Fachkongress Composite Simulation,
Schwabenlandhalle Fellbach, 28 February 2013

Design and FE Simulation of Energy Absorbing Composite Aero Subfloor Structures

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DLR

Overview

- Introduction
- Motivation
- Design Methods Development
- Design Methods Validation
- Conclusion & Outlook

Crash Management System

Role of a crashworthy structure :

- is to utilize energy absorbing mechanisms to absorb crash loads in a controlled progressive manner

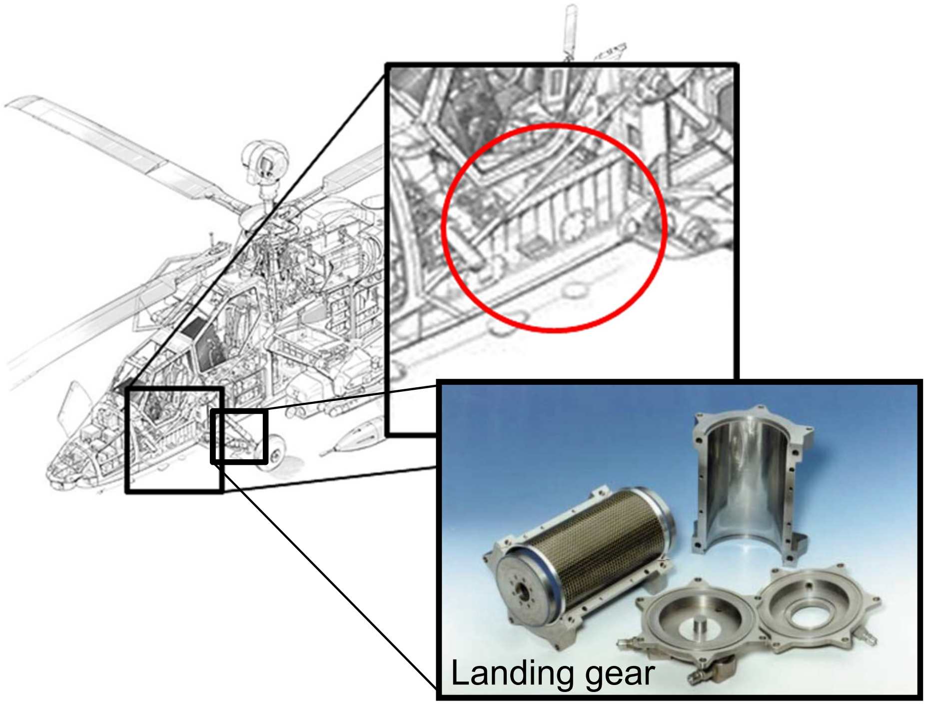
Goals of a crashworthy structure are :

- Limit deceleration on occupants
- Allow the safe evacuation of occupants by maintaining sufficient structural integrity

Full scale drop test of Bell UH-1D (Helisafe TA), Upon impact (left) and after (right)

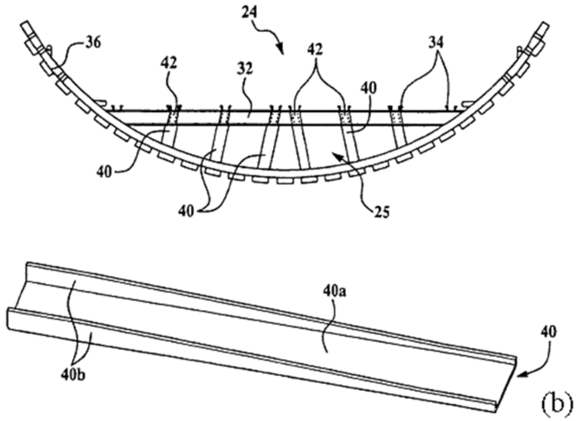
Crash Management System

Increasing usage of composite energy absorbers (EA) in aeronautics



(Wiggenraad 2003)

Helicopters



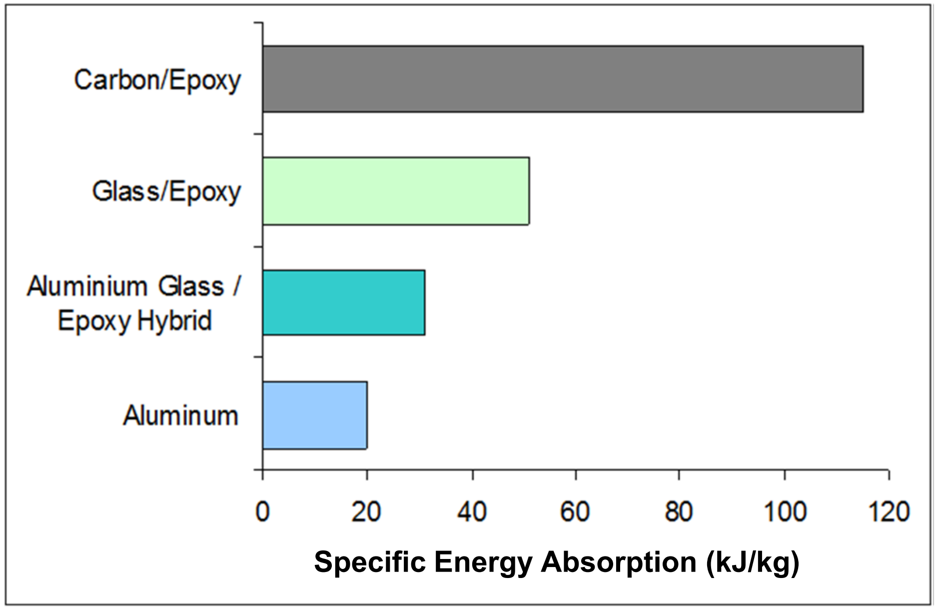
(Bolukbasi 2009)

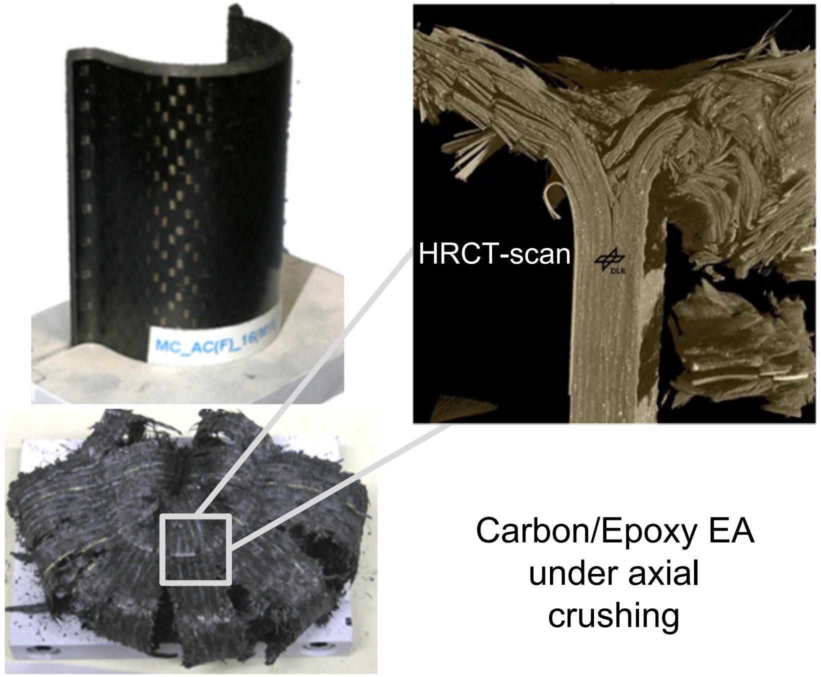
Aircrafts

Polymer Composite Materials

Advantages in utilizing composite EA:

