law enforcement, EMS, O&G, Private and Business aviation, Aerial work
- Entry into service in 2014
- More than 200 H/C in service
- Roughly 150,000 flight hours



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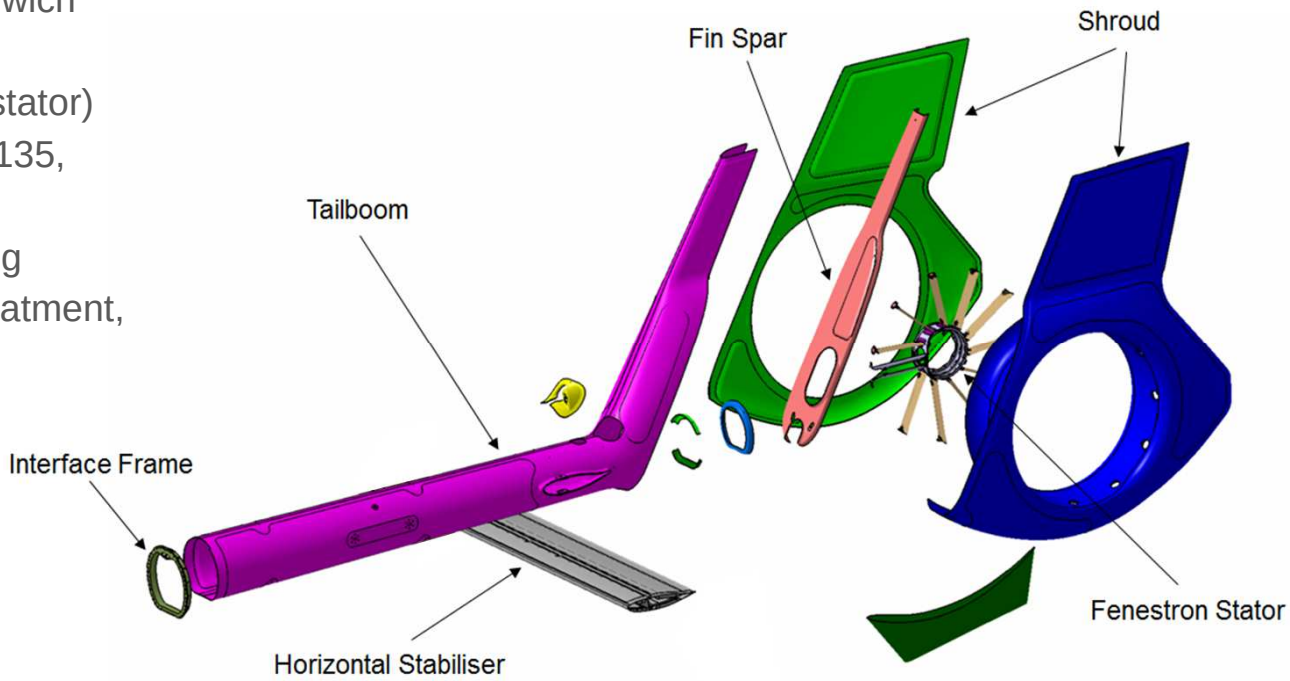
Tail unit structure design description

- Composite tail unit structure
- Made of carbon and hybrid monolithic and sandwich technology
- Few aluminum parts only (Interface frame and stator)
- All composite materials already in use at e.g. H135, Super Puma, NH90, Tiger
- Existing database: Design values, Manufacturing processes, pedigree data for non-conformity treatment, repair concepts and in-service experience



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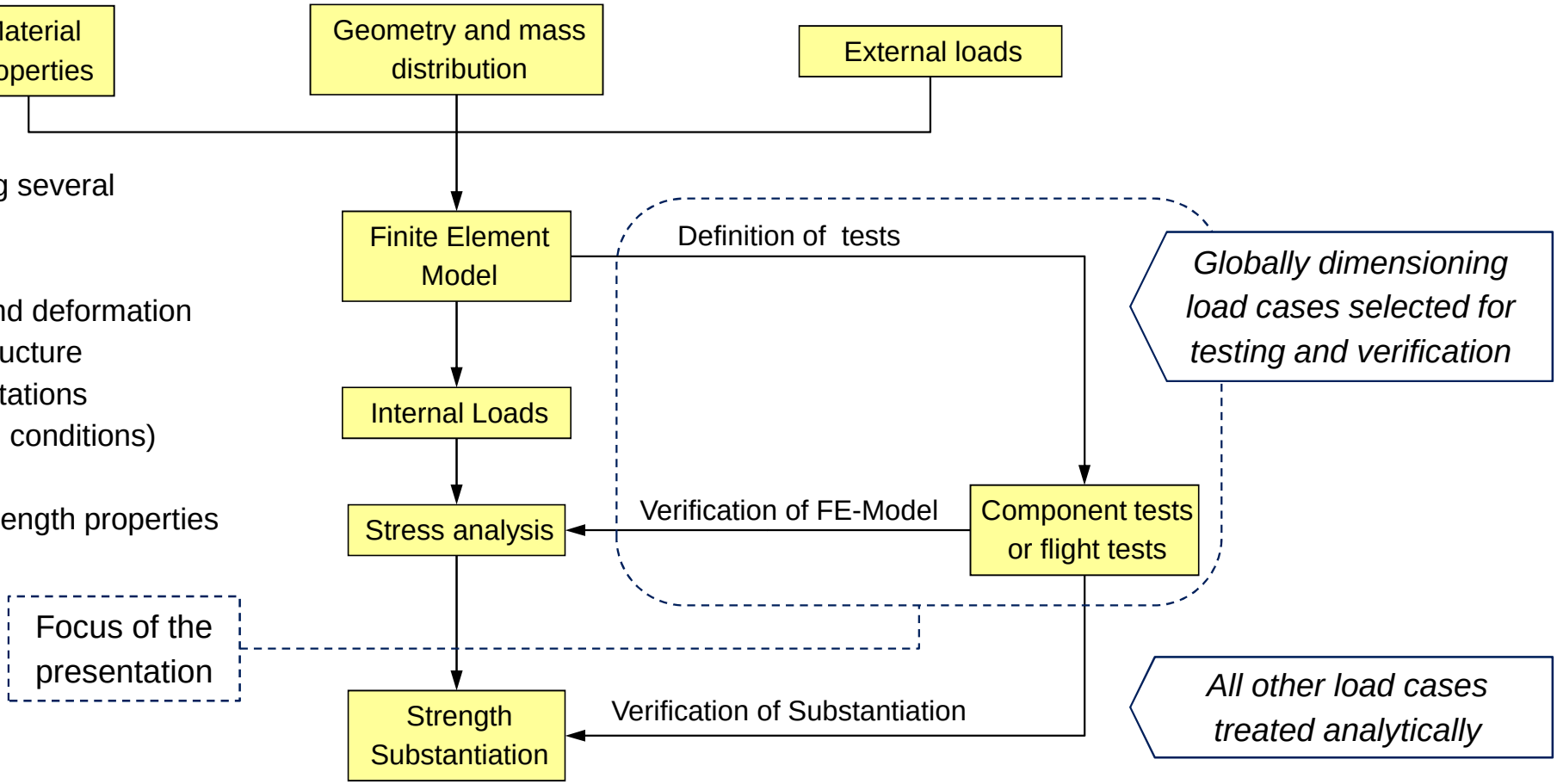
Strength Substantiation Principle: Analysis supported by test (1/3)

