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Investigation of an Alternative Crash Concept for Composite Transport Aircraft using Tension Absorption

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Overview

- **Introduction**

- **Development of the tension crash concept**
  - Macro input-characteristics (kinematics model)
  - Crash kinematics & results
  - Assessment of the passenger loads

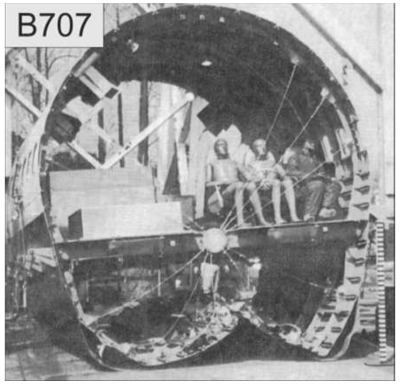
- **Consideration of cargo loading**
  - Modifications for cargo loading
  - Crash kinematics & results
  - Assessment of the passenger loads

- **Conclusion**

Introduction

Crash behaviour of nowadays metallic aircraft

- Fuselage section drop tests of nowadays metallic transport aircraft were conducted in the past to investigate the energy absorption behaviour of the aircraft structure



[3]

NASA/FAA joint transportation crash safety program

[2]

FAA crash dynamics and engineering development program

[6]

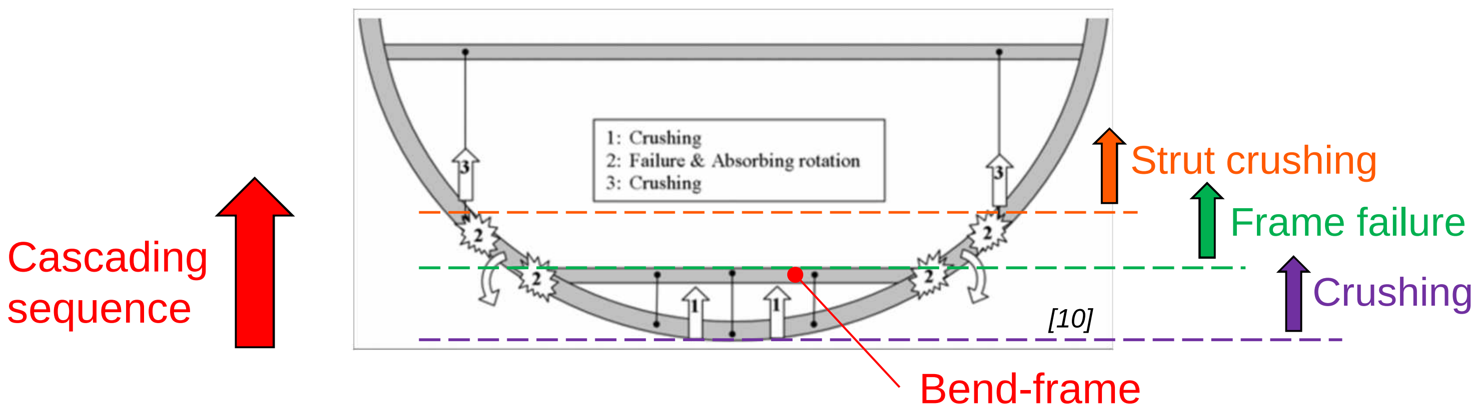
European research project: Crashworthiness for commercial aircraft

- The kinetic energy of the metallic fuselage sections is mainly absorbed by
  - **Plastic deformation (frame, sub-cargo area, skin)**
  - Damage & failure (frame rupture, sub-cargo area, joints)

Introduction

Crash concept for composite aircraft

- Specific crash concepts are required due to the generally brittle failure behaviour of composites
- In several research studies a so called 'bend-frame' concept was investigated
- The concept is characterised by a cascading crash sequence



- The research work identified critical mass penalty of the bend-frame concept

  ➔ The concept requires massive cargo crossbeam and frame design to sustain the crush forces that are generated below the cargo floor

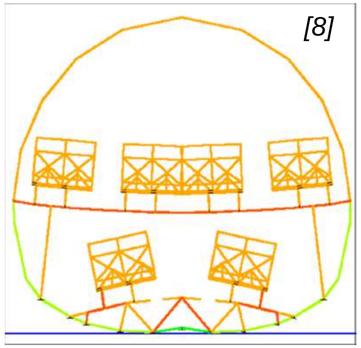
Introduction

Alternative crash concept for composite aircraft

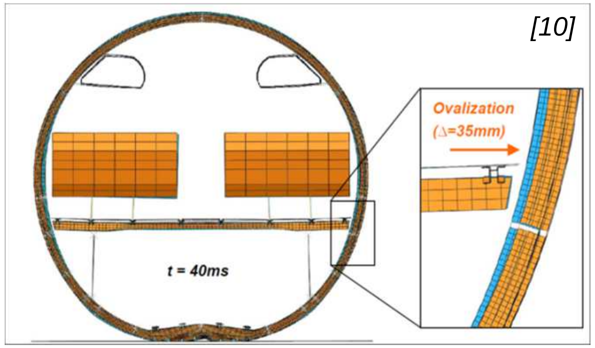
- Further studies on crash concepts identified high tension forces in typical crash events:

… in the cargo floor caused by high bending loads in the sub-cargo structure

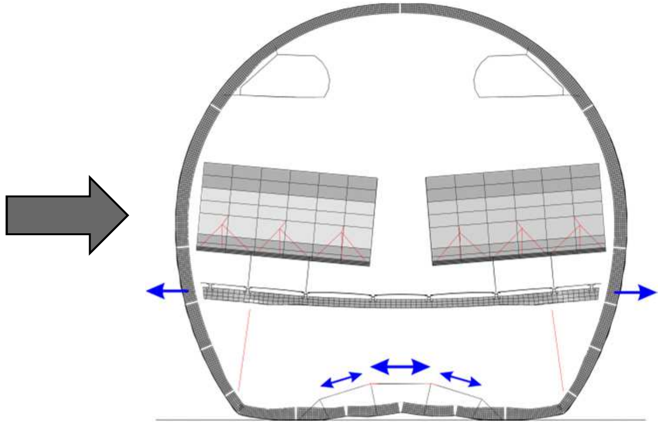
… in the cabin floor caused by the 'ovalisation effect'



Cargo floor tension



Cabin floor tension



➔ New concept: Crash kinematics with tension absorption as main absorption concept

