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Method development for full aircraft crash simulation at different levels of modeling detail

P. Schatrow, M. Waimer, M. Petsch, C. Leon Munoz, D. Kohlgrüber

German Aerospace Center (DLR) – Institute of Structures and Design

Stuttgart - Germany

DLR

Overview

Motivation

- Full aircraft crash analysis as a research goal at DLR

Strategy

- Method developments

Method development for full aircraft crash simulation

- Process chain tool

Current status: first results for tool & model check

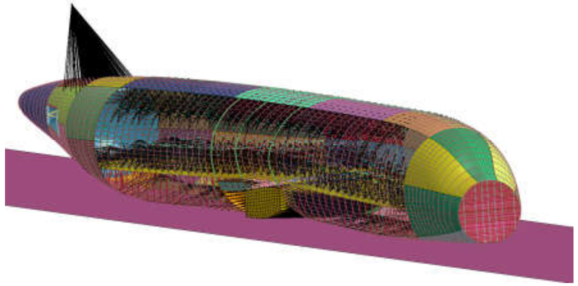
- Simulation model details
- Fuselage section crash analysis
- Full aircraft crash analysis

Summary & Next steps

Motivation

Full aircraft crash analysis as a research goal at DLR

Simplifications by analyzing a typical fuselage section instead of a full aircraft xz-crash



	Typical fuselage section (vertical drop)	***Full aircraft (combined xz-impact)***
• Local impact velocity	mainly constant	different along the fuselage stations (e.g. crash event with pitch angle)
• Local stiffness	mainly constant	different along the fuselage stations (e.g. typical and wingbox sections)
• Boundary conditions	free end-sections (partly "somehow" reinforced) (distinct ovalization)	real structural environment (real ovalization)
• Horizontal impact loads	neglected	considered

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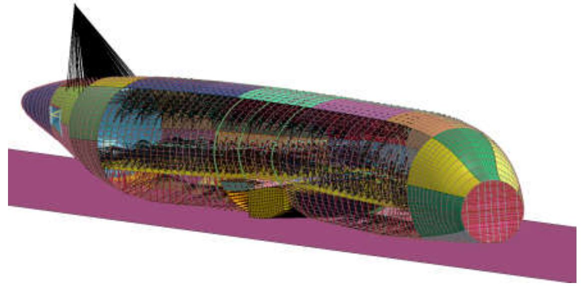

	Typical fuselage section (vertical drop)	Full aircraft (combined xz-impact)
• Horizontal impact loads	neglected	considered

Exemplary aspect

- What happens to a cabin floor structure damaged at the first vertical impact, when the max. horizontal load will apply at a subsequent phase? Still capable to remain structurally integer?
- What happens to specific crash structures at the sub-cargo area when high horizontal decelerations act during crushing, e.g. for xz-impact on soft soil? Still progressive crushing or structural collapse?

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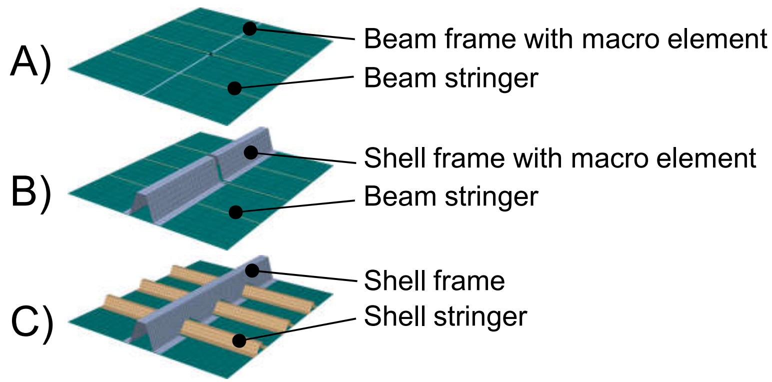
Different levels of model fidelity (application-driven)

- A) Low fidelity: Simplified, efficient beam modeling
- B) Medium fidelity: Hybrid macro-FE modeling
- C) High fidelity: Cost intensive shell modeling incl. further details



Automated finite element model generation

- Parametric modeling (geometry, FE meshes and models)
- Modules for aircraft structure, occupants, cargo, masses, impact terrains, etc.

Validation of method developments based on available experimental data

- Fokker F28 Pendulum Crash Test (performed by FAA/NASA in 2019)
  - Collaboration with Fokker Services, FAA, NASA (exchange of data)

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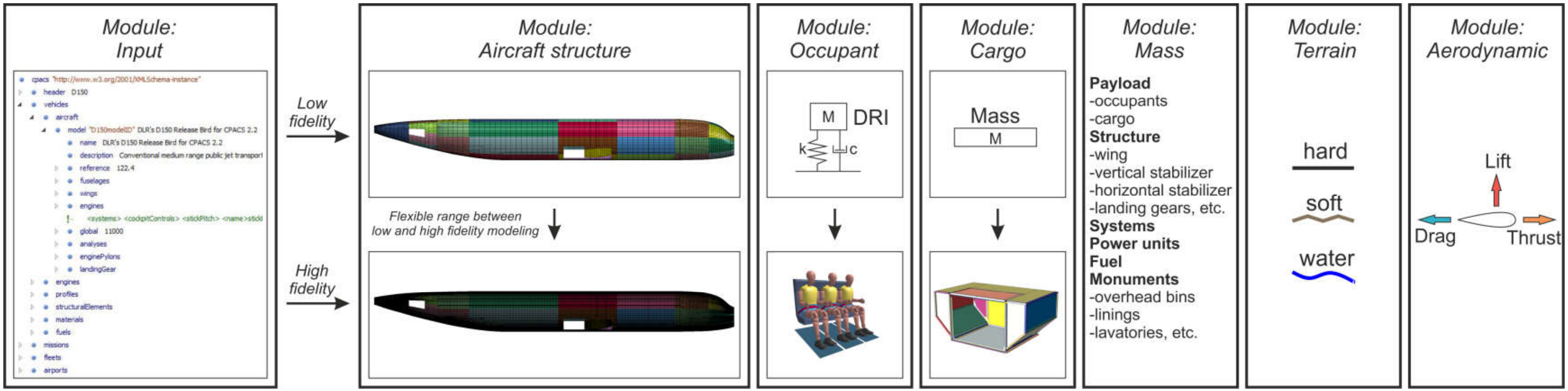
Method development for full aircraft crash simulation

Process chain tool

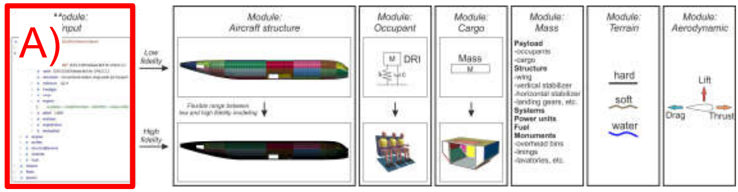
Automated finite element model generation

- Parametric modeling (geometry, FE meshes and models)
- Modules for input, aircraft structure, occupants, cargo, masses, impact terrains, etc.