- Composites have very high specific energy absorption
- Energy is absorbed through crushing failure that involves fiber fracture, matrix failure, delamination and friction





Carbon/Epoxy EA under axial crushing

Motivation

Current state-of-the-art :

- Design of composite energy absorbing structures based on extensive experimental data

Problem:

- The complex and interacting failure modes present significant challenges
- Limited ability to predict crushing response
- This poses a challenge for virtual certification

Project aim :

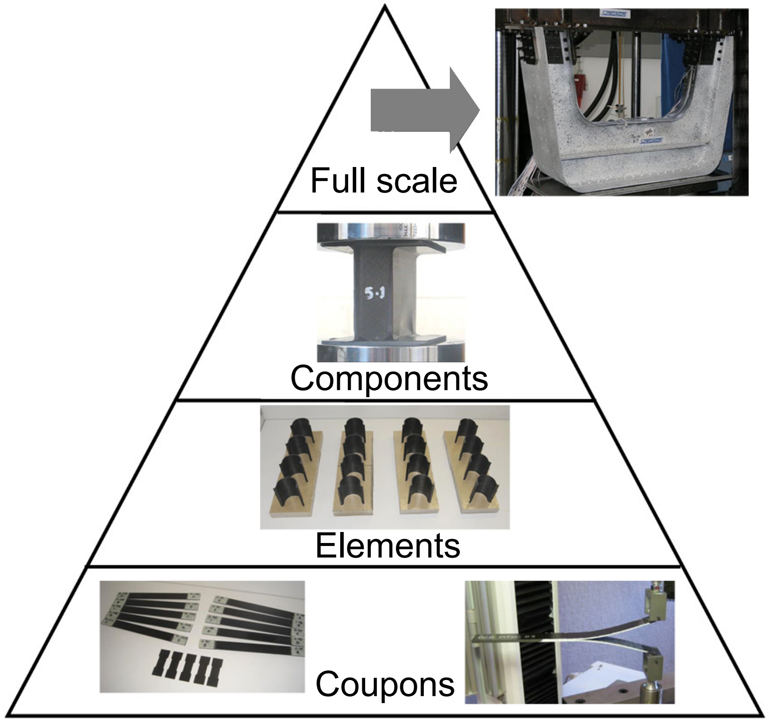
- To develop and validate methods to predict the energy absorption of composite structures

Project outcomes:

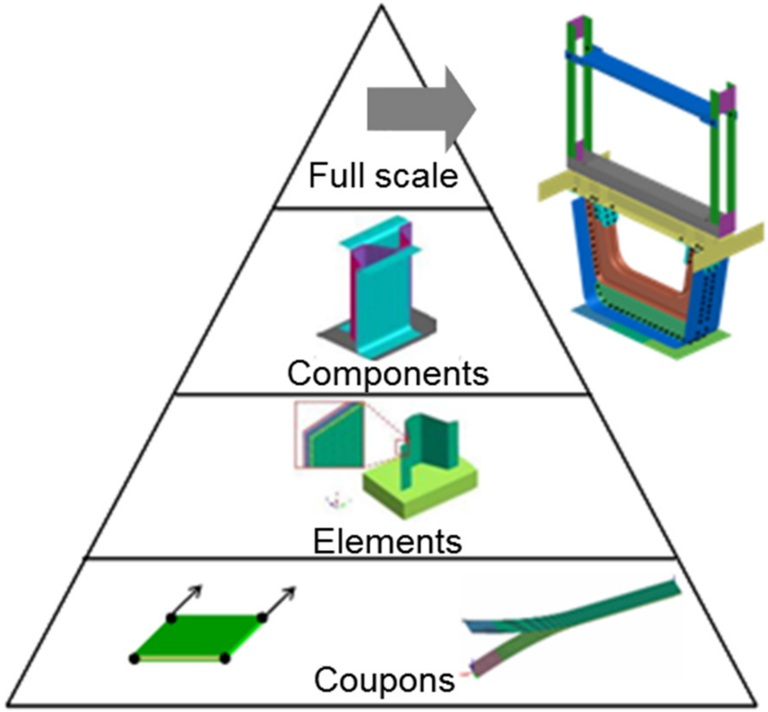
- Improved design confidence, robustness and occupant safety
- Reduced design cycle time and cost

Design Methods Development
Building Block Approach

- Experimental tests of increasing scale and complexity were performed
- Simulation methods developed and validated at each stage



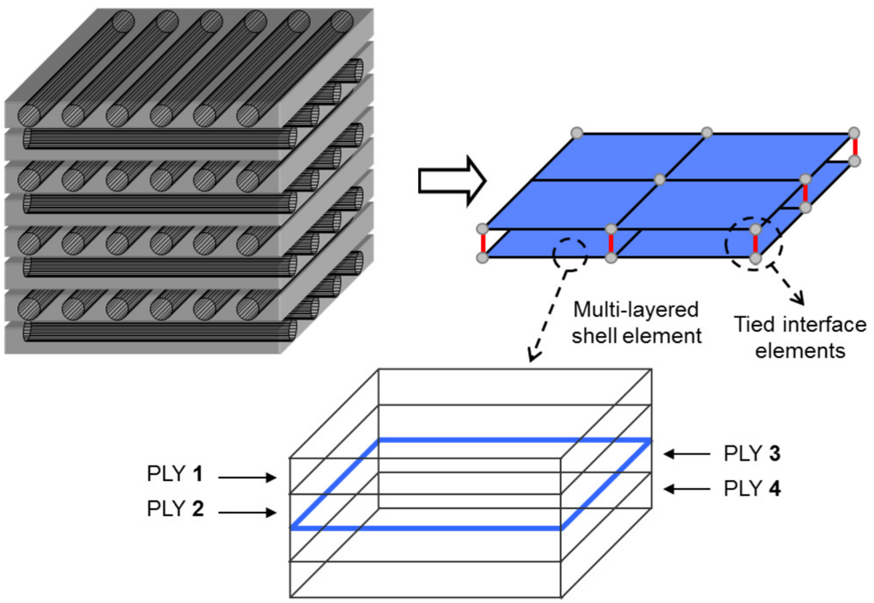
Experimental Building Block



Simulation Building Block
PAM-CRASH

Numerical Simulation Methodology
Ply Model

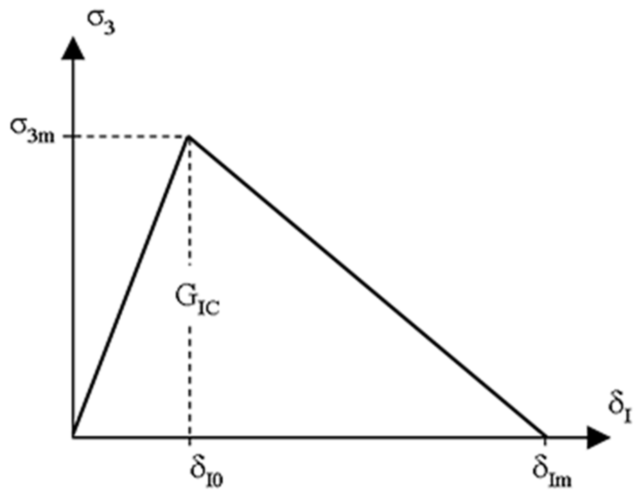
Stacked Shell Approach (Meso-scale model)