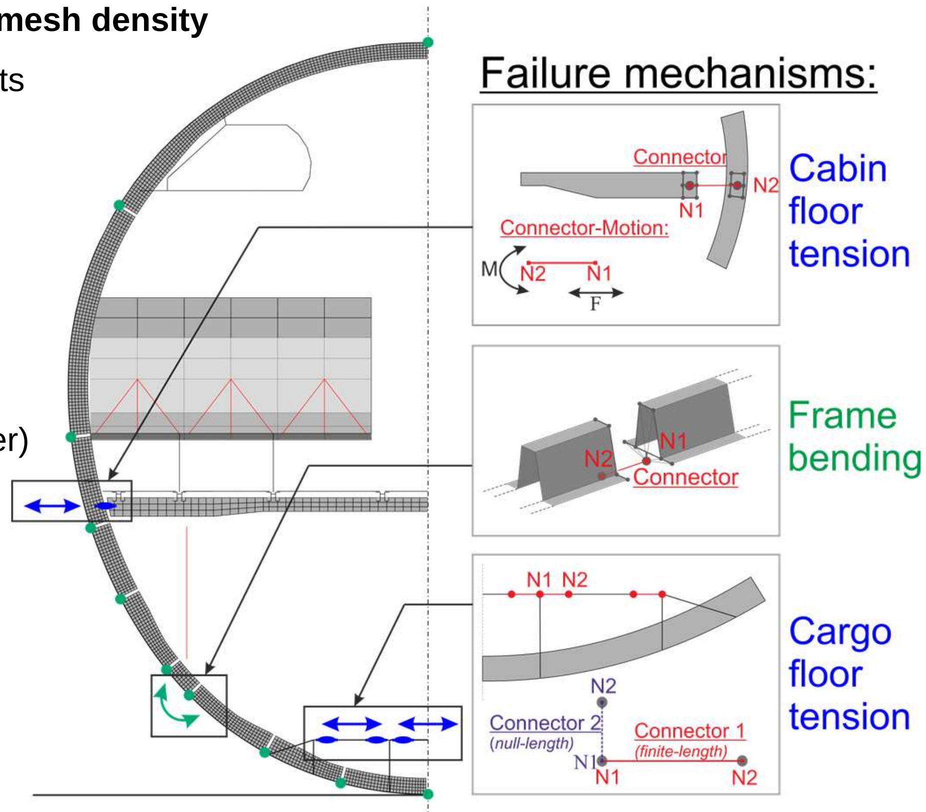
✓ Avoidance of massive backing structure in the lower fuselage section (bend-frame concept)

✓ Comparably simple absorber mechanisms for tensile loading (minor challenges w.r.t. instability)

✓ CFRP frames: Limited requirements for energy absorption acc. to typical brittle failure

Introduction
Kinematics modelling approach

- <u>Development of the tension crash concept using the kinematics modelling approach [10], [11]</u>
  - **Failure** in crash devices **is represented by macro elements**
  - **Linear elastic material law with coarse mesh density**
  - The input-characteristics of macro elements are obtained
    - ➔ from test results
    - ➔ from detailed FEM simulations
    - ➔ from assumptions
  - Simplified modelling:
    - ➔ without mouseholes (beam stringer)
    - ➔ without clips/ cleats
  - Assessment of:
    - ➔ required absorber characteristics
    - ➔ structural/ passenger loads
    - ➔ robustness crash cases



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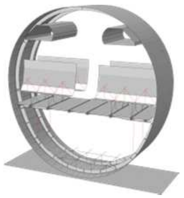


Development of the tension crash concept

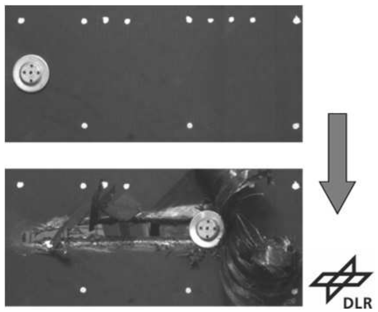
Macro input-characteristics (kinematics model)

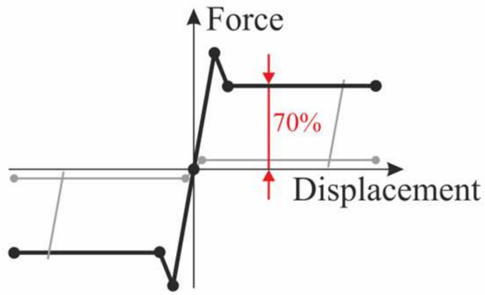
- Cabin floor
    - Due to typical crash loads the fuselage section deforms to an oval shape (‘ovalisation effect’)

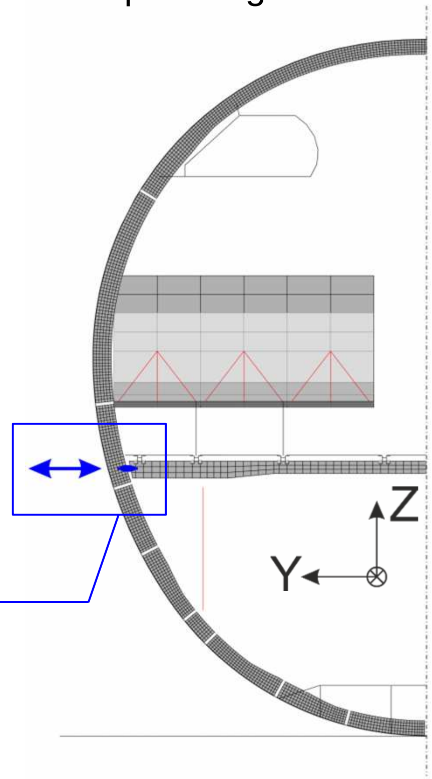
➡ Utilization of tension forces in the connection between the frame and the passenger crossbeam for energy absorption

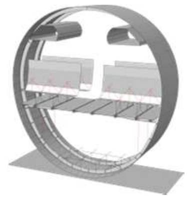
Tension absorption in the cabin floor

Potential physical device	*Macro input-characteristics*
➔ Bearing failure (bolt pulled through a laminate)	➔ Translational displacement in y-direction









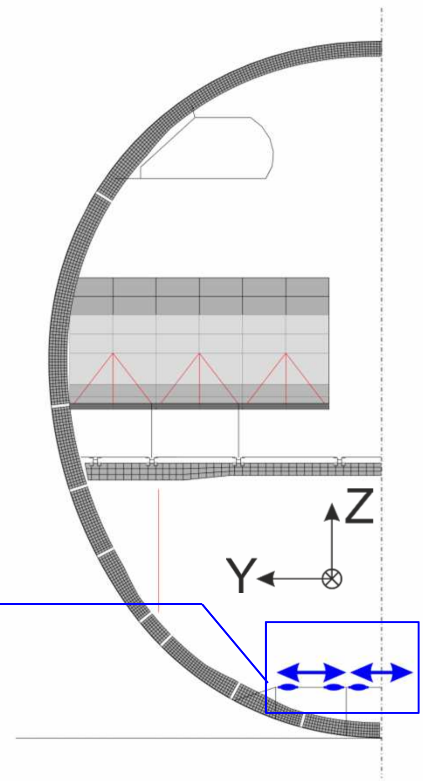
Development of the tension crash concept

Macro input-characteristics (kinematics model)

