The Kinematics Model –
A Numerical Method for the Development of a Crashworthy Composite Fuselage Design of Transport Aircraft

M. Waimer*) • D. Kohlgrüber*) • Dr. D. Hachenberg**) • Prof. Dr. H. Voggenreiter*)

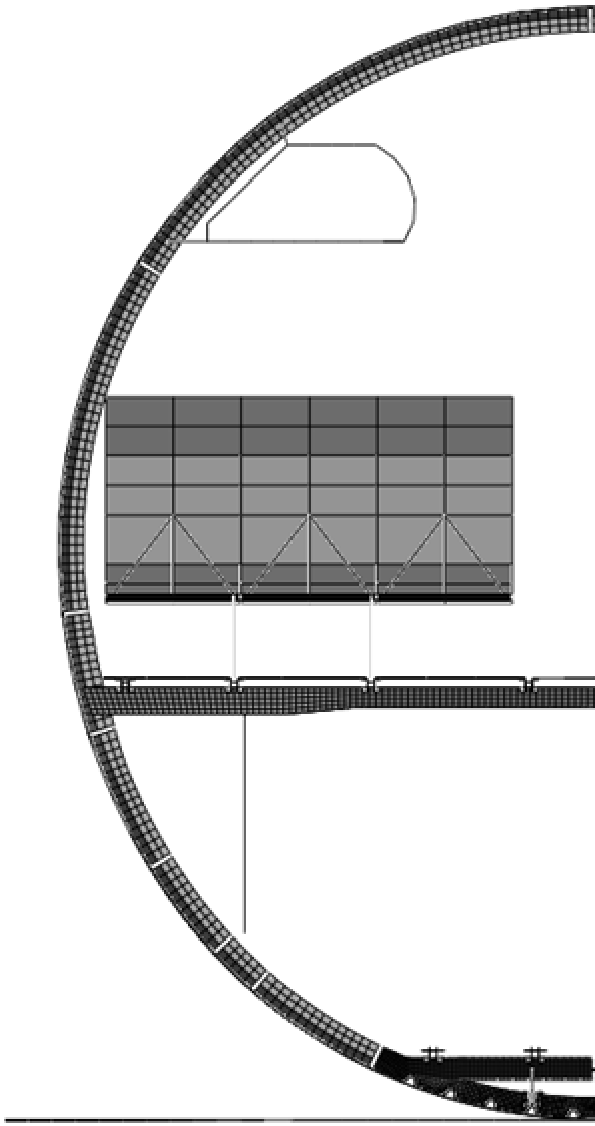
*) DLR German Aerospace Center - Institute of Structures and Design – Stuttgart, Germany
**) Airbus Operations GmbH – Numerical Simulation Development – Hamburg, Germany

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Sixth Triennial International Aircraft Fire and Cabin Safety Research Conference
October 25-28, 2010 – Atlantic City, New Jersey
Session ‘Crash Dynamics I’

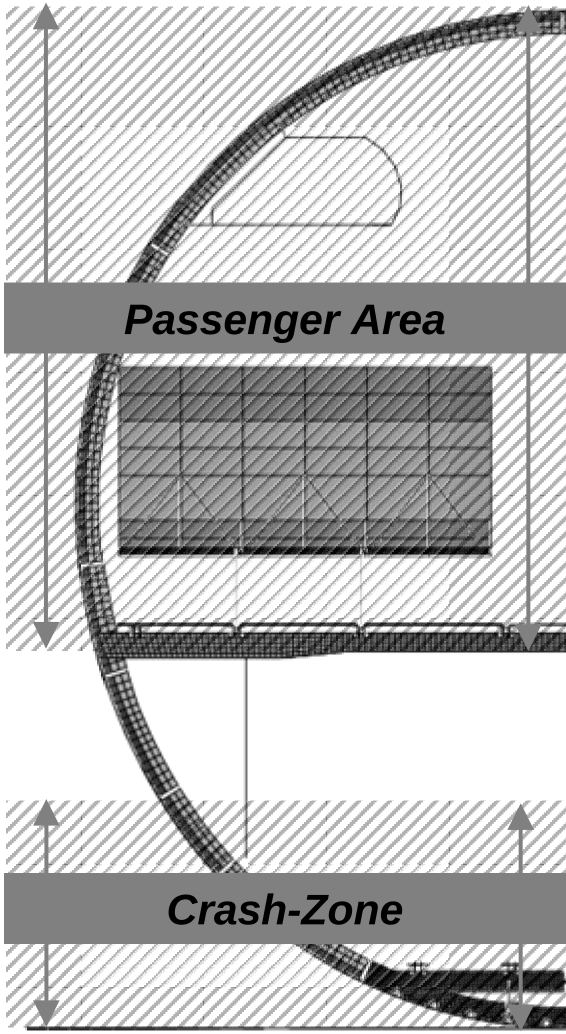
Overview

- **Introduction**
  - Crash Design of a CFRP Fuselage
    - Design Aspects
    - Simulation Methods
- **Kinematics Model**
  - Modelling Approach
  - Macro Modelling
- **Crash Design of a CFRP Fuselage**
  - Assessment of Crash Scenarios
  - Design of Scenario "A"
  - Results of the Final Crash Design
- **Investigation of a Design Concept Variation**
  - Ovalization
  - Cascading Scenario with Ovalization
- **Conclusion**



Introduction

Crash Design of a CFRP Fuselage

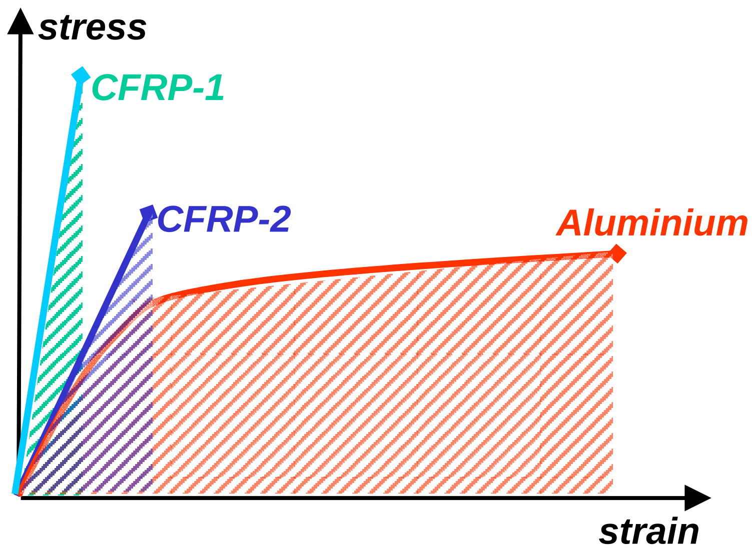


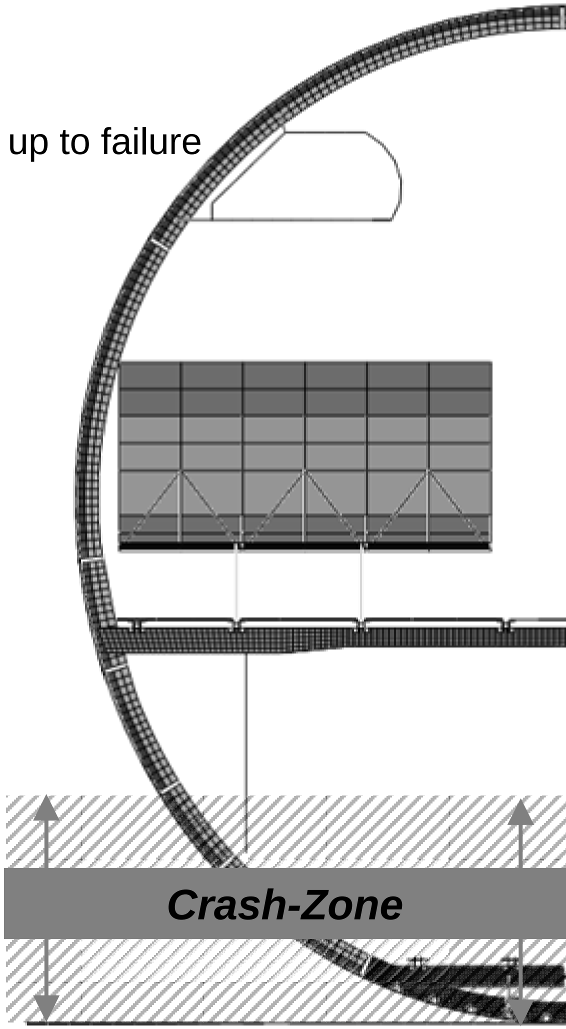
Introduction

Crash Design of a CFRP Fuselage - Design Aspects

- Generally brittle material behaviour with limited energy absorption up to failure

<u>Material behaviour</u>

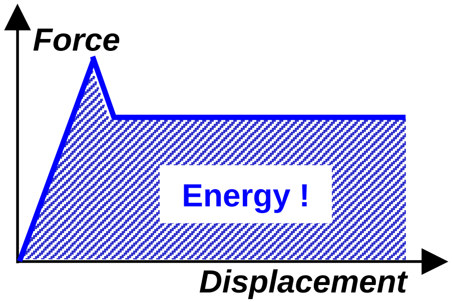


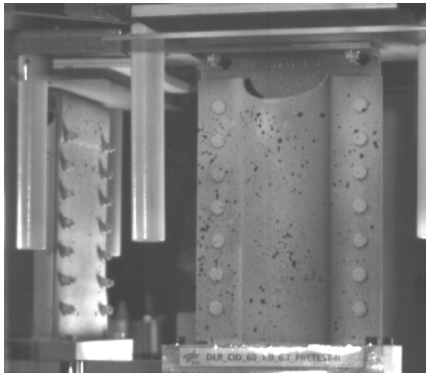


Introduction

Crash Design of a CFRP Fuselage - Design Aspects

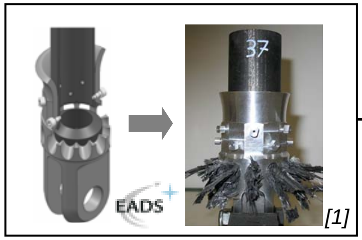
- Generally brittle material behaviour with limited energy absorption up to failure
- Necessity of additional crash devices to gain sufficient energy absorption!