Reflecting and covering several requirements, e.g.

- 29.301 Loads
- 29.305 Strength and deformation
- 29.307 Proof of structure
- 29.309 Design limitations
- 29.321 ff. (Loading conditions)
- 29.603 Materials
- 29.613 Material strength properties and design values



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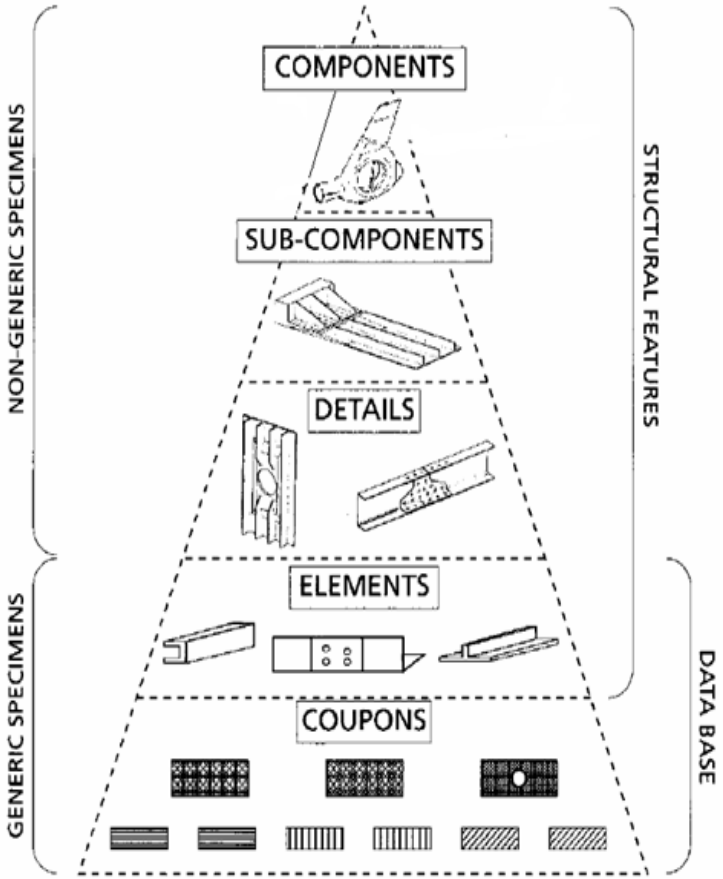
Strength Substantiation Principle: Analysis supported by test (2/3)

- Building Block Approach is followed
- Limit and ultimate loads as well as fatigue spectra are applied/demonstrated in representative tests
- Temperature / Humidity accounted for by
  - Load factors
  - And/or elevated temperatures applied in tests
  - And/or by analysis
- Tests account for minimum allowed manufacturing quality level and typical in-service damages
- Each component test is supported by and correlated with FEM, most of the lower level tests too (FEM model validation building block approach)