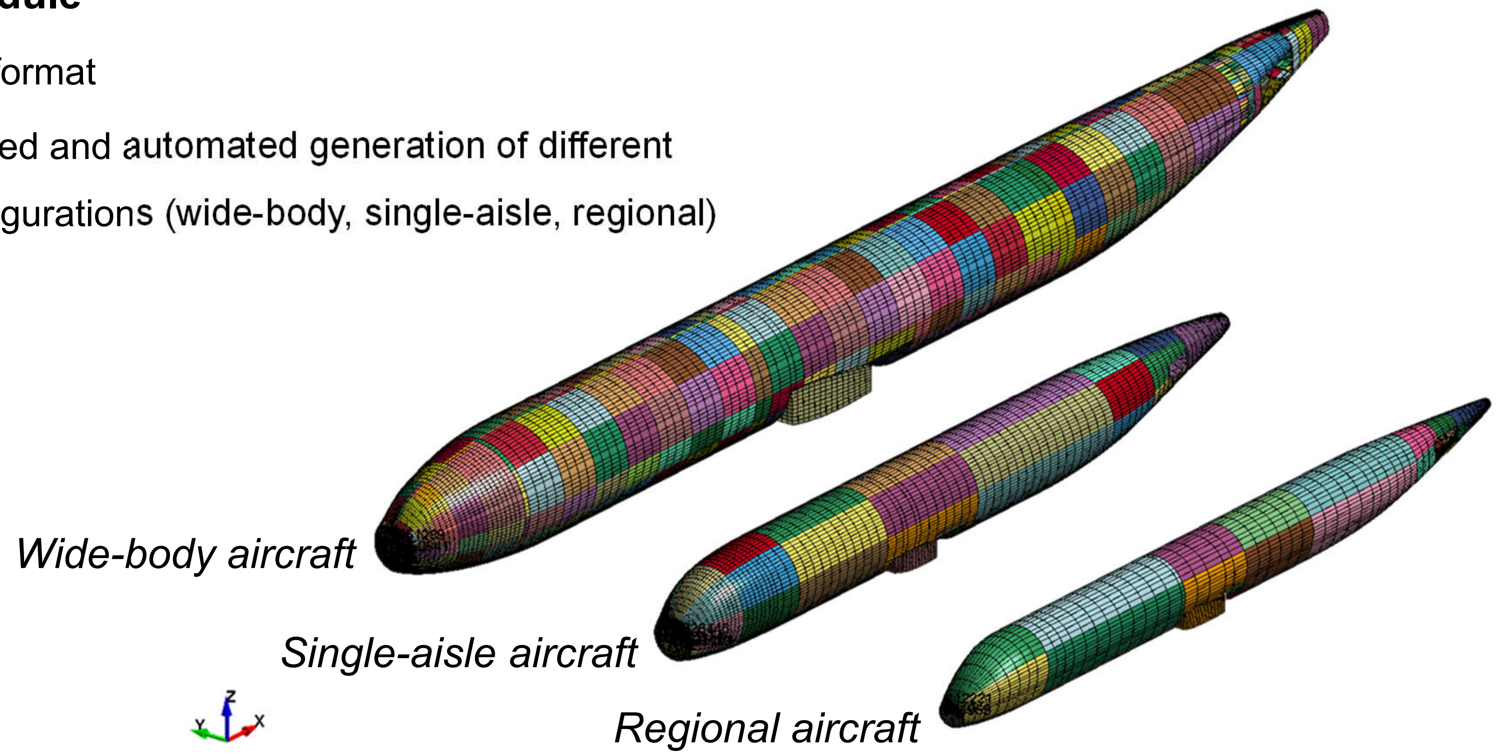
Method development for full aircraft crash simulation

Process chain tool



A) Input module

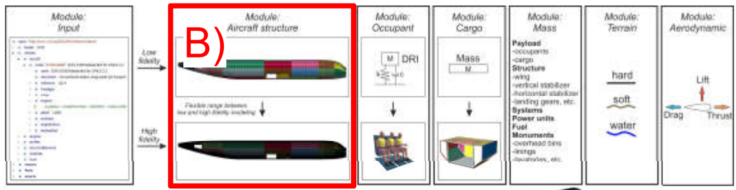
- CPACS file format
- Parameterized and automated generation of different aircraft configurations (wide-body, single-aisle, regional)



CPACS: Common Parametric Aircraft Configuration Schema
https://cpacs.de/

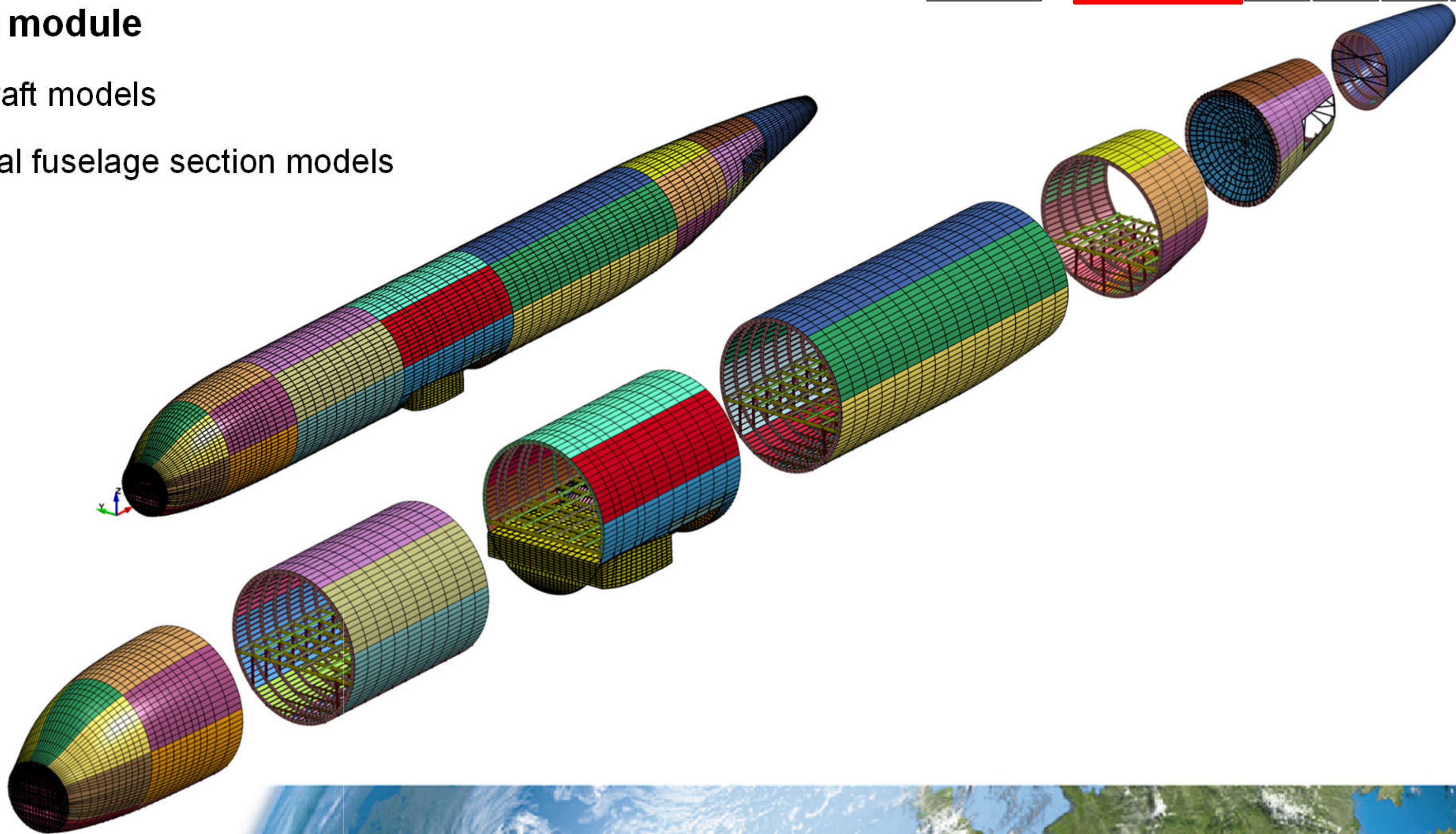
Method development for full aircraft crash simulation