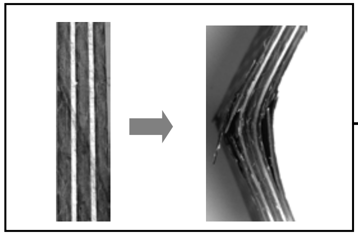


AVI

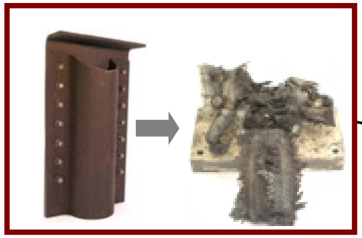
Crushable Struts

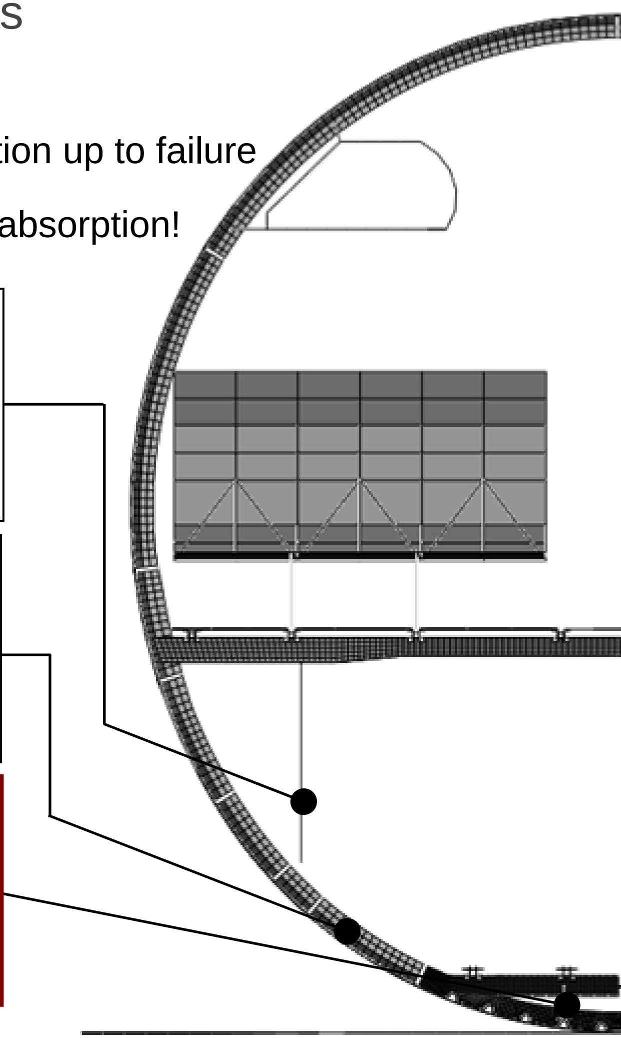


Plastic Hinges



Crushable Elements

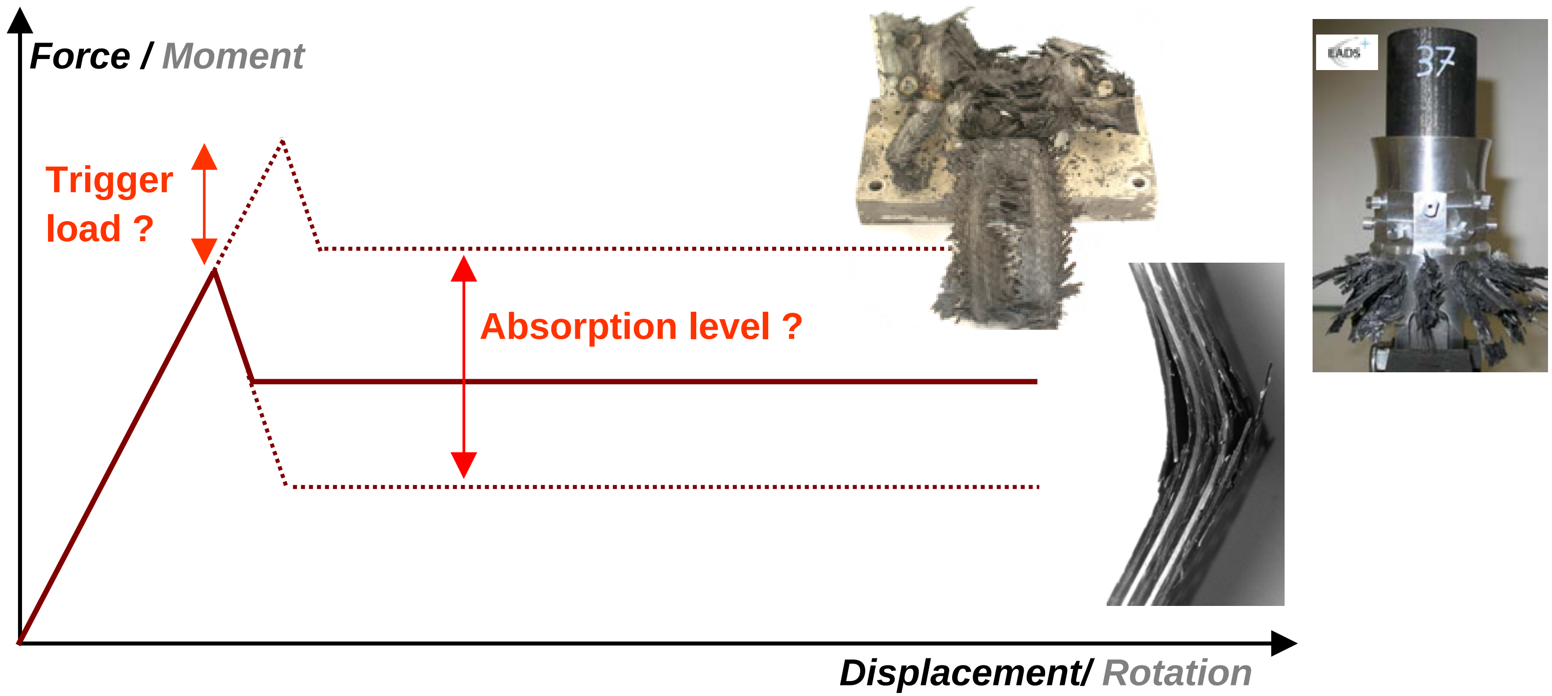




Introduction

Crash Design of a CFRP Fuselage - Design Aspects

- How to design the crash devices, to get appropriate interaction?

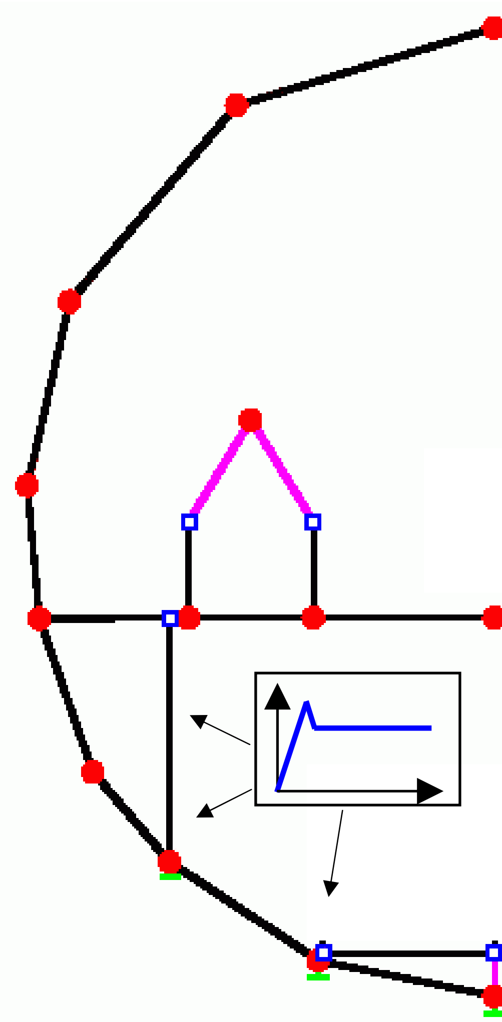


➔ Crash investigation on fuselage section level to design local crash devices!

Introduction

Crash Design of a CFRP Fuselage - Simulation methods

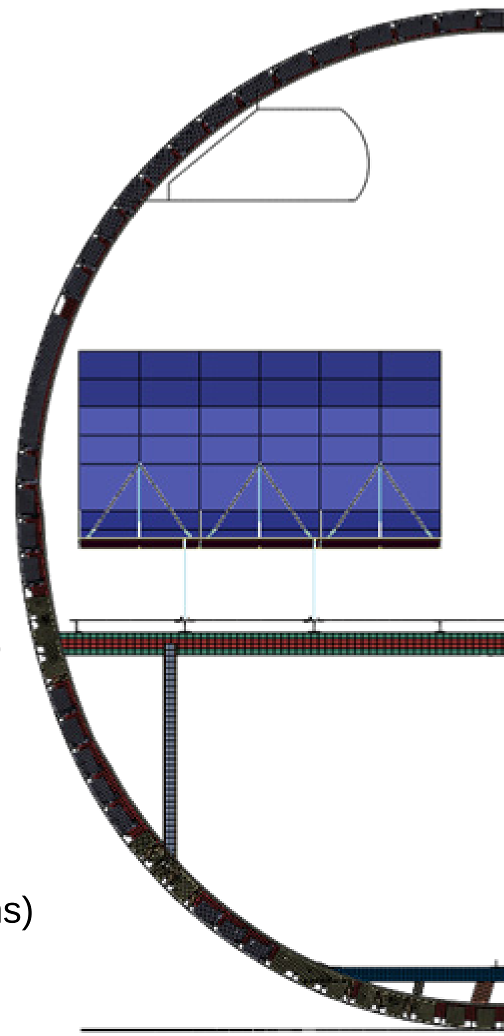
- Crash investigation on fuselage section level
  - Modelling approach: **hybrid Code** (e.g. DRI-KRASH)
  - Advantages:
    - Ideal tool for Macro inputs
    - Short calculation time (minutes)
  - Disadvantages:
    - Detailed conclusions about structural behaviour hardly possible (e.g. instabilities)
    - Interaction frame-skin not considered



Introduction

Crash Design of a CFRP Fuselage - Simulation methods

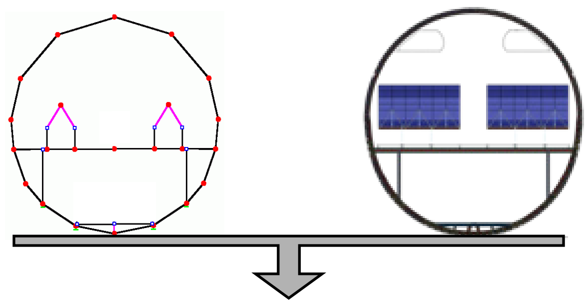
- <u>Crash investigation on fuselage section level</u>
  - Modelling approach: **full FEM** (e.g. ABAQUS/Explicit)
  - <u>Advantages:</u>
    - Detailed modelling of structure and material (material damage, contacts,…)
  - <u>Disadvantages:</u>
    - Large amount of data necessary (structure & material) (partly not available in a preliminary design phase)
    - Composite material models partly not predictable
    - No macro inputs (Modelling of damage & failure by material formulations)



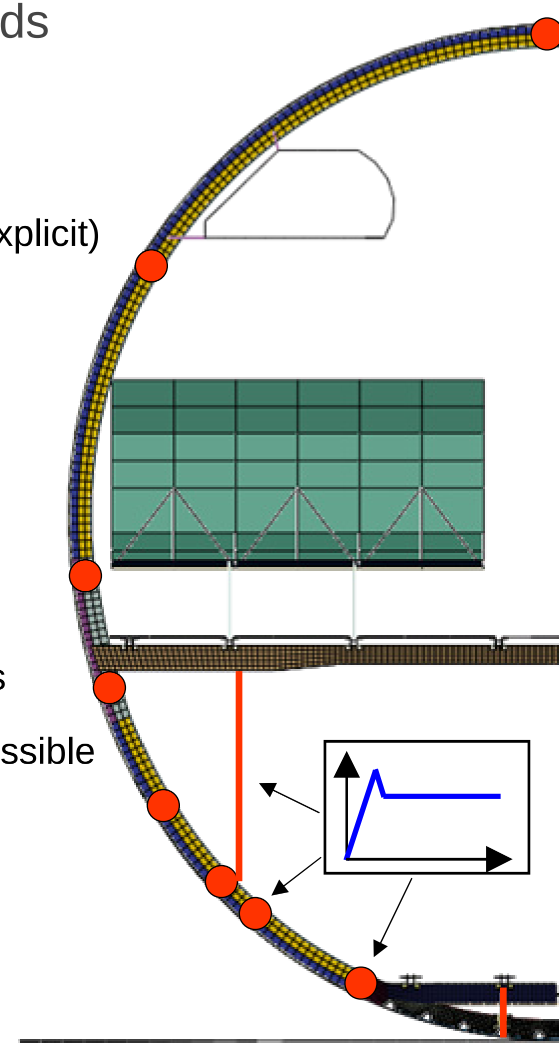
Introduction

Crash Design of a CFRP Fuselage - Simulation methods

- Crash investigation on fuselage section level
  - Modelling approach: **Kinematics Model** (e.g. ABAQUS/Explicit)