- Cargo floor

  - In the first crash phase high tension forces occur in the cargo floor caused by the bending loads in the sub-cargo structure

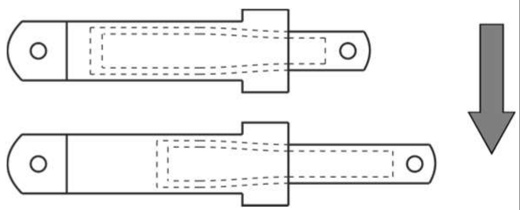
➡ Utilization of tension forces in the cargo floor for energy absorption



Tension absorption in the cargo floor

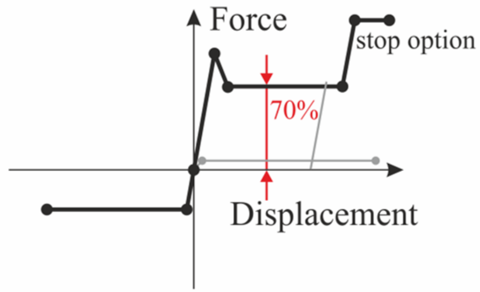
Potential physical device

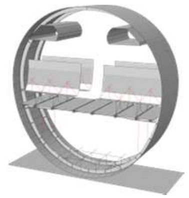
➔ Energy absorption by plastic decreasing of a tube diameter



Macro input-characteristics

➔ Translational displacement in y-direction





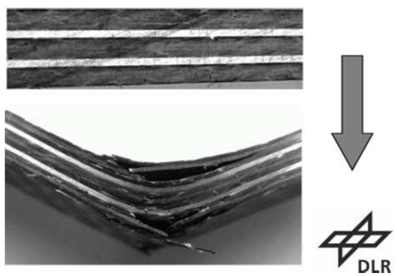
Development of the tension crash concept

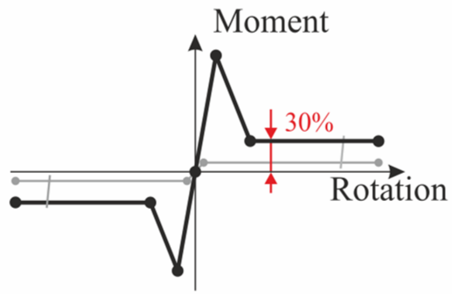
Macro input-characteristics (kinematics model)

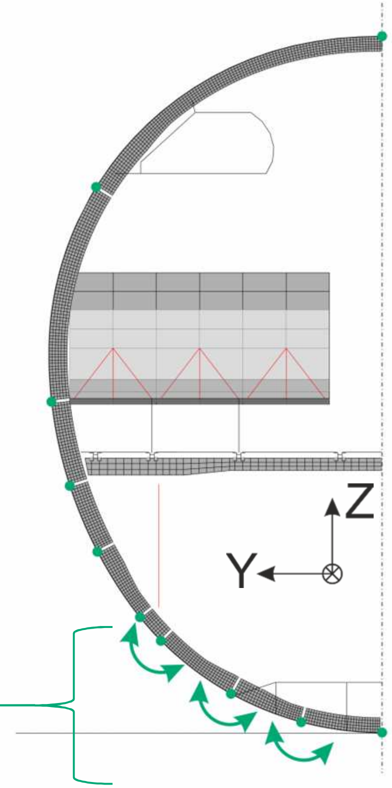
- Frame
  - Challenge to obtain high energy absorption by bending failure of CFRP frames
  - Therefore: moderate requirements for energy absorption in the frame

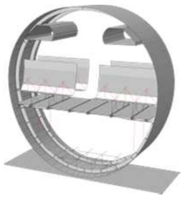
Bending absorption in the frame

Potential physical device	*Macro input-characteristics*
➔ Bending absorption with hybrid laminates	➔ Rotational displacement about the x-axis





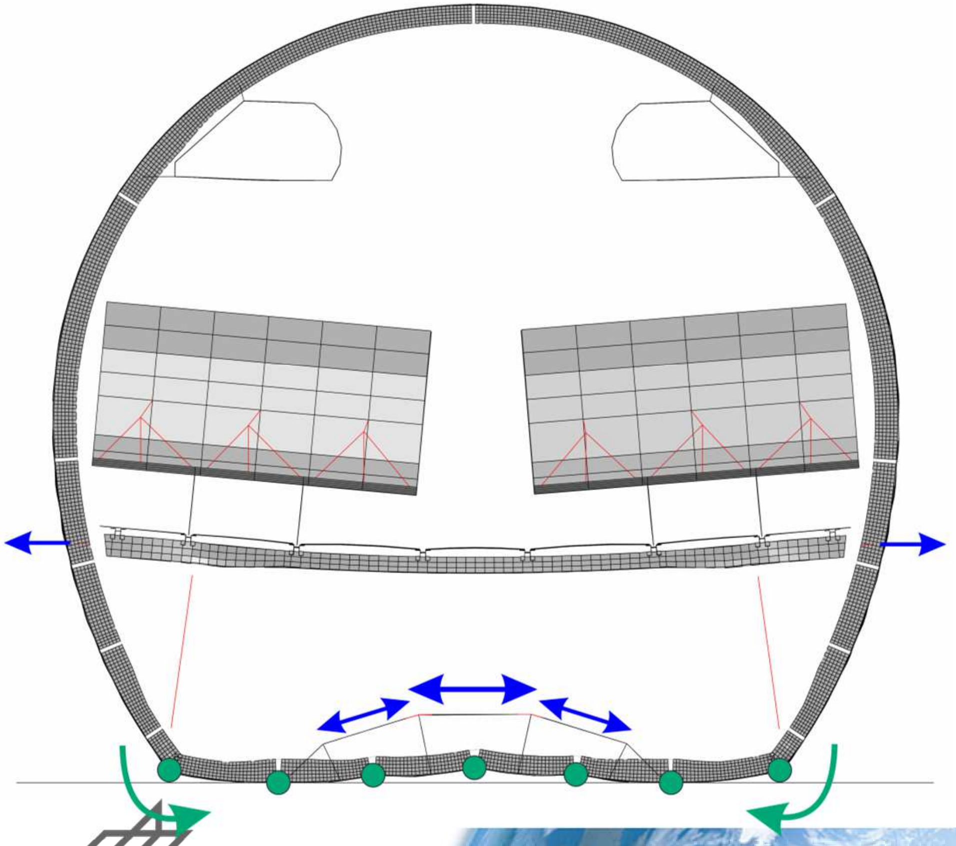




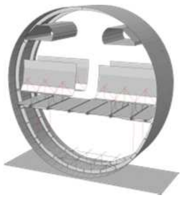
Development of the tension crash concept

Crash kinematics (with *flattening* of the lower fuselage section)