Process chain tool



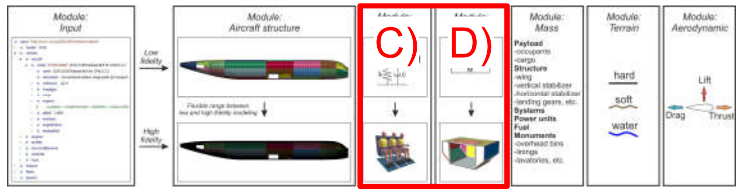
B) Aircraft structure module

- Generation of full aircraft models
- Generation of individual fuselage section models



Method development for full aircraft crash simulation

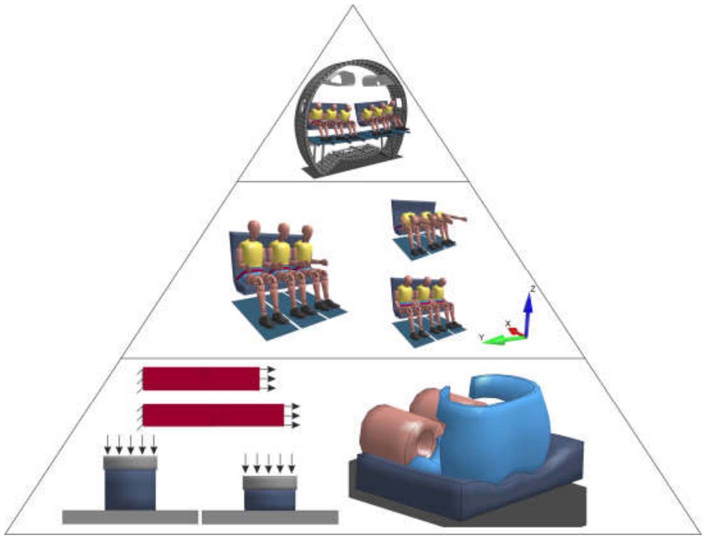
Process chain tool



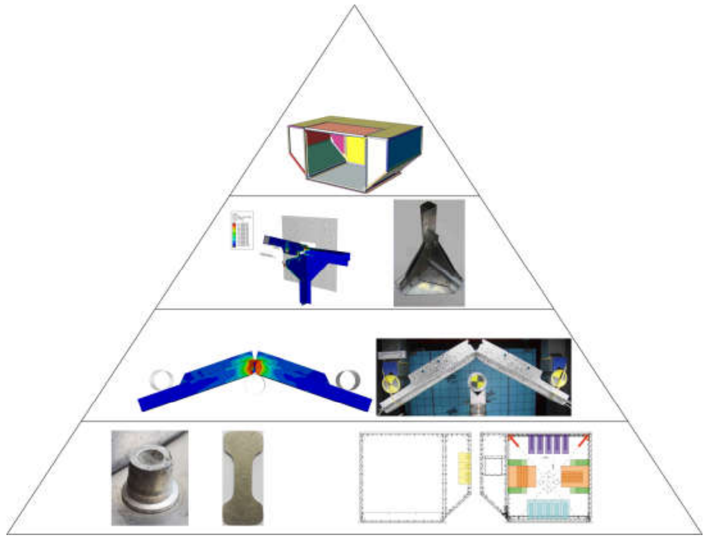
C) Occupant module and D) Cargo module

- Development of each module acc. to the building block (BB) approach

Occupant module
(BB for pax & seats)

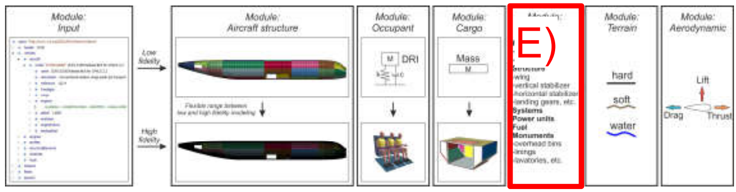


Cargo module
(BB for cargo container)



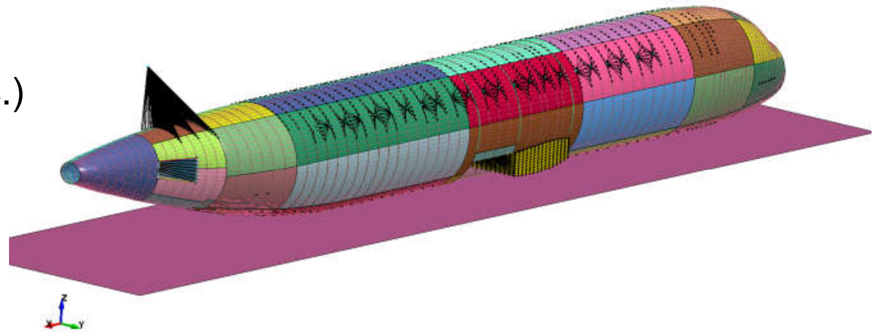
Method development for full aircraft crash simulation

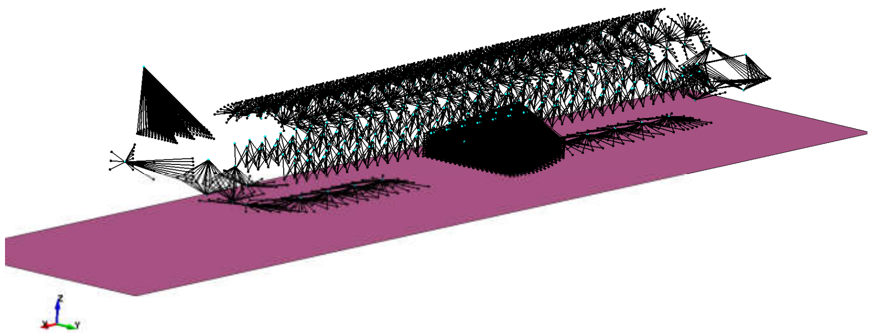
Process chain tool



E) Mass module

- Discrete masses for
  - Payload (occupants, cargo)
  - Structure (wing, vertical and horizontal stabilizer, landing gears, etc.)
  - Systems, power units, fuel
  - Interiors/monuments (overhead bins, linings, coverings, lavatories, gallies, etc.)