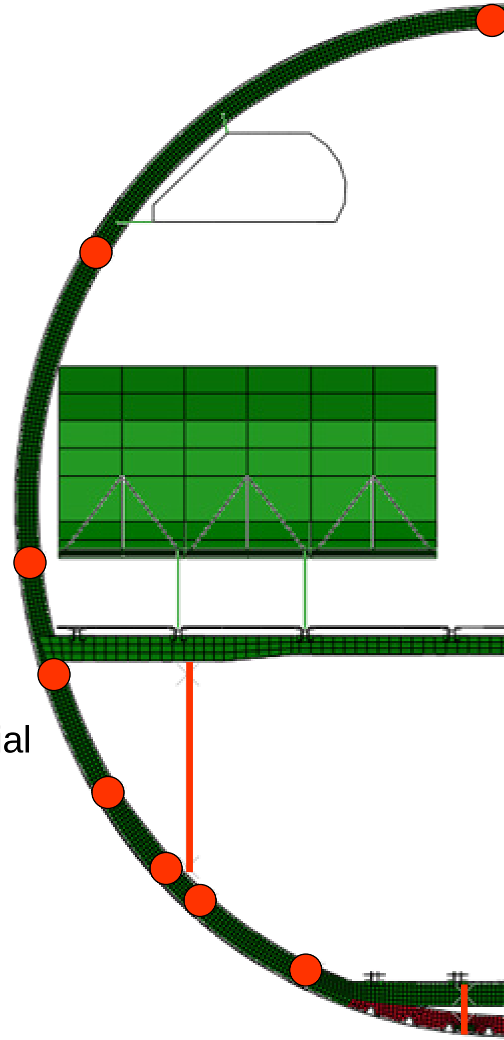
  - Combination of advantages of ‚hybrid Code' & ‚full FEM'
    - Macro input possible for energy absorption devices
    - Detailed conclusions about structural behaviour possible (local strains, interaction frame-skin,…)
    - Mainly linear-elastic material characteristics
    - Reduced calculation time compared to full FEM



Kinematics Model

Modelling Approach

- General approach: ‚**linear-elastic** + **Macros**'
  - Finite-Element Method (e.g. ABAQUS/Explicit)
  - Mainly linear-elastic material law (E_{11}, E_{22}, G_{12}, ν)
    - comparatively big element size possible!
  - Failure representation of crash devices by macro elements
  - Simplified Modelling
    - Stringer as beam elements
    - No mouseholes
    - No clips & cleats
  - Partly detailed modelling in the sub-cargo area using a material law with failure representation
    - Linear-elastic modelling leads in this area of complex crushing to kinematic constraints!

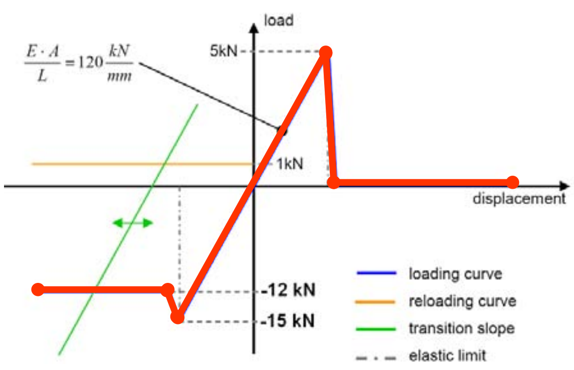


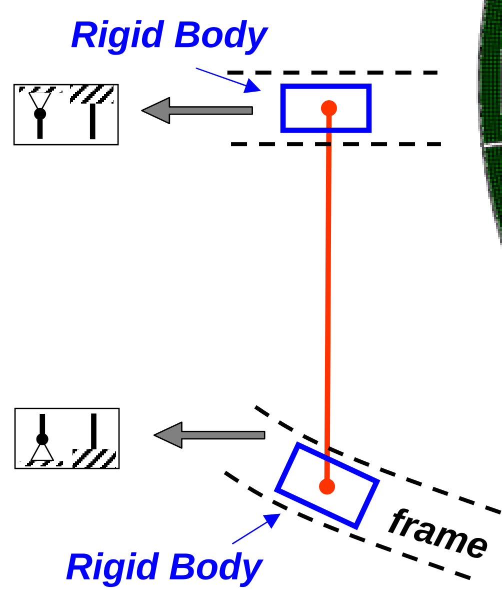
Kinematics Model

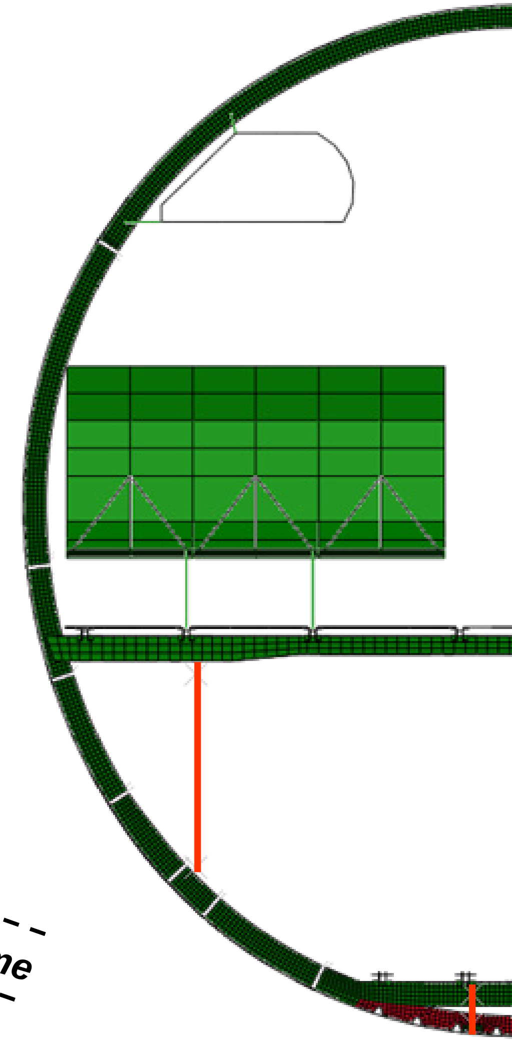
Modelling Approach

- Crushing absorbers
  - Connector elements
  - Arbitrary connection type (fixed, pin-jointed)
  - Connection to the structure by rigid body

Connector-Input



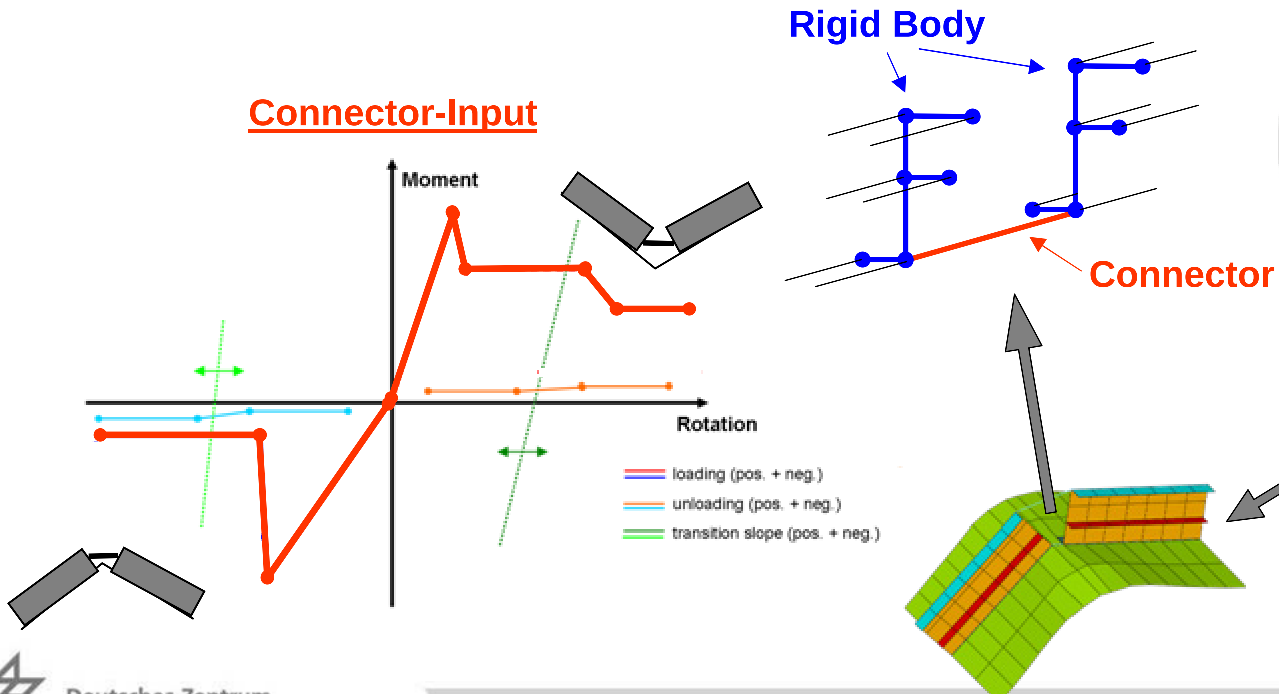


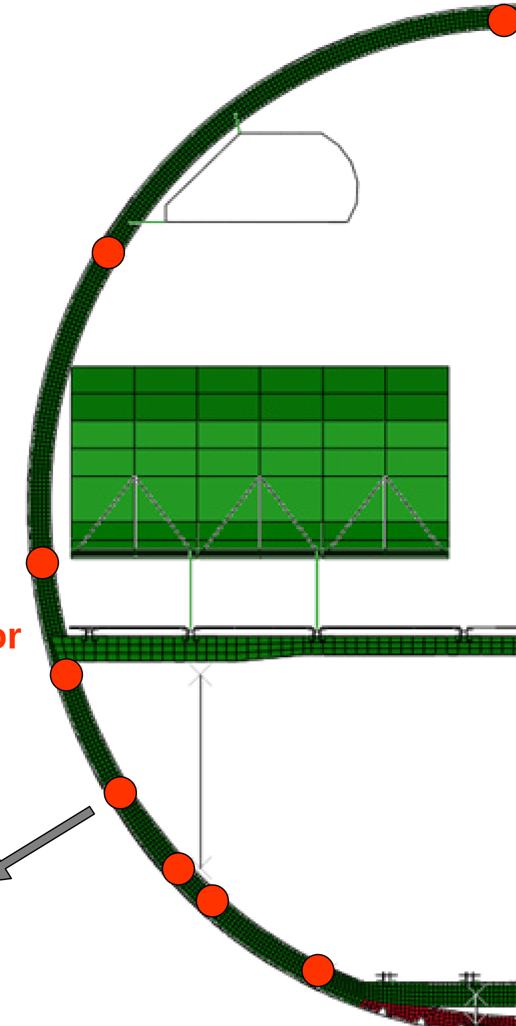


Kinematics Model

Modelling Approach

- Kinematic hinges
  - Connector elements
  - Connection to the structure by rigid body