- FE-Simulation



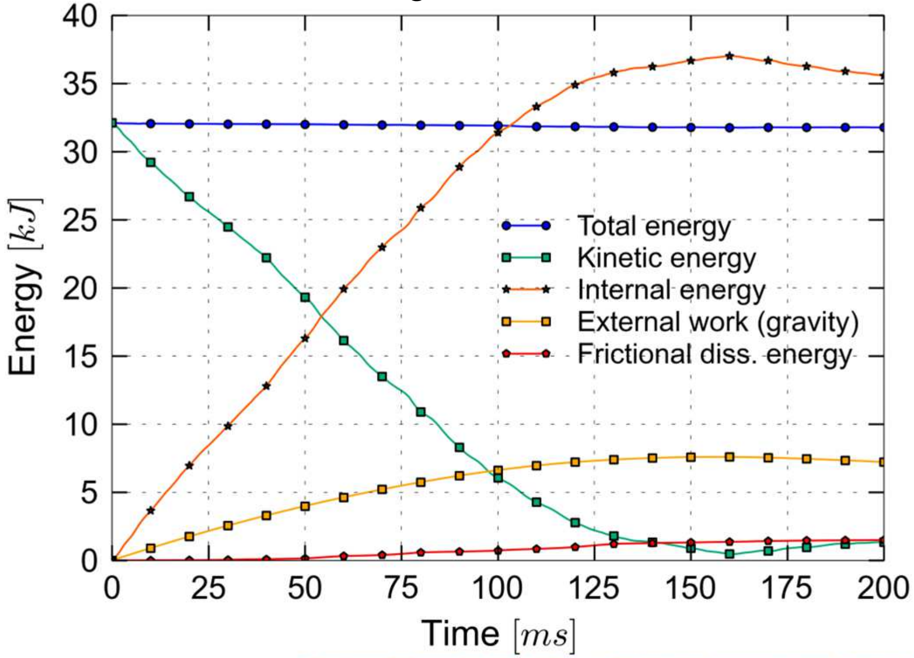
- FE-code: Abaqus/Explicit V6.11-1
- Fuselage section length (2-bay): 1270 mm
- Impact velocity: v_i = 6.7 m/s = 22 ft/s
- Total mass: 1430.4 kg

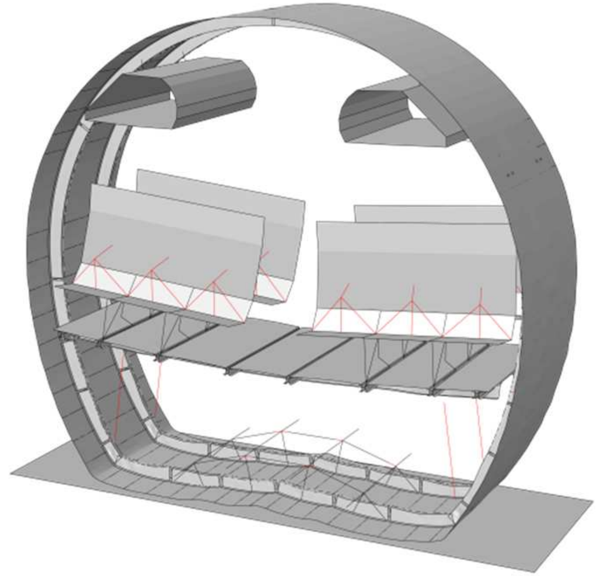


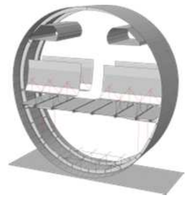
Development of the tension crash concept

Crash kinematics (energy output)

- Energy balance
    - Smooth decrease of kinetic energy
        - ➔ reduced structural loads and passenger loads
    - Little energy dissipated by friction due to the flattening kinematics of the lower fuselage section







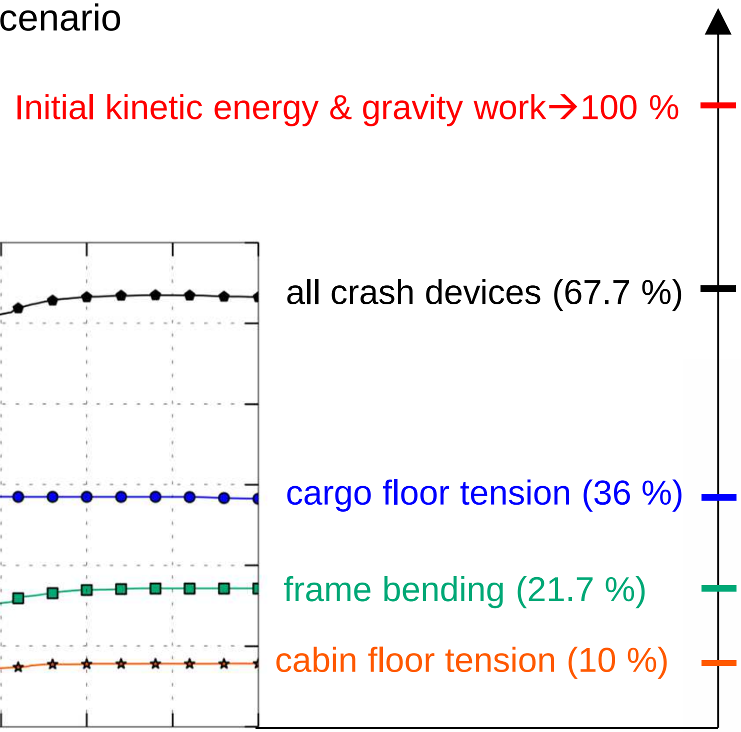
Development of the tension crash concept

Crash kinematics (energy output (cont'd))

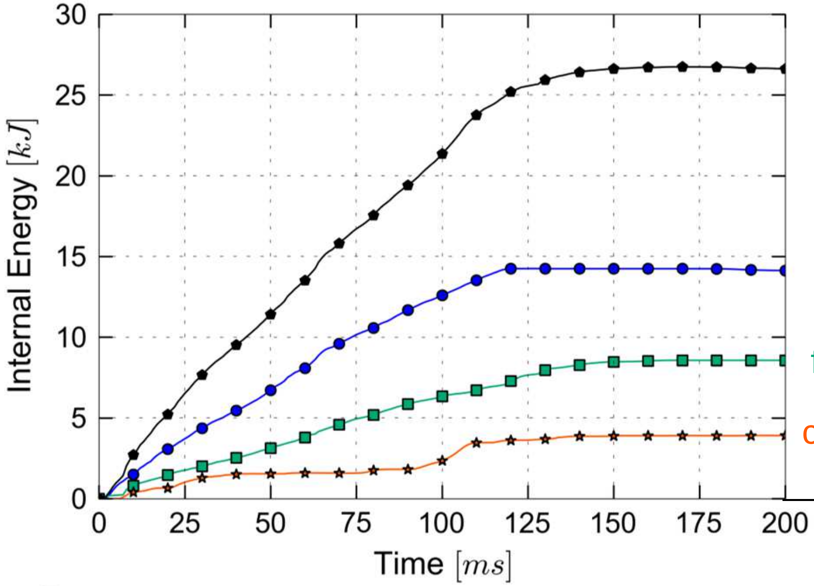
- Energy absorbed in the crash devices

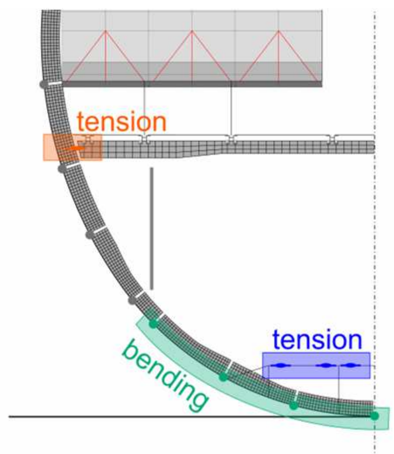
    - Smooth energy absorption due to **parallel activation of the absorbers**