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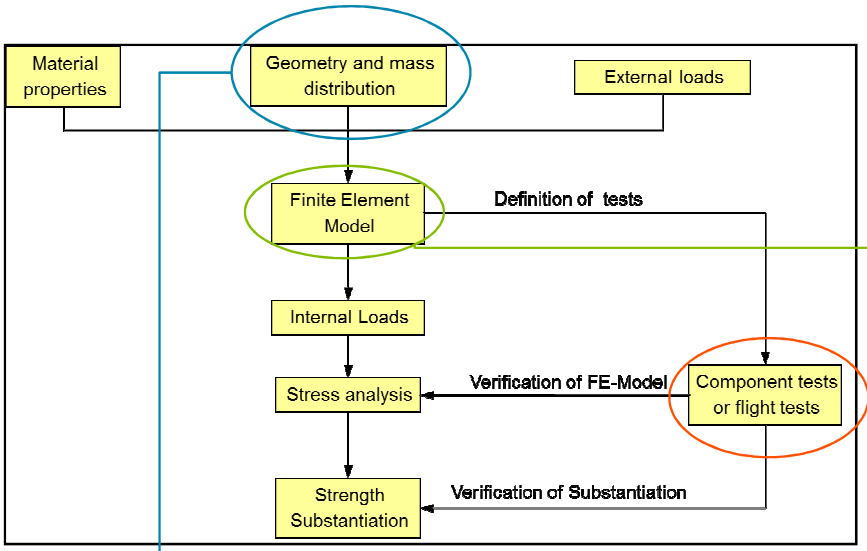
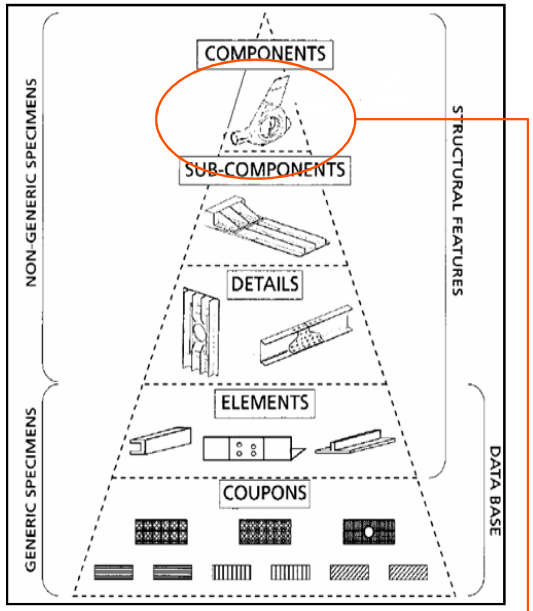
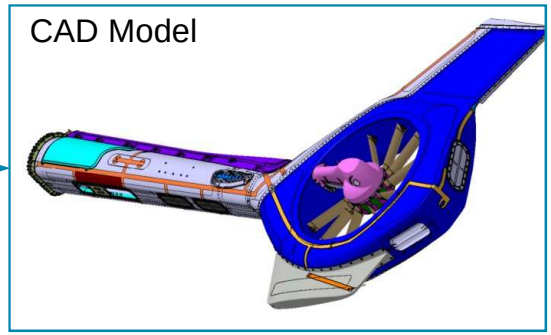
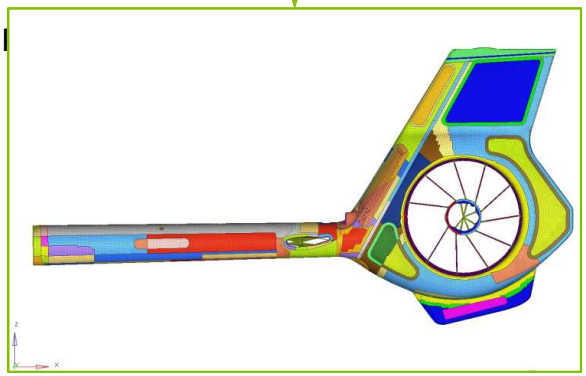
Strength Substantiation Principle: Analysis supported by test (3/3)