- Multi-layered shell element utilized for the modelling of the individual ply, sub-laminate or a laminate depending on the level of detail required
- Plies modelled with a homogeneous orthotropic elastic damaging material
- Parameters derived from material characterization tests
- Ply card validated using a single multi-layered shell numerical model in tension, compression and cyclic shear loading

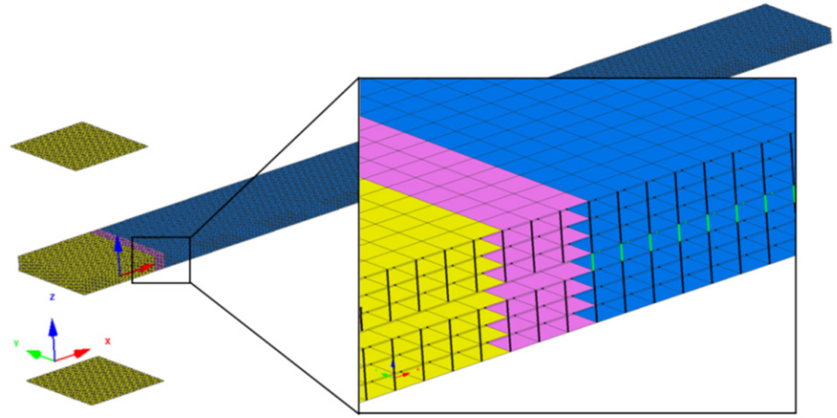
Numerical Simulation Methodology
Cohesive Interface

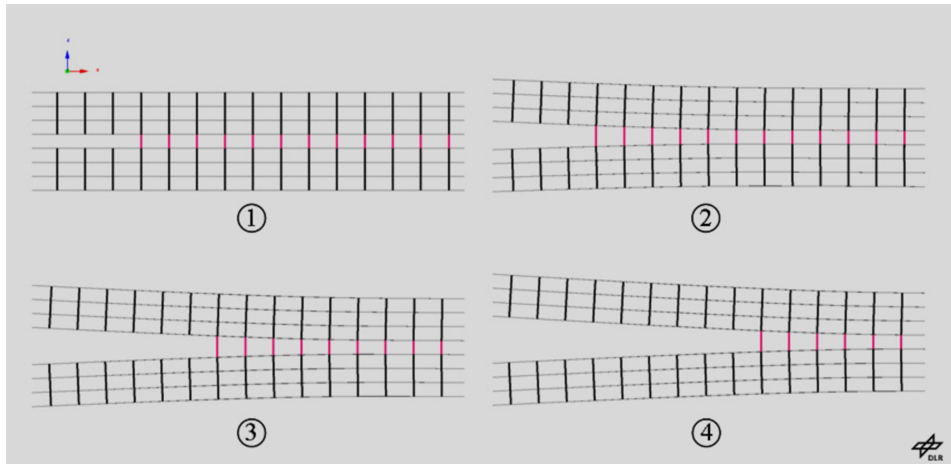
Tied Interface Element



- Bi-linear elastic damaging material law

- Crack propagation at damaged interface controlled by interlaminar fracture energy which is derived from Mode I (DCB) and Mode II (ENF) tests

