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Design of Energy-Absorbing CFRP Stanchions for the Cargo Floor Structure of Transport Category Airplanes

2013 Technical Review

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Design of Energy-Absorbing CFRP Stanchions for the Cargo Floor Structure of Transport Category Airplanes

Motivation and Key Issues

- Airframe-level crashworthiness regulations expected to enter CFR
- Crashworthiness of all-composite structures relatively new topic in aviation

Objective

- Streamline certification process
- Develop guidance material

Approach

- Develop crashworthiness certification protocol for a virtual generic all-composite Part 25 airplane

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Design of Energy-Absorbing CFRP Stanchions for the Cargo Floor Structure of Transport Category Airplanes

Principal Investigators & Researchers

- Paolo Feraboli, Research Professor (PI)
- Bonnie Wade (PhD student)
- Max Spetzler (PhD student)

FAA Technical Monitor

- Allan Abramowitz

Other FAA Personnel Involved

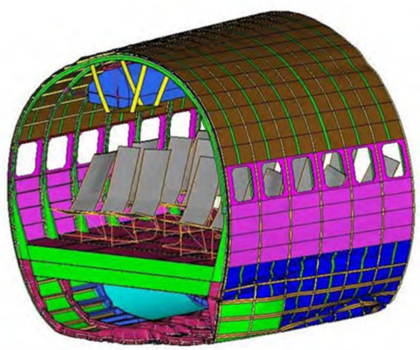
- Dr. Larry Ilcewicz (Technical Advisor)
- Curt Davies (JAMS Program Manager)

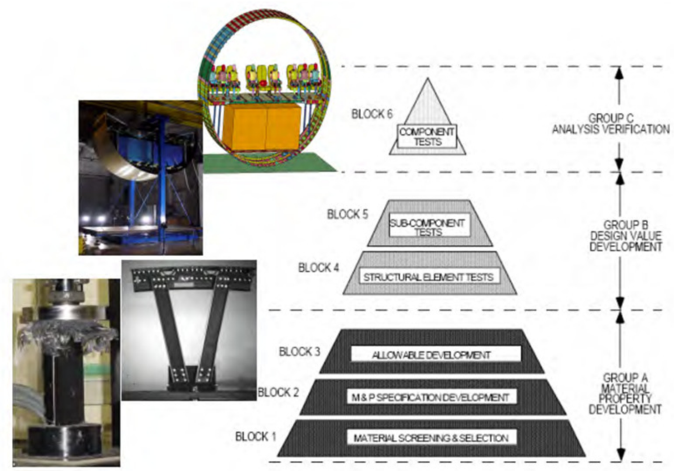
Industry Participation

- Dr. Mostafa Rassaian, Boeing/BR&T (Technical Advisor)
- Kevin Davis, Boeing/BCA (Technical Advisor)

Crashworthiness certification protocol

- Building Block Approach adapted to crashworthiness
- Based on analysis supported by test evidence
- Successfully adopted by Boeing for 787 to meet Special Conditions
- Certification by test not likely to be an option for Part 25 but may be considered for Part 23

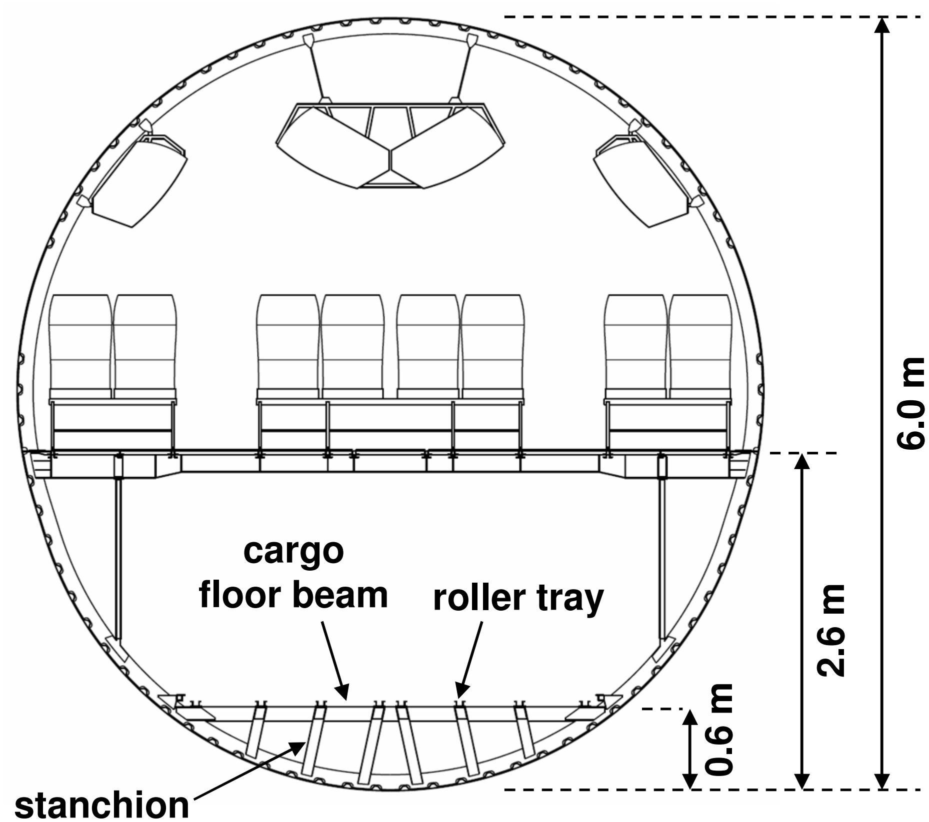




Courtesy: Boeing

Typical twin-aisle fuselage layout & dimensions

- Separate passenger and cargo floor
- Dimensions largely determined by
  - Passenger space requirements
  - Standard cargo container dimensions
- Cargo floor structure as ‘crush zone’ to improve vehicle crashworthiness