    - No cascading crash scenario



Residual energy:
elastic strain energy (22 %)
kinetic energy (3.4 %)
friction diss. energy (3.8 %)
neglected energies (3.1 %)



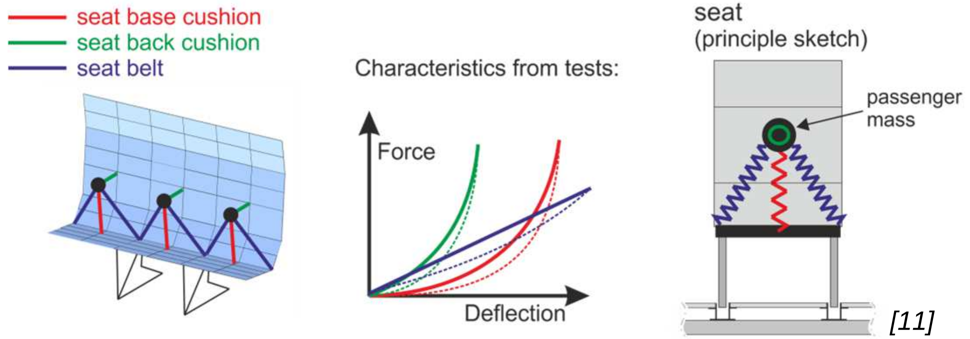


Development of the tension crash concept

Assessment of the passenger loads

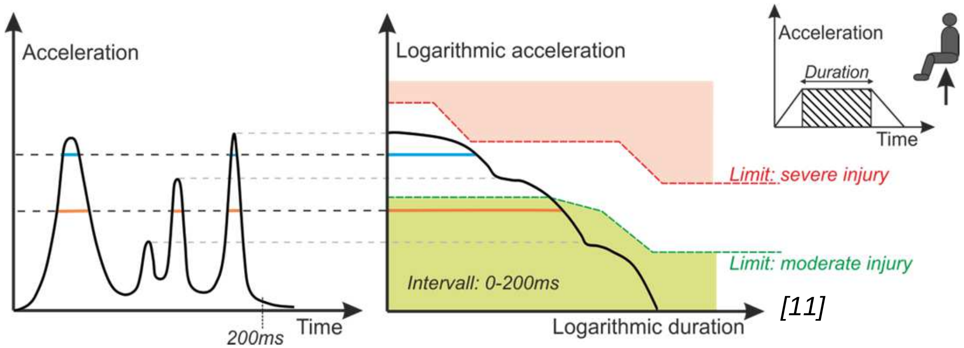
- Simplified seat-passenger model

  - Input-characteristics are calibrated according to experimental test data



- Eiband diagram

  - The Eiband curve is obtained by summing the total time of an acceleration level



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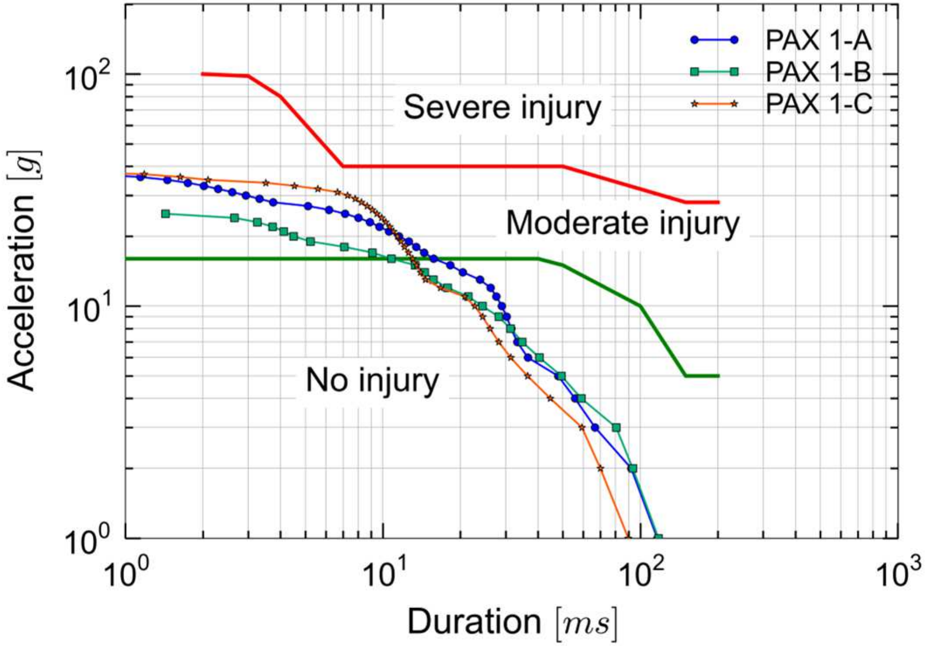
Development of the tension crash concept

Assessment of the passenger loads (cont'd)

- Vertical acceleration response of the passengers plotted in an Eiband diagram
  - Acceptable acceleration responses in the range of moderate injury
  - Accelerations in a certain range due to the cabin floor dynamics



Consideration of cargo loading

Influence of cargo loading

- Cargo loading has to be considered!
    - → High interaction of tension absorption mechanism (cargo floor) and cargo loading
    - → Functionality of the tension crash concept has to be ensured even in case of cargo loading!