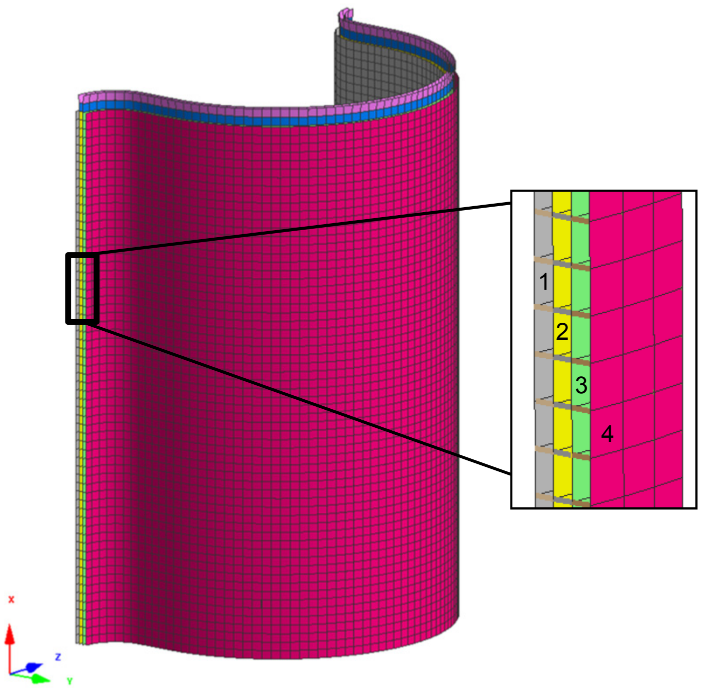


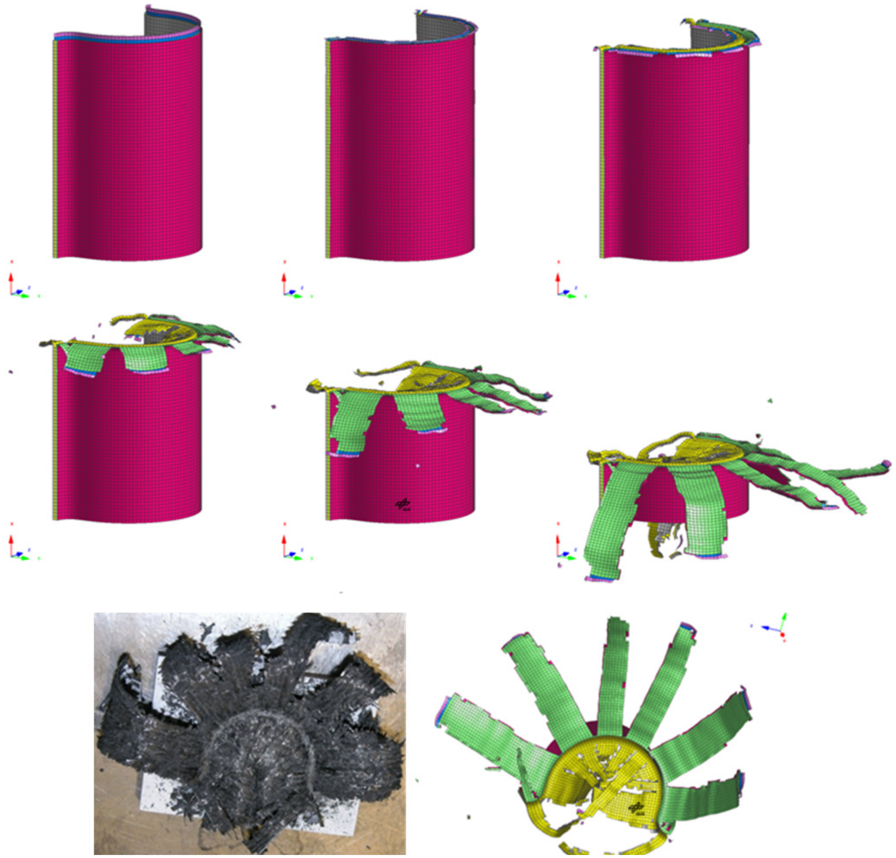


FEA of Double cantilever test (DCB) to derive input parameters

Numerical Simulation
Element Level

DLR Segment Specimen



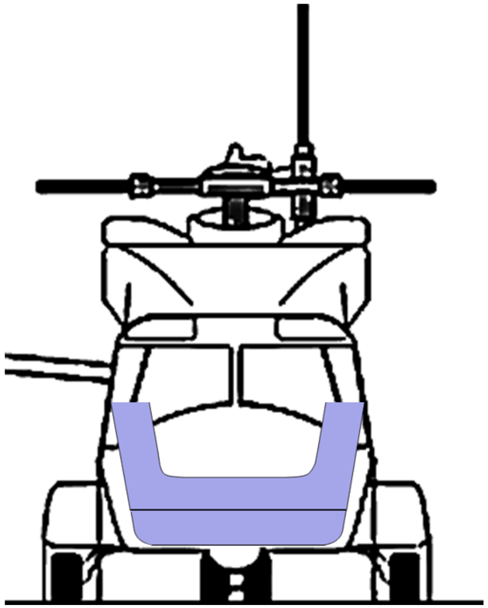


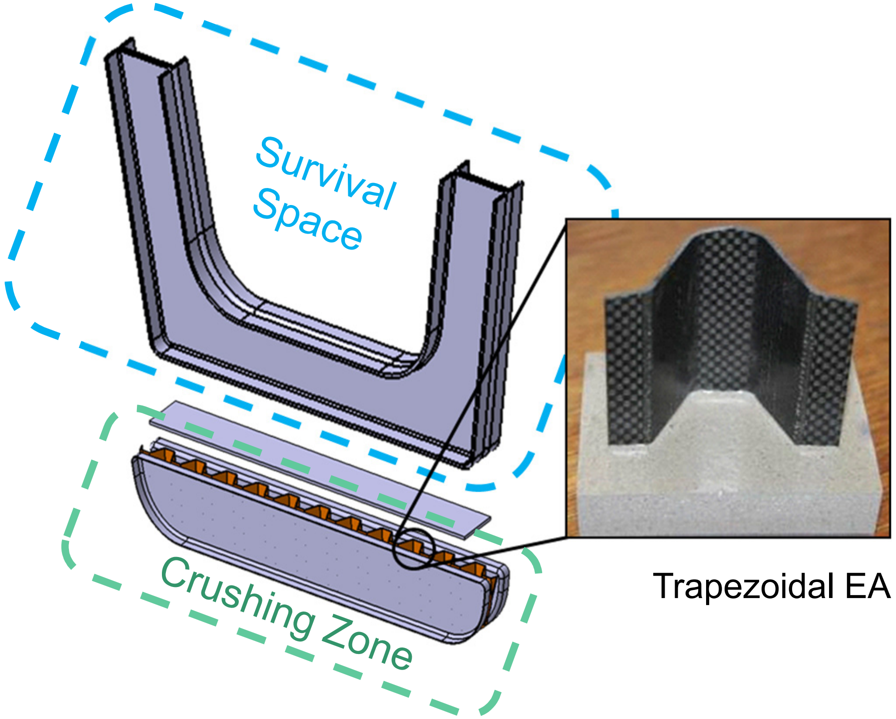
Quasi-static crush test

Design Methods Validation
Test Article Concept

Representative of a helicopter frame section (Carbon / Epoxy)

- Strong and stiff survival space
- Energy absorbing subfloor structure

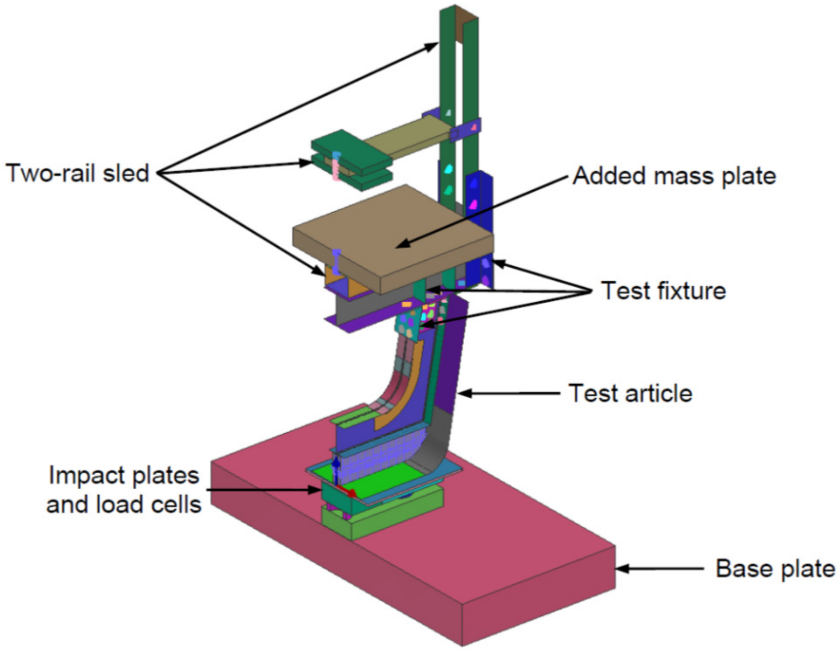


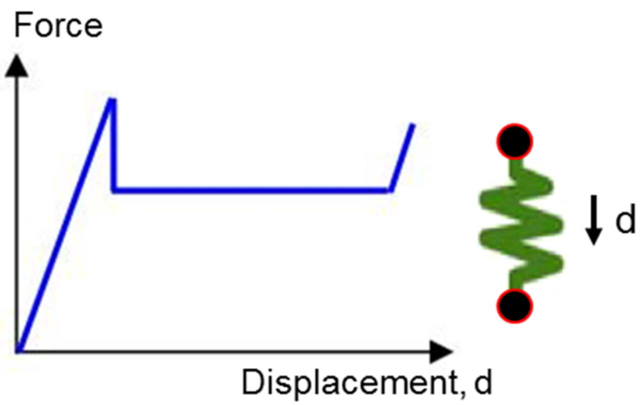


Design Methods Validation
Test Article Design

Pre-test simulation used in design of test article and test setup

- Global Modeling Method used together with macro model of the energy absorbing structure
- Nonlinear springs implemented to describe the crushing response



