Integration of Validated Methods for Virtual Product House

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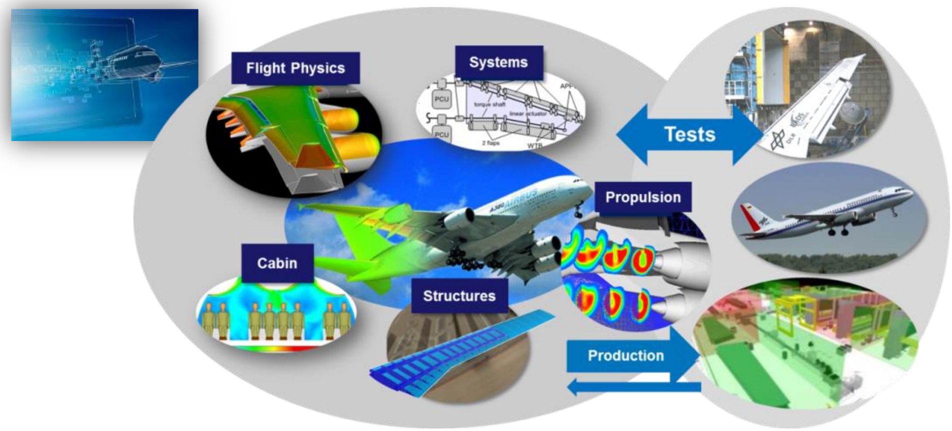
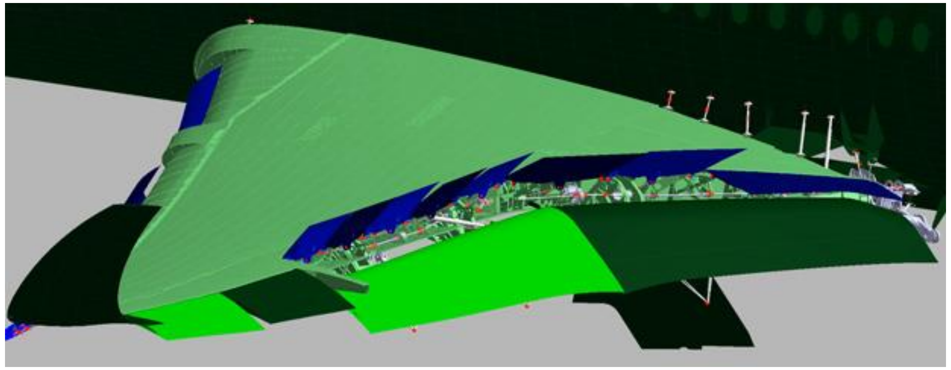
DLR Strategy on Digitalisation of Aeronautics

- Virtual Product as platform
  - Virtual design, testing, certification, production & MRO (connecting all disciplines along aircraft life cycle)
  - Starting point for digital twin



DLR Guiding Concept “Virtual Product ”

- Simulation-based certification
  - Reduce time, cost, risks
  - E.g. Airbus A350-1000 virtual wing bending test
    - simulated effects of deflection on the flight controls
    - validated models from A350-900 flight tests
  - Challenge to prove validity of simulations as Means of Compliance (MoC)



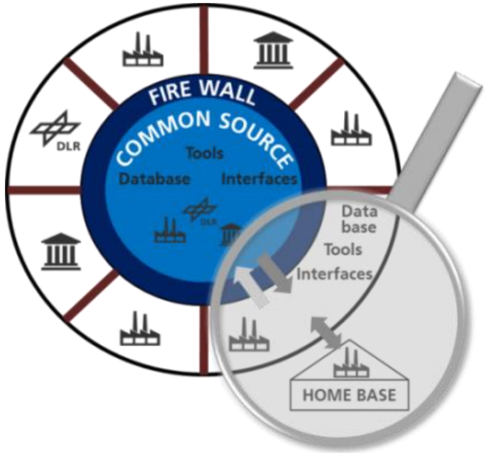
Physical A350-1000 wing bending test replaced by simulation; Image courtesy of Airbus

Virtual Product House (VPH) – Integration and Test Centre

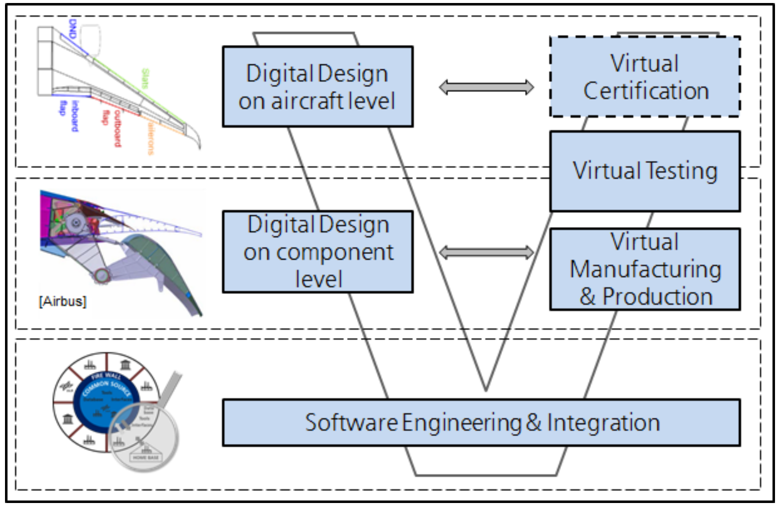
- VPH for simulation-based development of aircraft configurations and components

- Motivation
  - Demands & technology assessment (OEM, supplier, research)
  - Complement competences
  - Virtual testing and effective test design
  - Preparing simulation-based certification

- Technological Objectives
  - Common source framework
  - Validated simulation methods and reference data
  - Uncertainty quantification and validity range
  - Processes and tools for simulation-based testing and certification