- Diverse cargo types are loaded in a transport aircraft (shape, dimension, stiffness, weight, …):

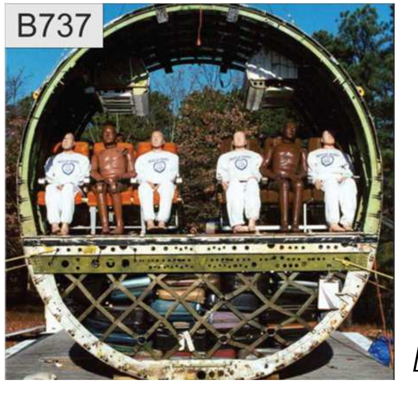
Auxiliary fuel tank

[1]

FAA crash dynamics and engineering development program

Pretest

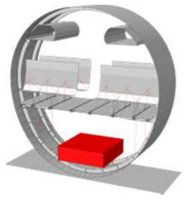
Bulk luggage



[2]

FAA crash dynamics and engineering development program

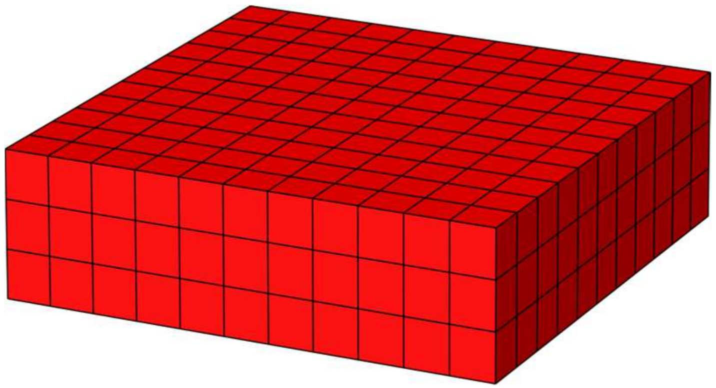
Pretest

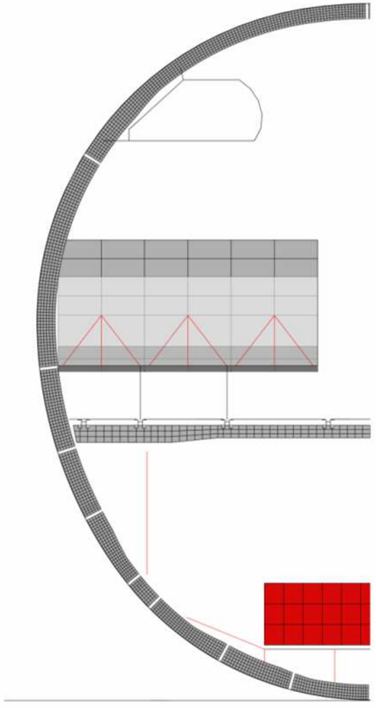


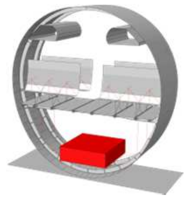
Consideration of cargo loading

Simplified cargo modelling

- <u>In this preliminary design study cargo is modelled with a simplified approach:</u>
  - Cuboid of solid elements, total mass m = 946 kg
  - Negligible energy absorption by the cargo deformation!
  - <u>Focus:</u> Influence of cargo mass & inertia
  - <u>Not considered</u>: Cargo stiffness & contact interaction with the passenger crossbeam







Consideration of cargo loading

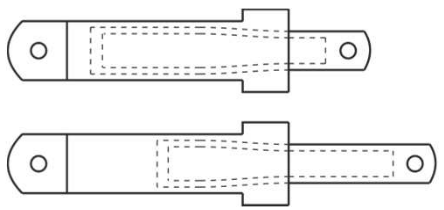
Modification of the crash concept

- Lateral strts (cargo floor structure)
    - **Extended lateral struts for improved energy absorption during frame bending failure**
      by additional tension absorption
    - Simultaneous energy absorption in the frame and lateral strut

Tension absorption in the lateral struts

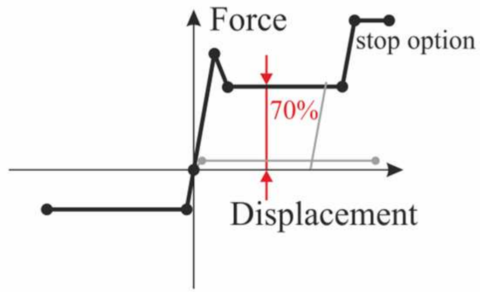
Potential physical device

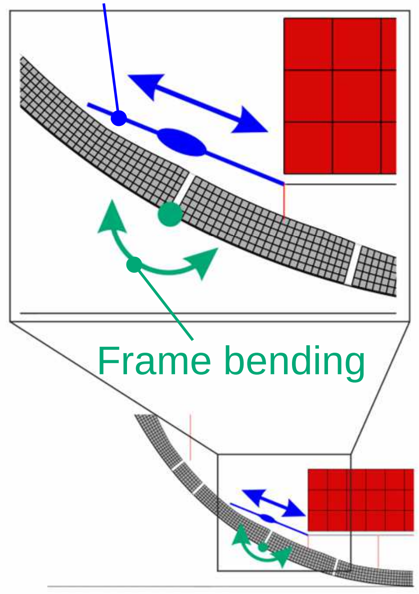
➔ Energy absorption by plastic decreasing of a tube diameter

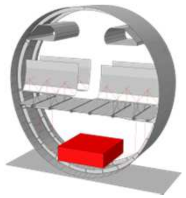


Macro input-characteristics

➔ Translational displacement in y-direction







Consideration of cargo loading

Modification of the crash concept (cont'd)

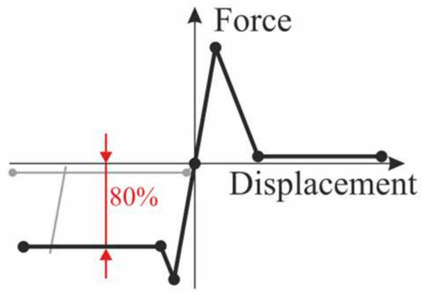
- Crushable struts (cargo floor structure)
  - **Limited crushing:**
    - remaining cargo framework height still sufficient to obtain tension loads
    - load limitation to avoid structural collapse of the cargo floor structure
  - **Activation:**
    - only in case of cargo loading
    - crushing on high load level (absorption of the cargo kinetic energy)

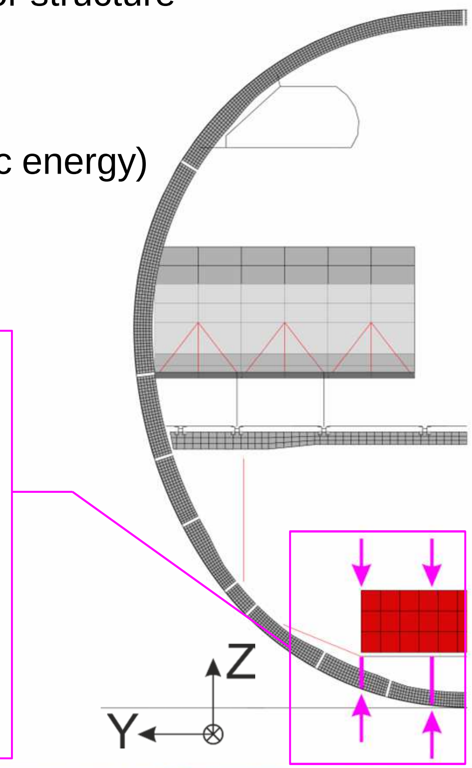
Potential physical device

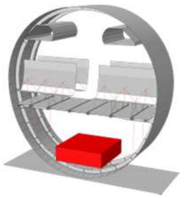
➔ Energy absorption by progressive crushing