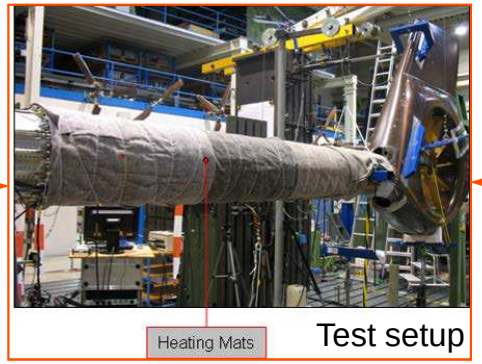


Application to H145 tail unit structure

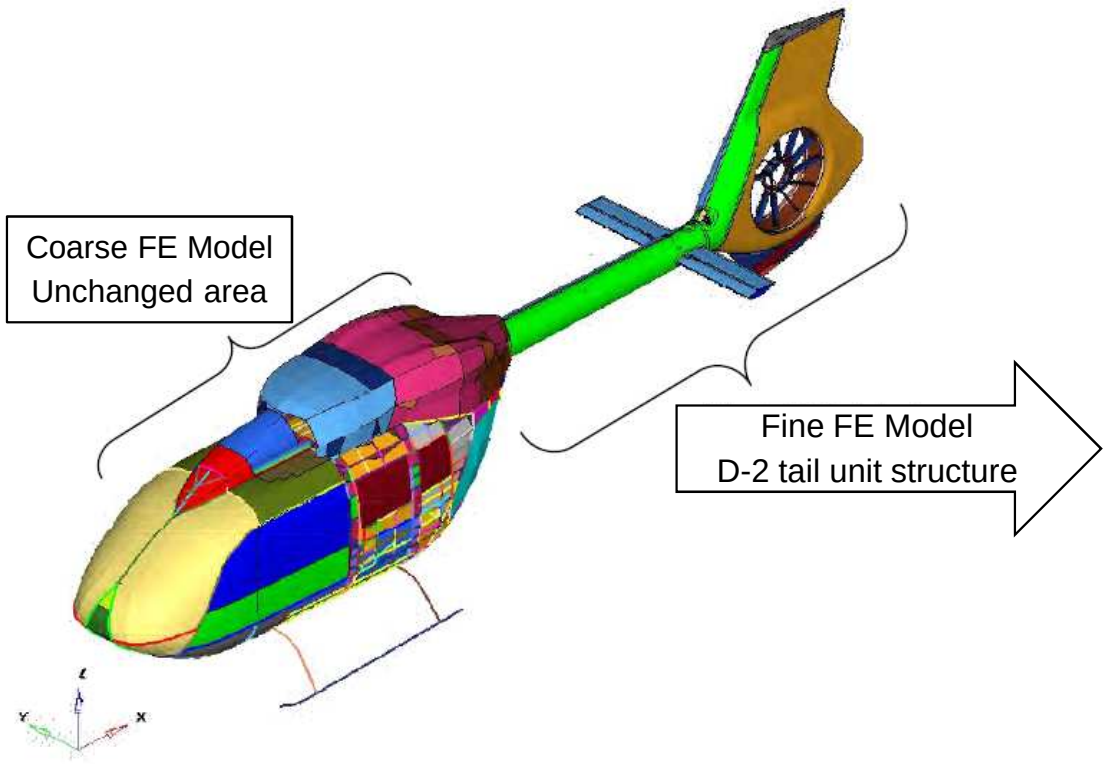








FE-Model description



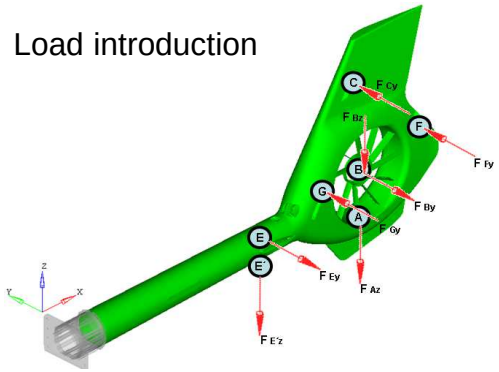
FE Model description of tail unit structure

- NASTRAN based model
- Shell mesh
- Approximately 120,000 nodes and elements, 285 properties and 23 materials
- PSHELL properties for metallic parts and PCOMP properties for CFRP parts
- Properties based on MAT1 cards for isotropic material and MAT8 cards for orthotropic material.
- Mean values for material stiffness
- Mostly linear static analysis (SOL 101) and linear buckling analysis (SOL 105) for strength substantiation

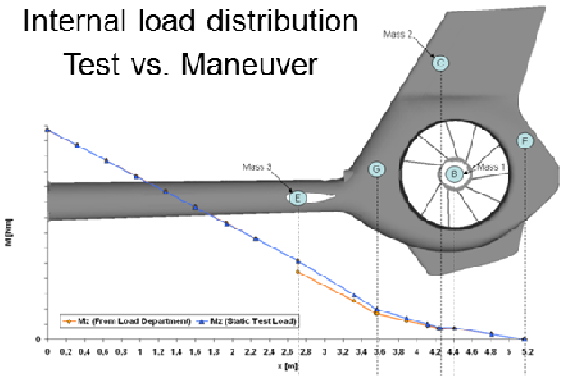
Test setup (1/2)

- Test load cases and load introduction
  - Selected load cases: Yawing maneuver and drag landing
  - Representative tail cone structure for tail unit attachment
  - 6 hydraulic actuators including load cells and stroke measurement
- Combination of load factor and additional heating to account for operational environment
- Presence of multiple manufacturing defects (artificial delaminations as well as quality inspection findings) and impact damages
- Test measurement/instrumentation
  - 11 displacement transducers
  - 45 single strain gauges, 9 rosettes
  - 4 temperature sensors
  - 2-3 areas of 3D digital image correlation measurement per load case