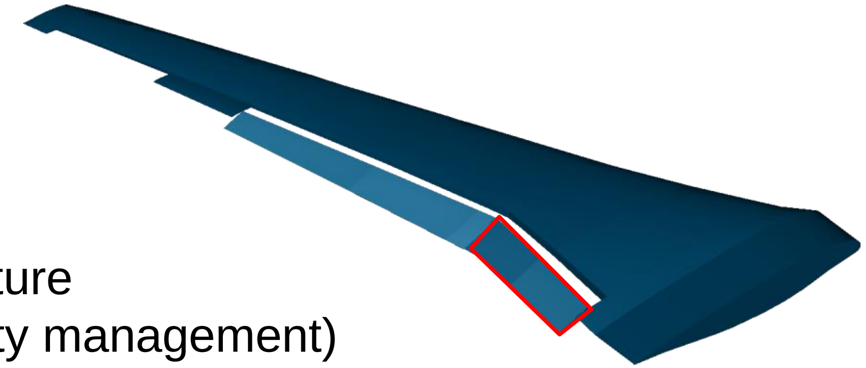


VPH common source framework

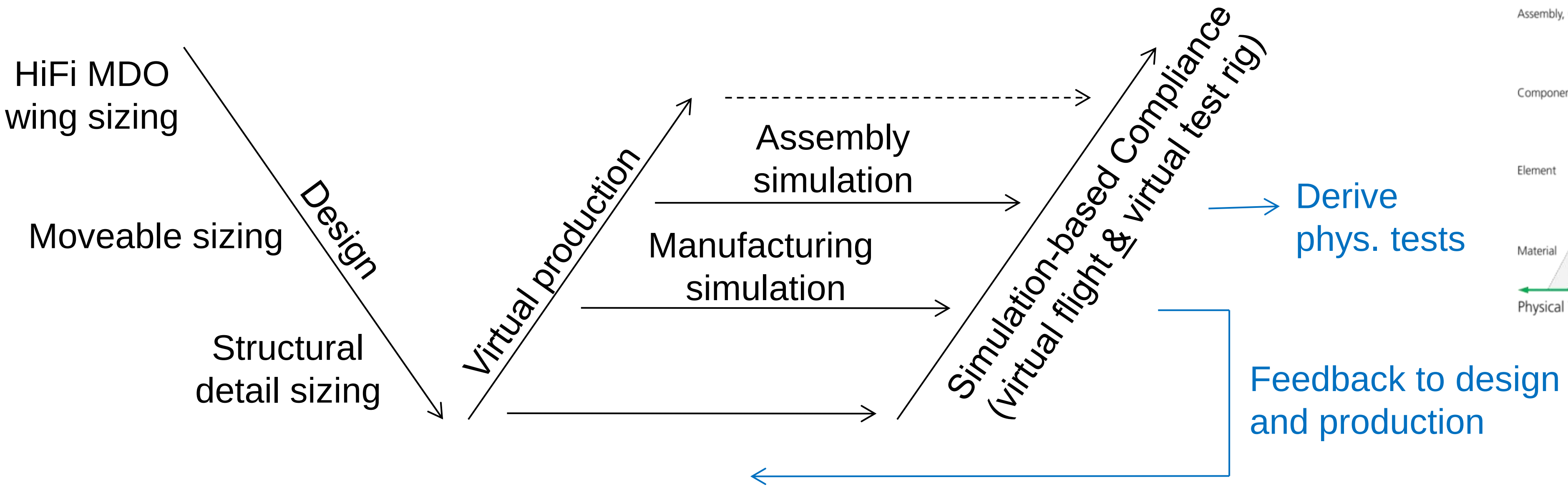


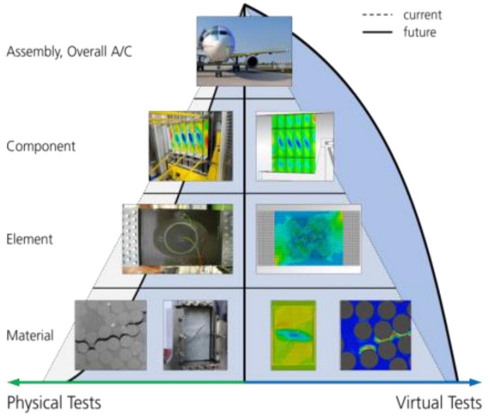
VPH-approach according to V-model

Use Case „Multifunctional Moveable“

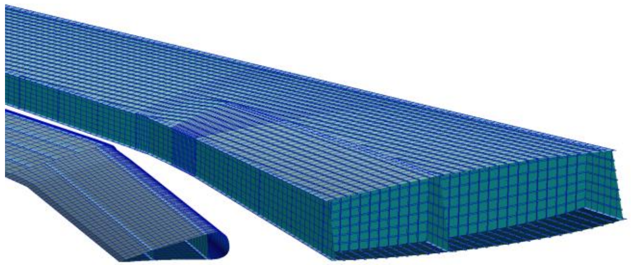


- Work flow based on classical V-process
  - Involving methods and tools from flight physics, systems, structure
  - Software-framework integration (traceability, provenance, quality management)
  - Evaluation and demonstration incl. uncertainties