Macro input-characteristics

➔ Translational displacement in z-direction



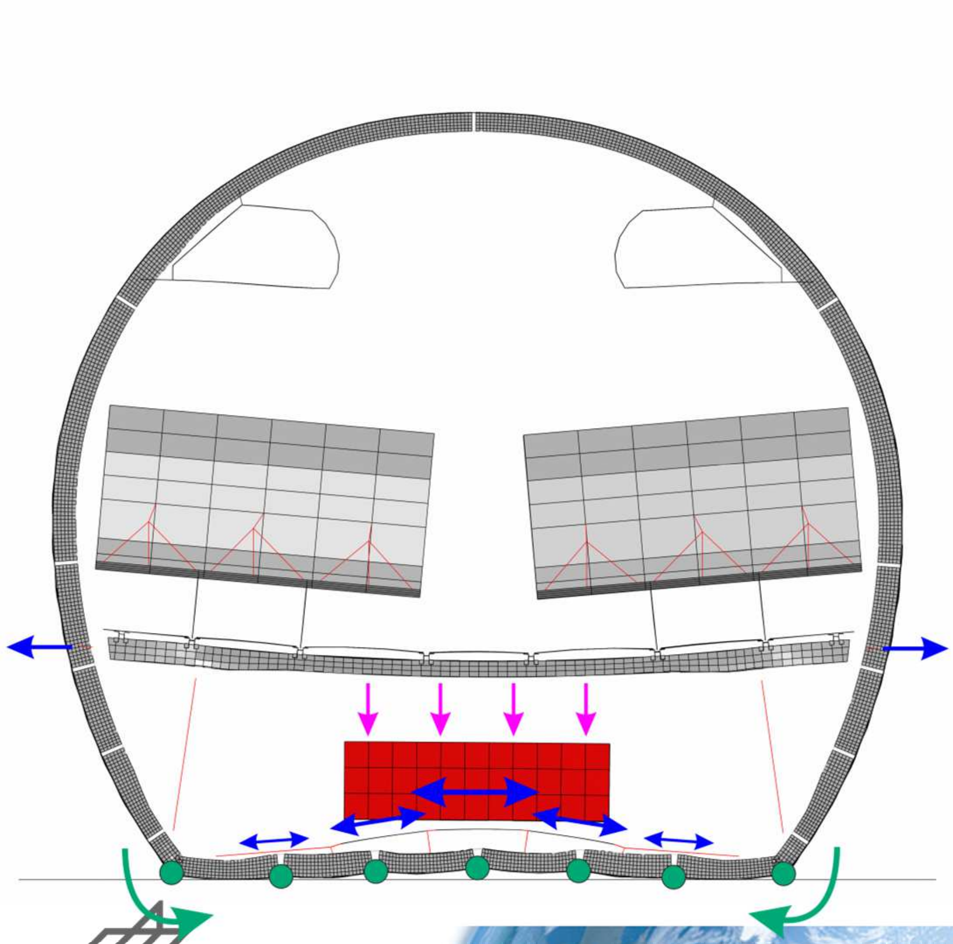




Consideration of cargo loading

Crash kinematics (with cargo loading)

- FE-Simulation



- FE-code: Abaqus/Explicit V6.11-1
- Fuselage section length (2-bay): 1270 mm
- Impact velocity: v_i = 6.7 m/s = 22 ft/s
- Total mass: 2376.4 kg
  (including cargo mass: 946 kg)

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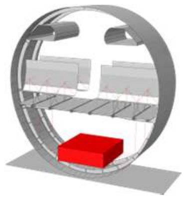


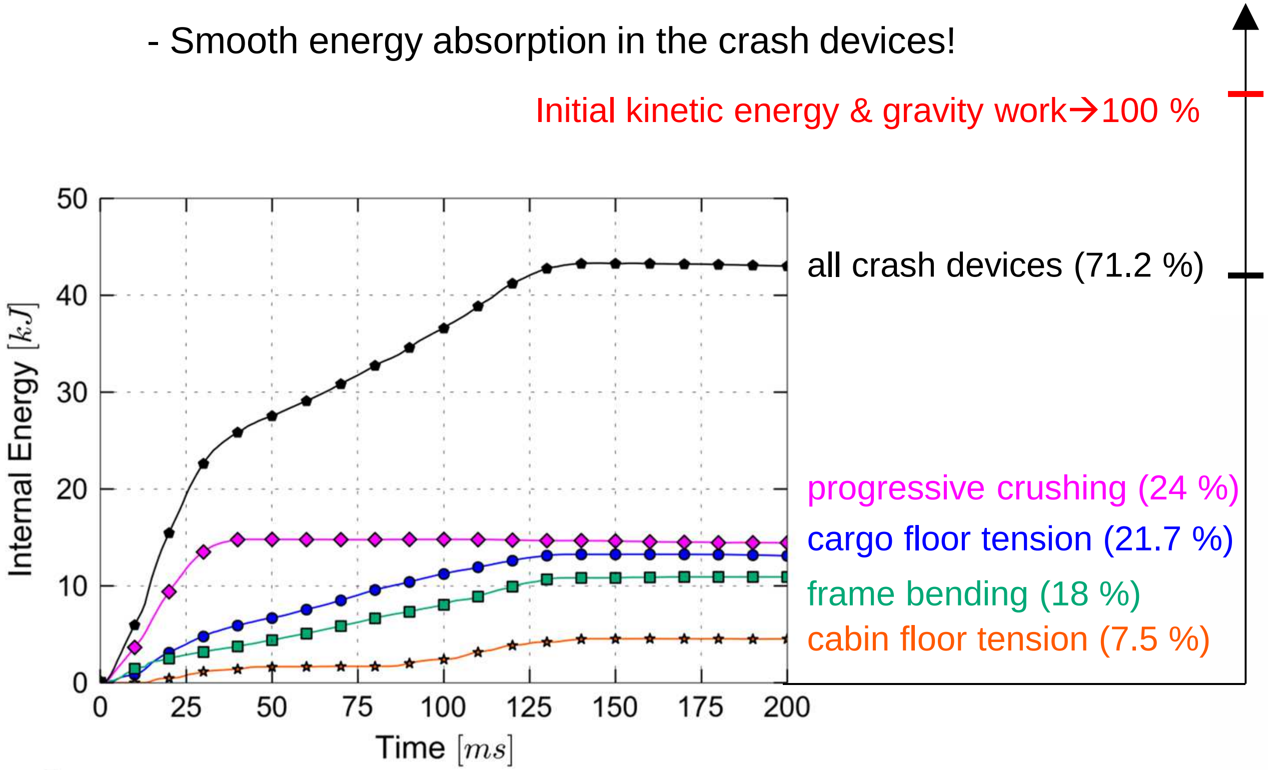
Consideration of cargo loading

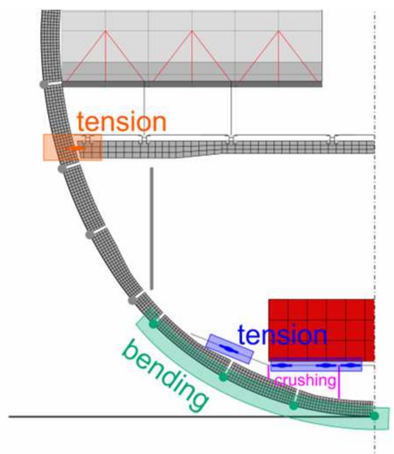
Crash kinematics (energy output)