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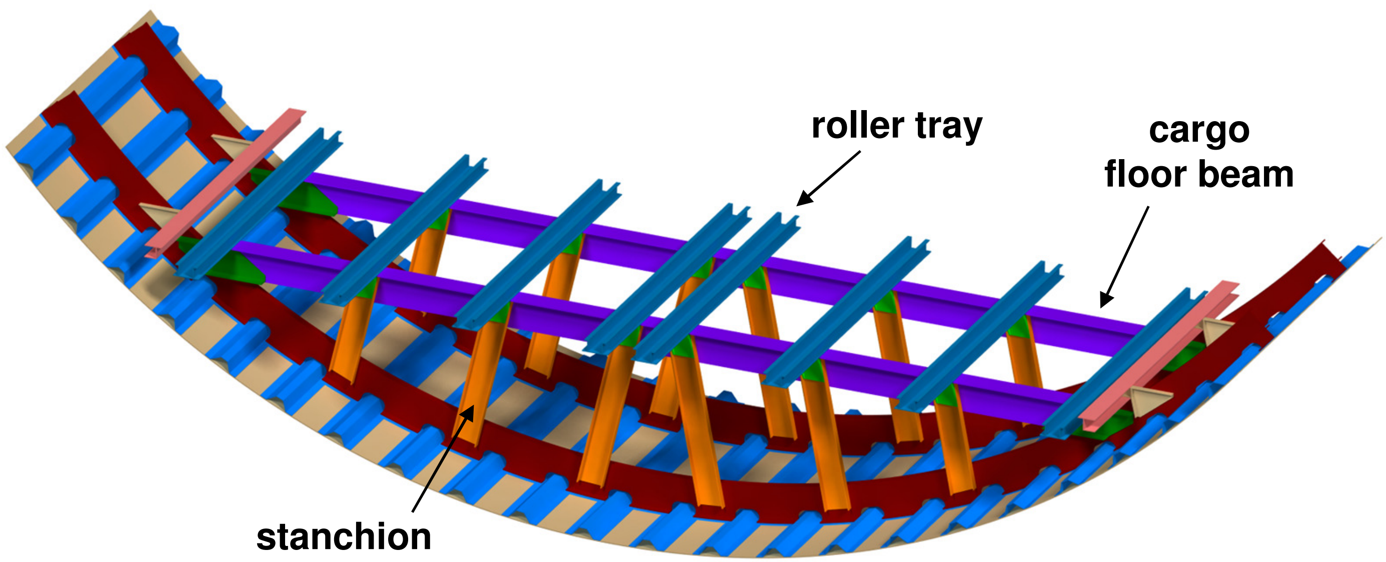
Cargo floor structure as ‘crush zone’

- Cargo floor stanchions may be designed to absorb energy through progressive crushing in case of a crash
- Dual functionality of stanchions
  - Carry all operational loads according to airworthiness requirements
  - In crash event: 1. Separate from frame
    2. Crush on inner skin surface to absorb energy



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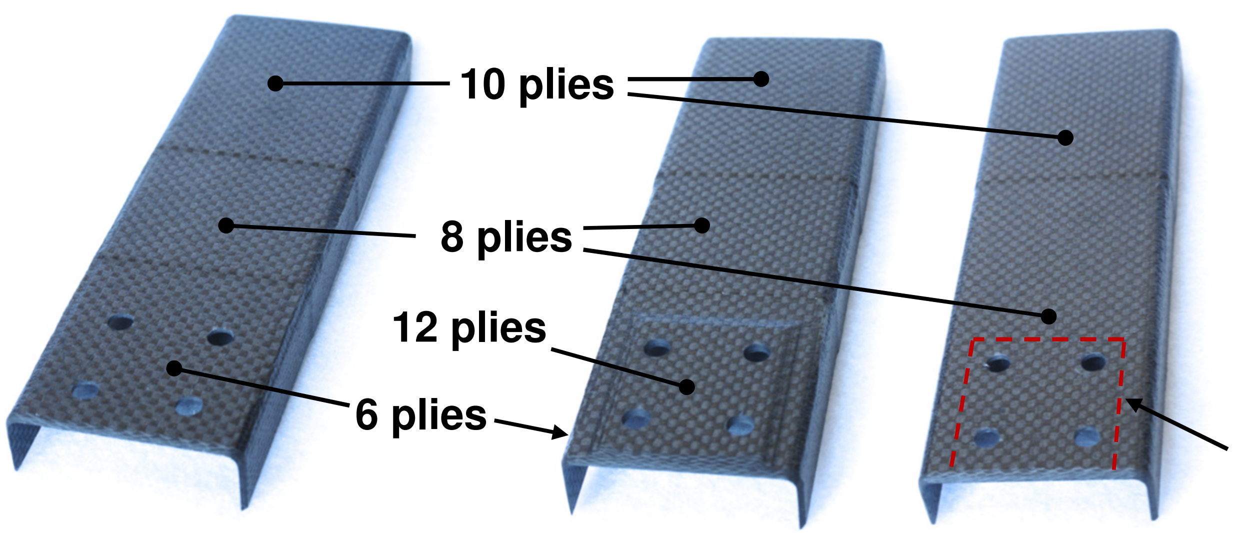
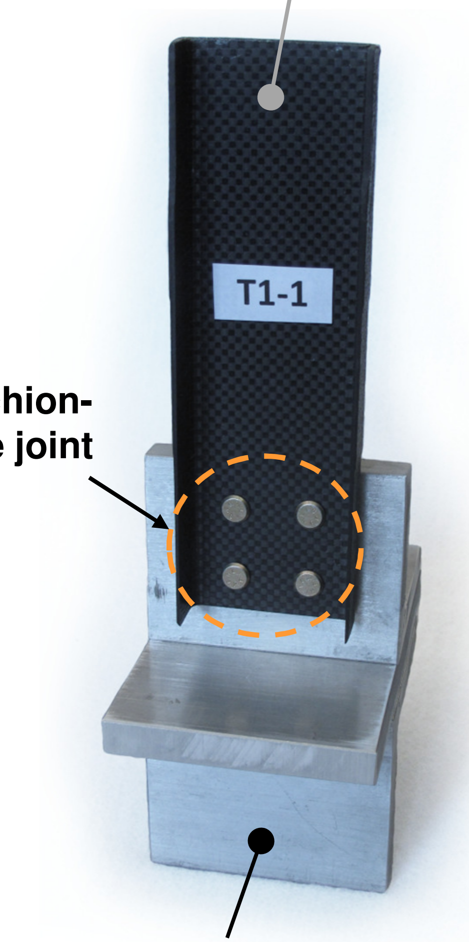
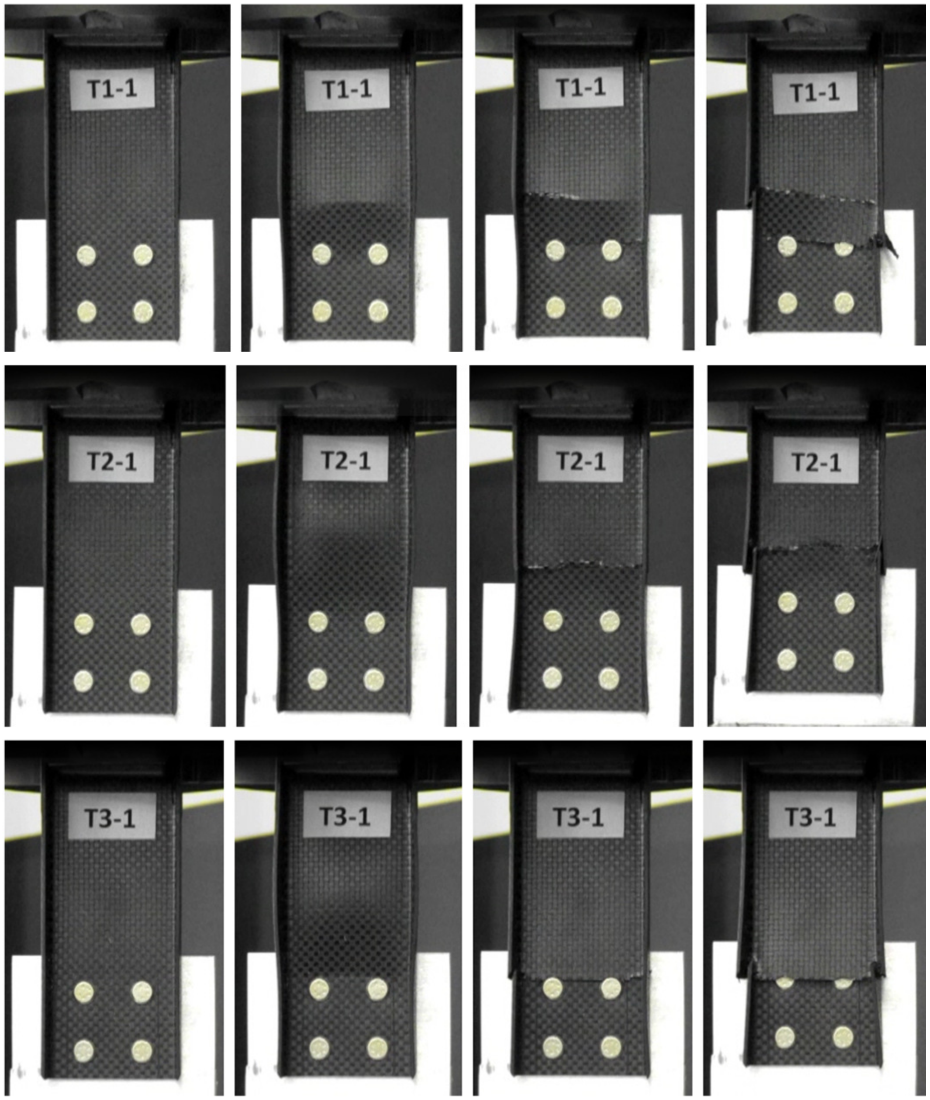
Stanchion separation