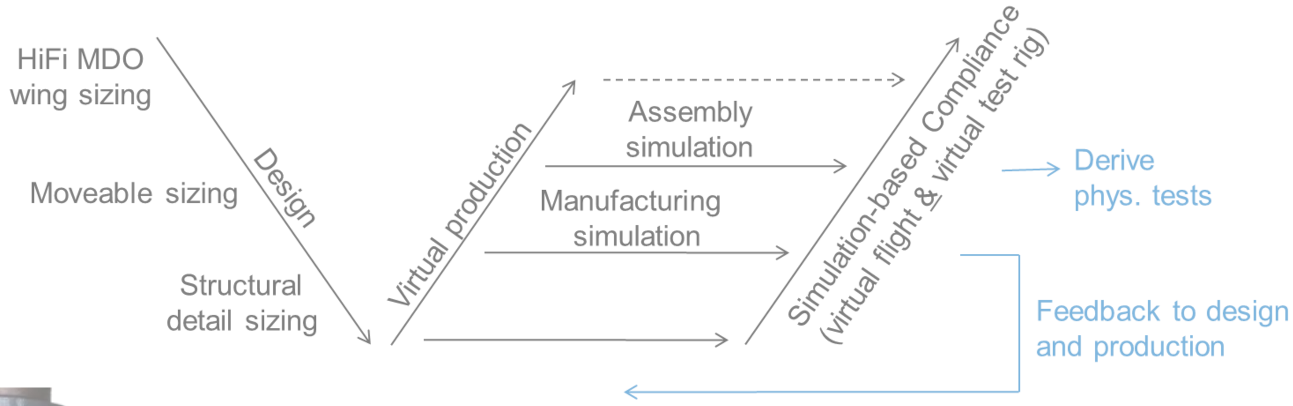


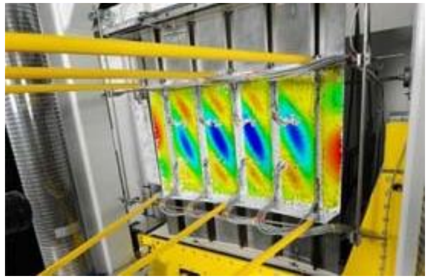


Selected Aspects for Detailed Analysis and Virtual Testing

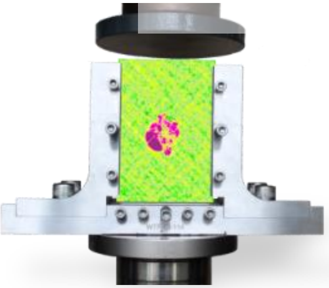


Part Design

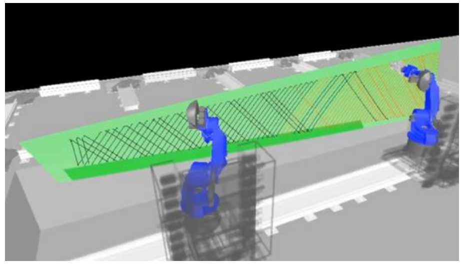




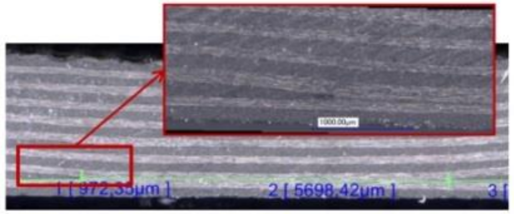
MoC on structural level



Damage Tolerance
Allowables



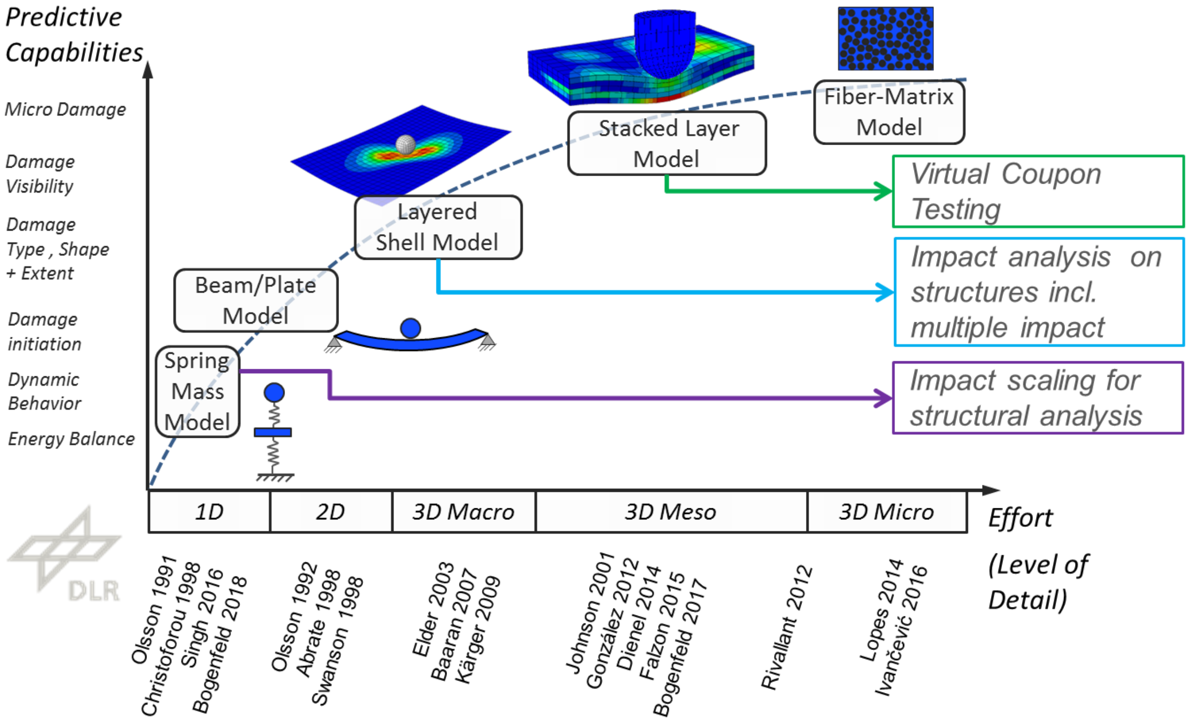
Detailed process design



Manufacturing Tolerances,
Engineering Requirements

Impact and Damage Tolerance Assessment

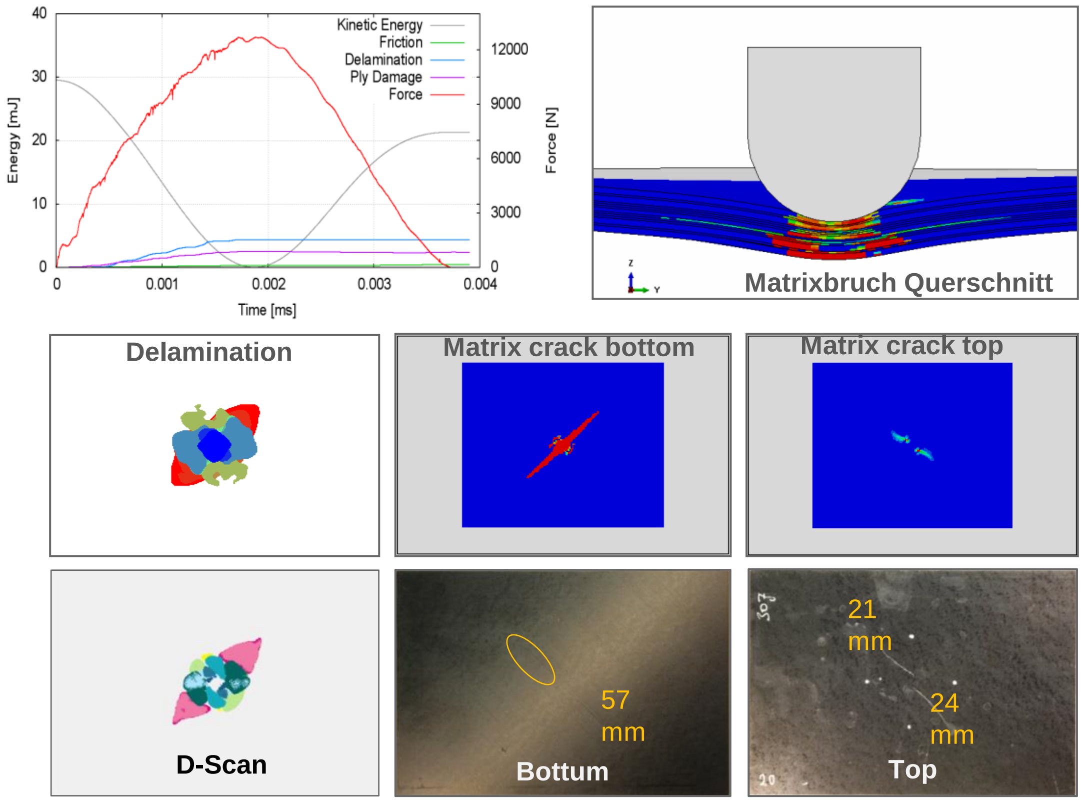
- BVID Assessment on Coupon Level
  - Determine conservative KDF and strain limits (incl. damage interaction, conditioning, scatter)
  - Mainly experimentally, supported by simulation
- Structural assessment
  - Use of strain limits from BVID
  - Detailed high fidelity structural analysis
  - Experimental validation
- Challenges for increased exploitation of simulations
  - Capture uncertainties (modelling, material)
  - Validity of models for new materials or designs
  - Robust simulation chains