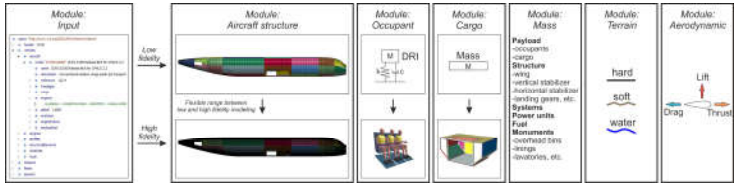




DLR

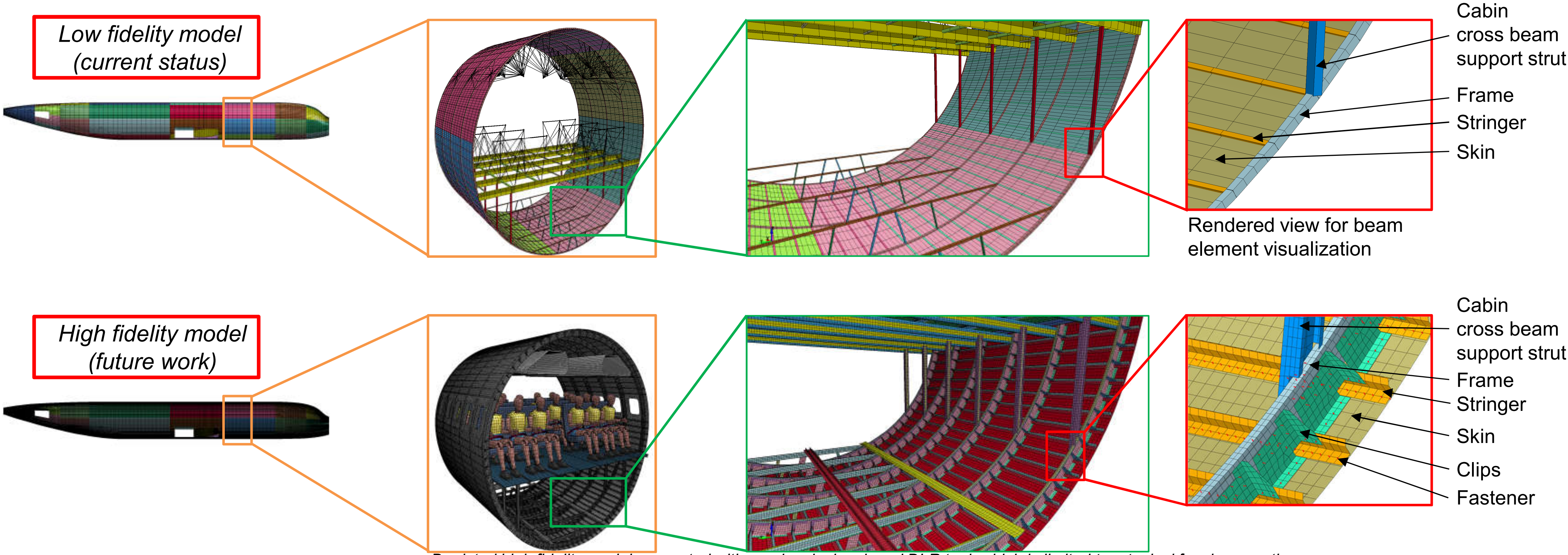
Method development for full aircraft crash simulation

Process chain tool



“Ready to use” simulation model (process chain output)

- Each module provides individual levels of model fidelity (structure, occupants, cargo, terrain, etc.)



Depicted high fidelity model generated with previously developed DLR tool, which is limited to a typical fuselage section.

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- Simulation model details
- Fuselage section crash analysis
- Full aircraft crash analysis

Summary & Next steps

Current status: first results for tool & model check

Simulation model details (low fidelity)

Code

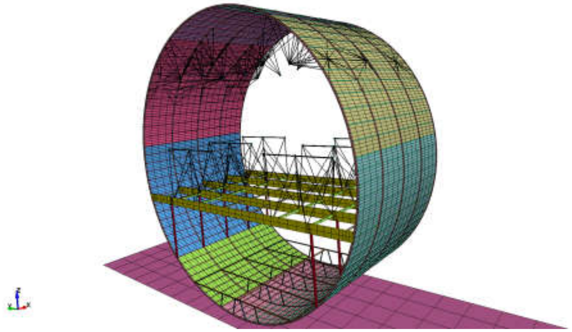
- LS-Dyna R10.2.0
- Linux cluster

Element formulation and material model

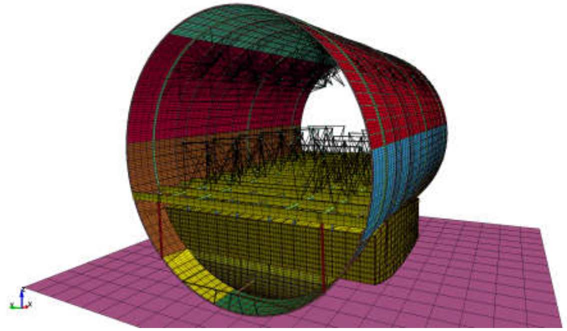
(simplified assumptions for tool & model check)

- Beam elements
  - ELFORM = 2 (Belytschko-Schwer)
  - ELFORM = 1 (Hughes-Liu)
  - *MAT_SIMPLIFIED_JOHNSON_COOK (*MAT_098) (isotropic)
- Shell elements
  - ELFORM = 2 (Belytschko-Tsay)
  - *MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_024) (isotropic)