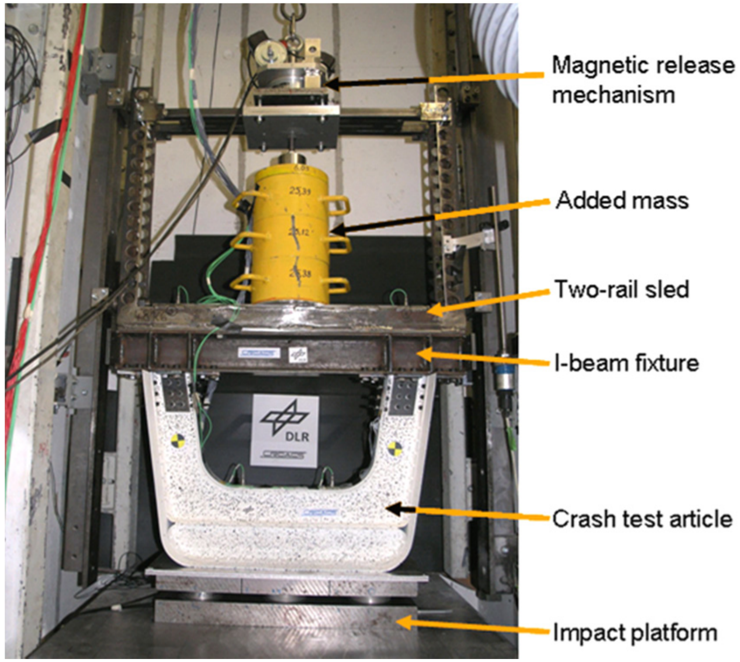


Design Methods Validation
Test Setup

Testing at DLR, Stuttgart

- 1 Quasi-static test
- 2 Dynamic tests

Static test setup



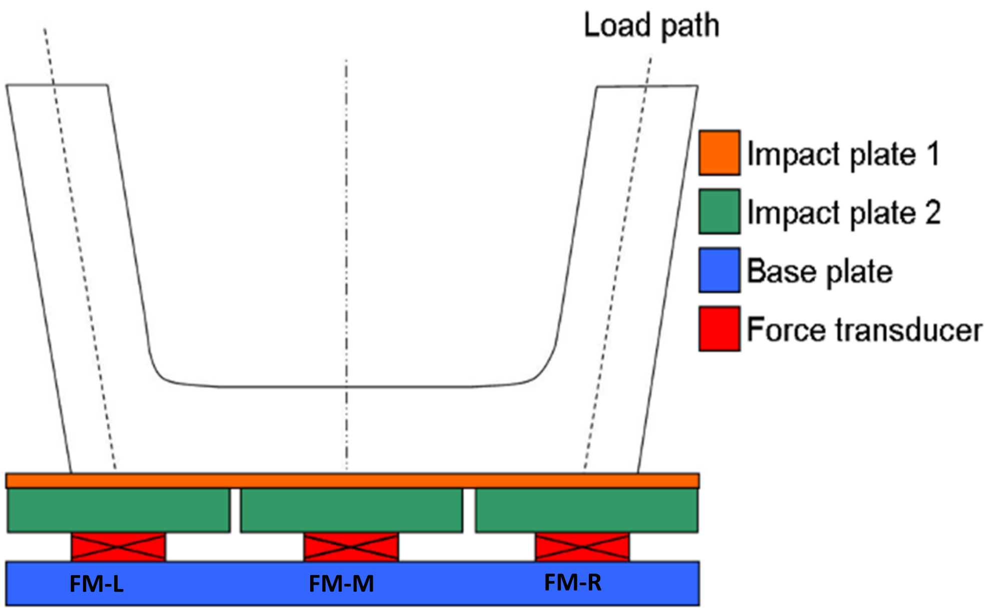
Drop tower test setup

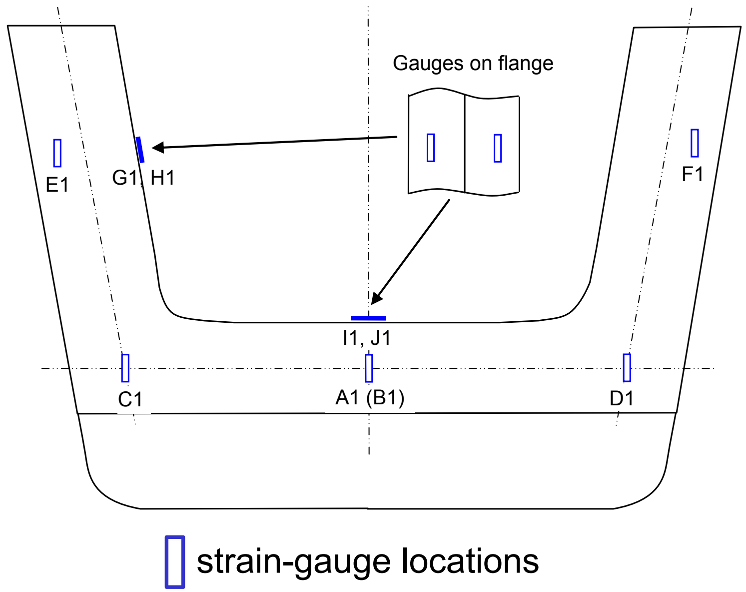
Design Methods Validation
Impact Platform and Instrumentation

A novel impact platform designed for testing

- reduced the occurrence of undesired vibration response in the impact platform
- Sensitive to off-axis impact conditions

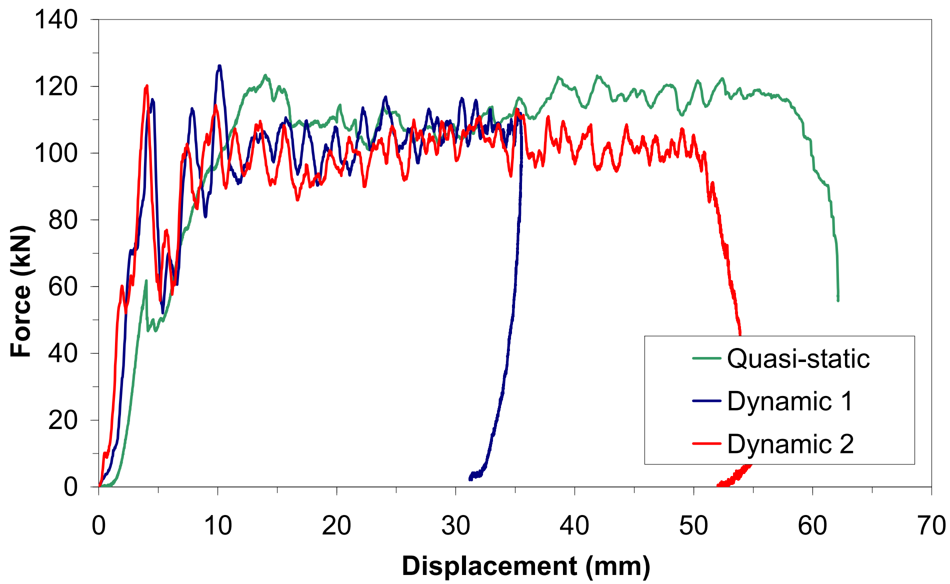
Test articles instrumented with strain gauges, accelerometers and high video