- <u>Energy absorbed in the crash devices</u>
  - The vertical structural elements absorb most of the kinetic energy of the cargo mass
  - Similar energy absorption in cargo floor tension absorbers despite of cargo loading!
  - Smooth energy absorption in the crash devices!

Initial kinetic energy & gravity work→100 %

Residual energy:
elastic strain energy (14 %)
kinetic energy (7.4 %)
friction diss. energy (5.0 %)
neglected energies (2.4%)





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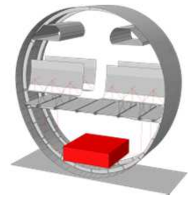
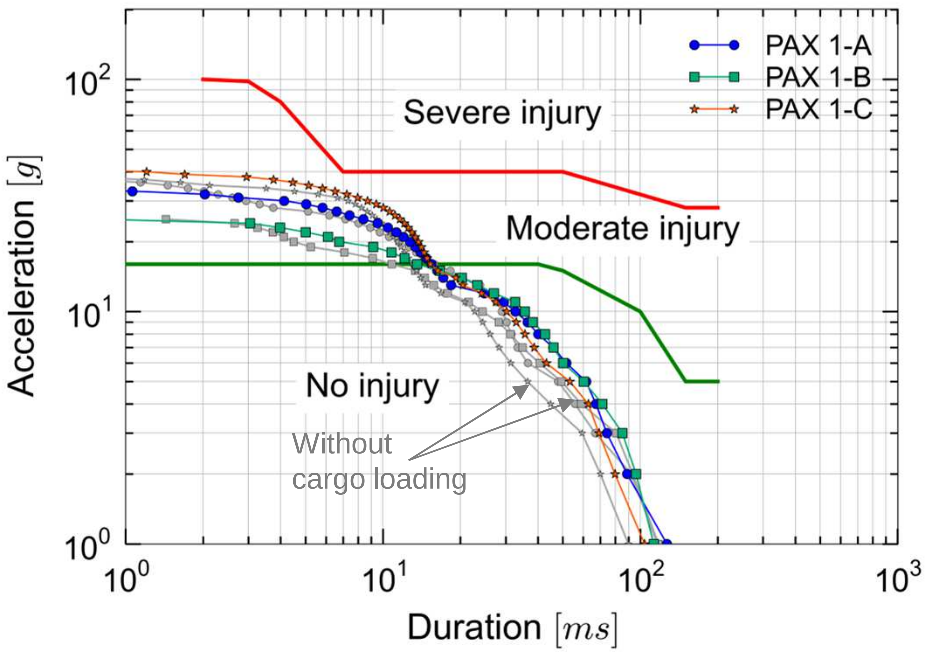


Consideration of cargo loading

Assessment of the passenger loads

- <u>Vertical acceleration response of the passengers plotted in an Eiband diagram</u>
    - Slightly increased passenger loads compared to the crash case without cargo loading
    - However: All passenger loads are clearly below the limit for severe injury



Conclusion

➔ **An alternative crash concept for CFRP transport aircraft was developed**

- with tension absorption in the cargo floor and cabin floor structure as main absorption mechanism

- based on a preliminary design tool for crash (kinematics model)

➔ **The tension crash concept was investigated based on a generic CFRP fuselage section**

- considering load cases with and without cargo loading

➔ **The developed tension crash concept shows some advantages:**

- smooth energy absorption during the whole crash sequence

- simultaneous energy absorption in the crash devices (parallel activation, no cascade)

- filigree sub-cargo structure can be realised, tension loads do not require massive backing structures (cargo crossbeam, frame) as it is known from the bend-frame concept

➔ **Simulation results can be used for detailed development of the tension concept**

- The macro element output data (required crash absorber characteristics) can be used to develop absorption mechanisms for tension, compression and frame bending failure

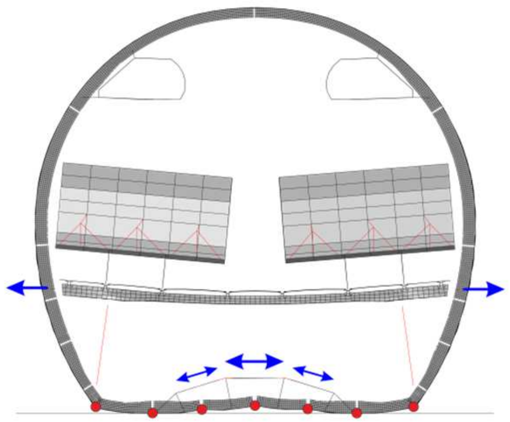
Conclusion (cont´d)

➔ **Conference paper**

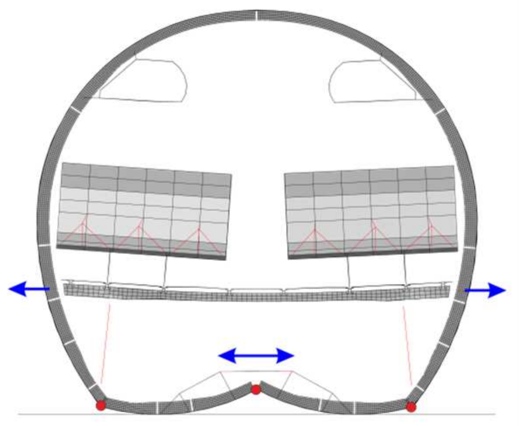
- Further details and results on the tension crash concept are documented in the conference paper

➔ **Consideration of different crash kinematics**

- Results of the flattening crash kinematics are presented on this conference
- Results of the unrolling crash kinematics will be published soon (journal paper)



Flattening kinematics



Unrolling kinematics

References

[1] A. Abramowitz, T. G. Smith, and T. Vu, *Vertical drop test of a narrow-body transport fuselage section with a conformable auxiliary fuel tank onboard*, DOT/FAA/AR-00/56, 2000.

[2] A. Abramowitz, T. G. Smith, T. Vu, and J. R. Zvanya, *Vertical drop test of a narrow-body transport fuselage section with overhead stowage bins*, DOT/FAA/AR-01/100, 2002.

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