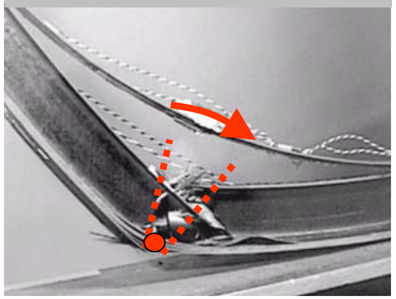




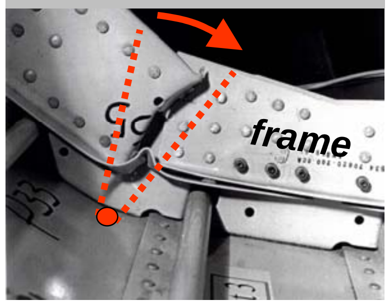
Kinematics Model

Kinematic Hinge

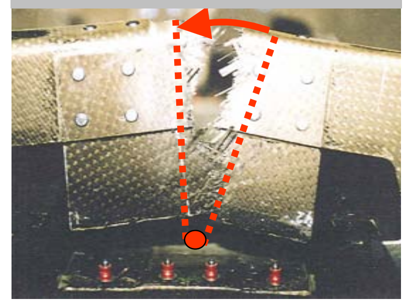
closing hinge		***opening hinge***	
CFRP structure	Metallic structure	CFRP structure	Metallic structure



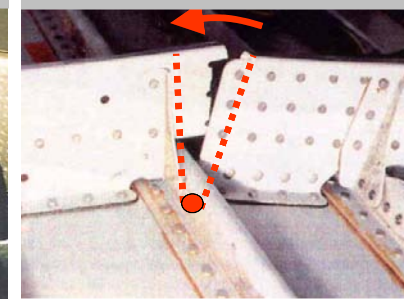
[2]



[3]

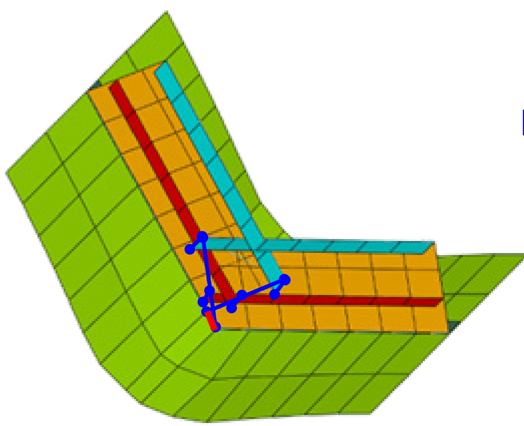


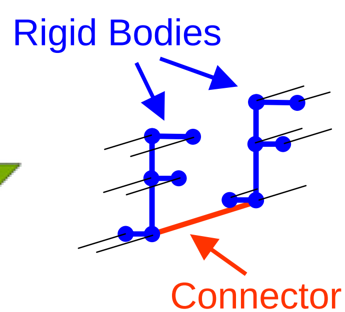
[4]

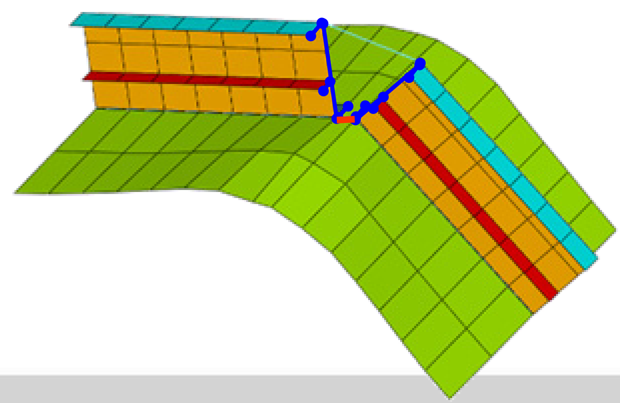


[5]

● ***pivot point***







Kinematics Model

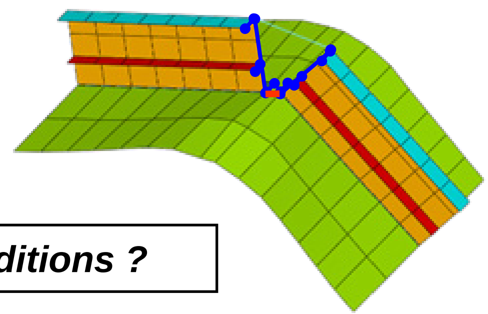
Kinematic Hinge

- Additional information on the development of the frame failure representation (kinematic hinge) is presented in the Conference Paper:

Positioning ?

Pre-Failure: elastic behaviour (neutral axis,…) ?

Modelling Simplifications ?



Post-Failure: hinge kinematics ?

Influence of loading conditions ?

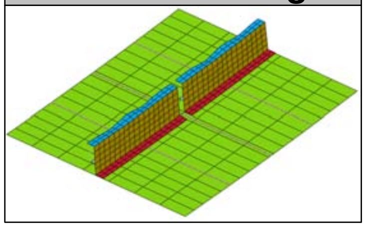
Lateral frame stability ?

Experimental results

[2]

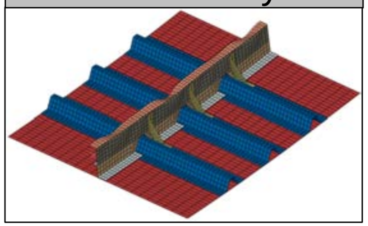
→

Kinematic Hinge



←

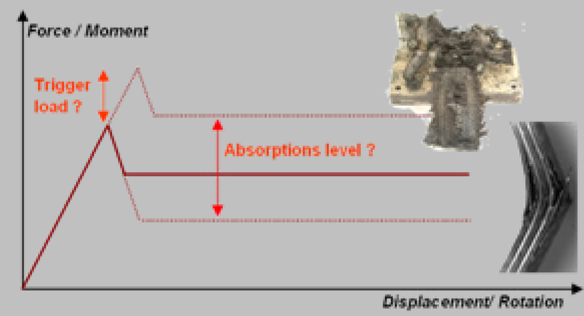
Full FEM analyses



Crash Design of a CFRP Fuselage

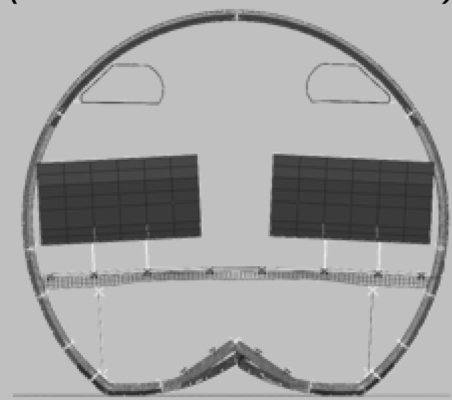
inverse crash design

Definition of the characteristics



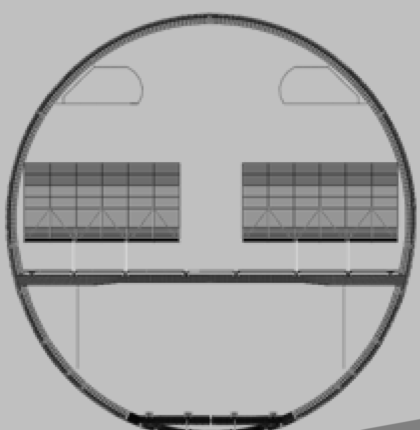
Design of the crash scenario

(characteristics + structure)



CFRP fuselage structure

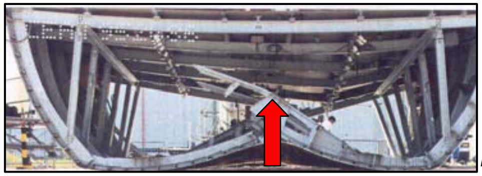
(statically sized)



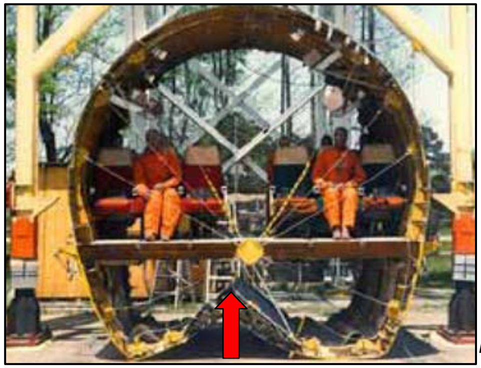
Crash Design of a CFRP Fuselage

(Natural) Crash Kinematics of typical Fuselage Structures

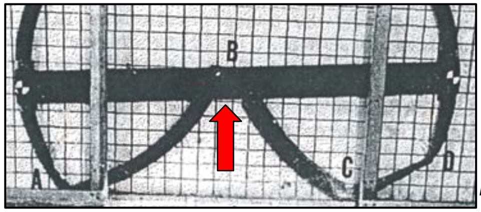
unrolling
of lower fuselage shell:



[5]



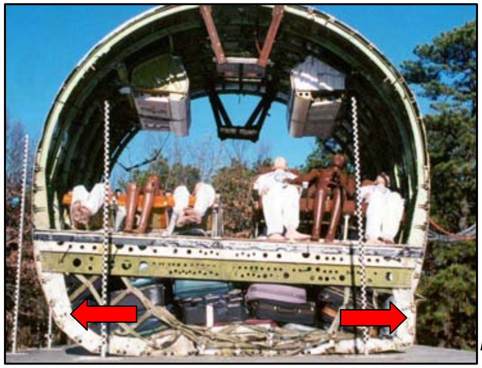
[6]



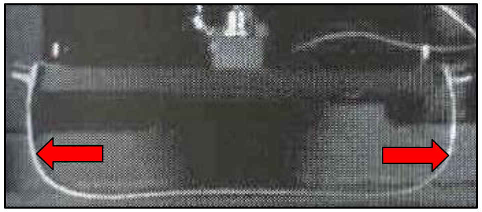
[8]

flattening
of lower fuselage shell:

[5]



[7]

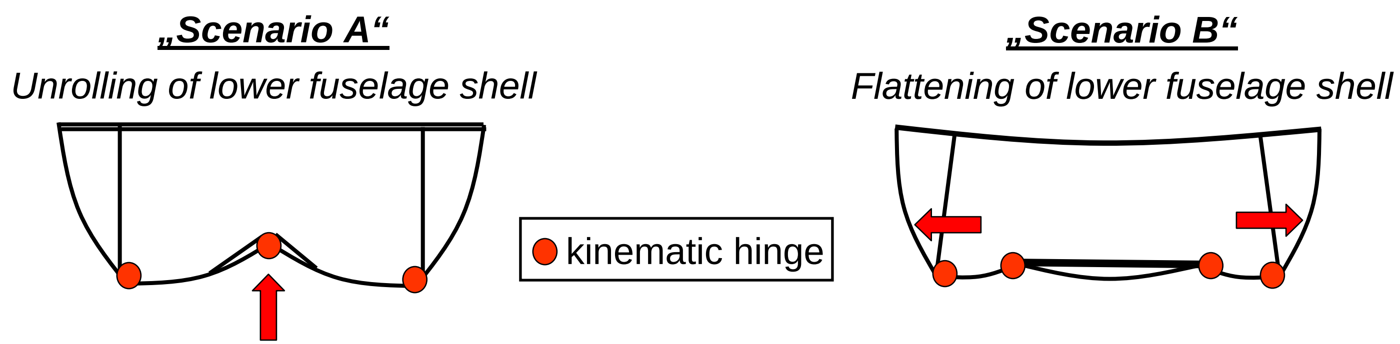


[9]