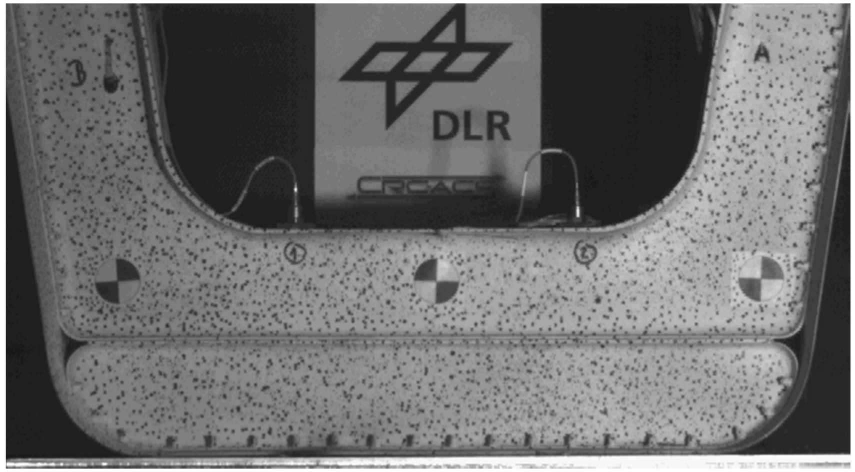




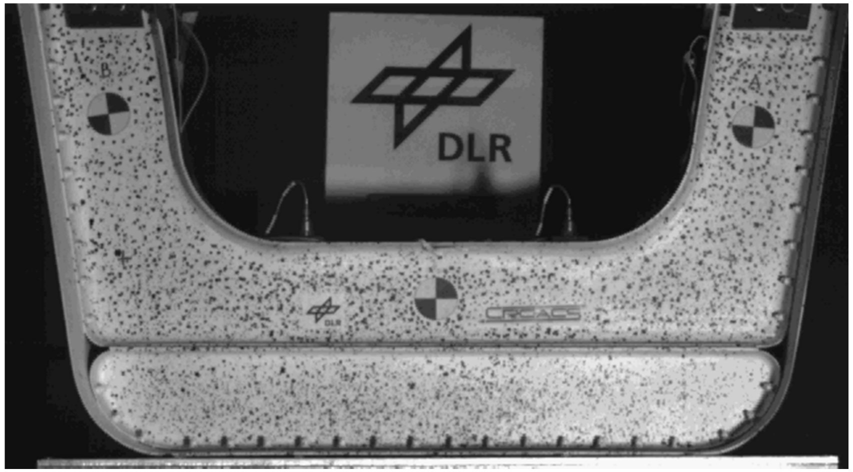
Design Methods Validation
Experimental Results

Quantity	Quasi-Static	Dynamic 1	Dynamic 2
Mass (kg)	-	98	159
Impact Velocity (m/s)	-	8.05	7.99
Impact Energy (kJ)	-	3.2	5.1
Absorbed Energy (kJ)	6.3	2.9	5.1
Crush Distance (mm)	62	32	56
Maximum Load (kN)	123	126	120
Steady Crush Load (kN)	113	104	101