- Three configurations tested to investigate how failure can be triggered at desired location
- Channel-section type stanchions, 190mm long
- T800/3900-2 PW fabric, all 0°
- Displacement control, 50mm/min





Stanchion separation



- Failure preceded by local buckling in all cases
- Rupture triggered by any kind of discontinuity
- Interaction between separated pieces
  - Tearing into flat segments

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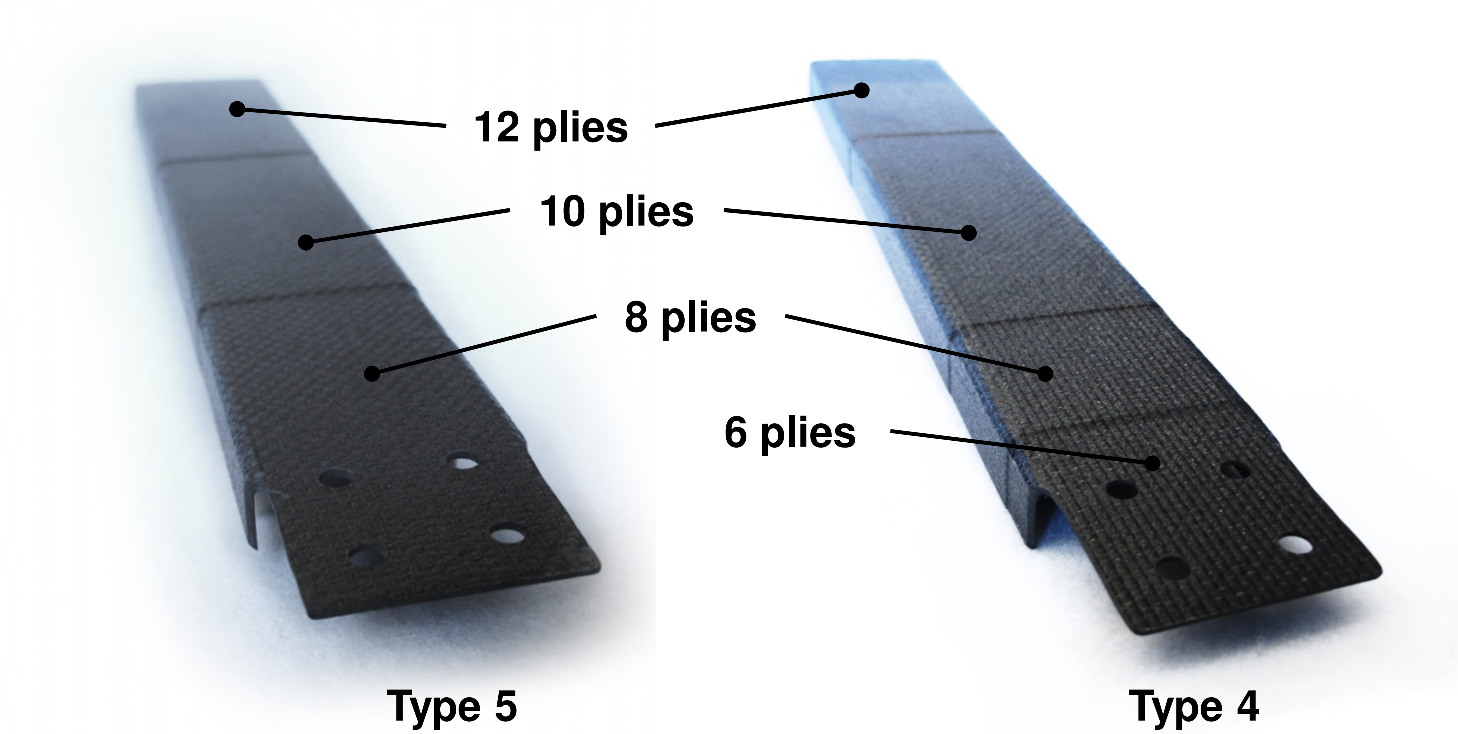
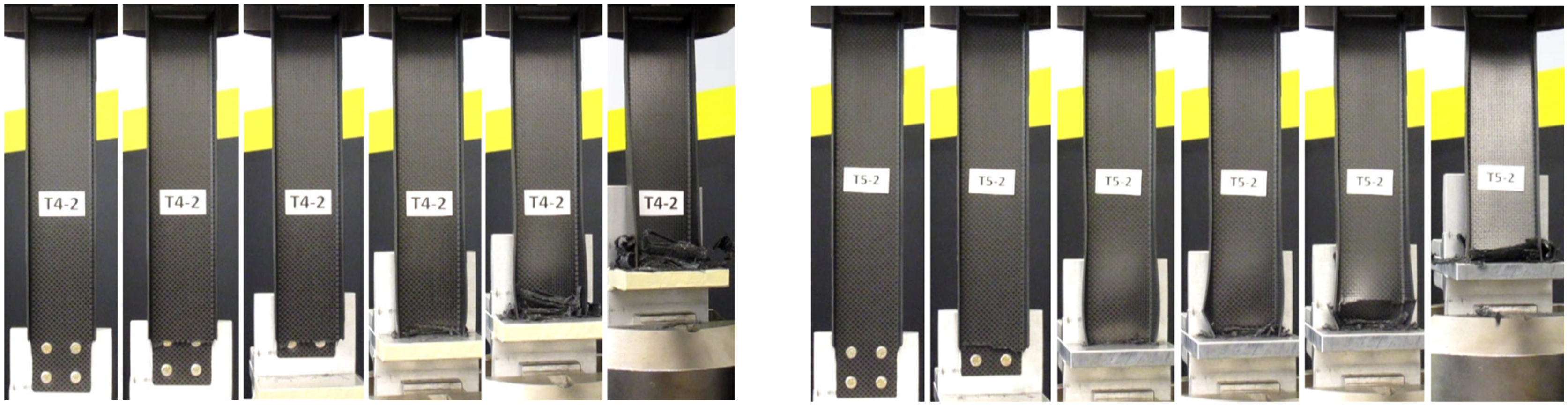