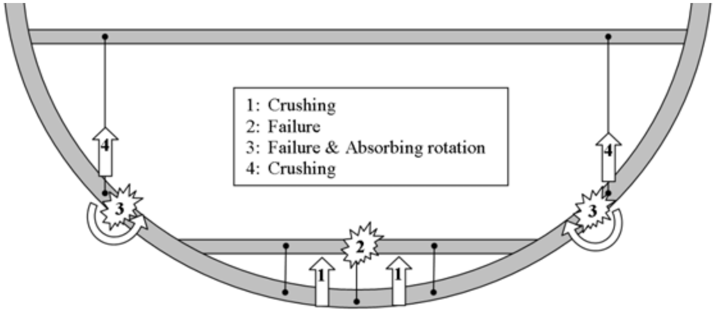
Crash Design of a CFRP Fuselage

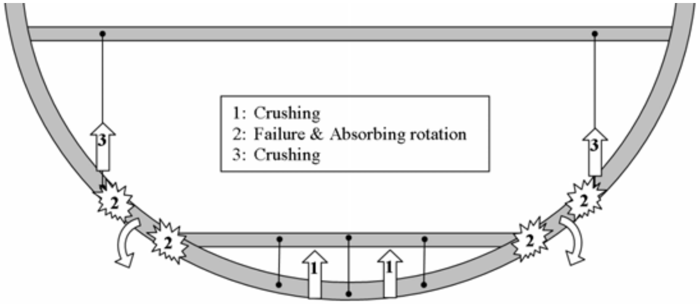
(Natural) Crash Kinematics of typical Fuselage Structures

- Two different, general scenarios:



- Assessment of both scenarios based on a generic, statically sized CFRP fuselage structure:
  - Including a stiff cargo-crossbeam which allows crushing in the sub-cargo area



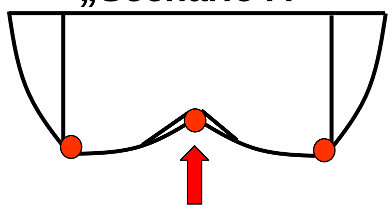


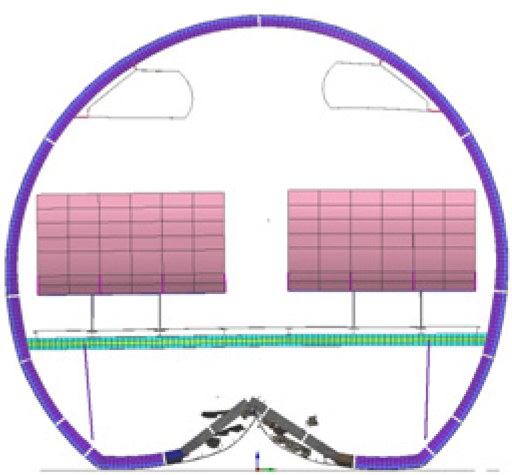
Crash Design of a CFRP Fuselage

Assessment of Crash Scenarios

- Based on a generic, static sized CFRP fuselage structure:

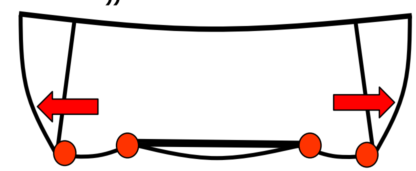
„Scenario A“

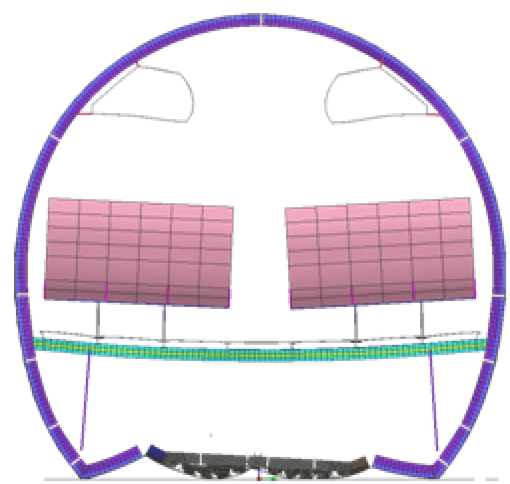




AVI

„Scenario B“

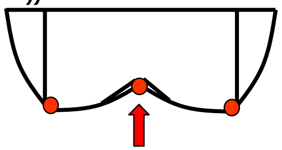




AVI

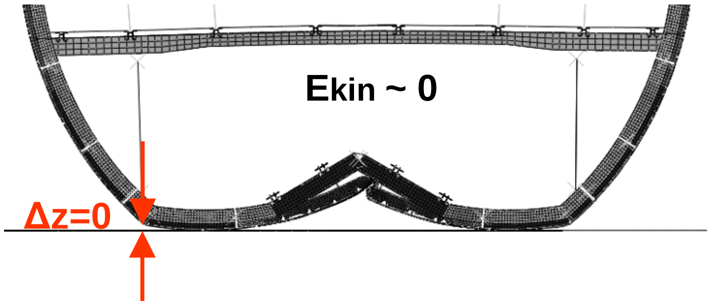
Crash Design of a CFRP Fuselage

Design of Scenario “A”



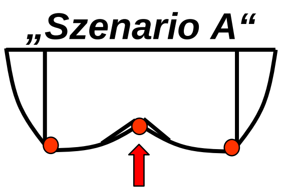
- I. Requirements: Fulfilment of the standard crash case (22ft/s) with passive vertical struts!
  - The whole crash energy shall be absorbed up to the vertical struts

- II. Identification of the required characteristics in the local crash devices to achieve…
  - … an optimised crash kinematics utilizing the whole crash distance
  - … reduced crash loads (reduced risk of passenger injury & reduced structural mass)

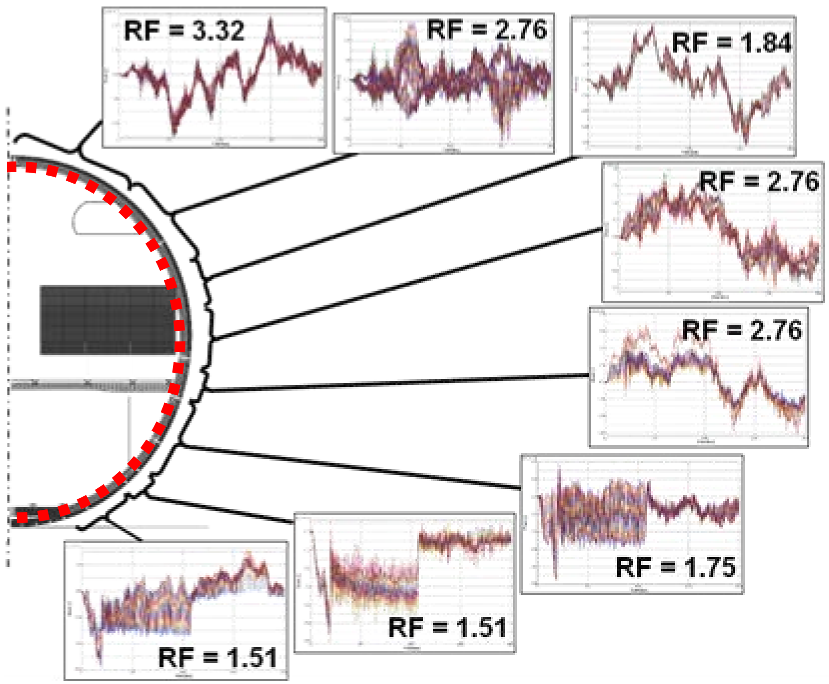


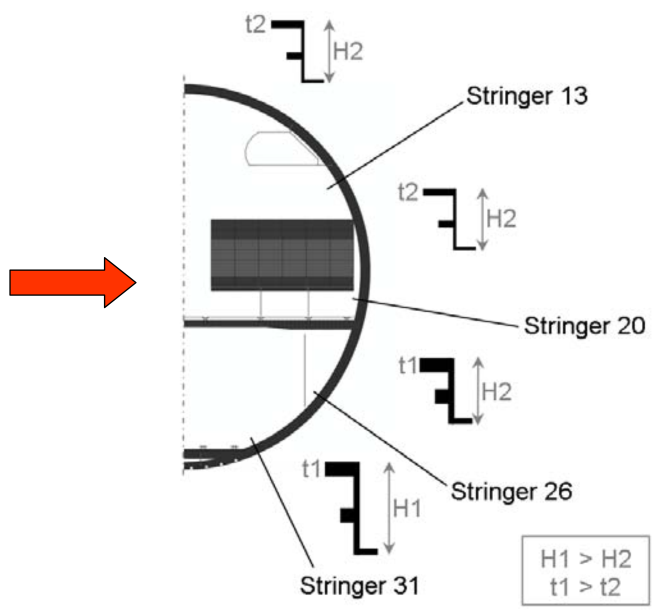
Crash Design of a CFRP Fuselage

Design of Scenario "A"



- <u>III. Determination of the required frame profile distribution</u>
  - Based on the reserve factors of an 'optimised' crash scenario

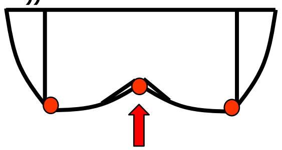




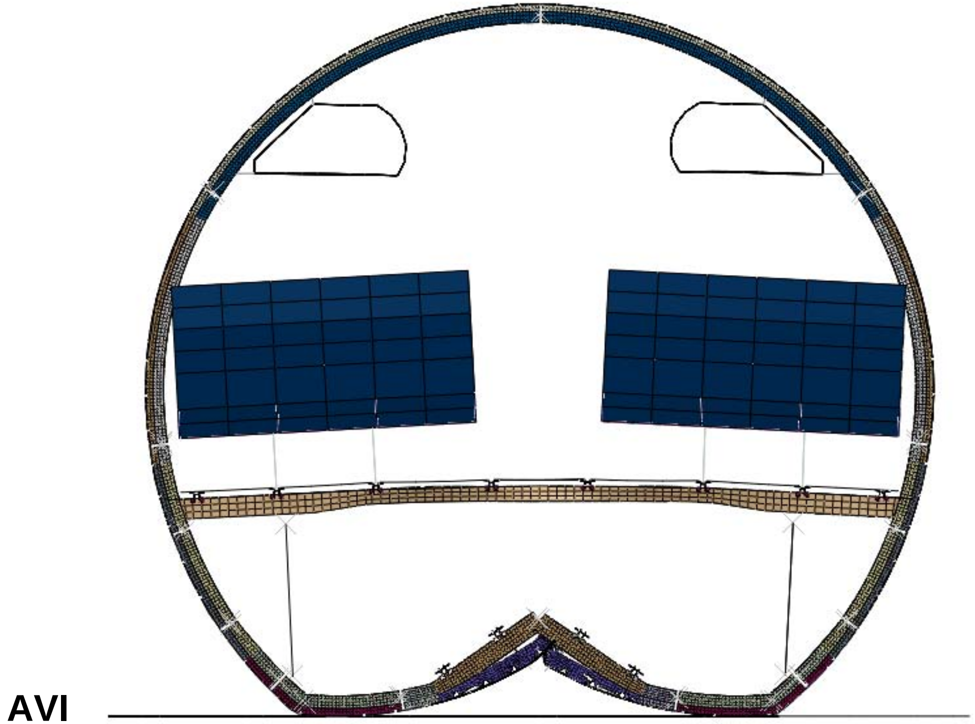
➔ Proposal for final crash design

Crash Design of a CFRP Fuselage

Results of the Final Crash Design

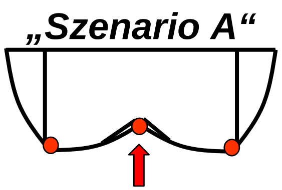


- Crash-Sequence (v_0=22ft/s)