Impact simulation and analysis methods

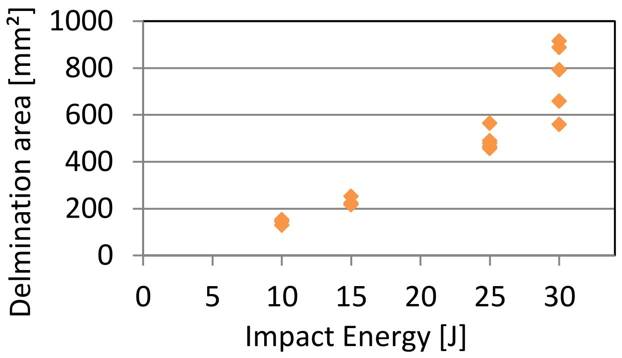
Impact Simulation for CAI Coupon

- FE-based impact simulation

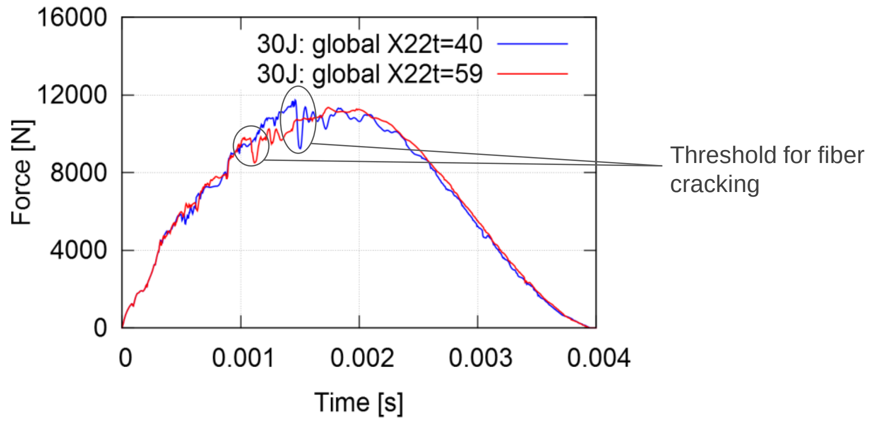


→ High validation level for specific tests [2]

- Testing may show strong scatter of damage

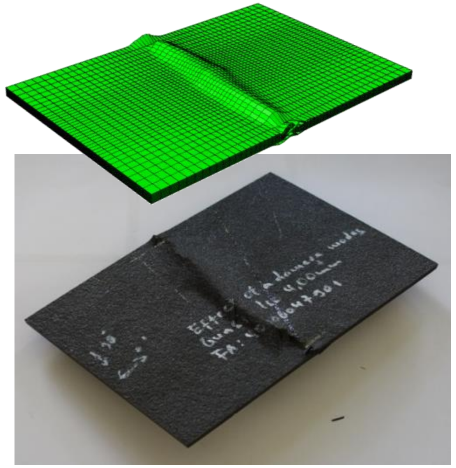


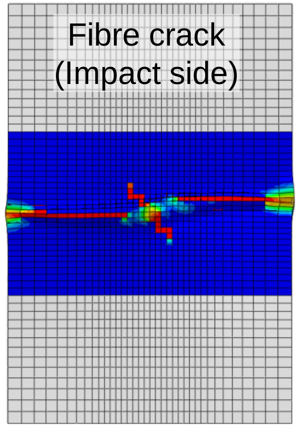
→ Requires uncertainty analysis and conservatism



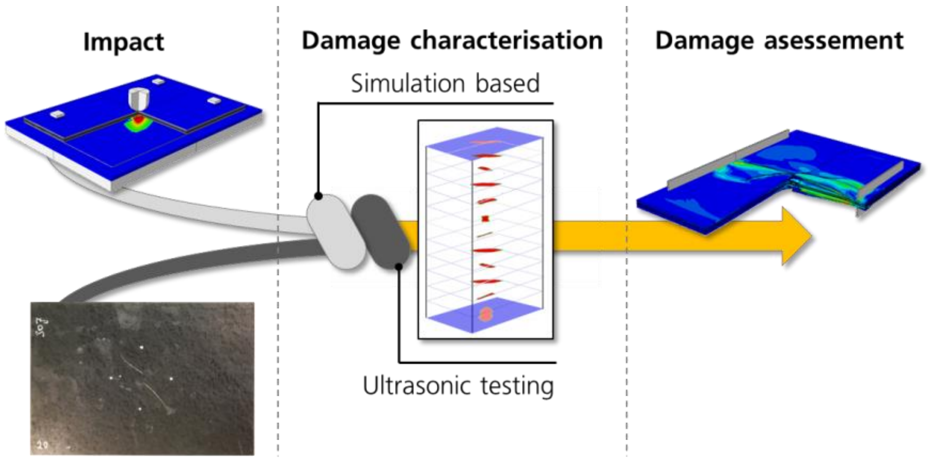
Residual Strength of CAI Coupon

- Residual Strength Analysis
  - Follow-up simulation after impact simulation
  - Result transfer (DaMapper) between analysis steps to increase efficiency