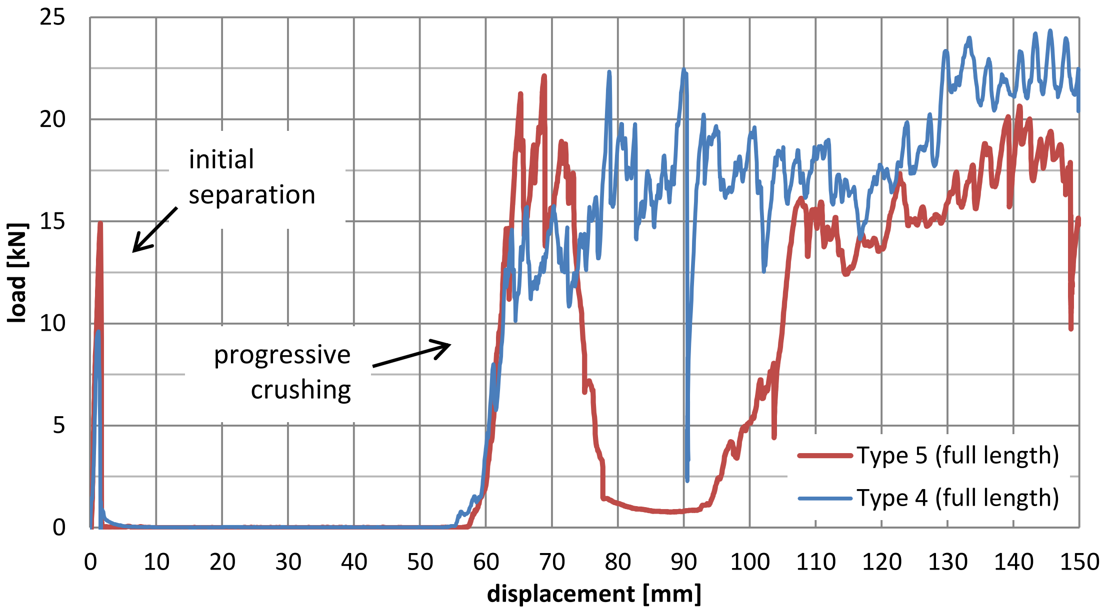
Proof of concept with full-length stanchions

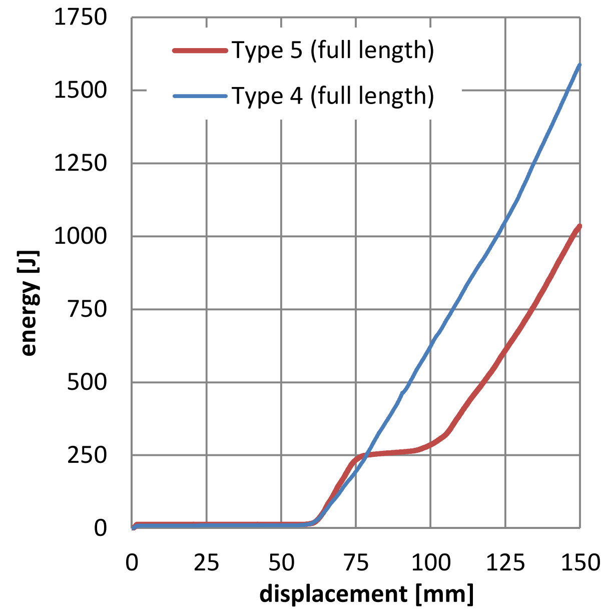
- 4th and 5th configuration derived from test results
  - Flanges trimmed off to trigger failure and avoid interaction
  - 380mm length
  - Multiple thickness transitions to encourage progressive failure



Proof of concept with full-length stanchions







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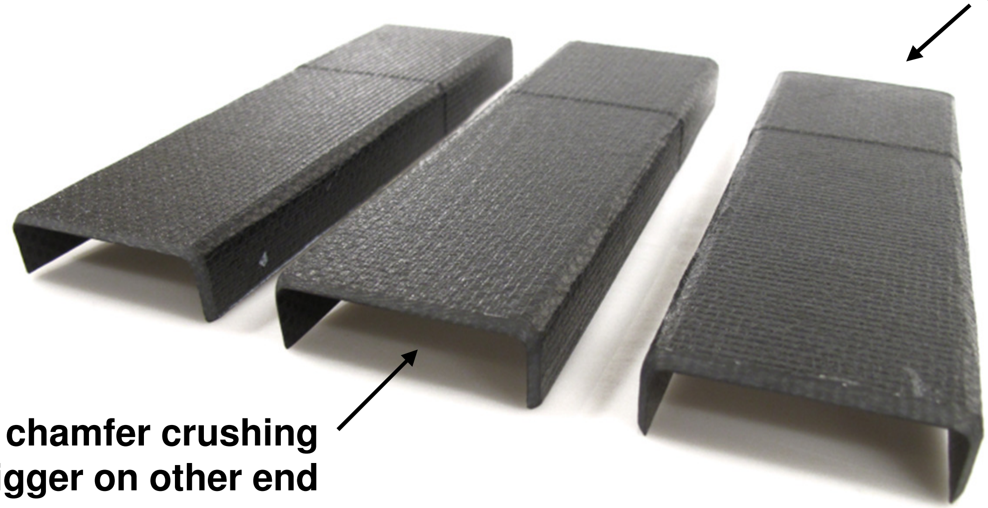
Stability of progressive crushing - Test