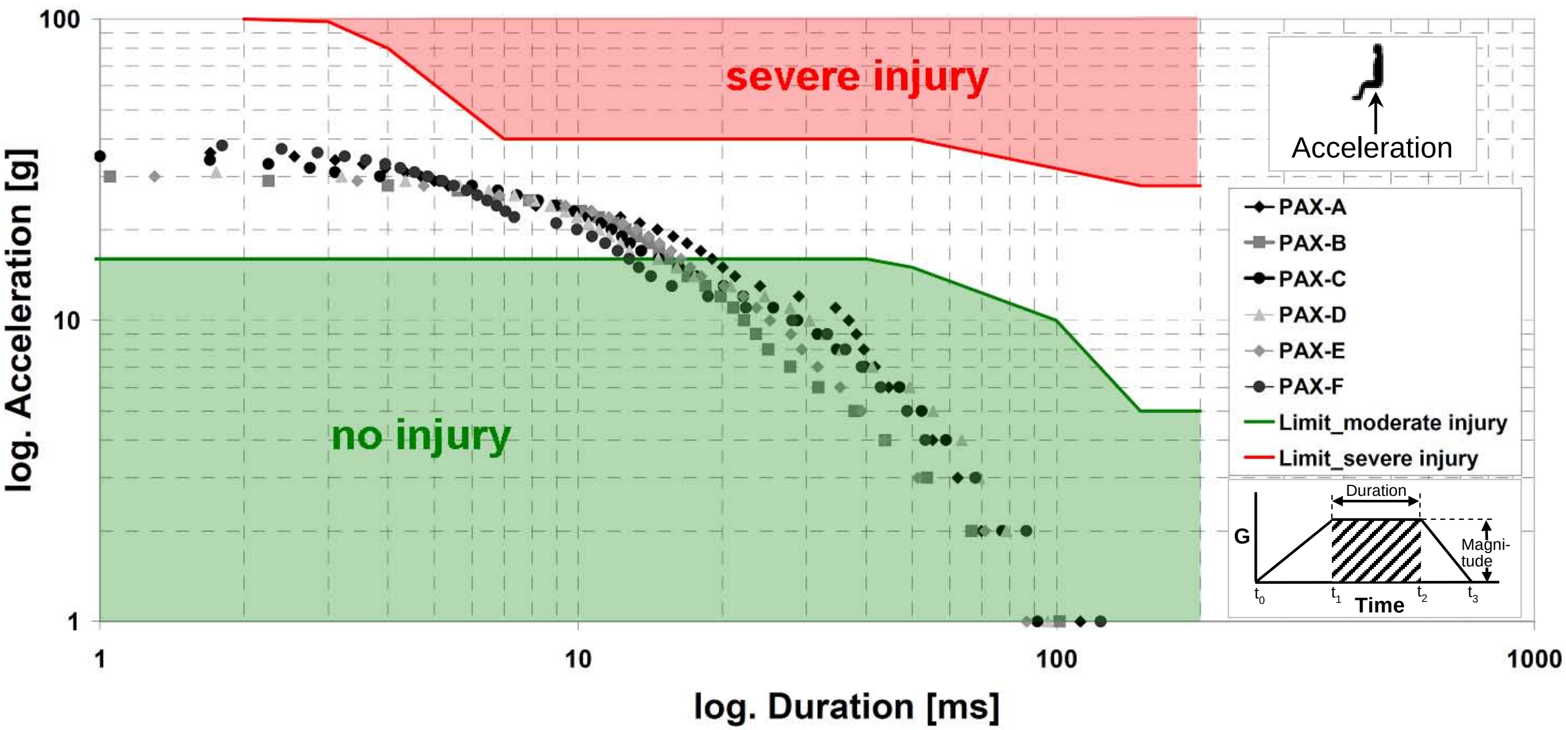


Crash Design of a CFRP Fuselage

Results of the Final Crash Design

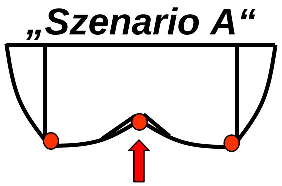


- Passenger loads: Accelerations in the Eiband diagram (v_0=22ft/s)

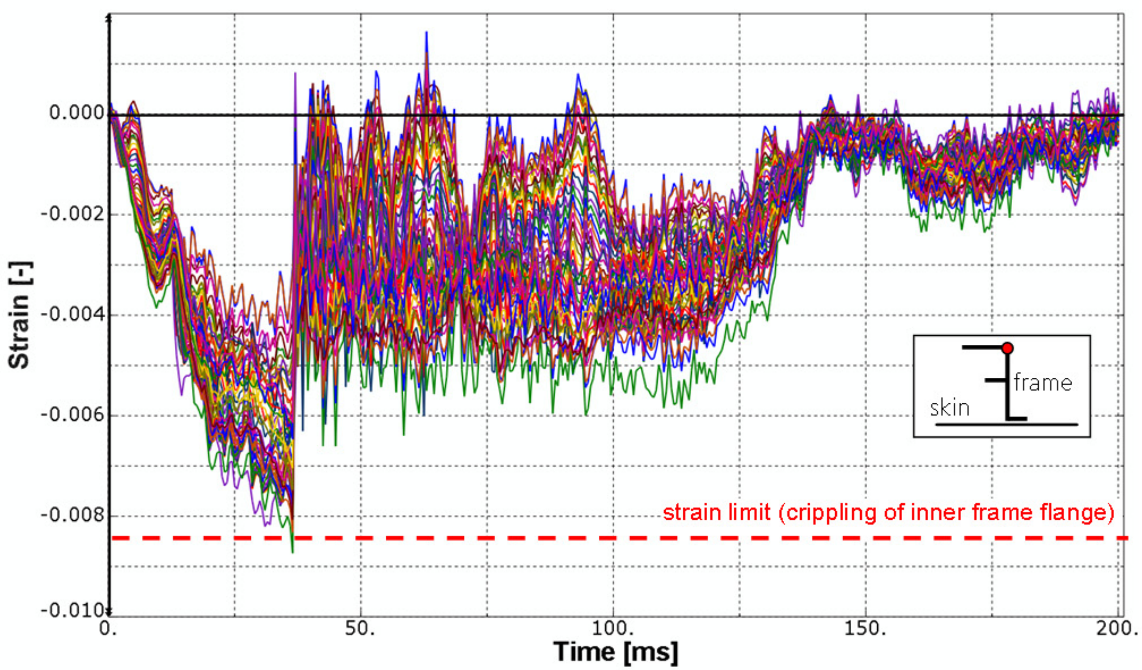


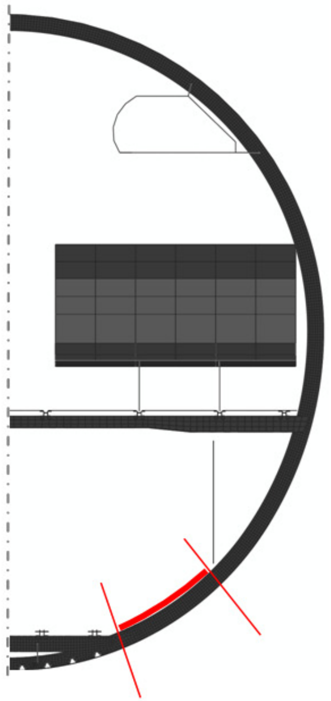
Crash Design of a CFRP Fuselage

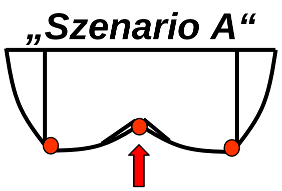
Results of the Final Crash Design



- Structural loads: Strain along the frame (inner flange) (v_0=22ft/s)



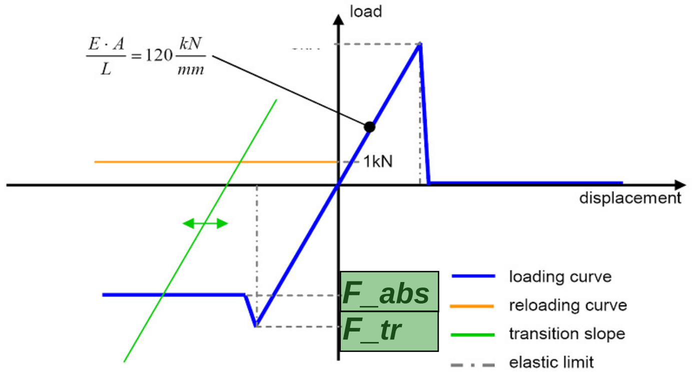


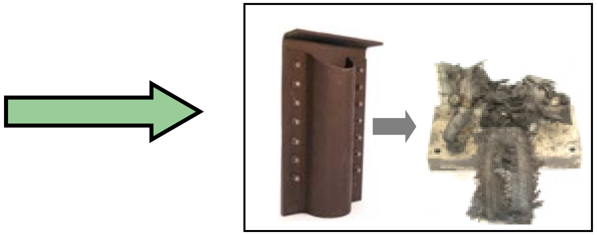


Crash Design of a CFRP Fuselage

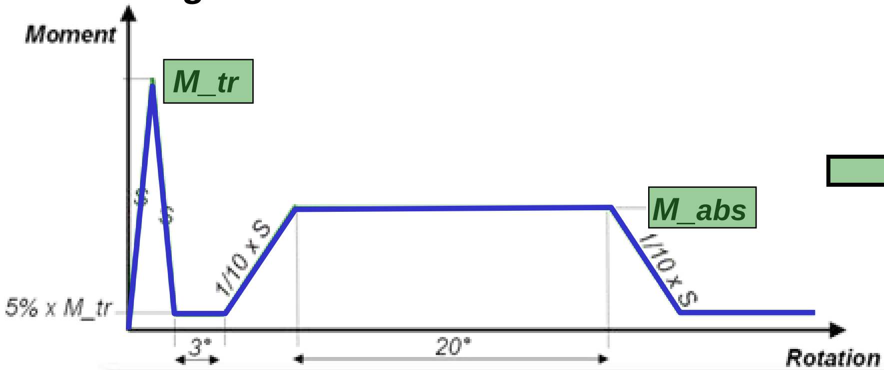
Results of the Final Crash Design

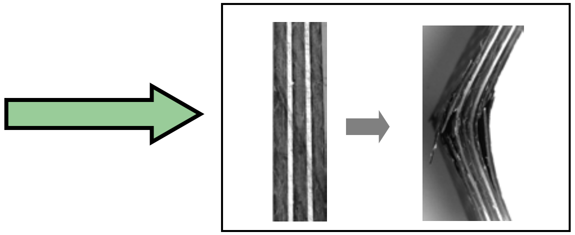
- Characteristics of local crash devices
  - ***Crushable elements***