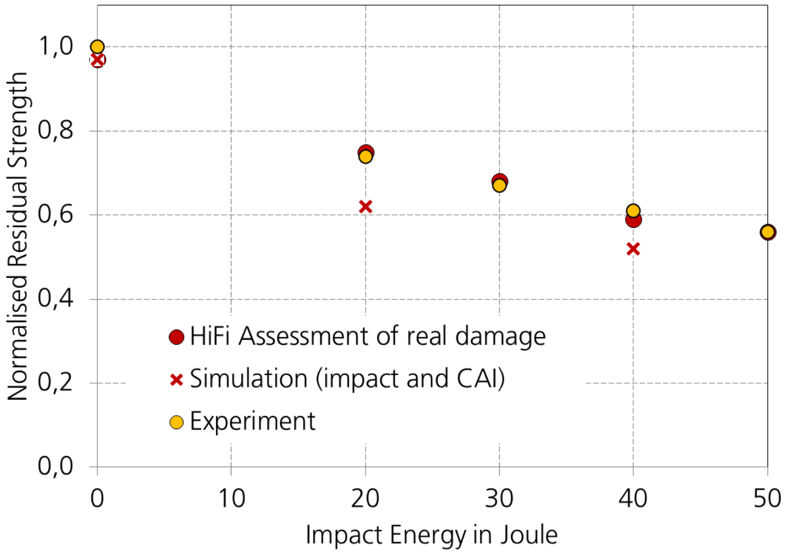




→ High level of CAI validation for known damage [3]
→ Remaining uncertainty rather to predict impact damage



Impact and CAI simulation chain



Validation of impact and CAI simulation results

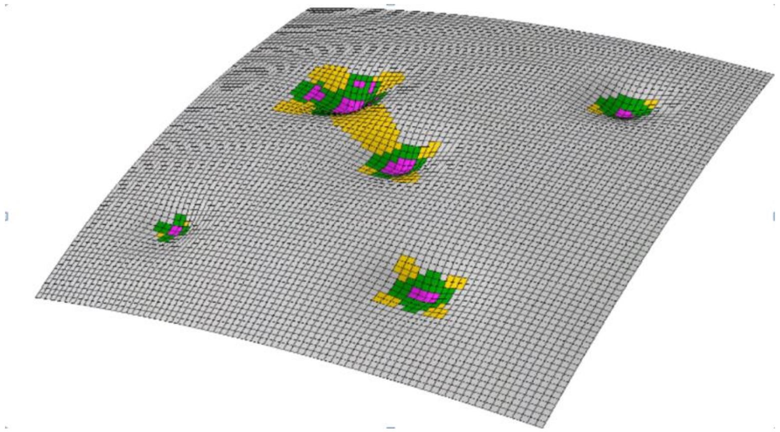
Damage Assessment on Structural Level

- Application of CAI strain criteria

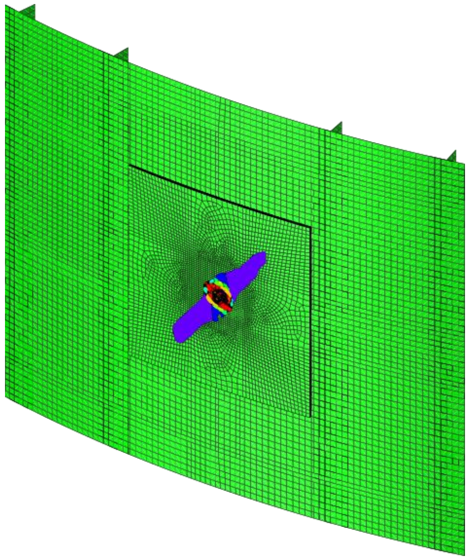
- Layered shell based modelling and simulation [4]
    - Contact laws, single layer shell
    - 3D stress state, 3D failure criteria, material degradation

- High DOF models, refinements, sub-modelling
    - Verification
    - Testing specific cases

- Analytical local-to-global Method [1]



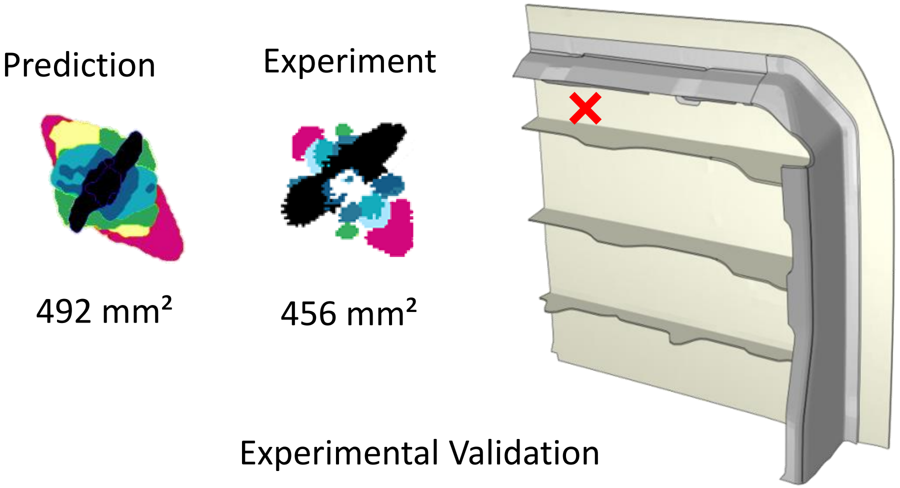
Multiple impact assessment (5 impactors 25-60J)