- Full-length tests showed that crushing is not necessarily stable
- Conditions for stable crushing of interest

- Crushing tests of C-section specimens with varying thickness (6, 8, 10 and 12 plies, all in 0°-direction)



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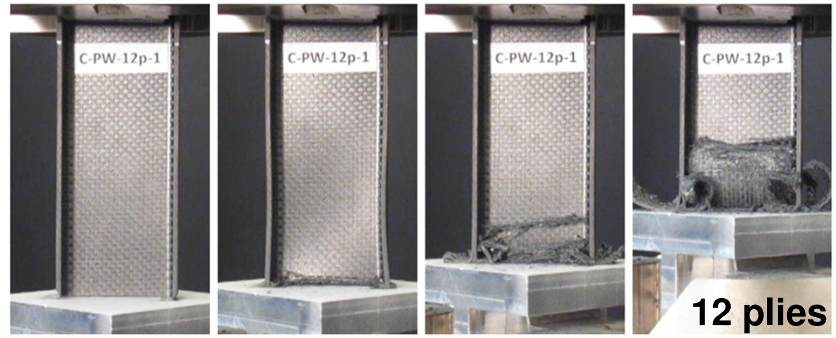
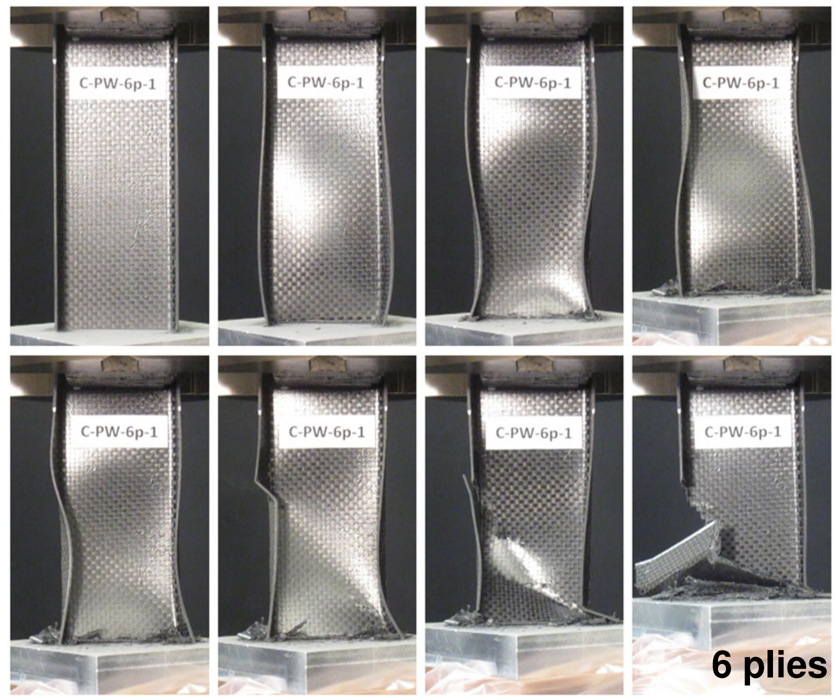
Stability of progressive crushing - Test

- Thick specimens (10-12 plies)
  - Local buckling patterns of low amplitude visible initially
  - Stable crushing
  - High specific energy absorption