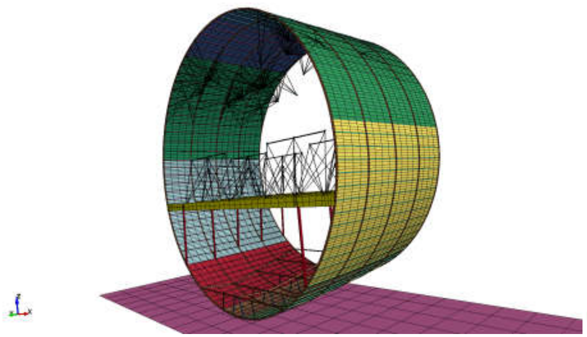
Typical section



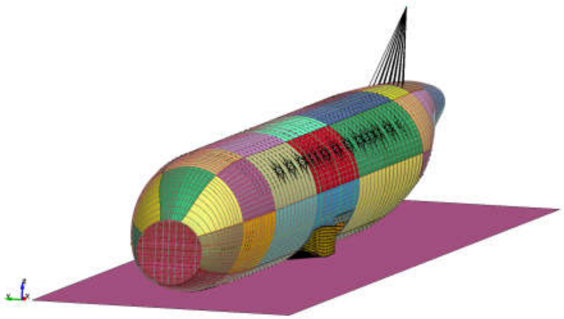
Center section



Rear conical section



Full aircraft

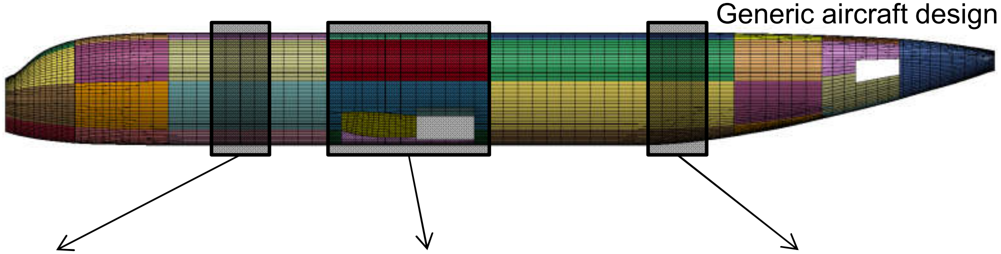


Current status: first results for tool & model check

A) Fuselage sections vertical drop (low fidelity)

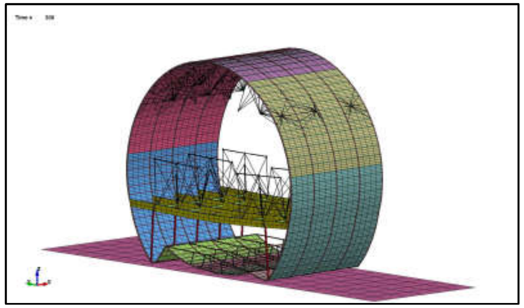
For tool & model check only!
Not yet validated!

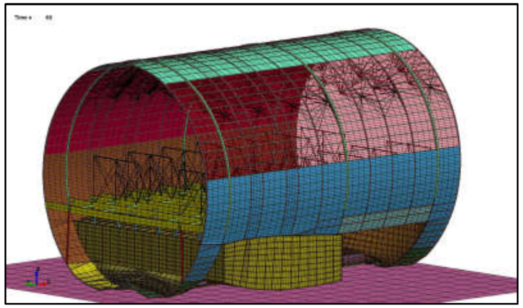
Generic aircraft design

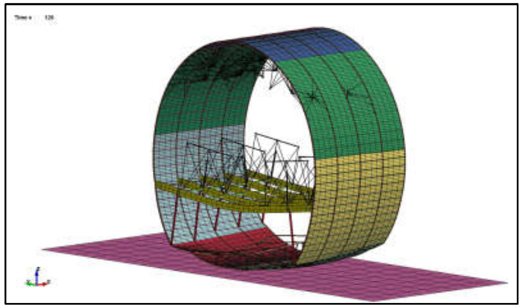


Crash kinematics

- v_z = 7.6 m/s (25 ft/s)
- Rigid impact surface







	Typical section	*Center section*	*Rear conical section*
Length	2130 mm (3 seat rows)	5990 mm (7 seat rows)	2130 mm (3 seat rows)
Mass	2215 kg	6972 kg	2209 kg
Number of nodes	≈ 7400	≈ 64,100	≈ 7703
Number of mass elements	≈ 64	≈ 160	≈ 64
Number of beam elements	≈ 3900	≈ 29,300	≈ 3900
Number of shell elements	≈ 5700	≈ 56,300	≈ 5700

Discrete mass elements

- Occupants & seats
- Carry-on luggage
- Overhead bins

Current status: first results for tool & model check

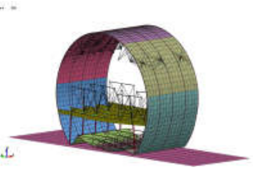
A) Fuselage sections vertical drop (low fidelity)

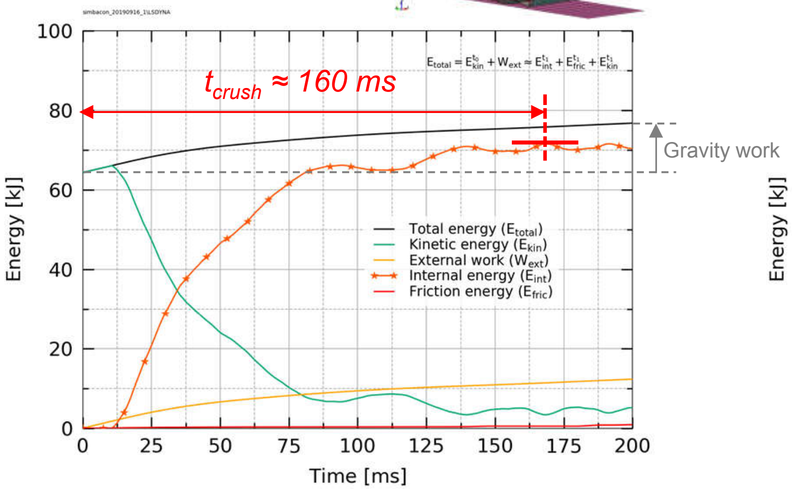
For tool & model check only!
Not yet validated!