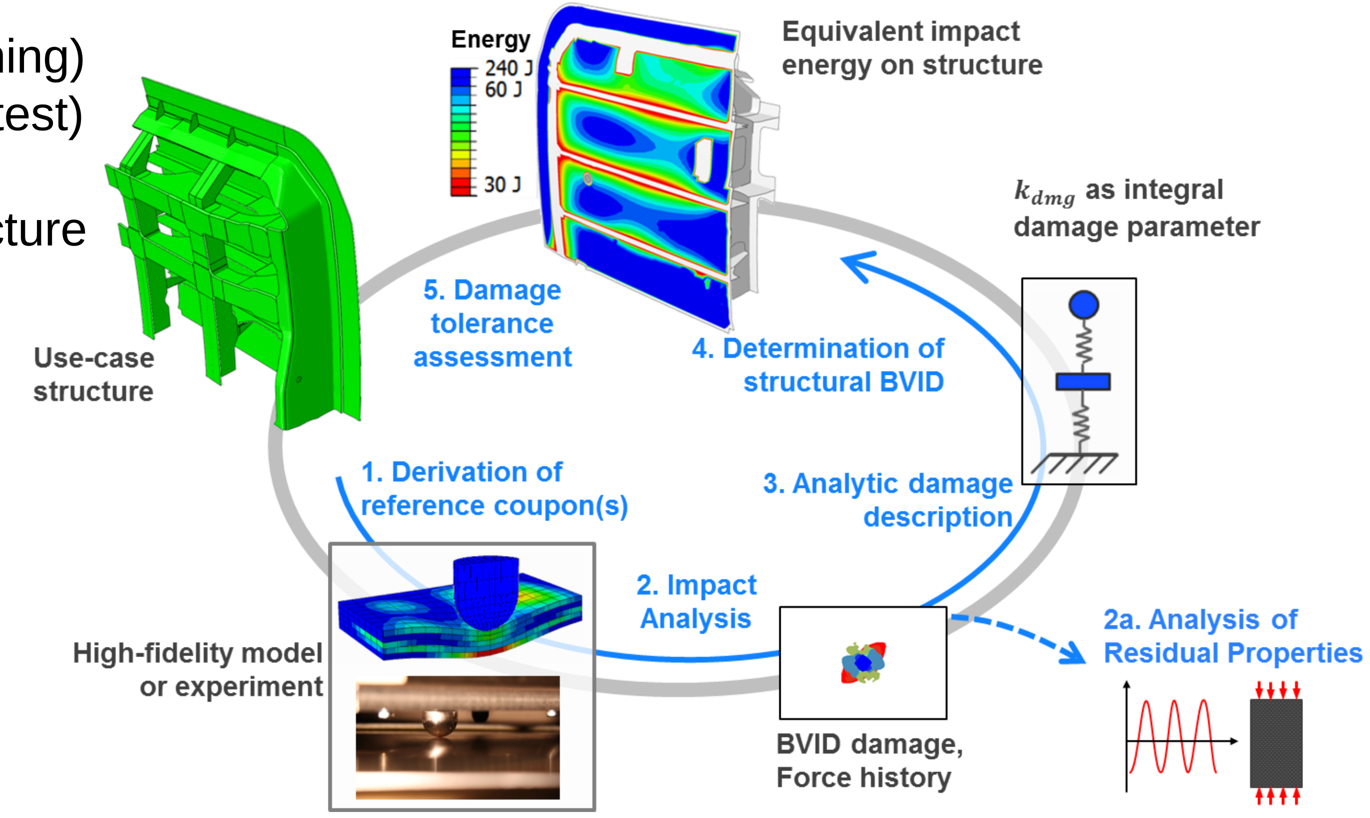
Sub-modelling to assess critical impacts on structural level

Impact Scaling Method for Analytical Local-to-Global Coupling

- Impact Scaling Method [1]
  - Representative substructures (layup, stiffening)
  - BVID limits from CAI results (simulation or test)
  - Determine damage variable
  - Analytical scaling of impact energy on structure
    - → BVID-equivalent impact energy or
    - → Damage for given impact energy



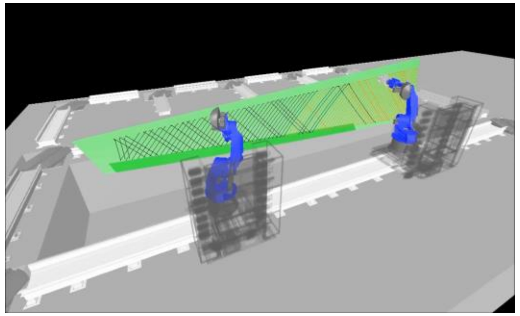
Experimental Validation

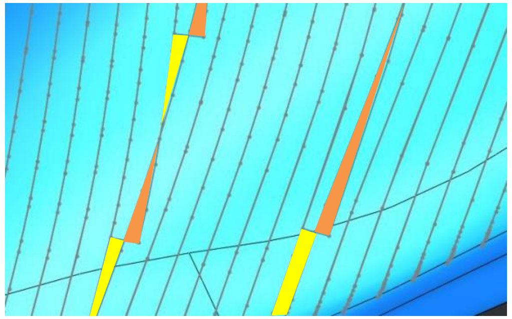


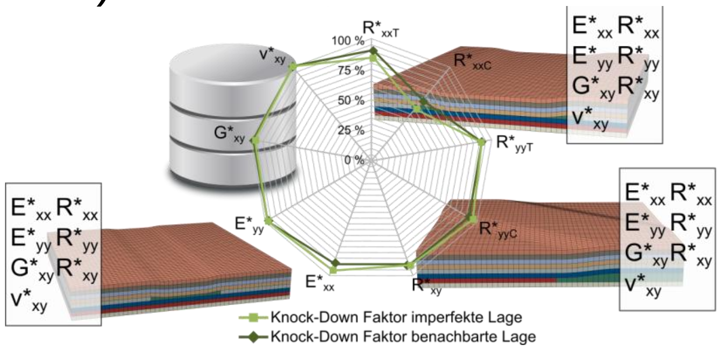
Analytical Local-to-Global Coupling Method

Definition of Manufacturing Tolerances for Fibre Deposition

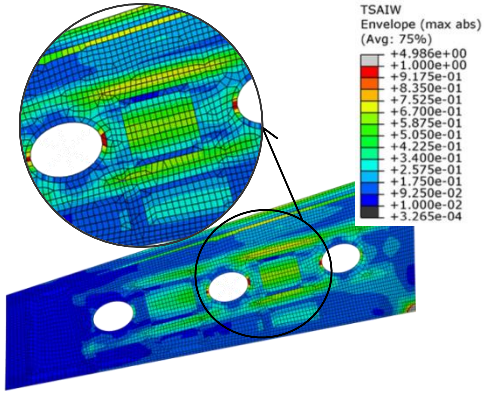
- AFP Simulation
  - Courses, fibre orientation
  - Gaps and overlaps e.g. due to double curvature
- Effects-of-defects analysis [6], [7]
  - Coupon assessment
    - Gaps, overlaps, waviness (simulation & empirics)
    - Analytical & numerical analysis & testing
  - KDF feedback for structural analysis
- Benefits
  - Derive tolerances (engineering requirements)
  - Limited experimental characterisation
    - Reproducibility
    - High amount of samples by combinatorics
  - Baseline for Digital Twin and in-situ assessment