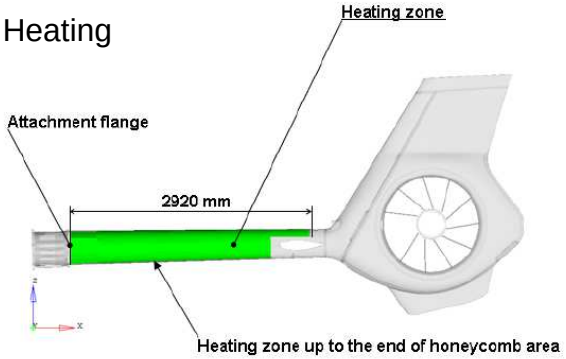
Load introduction

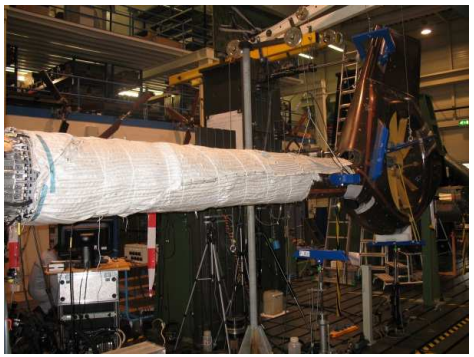


Internal load distribution
Test vs. Maneuver



Heating





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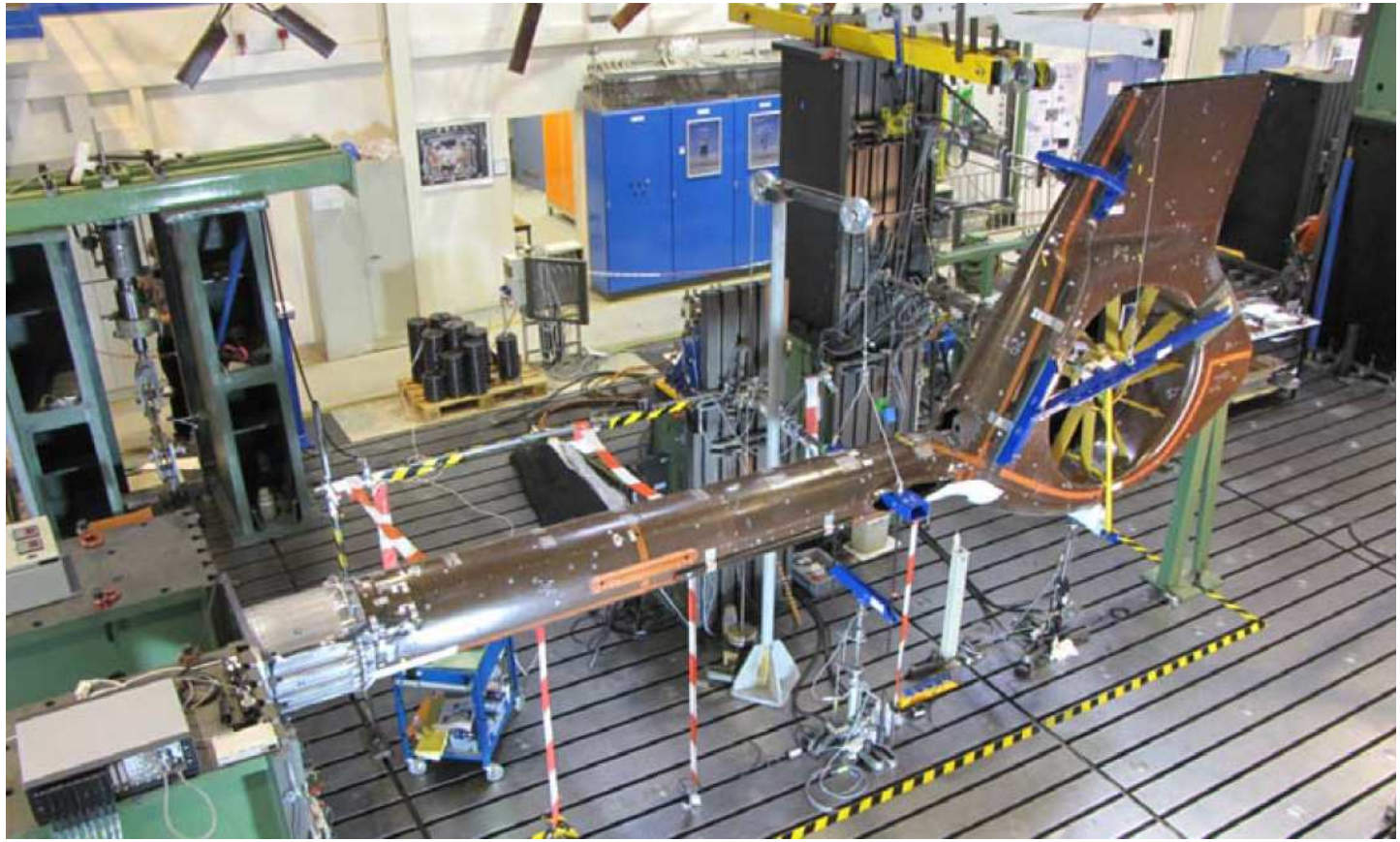
Test setup (2/2)

- The BK117 D-2 tail unit structure test campaign was successfully finished after the completion of several limit and ultimate load certification tests for the globally dimensioning landing and yawing conditions.
- The reliability of the structural analysis FE model was verified by the relevant verification steps. Sufficient confidence in the prediction capability of the FEM model was established.
- The break-away test triggered a serial design modification for increased robustness at the failure area as well as an improvement of the analysis model.