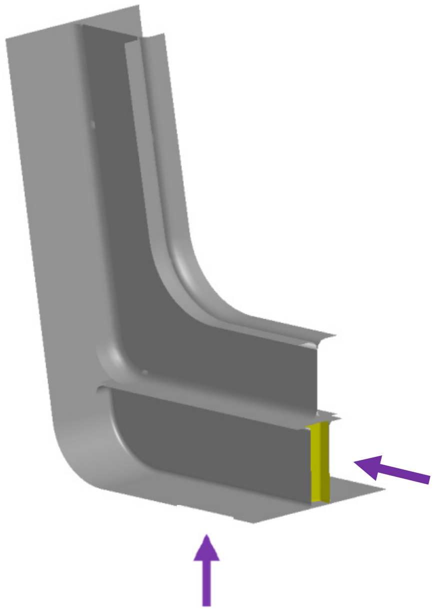


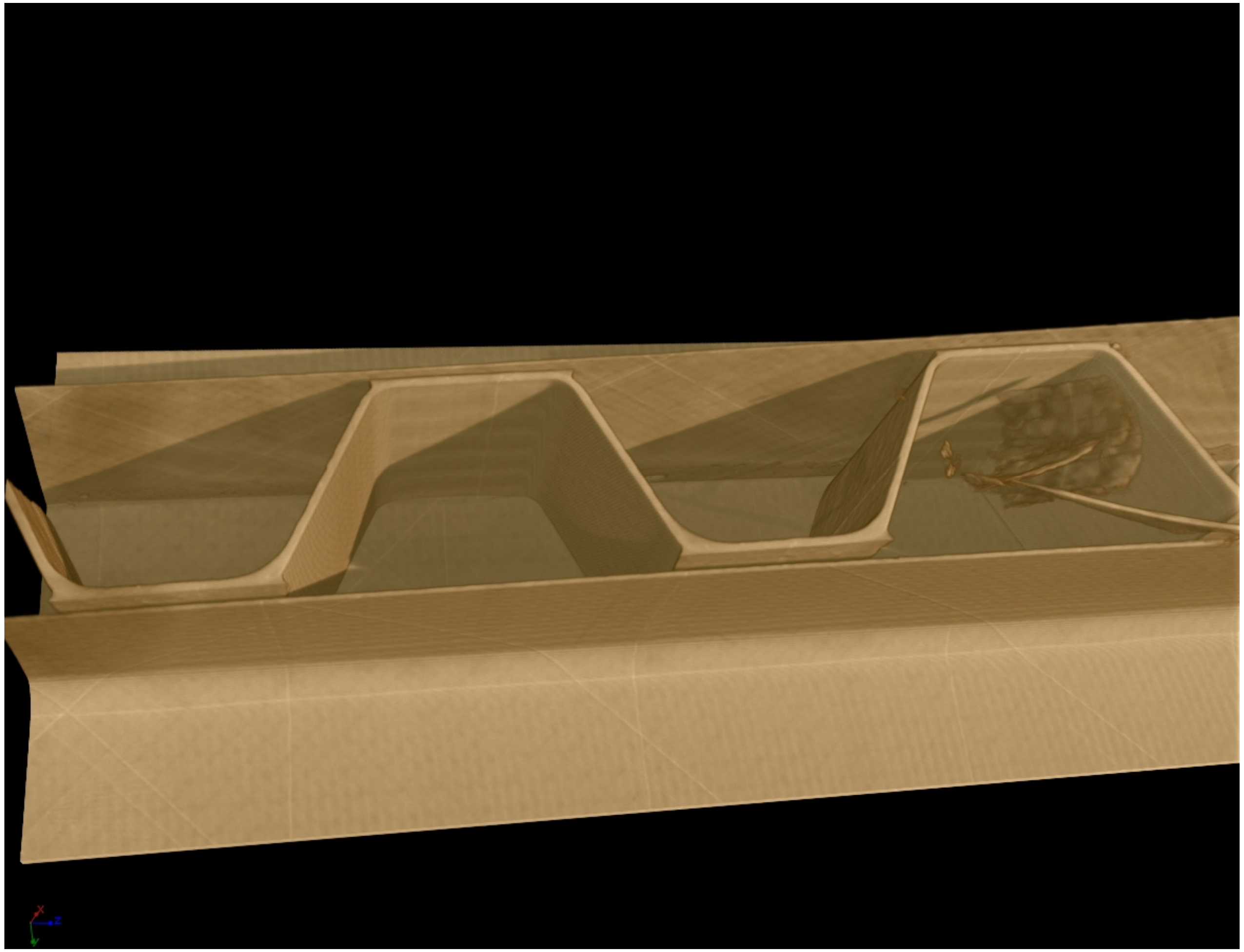
Dynamic 1



Dynamic 2

Design Methods Validation
HRCT Scan Images of Test Article



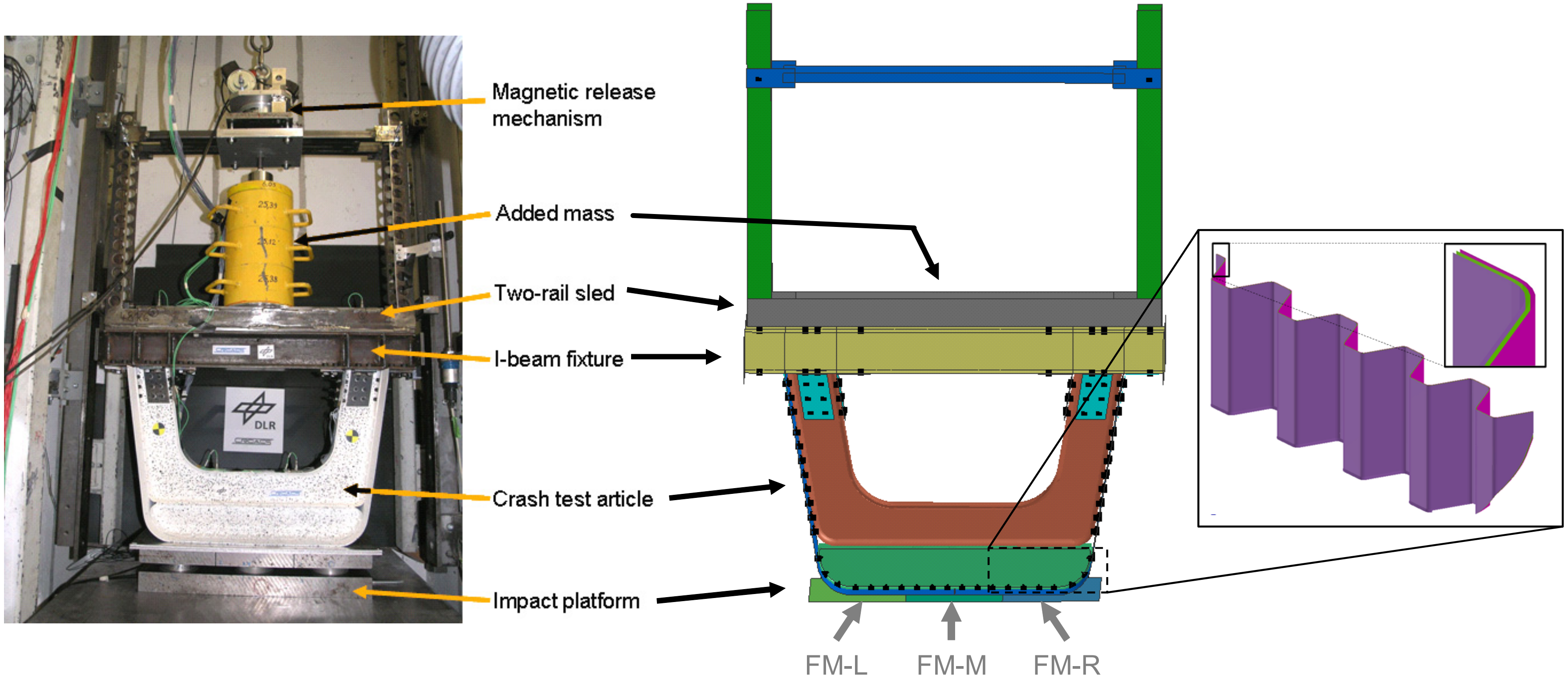


Dynamic 1

Design Methods Validation
Numerical Model

Detailed FE model of the test setup and test article constructed

- Global modeling method with meso-model for energy absorbing structure
- Modeling methods validated at coupon, element and component levels

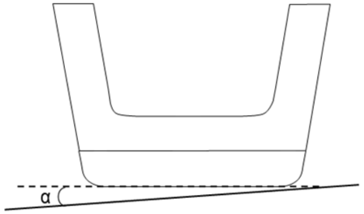


Design Methods Validation

Numerical Model - Features

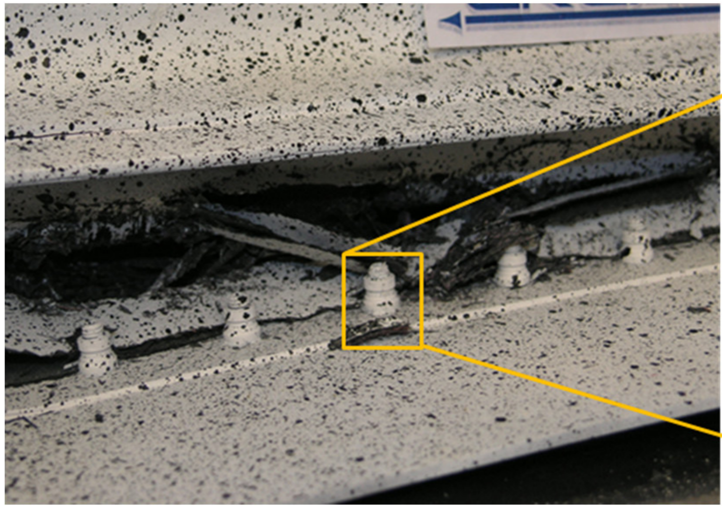
Off-axis loading condition introduced to model the actual test conditions