Energy plot (v_z = 7.6 m/s, rigid impact surface)

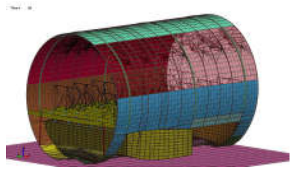
- Plot of energies indicate different deformation/ stiffness of the fuselage sections (reasonable result) ✓

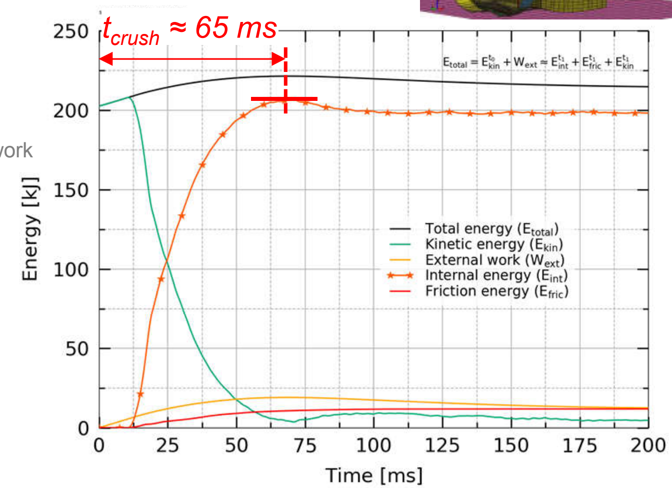
Typical section



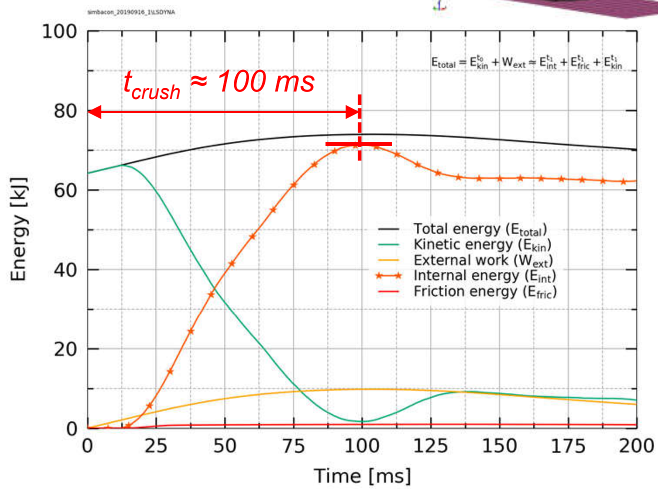


Center section





Rear conical section



For tool & model check only!
Not yet validated!

Current status: first results for tool & model check

A) Fuselage sections vertical drop (low fidelity)

Injury criteria for spinal injuries: Dynamic Response Index (DRI)

- DRI values indicate different deformation/ stiffness of the fuselage sections (reasonable result)

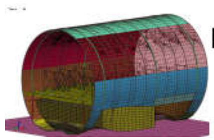
[1]

Dark green	0 < DRI ≤ 15.0	Risk of injury (< 1 %)
Light green	15.0 < DRI ≤ 17.7	Risk of injury (1 % to 10 %)
Orange	17.7 < DRI ≤ 21.3	Risk of injury (10 % to 50 %)
Red	21.3 < DRI	Risk of injury (> 50 %)

Typical section

	4	5	6
F	18.8	19.0	19.0
E	12.8	12.6	12.9
D	13.1	12.4	12.6
C	13.6	12.8	13.1
B	13.1	13.2	13.5
A	19.0	19.4	19.4

Center section



	10	11	12	13	14	15	16
F	20.0	19.2	20.7	19.9	20.9	18.6	17.4
E	18.9	17.4	19.4	19.9	21.3	17.3	14.8
D	19.4	18.7	20.9	21.6	23.9	19.4	15.6
C	19.2	18.4	20.5	21.5	23.8	19.2	15.8
B	18.4	17.3	18.5	19.7	21.2	17.0	14.4
A	18.6	18.3	19.9	19.3	20.5	18.4	17.1

Rear conical section

	24	25	26
F	19.0	19.0	19.0
E	16.7	15.6	15.0
D	25.2	18.1	13.0
C	25.2	18.0	12.8
B	16.7	15.6	14.9
A	18.9	19.0	18.8

[1] Brinkley, J.W., Shaffer, J.T.: Dynamic simulation techniques for the design of sscape systems: Current applications and future air force requirements., AMRL-TR-71-29 (1971).

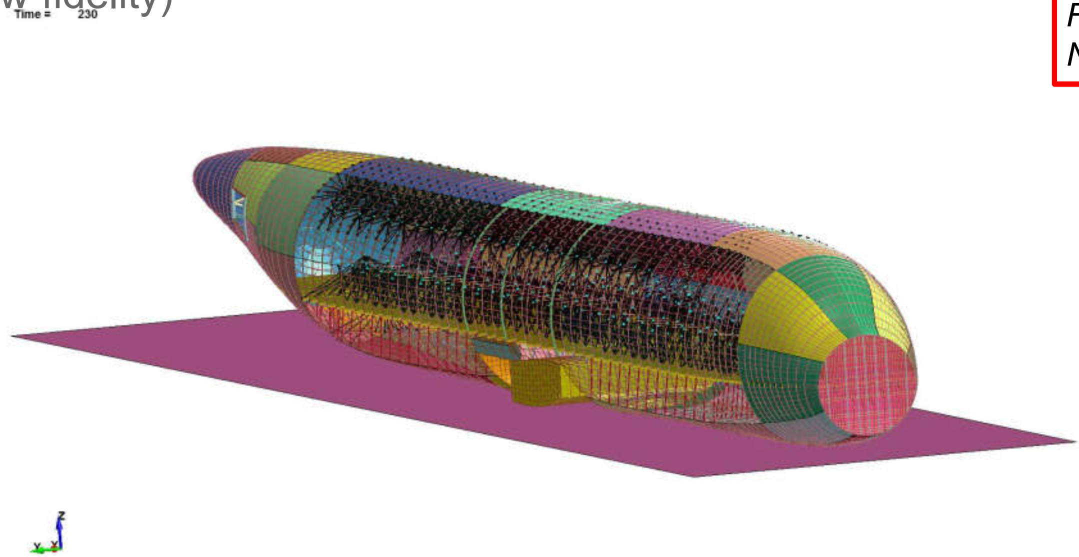
Current status: first results for tool & model check

B) Full aircraft vertical drop (low fidelity)

For tool & model check only!
Not yet validated!

Crash kinematics

- v_z = 7.6 m/s (25 ft/s)
- Rigid impact surface
- 5° pitch angle



	Full aircraft
Length	36,495 mm (26 seat rows)
Mass	23,974 kg [1)]
Number of nodes	≈ 205,600
Number of mass elements	≈ 586
Number of beam elements	≈ 96,400
Number of shell elements	≈ 177,400

Discrete mass elements [1)]
- Occupants & seats
- Carry-on luggage
- Overhead bins

[1)] Further masses not included, for direct comparison with fuselage section drop tests: cargo, wing, vertical & horizontal stabilizer, power units, systems, fuel, landing gear, pylons, galley, lavatory, etc.