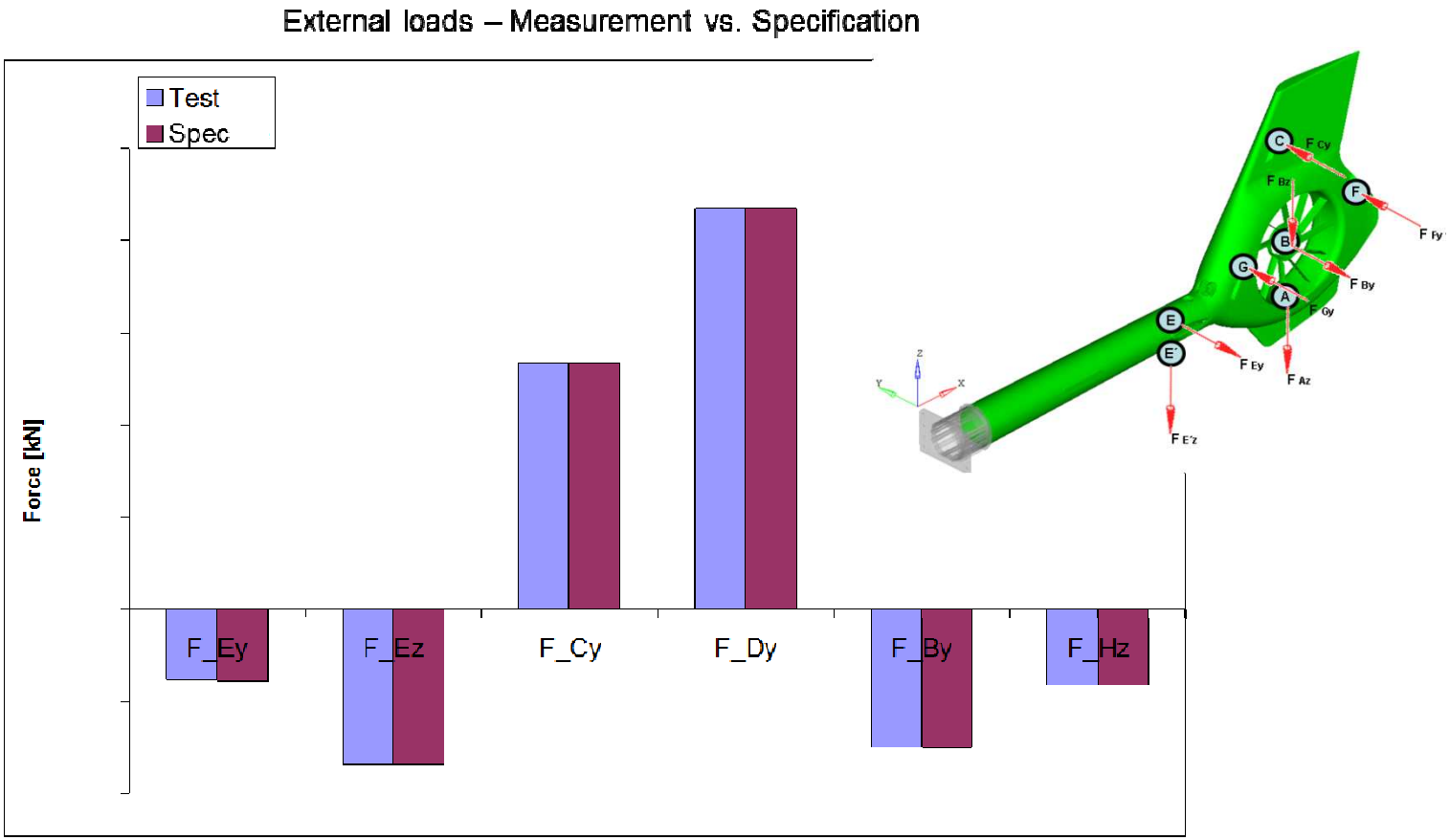
FE Model Verification (Step 1/4)

External loads

- This is a rather formal check if the forces specified in the test order were applied as required.
- Target: 100% match

Interface loads

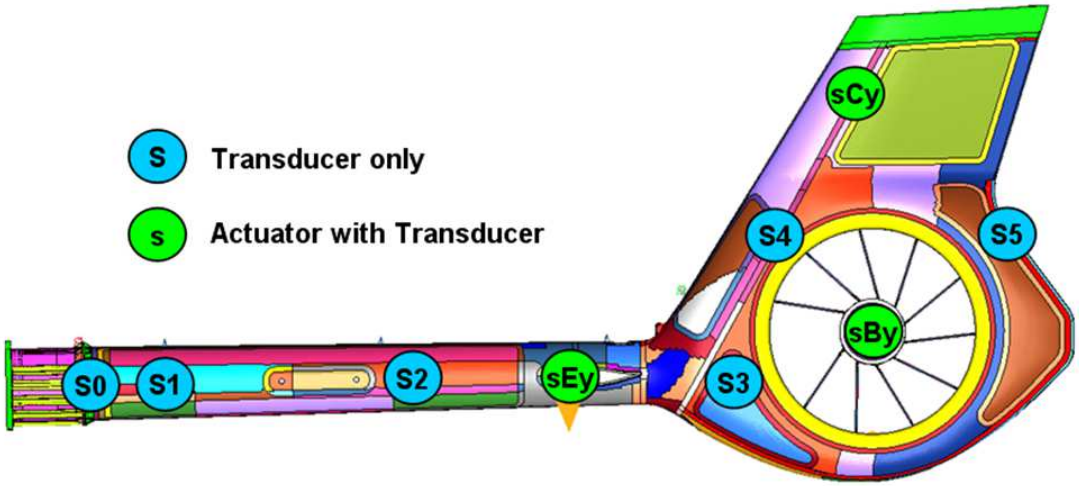
- E.g. interface loads like gear box or landing gear struts, loads at attachment points
- Not applicable for the tail unit test, but necessary for more complex components and test setups
- Primary indicator for deficiencies in the test setup like e.g. misalignment of load actuators due to large deflections, non-rigid suspension, etc.
- Target: Minor or traceable deviations only

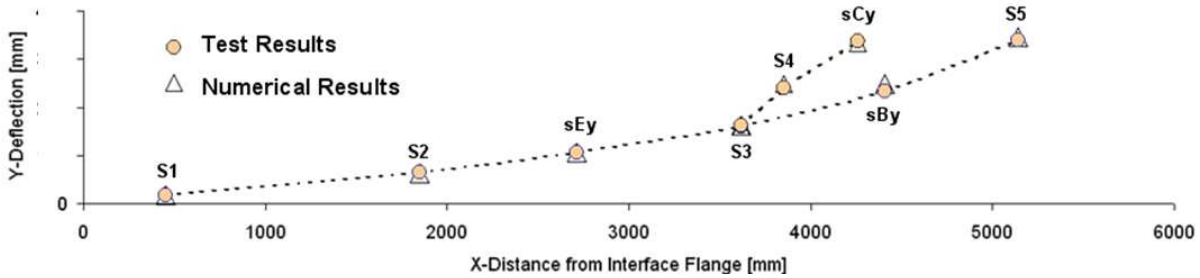


FE Model Verification (Step 2/4)