  - ***Kinematic hinges***



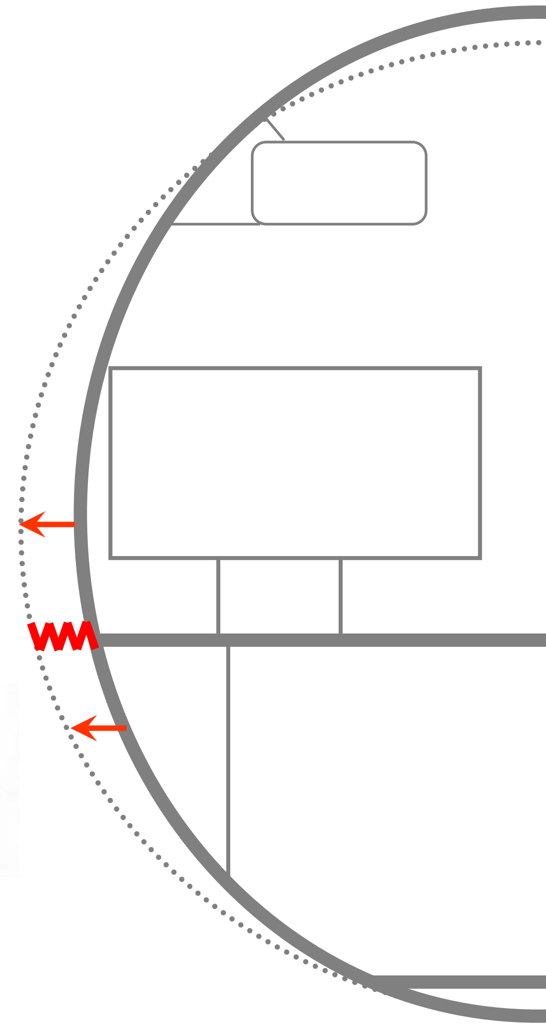


Investigation of a Design Concept Variation

Ovalization

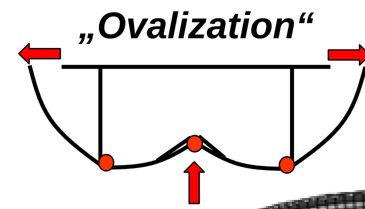
- Flexibility of the passenger crossbeam connection
  - Increased part of the kinetic energy can be stored in the frame structure as elastic energy!

- Potential concept:
  - Additional crash device in the crossbeam connection
  - Possibility of additional energy absorption, e.g. bearing absorber:



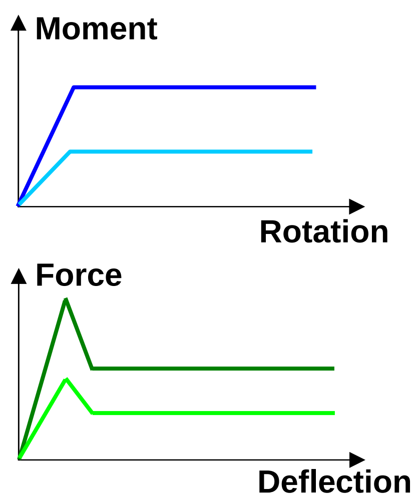
Investigation of a Design Concept Variation

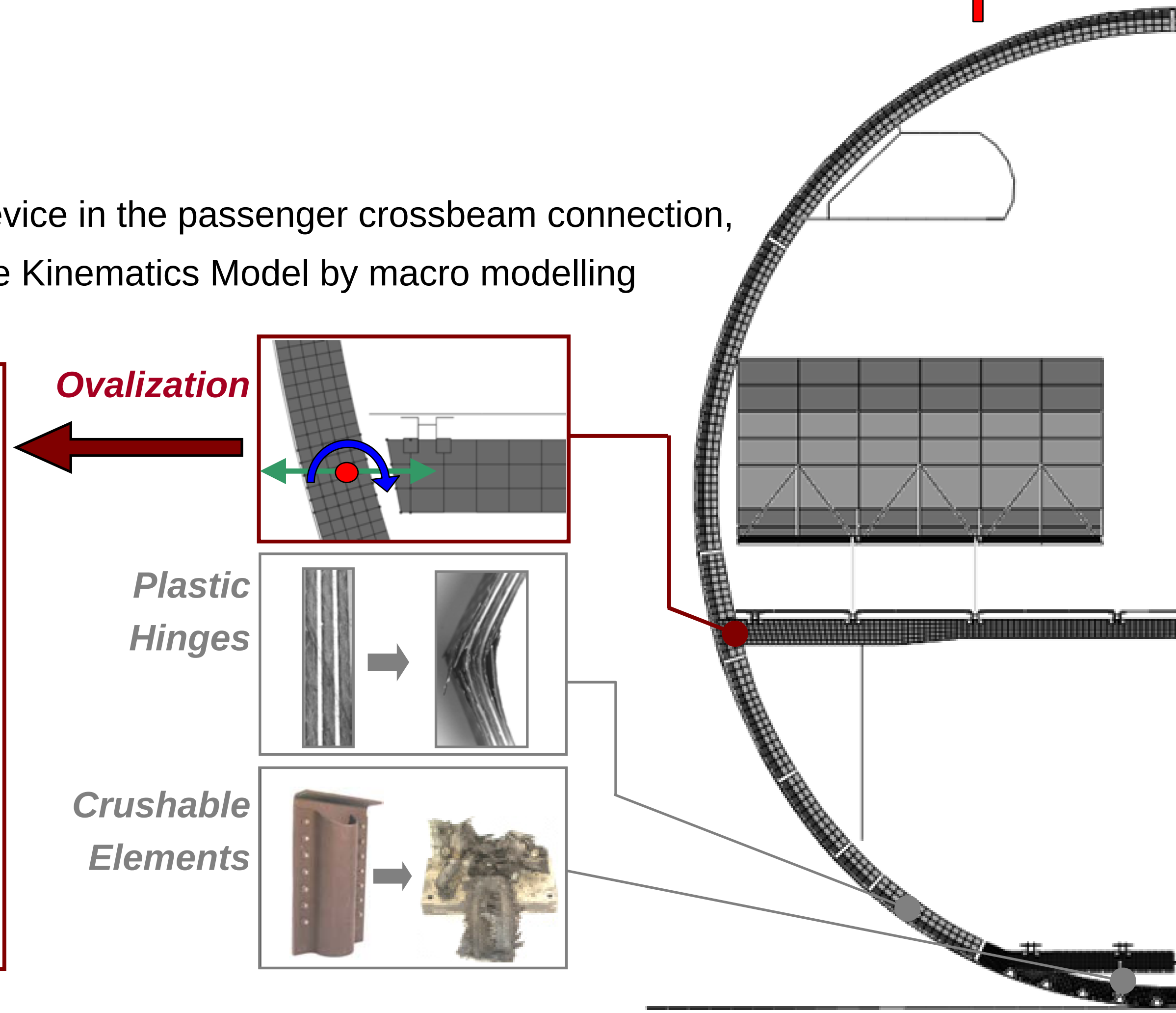
Ovalization



- Modified crash concept:
  - Additional crash device in the passenger crossbeam connection, characterised in the Kinematics Model by macro modelling

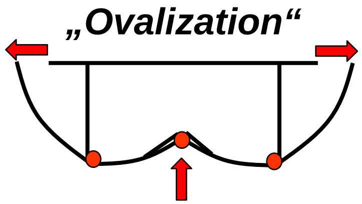
Exemplary characterisation of the crash device:



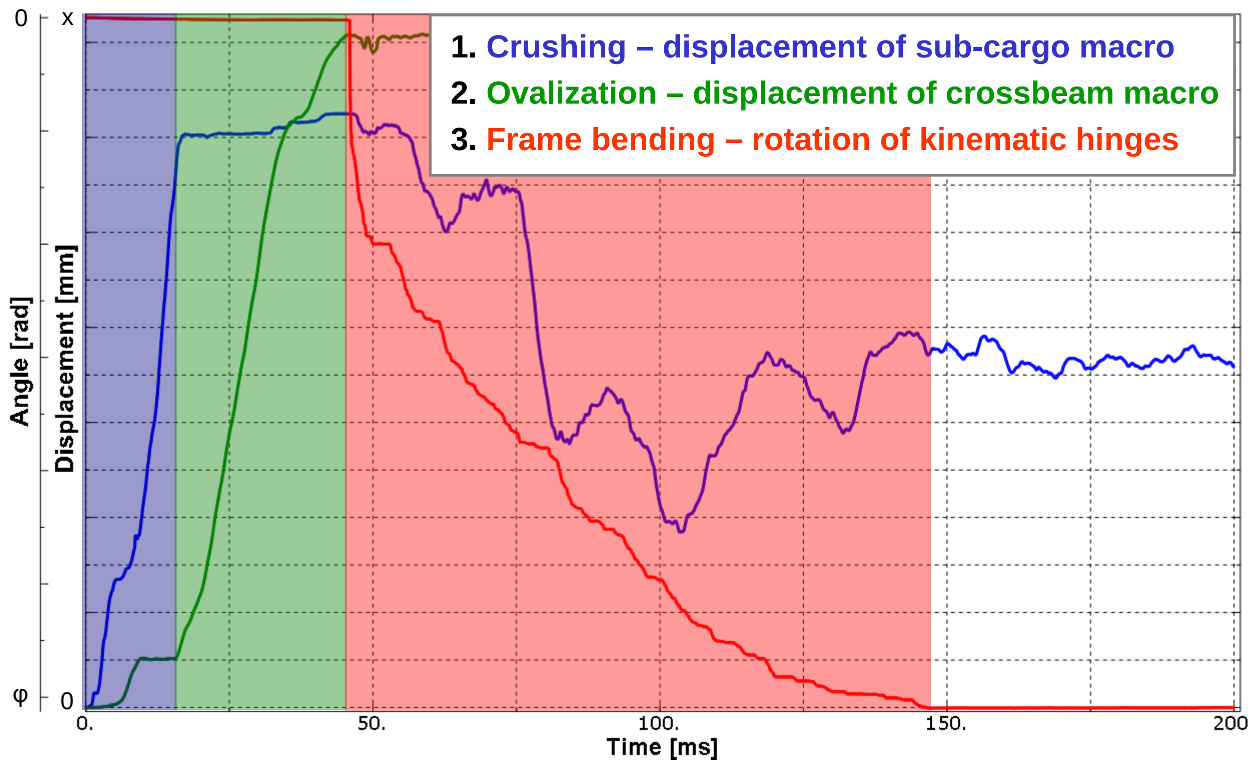


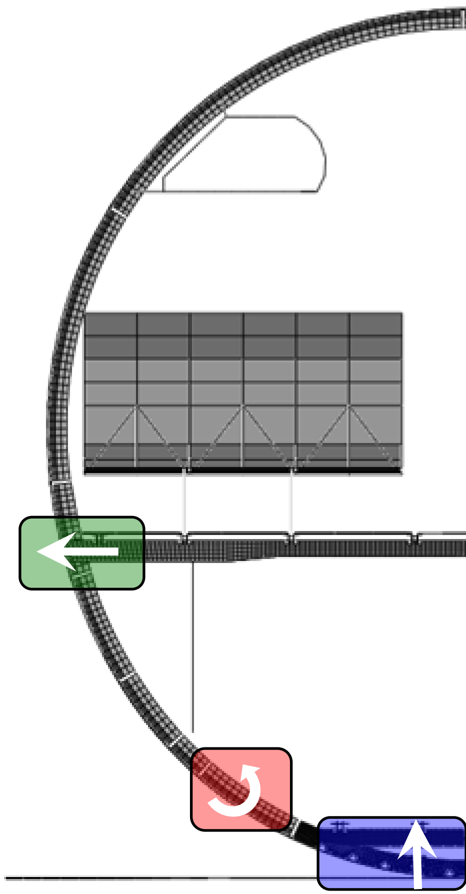
Investigation of a Design Concept Variation

Cascading Scenario with Ovalization



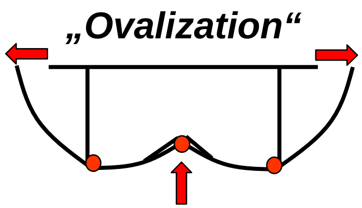
- Output data of the macro elements: Cascading Scenario!