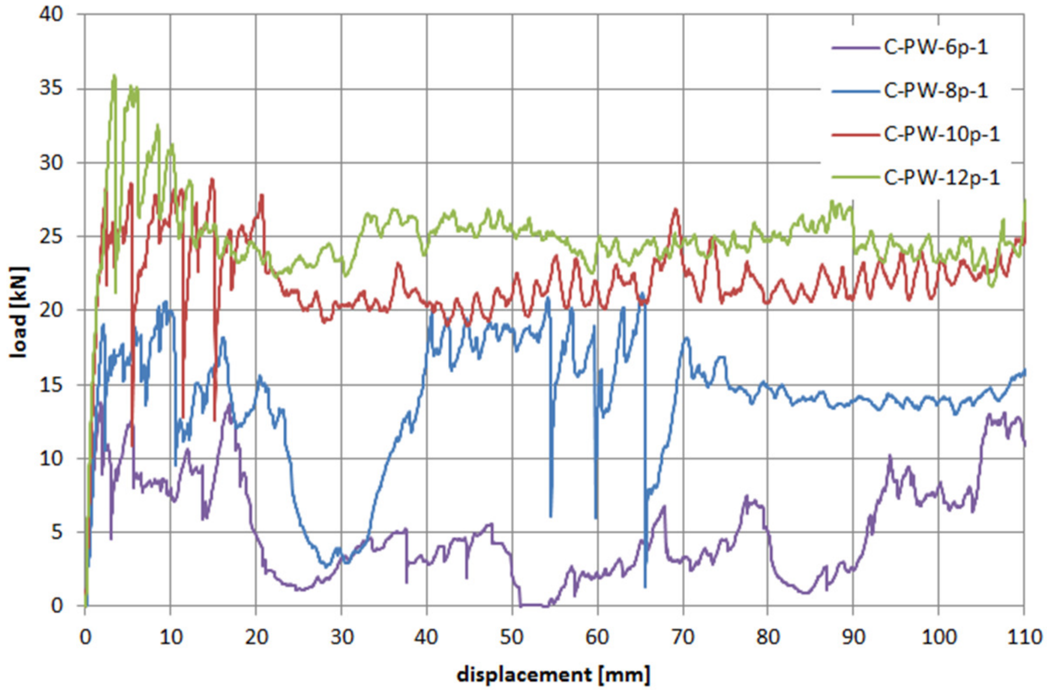


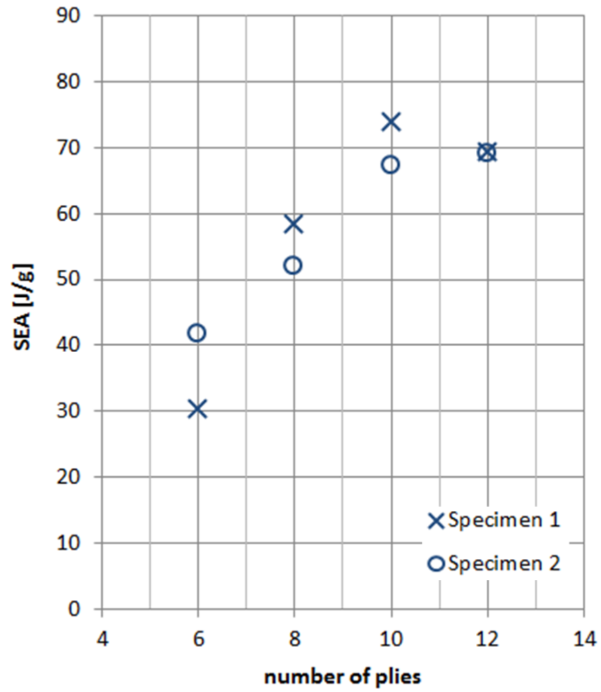
- Thin specimens (6-8 plies)
  - Severe buckling of web and flanges throughout process
  - Crushing repeatedly disturbed by rupture at a distance form the crush zone
  - Significantly lower specific energy absorption



Stability of progressive crushing - Test

- Crushing under buckling deformation coincides with unsteady part force-displacement curves
- Laminate failure outside of crush zone causes load to drop and reduces energy absorption





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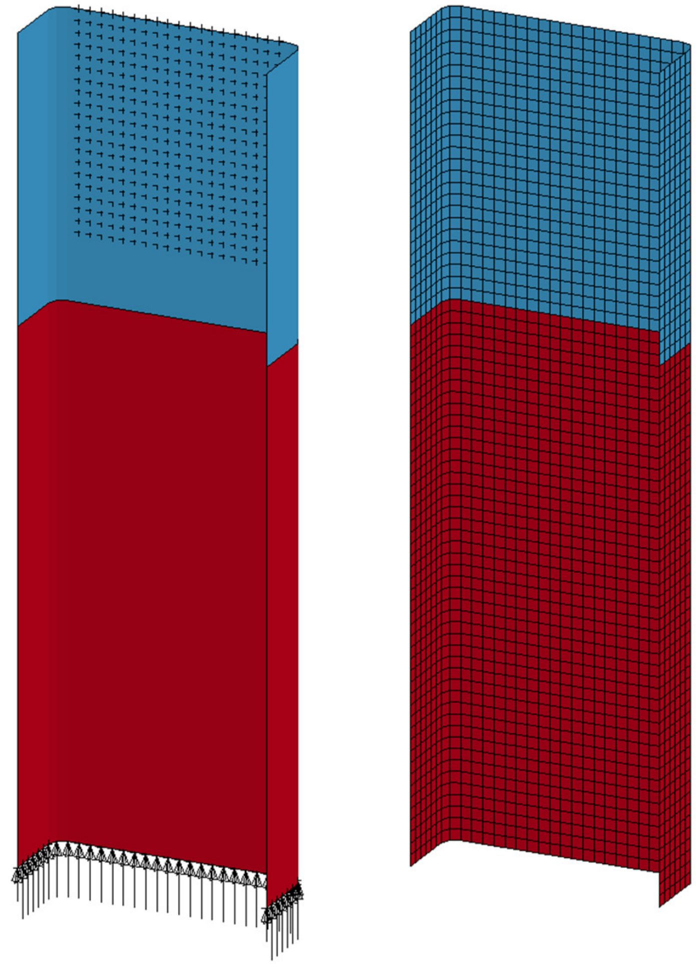
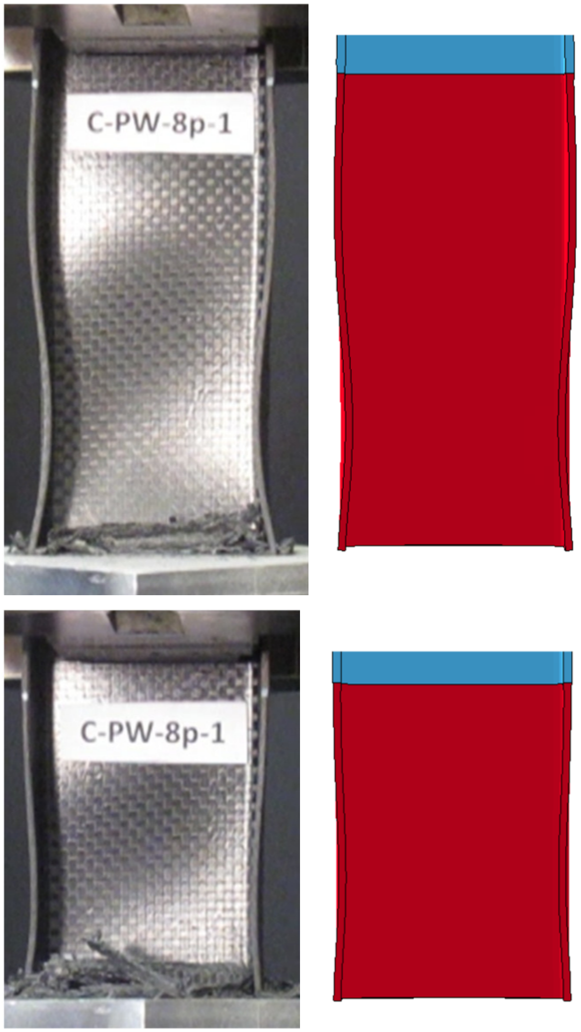
Stability of progressive crushing - Analysis

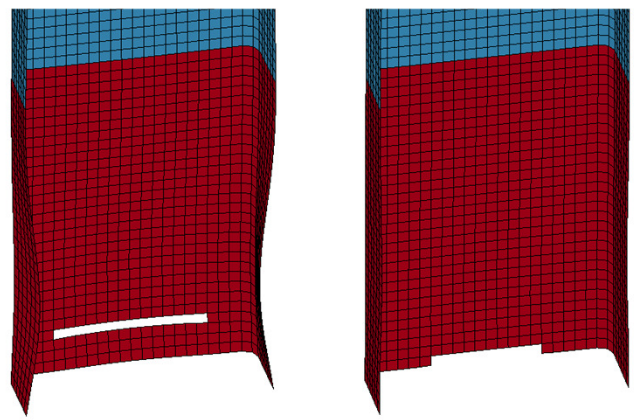
- Finite element model of specimen (LS-DYNA)
  - 2.5mm mesh size, fully integrated shell elements (type 16), MAT54
  - Nodes constrained at location of hydraulic grips
  - Edge load applied at other end (Represents load imposed onto specimen by the crush zone)
  - Loaded edge ‘pinned’
- Length of specimen varied
- Two types of analysis
  1. Implicit buckling analysis (eigenmode analysis)
  2. Explicit non-linear failure load analysis