Deformation

- Measured by mechanical displacement transducers and/or photogrammetry
- In most cases a correction of the test measurements for rigid body movement is necessary, especially at long tail-boom-like structures which are fixed on one side only. A tiny rotation at the fixation causes large defections at the free end.
- Target: Minor or traceable deviations only after correction for rigid body rotation and translation





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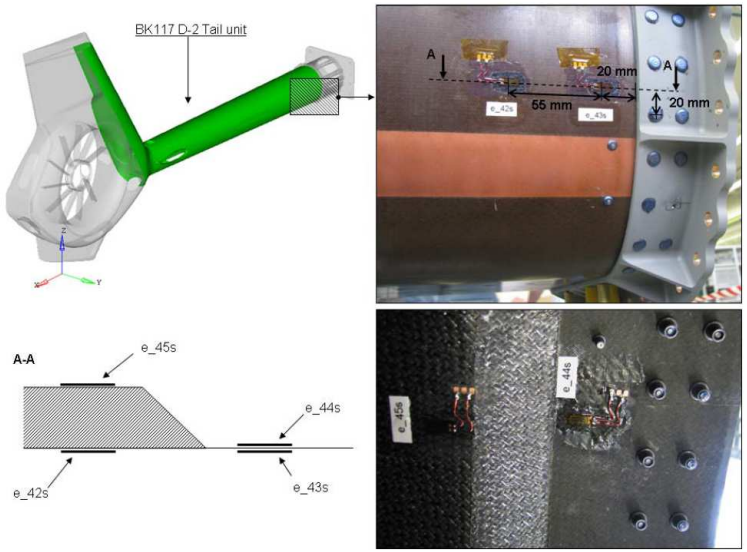
FE Model Verification (Step 3/4)

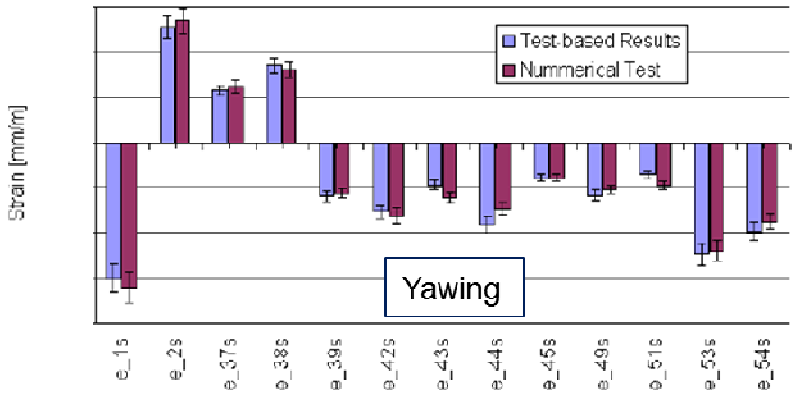
Surface Strain (Strain gauges)

- Evaluation only at gauges with noteworthy amplitude, e.g. > 1 ‰
- Mostly linear behavior is expected.
- Target: ±10% or traceable deviation

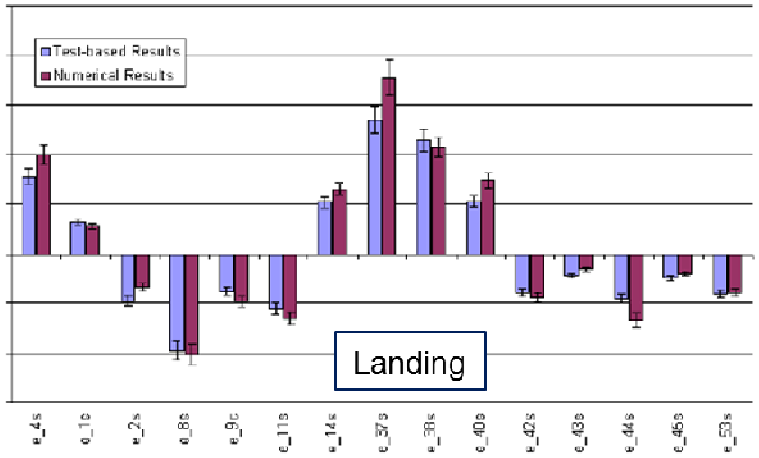
Example of strain gauge application



Strain Gauge	
ID	Area
e_1s	Transition Frame
e_2s	
e_37s	Tail Tube LH
e_38s	
e_39c	Tail Tube Leading Edge RH
e_42s	Tail Tube RH
e_43s	
e_44s	
e_45s	
e_54s	
e_51s	
e_49s	Vertical Spar
e_53s	Tail Tube RH at HS cut out



Strain Gauge	
ID	Area
e_1s	Transition Frame
e_2s	
e_4s	Attachment Flange
e_8s	Tail Tube LH
e_9c	
e_11s	
e_14s	
e_37s	
e_38s	
e_40s	Attachment Ring
e_42s	Tail Tube RH
e_43s	
e_44s	
e_45s	
e_53s	Tail Tube Cut Out at H.S.