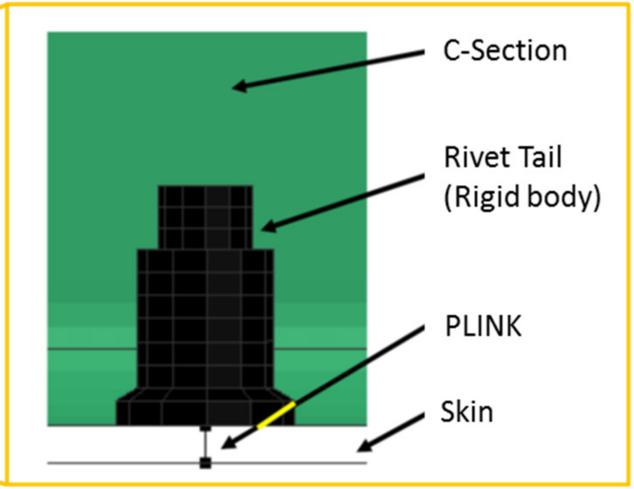
- Dynamic 1 : 0.11˚, Dynamic 2 : 0.27˚



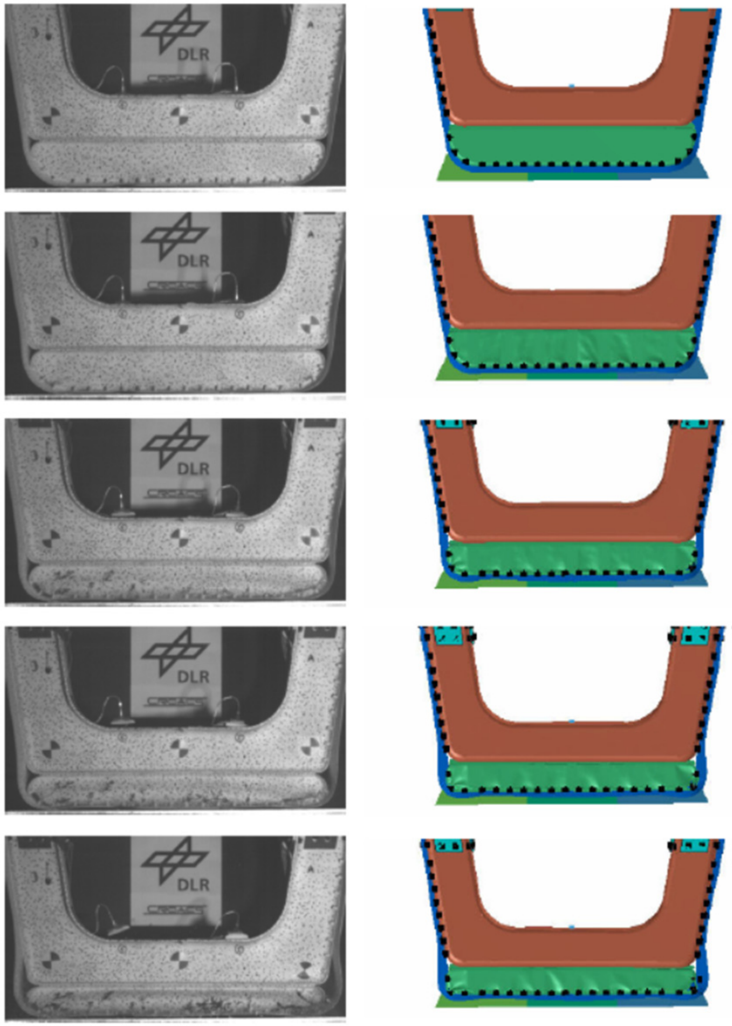
Rivets modeled in detail

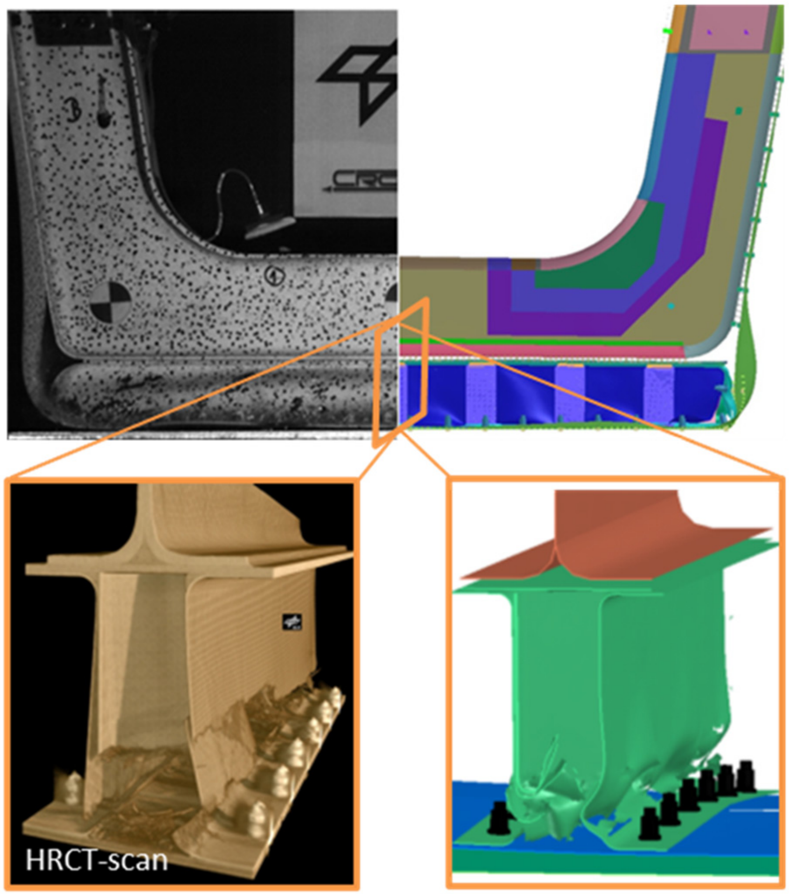
- The rivet tails affected the failure mode and energy absorption by contact with the C-section web that separates from the flange





Design Methods Validation
Results – Deformation & Damage





Dynamic 1

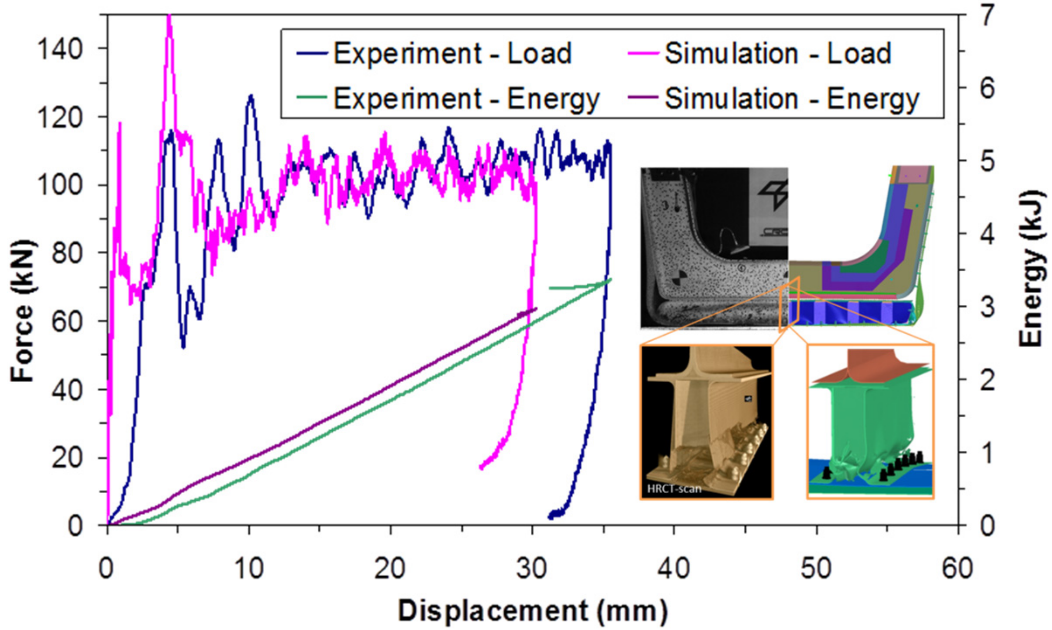
Design Methods Validation

Results – EA Performance Parameters

Overall response very well predicted

- Steady-state crush force closely predicted
- Absorbed energy closely predicted
- Peak load over predicted

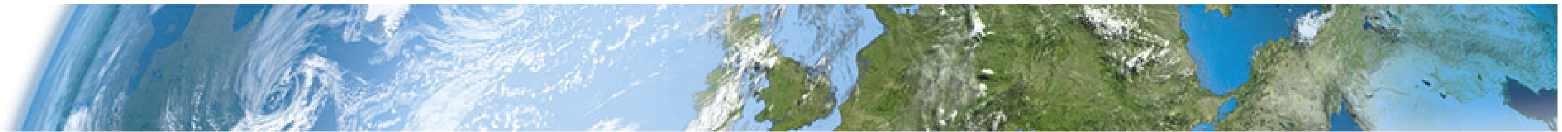
Quantity	Dynamic 1	
	Test	FE
Absorbed Energy (kJ)	2.83	2.93
Crush Distance (mm)	31.5	30.3
Peak Load (kN)	120	150
Steady Crush Load (kN)	104	105



Conclusion & Outlook

- Improved methods for the design of composite energy absorbing structures developed and validated
- These methods can be used to design complex composite energy absorbing structures
    - can act as enabling technology for improved designs
    - potential to significantly reduce the need for expensive physical testing

- Further develop composite energy absorbers
    - Optimization of crush structure geometry, material system, fibre type, matrix type, fibre-matrix interface and fibre orientation
- Application of FE simulation methods to other energy absorber elements with varied failure mechanisms and validated by tests – virtual crash testing



Acknowledgments

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