Stability of progressive crushing - Analysis

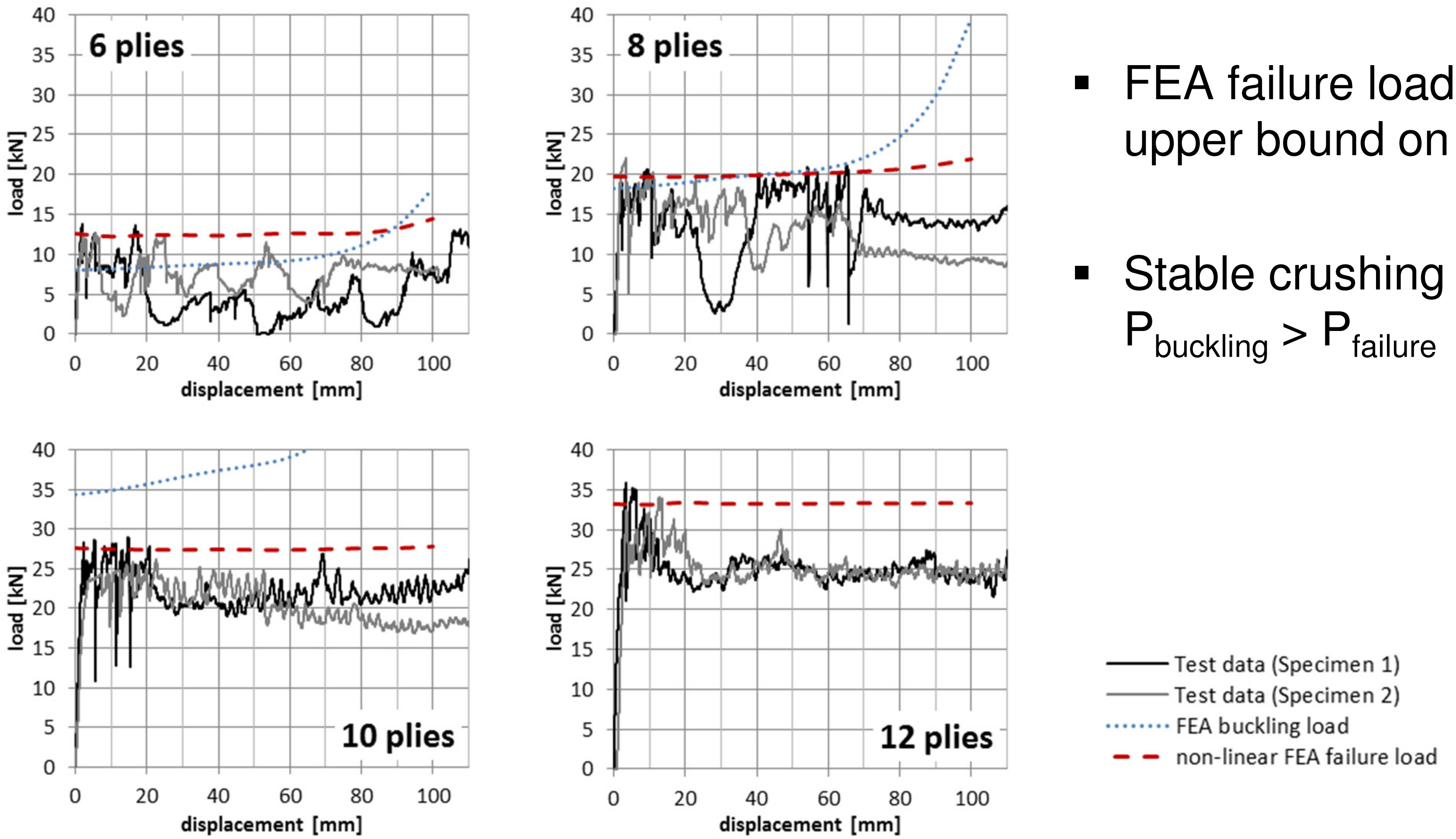


- Both analysis types predict buckling patterns (pictures from non-linear analysis)
- Failure location (non-linear analysis) depends on laminate thickness
  - 6-8 plies → at a distance from crush zone
  - 10-12 plies → at loaded edge



6 plies **10 plies**

Stability of progressive crushing - Analysis



- FEA failure load gives upper bound on loads
- Stable crushing if $P_{buckling} > P_{failure}$

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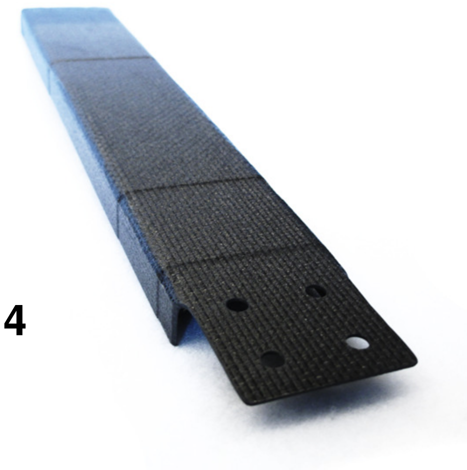
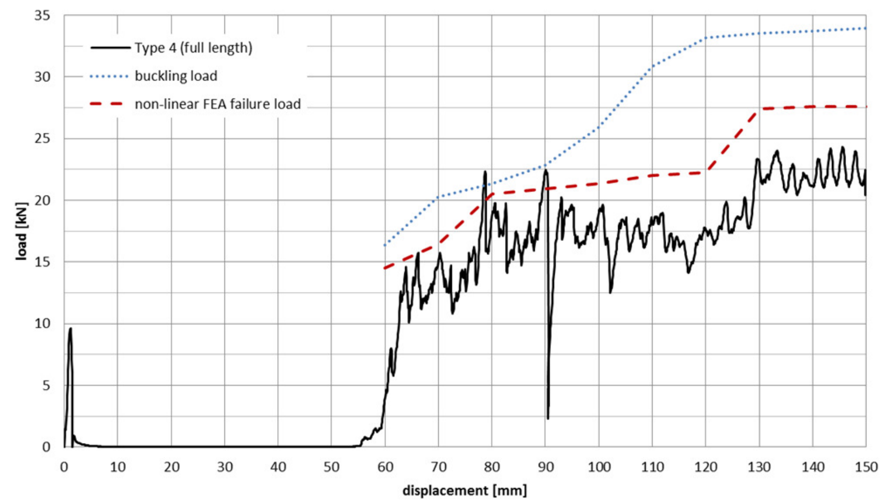
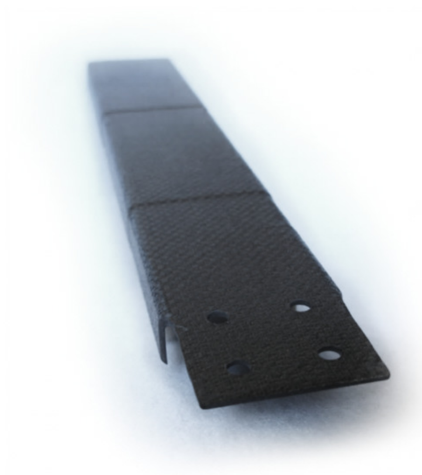
Stability of progressive crushing - Analysis