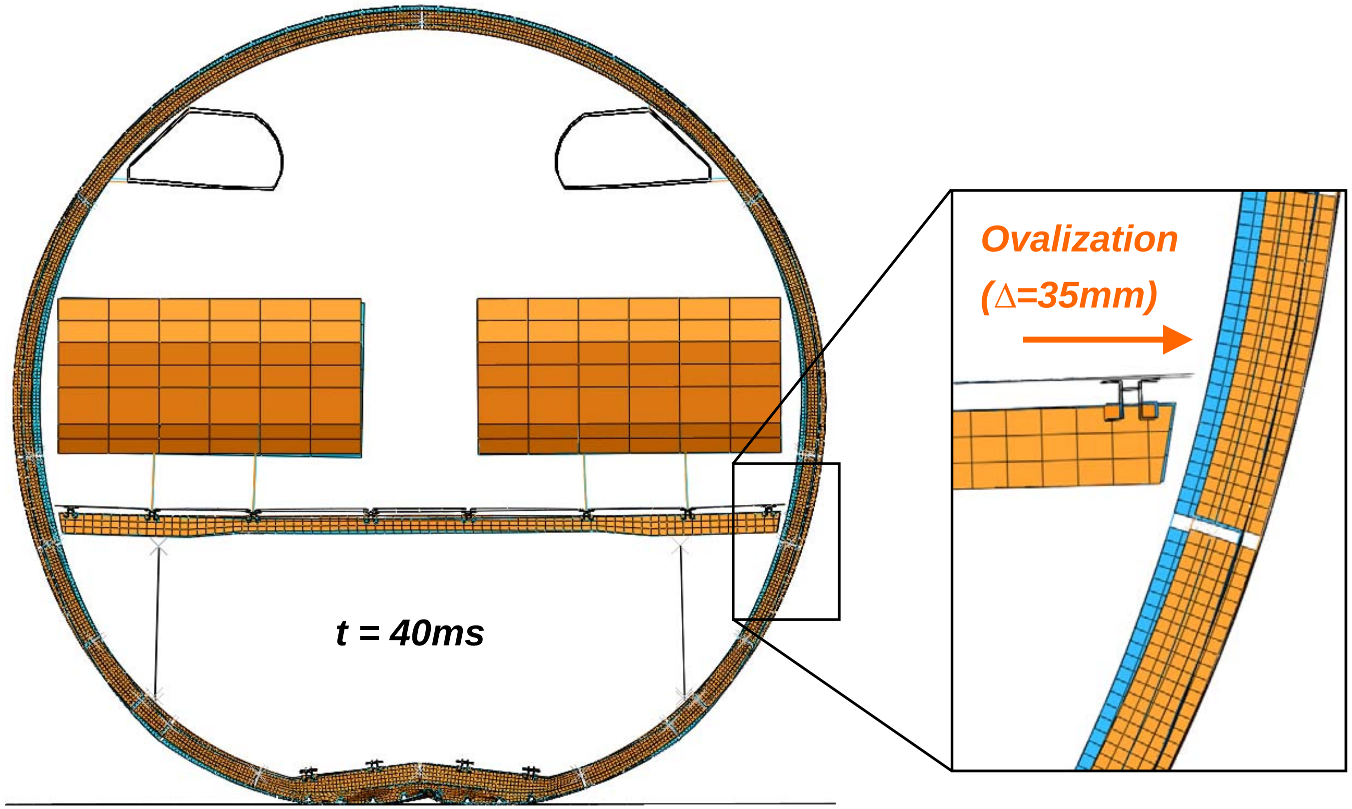


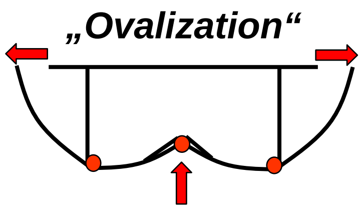
Investigation of a Design Concept Variation

Cascading Scenario with Ovalization



- Crash Sequence: without Ovalization / with Ovalization

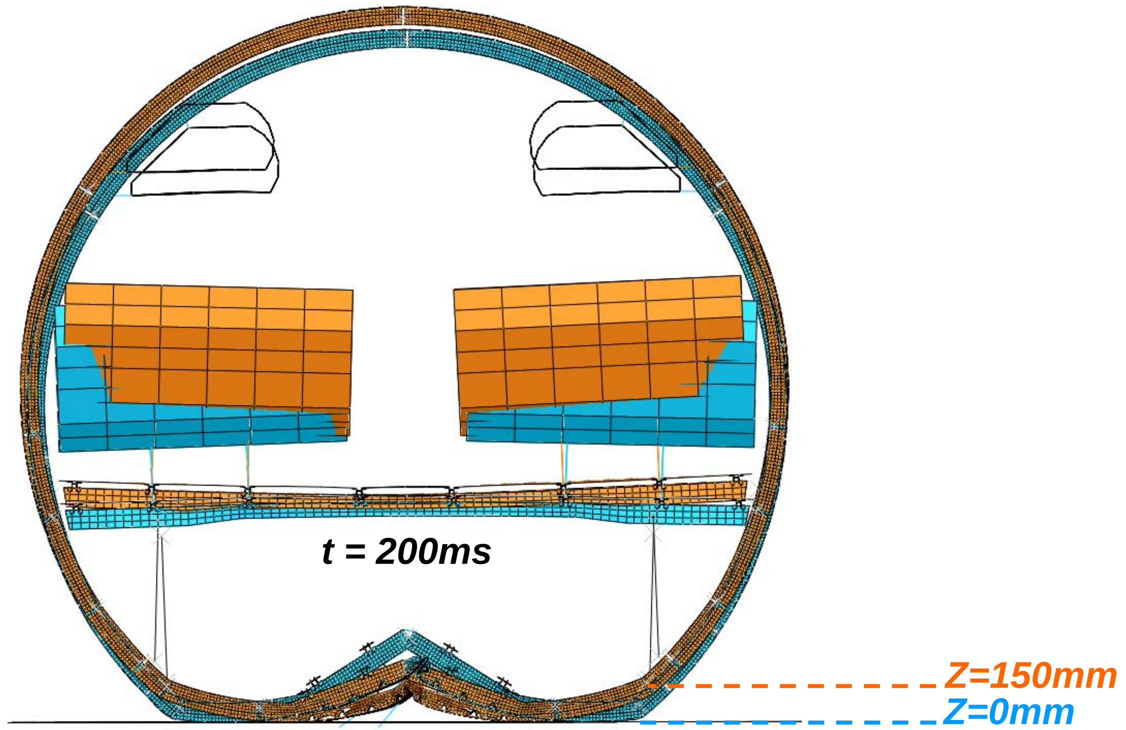




Investigation of a Design Concept Variation

Cascading Scenario with Ovalization

- Crash Sequence: **without Ovalization** / **with Ovalization**
  - Ovalization concept provides a reduced crash distance!



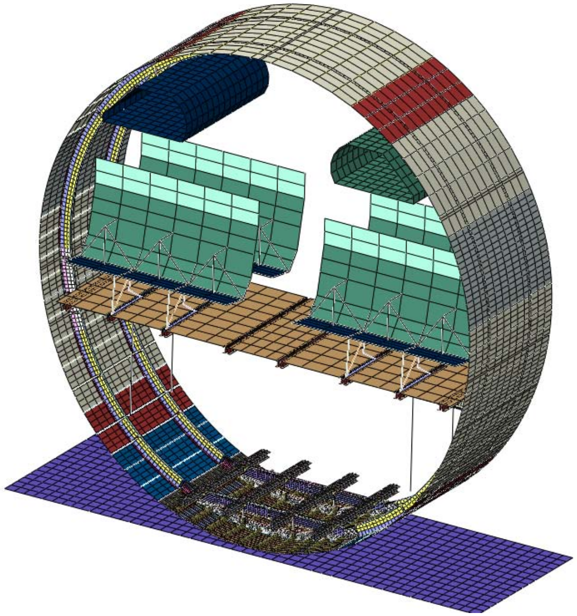
Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Conclusion

- **A new modelling method was developed: ‚Kinematics Model‘**
  - Modelling approach: mainly linear-elastic + macro elements
  - Detailed investigation of the modelling approach (e.g. kinematic hinges)
- **Crash scenarios were analysed and assessed**
  - With respect to a generic CFRP fuselage structure
- **A preliminary crash design development was conducted**
  - Identification of required trigger loads and absorptions levels
  - Determination of required dimensioning of the frame structure
- **A design concept variation was investigated – the ovalization concept**
  - Identification of effects of the ovalization concept

➔ ***The feasibility of an inverse crash design development was demonstrated successfully!***

Thank you for your attention!



Matthias Waimer
DLR - Institute of Structures and Design
Pfaffenwaldring 38-40
70569 Stuttgart
Germany
Email: matthias.waimer@dlr.de

References

[1] Heimbs, S.; Strobl, F.; Middendorf, P.; Guimard, J.M.: Composite Crash Absorber for Aircraft Fuselage Applications; Structures Under Shock and Impact XI, WIT Transactions on The Built Environment, Vol. 113 - 2010

[2] Pérez, J. G.: Energy Absorption and Progressive Failure Response of Composite Fuselage Frames; Master Thesis, Virginia Polytechnic Institute – 1999

[3] Hashemi, R.: Sub-Component Dynamic Tests of an Airbus A320 Rear Fuselage; Cranfield Impact Centre – 1994

[4] Le Page: Results of the Commuter Sub-Passenger Floor Structure Drop Test; CEAT test report N°S98/4449000 P3 - 1997

[5] Le Page, F.: A320 Fuselage Section Vertical Drop Test, Part 2: Test Results; CEAT test report N°S95 5776/2 – 1995

[6] Williams, M.S.; Hayduk, R.J.: Vertical Drop Test of a Transport Fuselage Section located Forward of the Wing; NASA TM85679 – 1983

[7] Abramowitz, A.; Smith, T.G.; Vu, T.; Zvanya, J.R.: Vertical Drop Test of a Narrow-Body Transport Fuselage Section with Overhead Stowage Bins; FAA DOT/FAA/AR-01/100 – 2002

[8] Boitnott, R.L. et al.: Impact Response of Composite Fuselage Frames; SAE Technical Paper 871009 – 1987

[9] Meng, F.X.: Improvement of Crashworthiness Behaviour for Simplified Structural Models of Aircraft Fuselage; Beijing University of Aeronautics and Astronautics - 2008

[10] Waimer, M.; Kohlgrüber, D.; Hachenberg, D.; Voggenreiter, H.: Development of a Crashworthy Composite Fuselage Design Using a Kinematics Model; EUCOMAS - 2010