AFP simulation and planning


Gap/ overlaps from AFP simulation



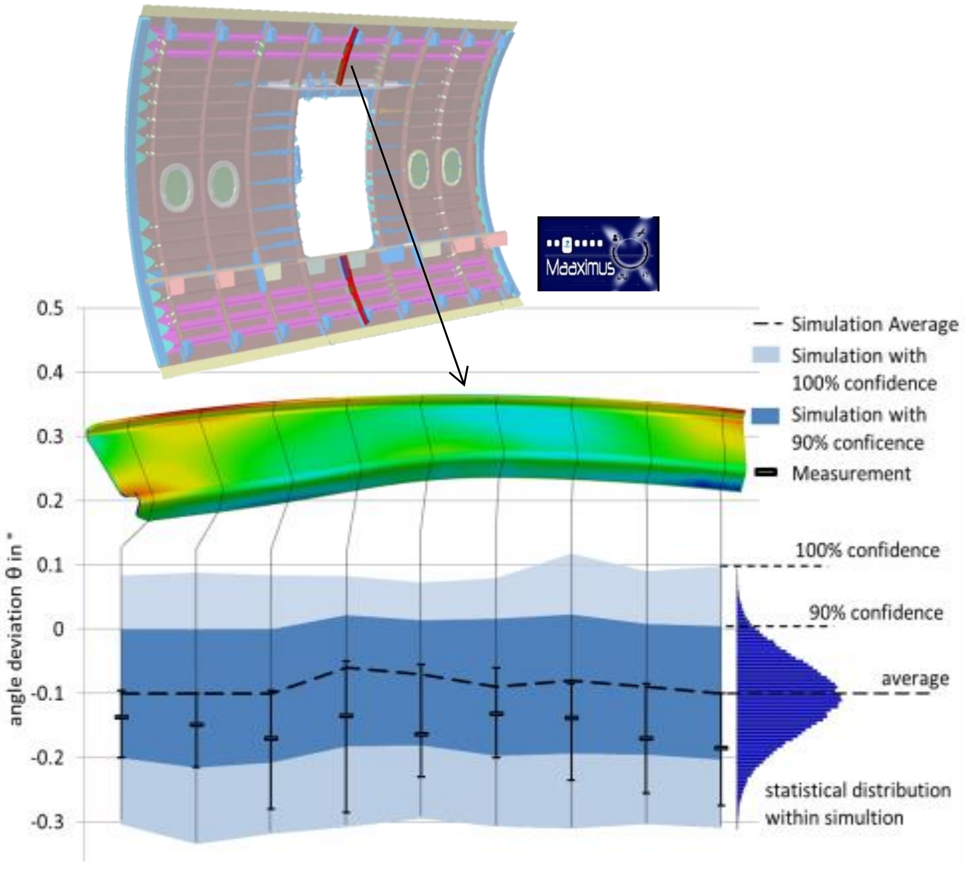
Effects-of-defects database



Structural assessment

Predicting Part Distortions and Deriving Robust Process Windows

- FE-based process simulation
  - Temperature, degree of cure, gelation, glass transition
  - Distortion, residual stresses
- Probabilistic prediction based on surrogate models [5] (varying material and process parameters)
  - Quantification of simulation uncertainties
  - Geometrical tolerances required for assembly
  - Residual stresses
- Robustness optimisation of process parameters
- Derive hot spots for process monitoring (temperature, cure, strain)

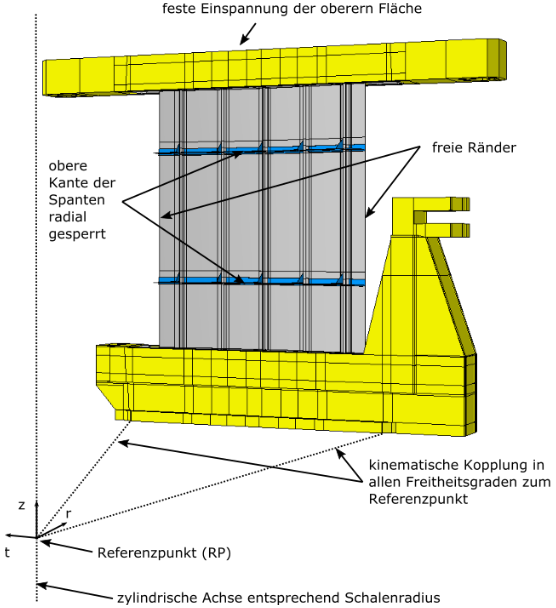


Probabilistic distortion prediction of C73 frame [5]

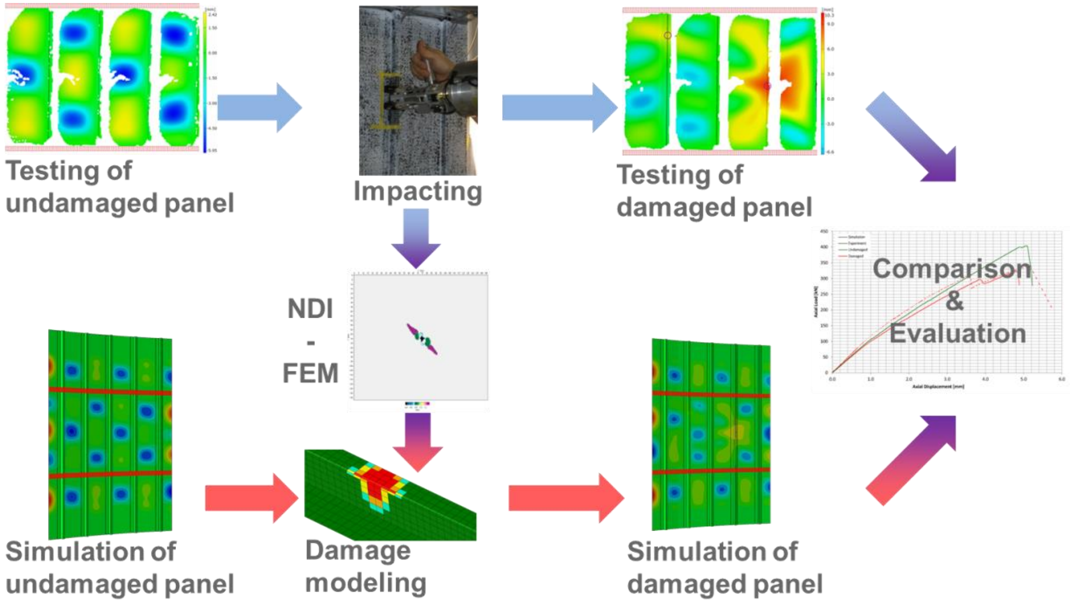
Simulation-based Structural Testing

- Transfer of findings and methods from coupon to structural level
- Assessment of generic and specific damages during virtual testing
- Evaluation of structural behaviour under combined loading
- Test matrix definition