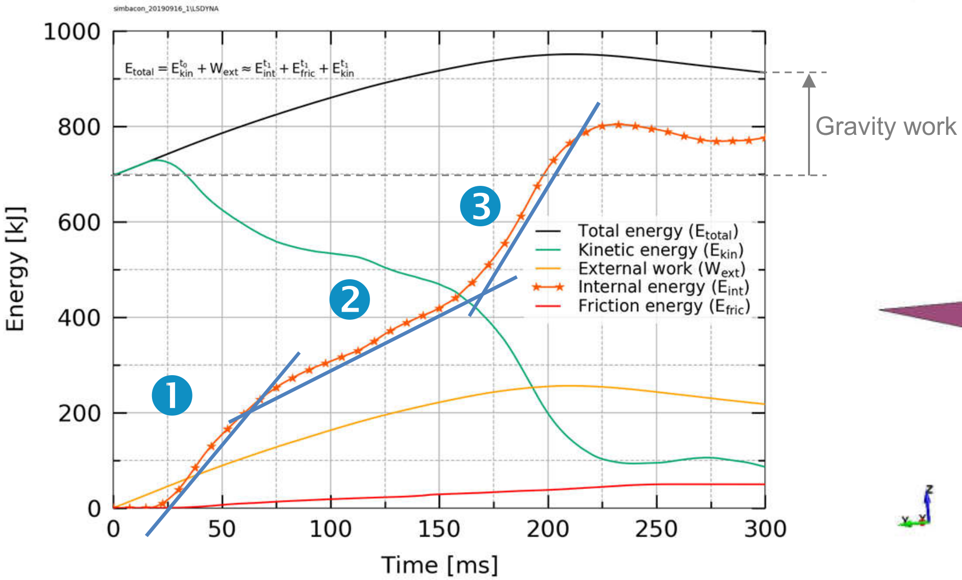
Current status: first results for tool & model check

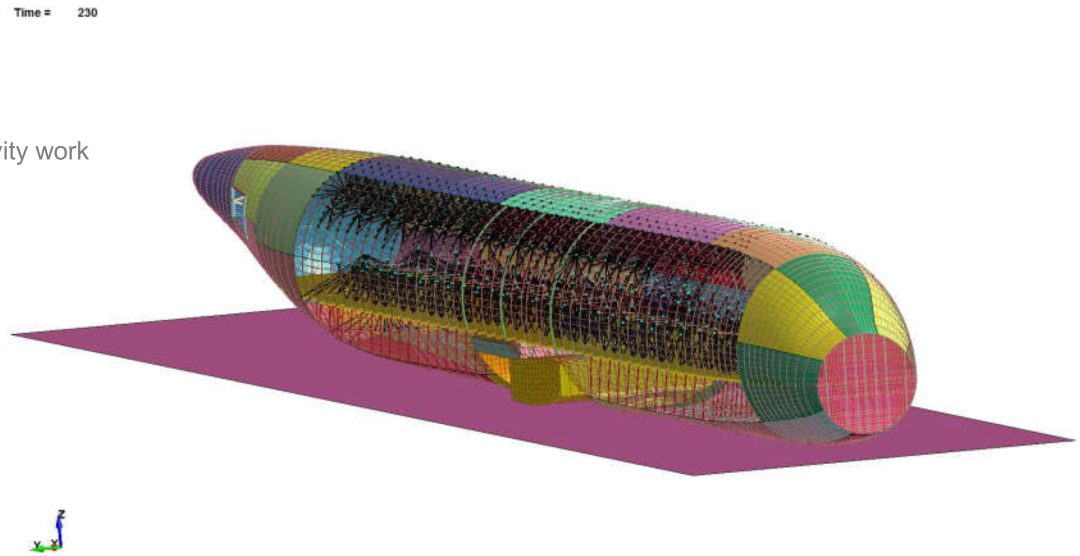
B) Full aircraft vertical drop (low fidelity)

For tool & model check only!
Not yet validated!

Energy plot (v_z = 7.6 m/s, rigid impact surface)

- Energy plot indicates different phases during the drop test of the aircraft with 5° pitch angle ✓
  - Phase 1: impact at the rear
  - Phase 2: rotation of the aircraft
  - Phase 3: impact of the center and forward fuselage





For tool & model check only!
Not yet validated!

Current status: first results for tool & model check

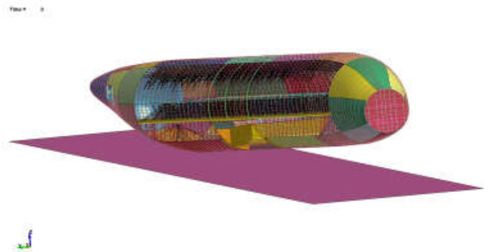
B) Full aircraft vertical drop (low fidelity)

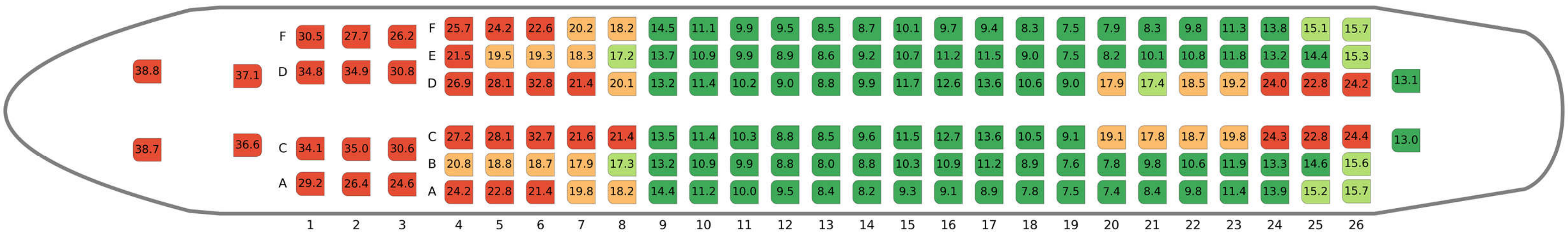
[1]
- 0 < DRI ≤ 15.0 Risk of injury (< 1 %)
- 15.0 < DRI ≤ 17.7 Risk of injury (1 % to 10 %)
- 17.7 < DRI ≤ 21.3 Risk of injury (10 % to 50 %)
- 21.3 < DRI Risk of injury (> 50 %)

Injury criteria for spinal injuries: Dynamic Response Index (DRI)

- After the first impact at the rear, the aircraft rotates (pitch rotation)
- Pitch rotation results in increasing local impact velocity towards the forward fuselage
- Known from accidents: typical passenger injuries are higher in the forward fuselage for similar crash scenarios ☑

5° pitch angle





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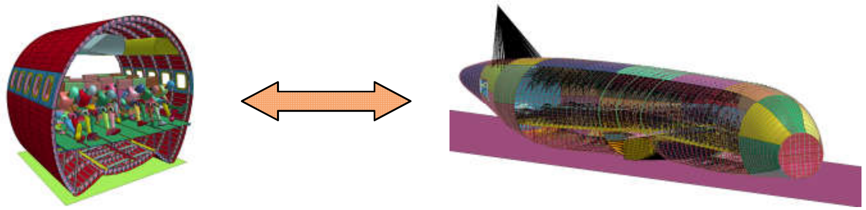
Summary