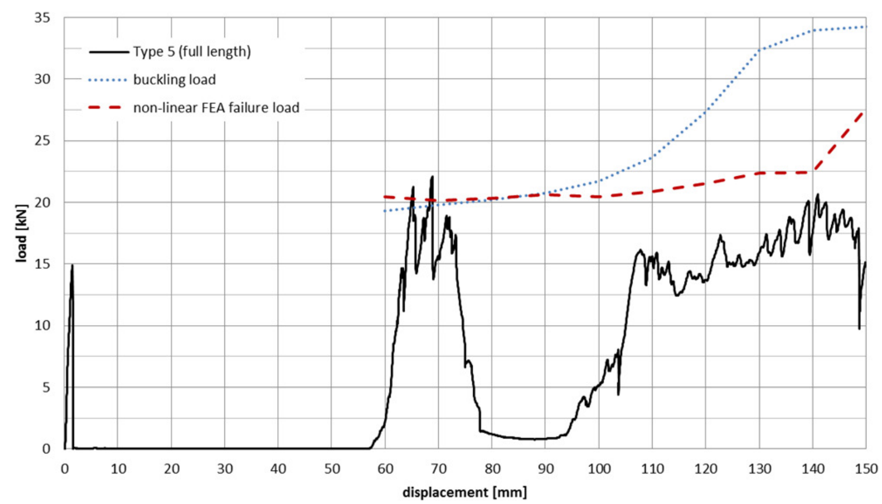
Type 4





Type 5



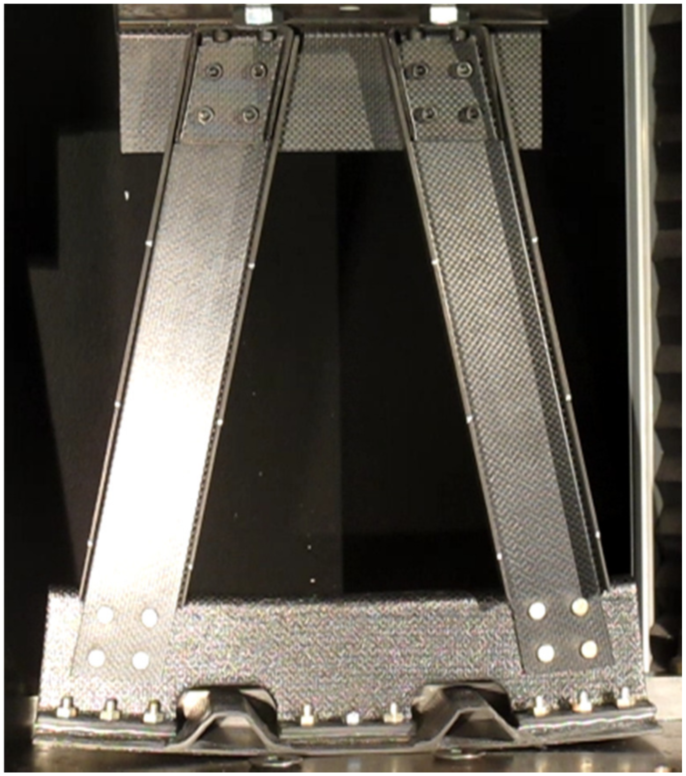


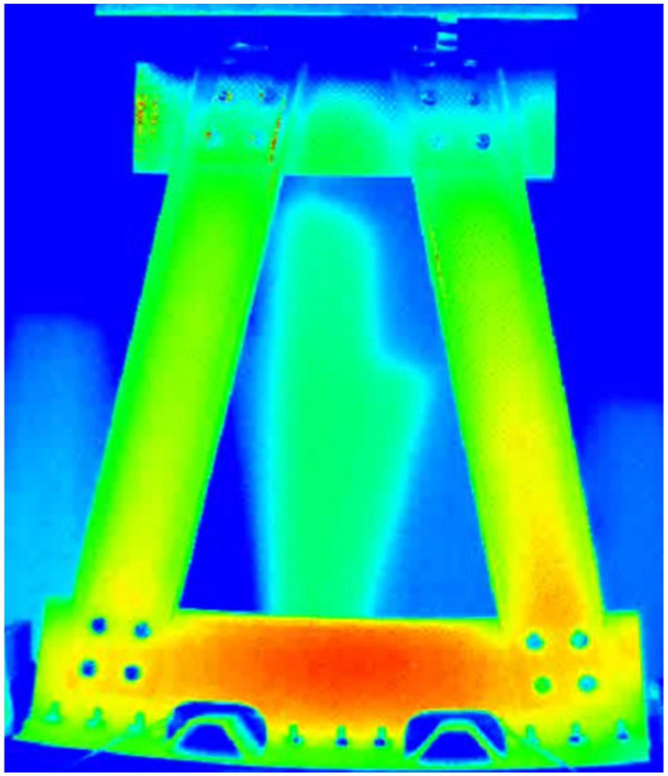
Conclusion

- Typical transport category airplanes feature stanchions in the cargo floor structure, which can be designed to improve crashworthiness of the airframe
- Energy absorption through progressive crushing of CFRP stanchions requires certain design features in the stanchions
- To increase energy absorption, the C-channel stanchions need to separate from the structure on one side so that they may subsequently crush
- A discontinuity (thickness transition, change of flange height) at the desired location can trigger separation after local buckling of web and flanges
- Stable crushing requires that the laminate does not fail outside the crush process zone
- Buckling and failure loads obtained from finite element analysis may be used to assess if crushing will be stable or not

Looking Forward

- Subcomponent-Level Test and Analysis





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Looking Forward

Benefit to Aviation

- Provide guidance for certification process
- Increase confidence and therefore level of safety

Future needs

- Guidance material for all levels of the BBA

End of Presentation.

Thank you.

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