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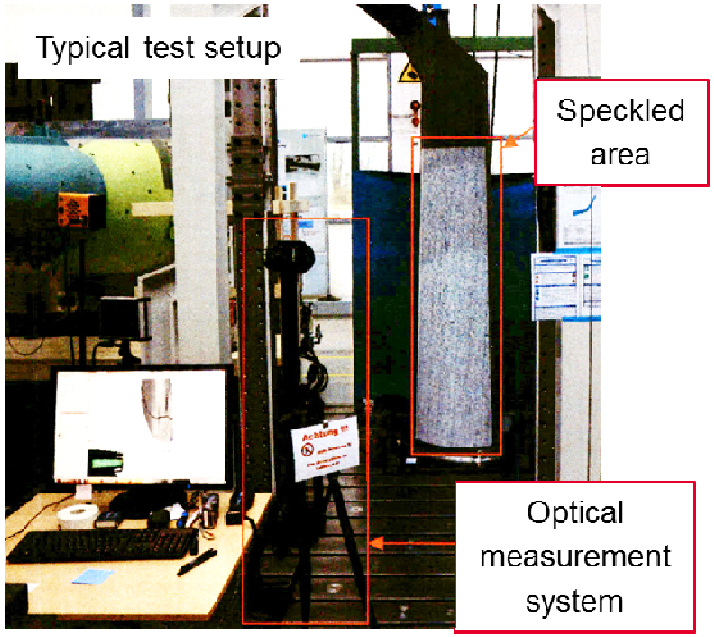
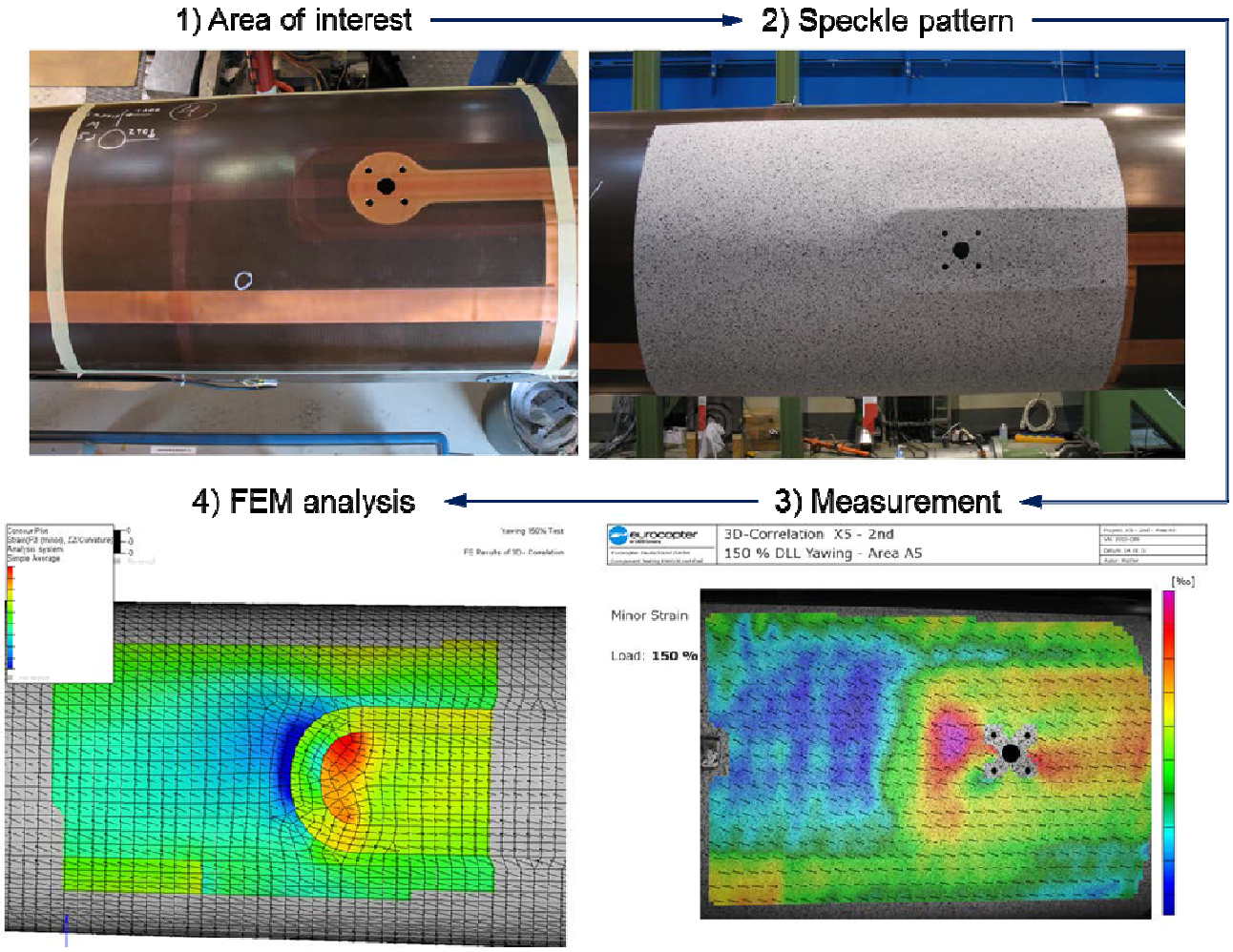
FE Model Verification (Step 4/4)

Surface Strain (3D digital image correlation)

- 3D digital image correlation is an optional verification step after strain gauge verification is done.
- For each point of the observed surface the 3D coordinates are determined and further processed for e.g. deformation and strain evaluation.





Conclusions

- The following FEM model verification steps were performed by comparing the measured parameters with the respective predictions:
  1. External loads ➔ Very good match
  2. Deformations ➔ Very good match after correction for rigid body movement
  3. Local and zonal surface strain ➔ ±10% deviation are acceptable
- All comparisons resulted in the required match of test and analysis data. It always has to be kept in mind that there are several sources for scatter, variability and uncertainty in test setup, test article, measurement technology and FEM model.
- The reliability of structural analysis was confirmed and sufficient confidence in the prediction capability of the FEM model was established.

Thank you for your attention.

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