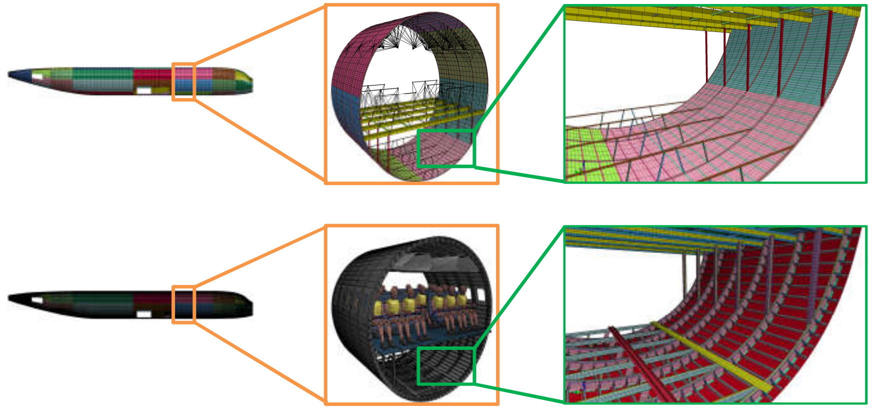
Motivation: Full aircraft crash analysis as a research goal at DLR

- Today's simplifications in analyzing a fuselage section drop test instead of a full aircraft xz-crash



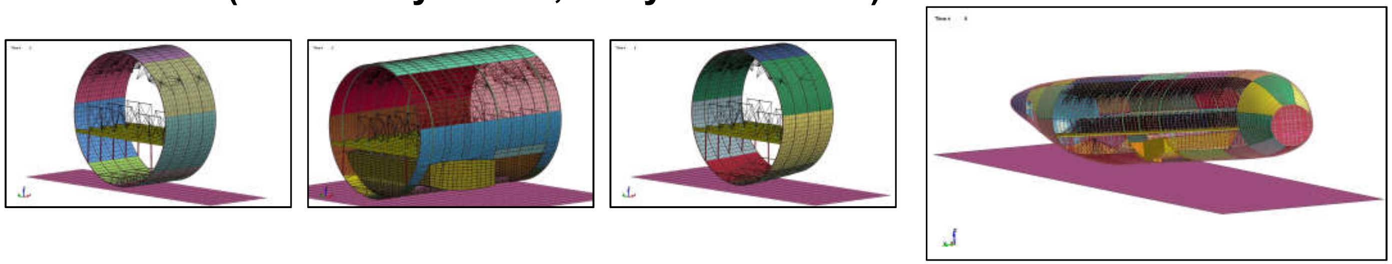
Strategy: Method development for full aircraft crash simulation

- Different levels of model fidelity (application-driven: suitable model fidelity for any given application)
- Development of individual modules for aircraft structure, occupants, cargo, masses, impact terrains, etc.
- Validation of method developments based on available experimental data

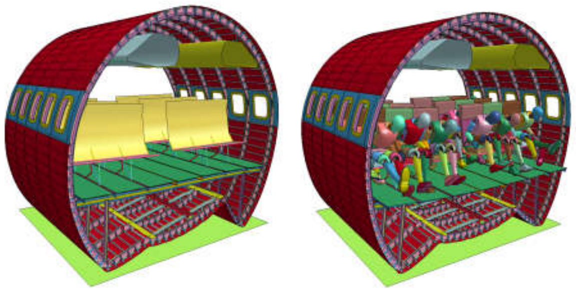


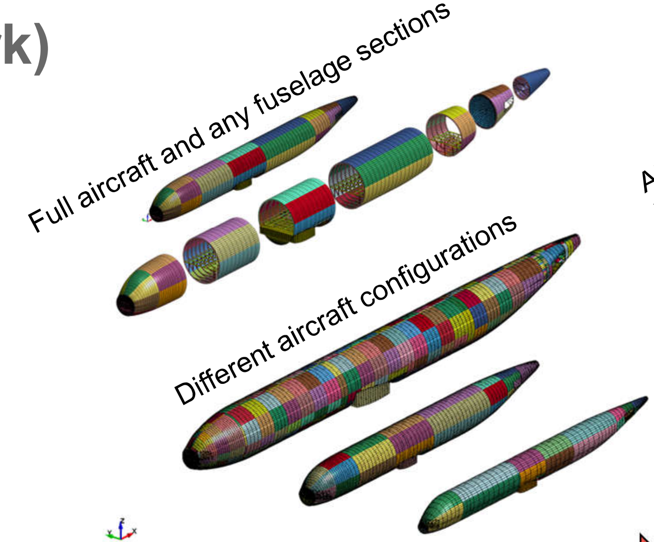
Current status: first results for tool & model check (low fidelity model, not yet validated)

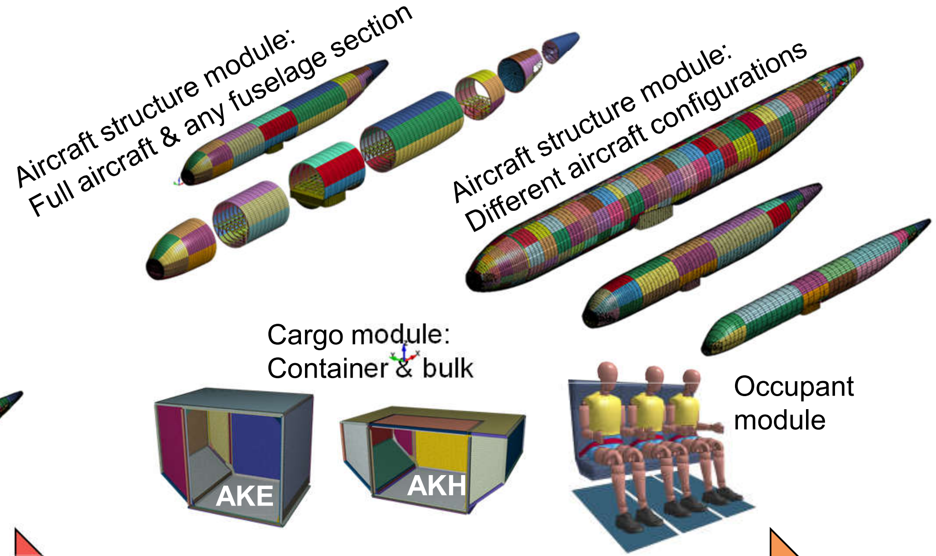
- Fuselage section: vertical drop of typical, center and conical section
- Full aircraft: vertical drop with 5° pitch angle



Next steps (future work)







Past

- Previously developed DLR tool
- Limited to typical fuselage sections (low and high fidelity modeling)

Present

- New DLR tool (in development)
- Full aircraft parametric modeling
- Currently limited to **low fidelity modeling**

Future

- New DLR tool (further developments)
- Full aircraft parametric modeling
- **Low & high fidelity modeling**
- Development of modules for occupants, cargo, impact terrain, etc.

Thank you for your attention!