Physical Test Rig



Virtual Test Rig

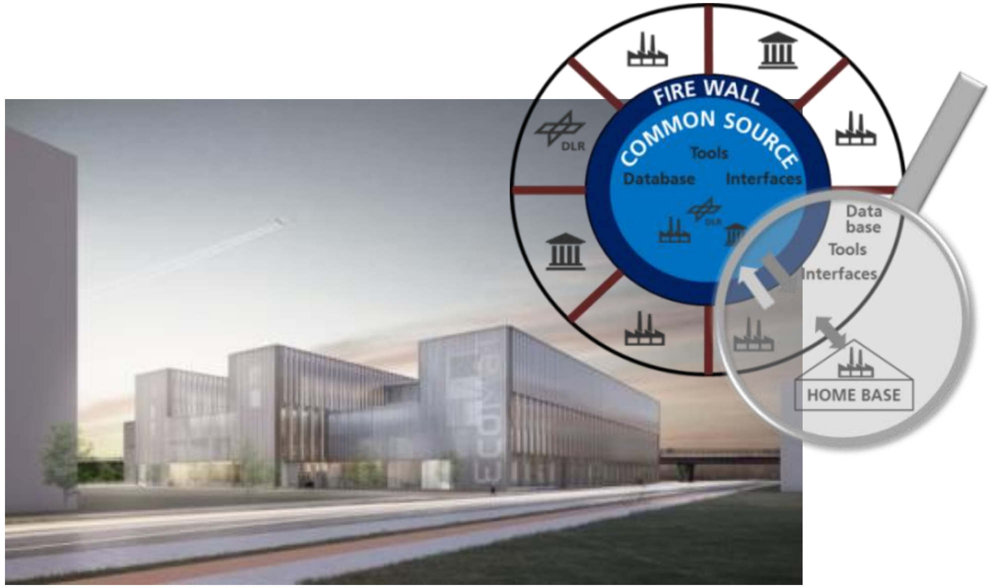


Damage Tolerance Assessment

Summary and Next Steps

- VPH tasks
  - Integrating available tools according to requirements
    - Interfaces
    - Software testing
    - Automated reporting of simulation
  - Continuous verification and uncertainty quantification
  - Methods and processes for simulation-based certification
  - Multifunctional Moveable demonstration

- Parallel research projects on
  - Development and validation of enhanced methods and tools
    - Individual analysis steps where required
    - Scale transfer and mapping
  - Assessment and development of new technologies



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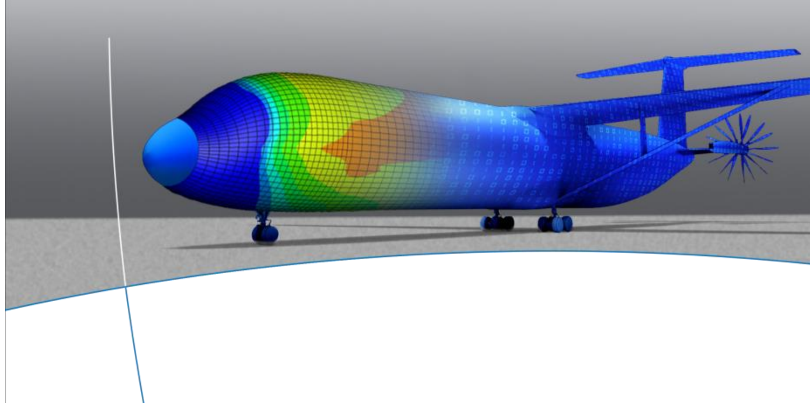
			Titel / Bezeichnung *bzw. Bemerkung*	Dok.-/Zeichn.-Nr.	Datum	Ausg.
	SUBPART C – STRUCTURE					
	GENERAL					
25.301	Loads.	02	HALO Component Design Loads			
25.303	Factor of safety.	02 04	Loads and Stress Report Load Test Report			
25.305	Strength and deformation.	02 04	Loads and Stress Report Load Test Report			
25.307	Proof of structure.	02 04	Loads and Stress Report Load Test Report			
	SUBPART D – DESIGN AND CONSTRUCTION					
	GENERAL					
25.601	General.	01	Engineering drawings			
25.603	Materials.	01 04	Engineering drawings Material test program static, dynamic, temp.			
25.605	Fabrication methods.	01	Engineering drawings			
25.607	Fasteners	01	Engineering drawings			
25.609	Protection of structure.	01	Engineering drawings			
25.611	Accessibility provisions.	01	Engineering drawings			
25.613	Material strength properties and design values	02 04	Stress Report Material test program static, dynamic, temp.			
25.619	Special factors.	02	Stress Report			
25.621	Casting factors.	02	Stress Report			
25.623	Bearing factors.	02 04	Stress Report Material Test Program			
25.625	Fitting factors.	02	Stress Report			



Thanks to All Colleagues and Project Partners!

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Institute of Composite Structures and Adaptive Systems
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- Selected references

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[2] Bogenfeld, Kreikemeier, Wille (2018) *Review and benchmark study on the analysis of low-velocity impact on composite laminates.* Engineering Failure Analysis, 87 (87), Seiten 72-99. Elsevier. DOI: 10.1016/j.engfailanal.2017.12.019 ISSN 1350-6307

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[7] Heinecke, Willberg (2019) Manufacturing-induced imperfections in composite parts manufactured via automated fibre placement. Journal of Composites Science, 3 (2), Seiten 1-24. Multidisciplinary Digital Publishing Institute (MDPI). DOI: 10.3390/jcs3020056 ISSN 2504-477