METHODENENTWICKLUNG FÜR DIE GESAMTFLUGZEUG-CRASHSIMULATION

DLR-PROJEKT SIMBACON

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Deutscher Luft- und Raumfahrtkkongress, 27.-29. September 2022 - Dresden

Overview

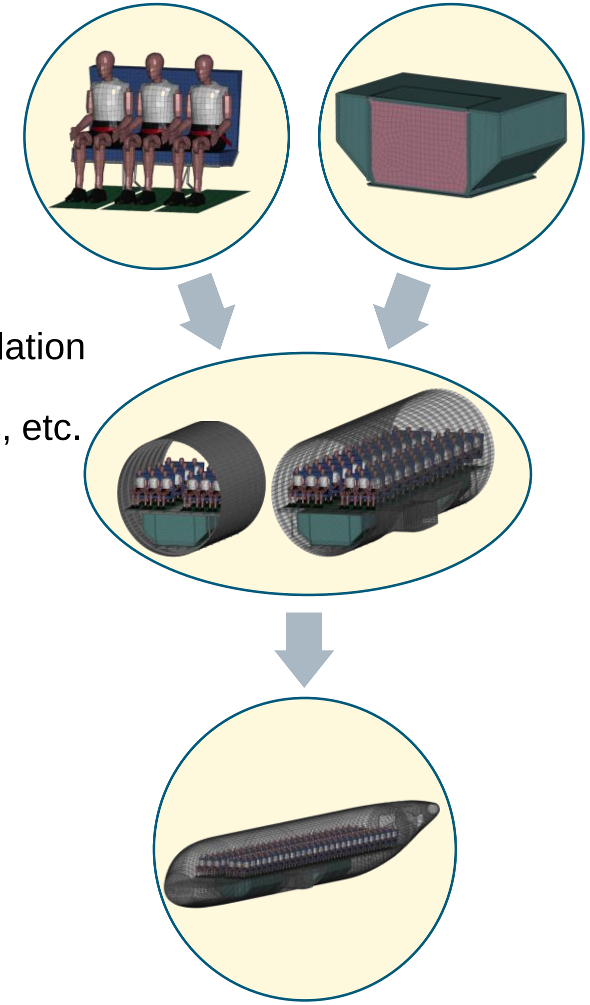
- **Motivation**
- **1 Method development**
- **2 Method validation**
- **3 Method application**
- **Summary**

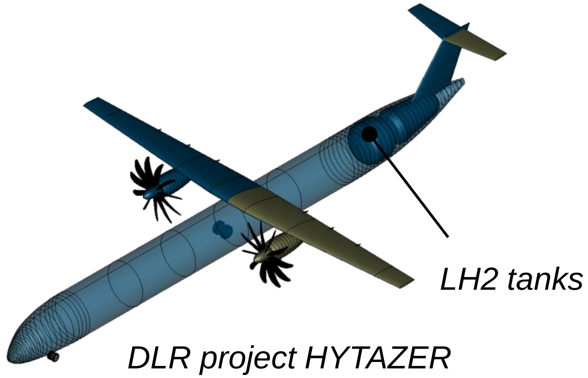
Motivation

Full aircraft crash simulation as a research goal at DLR

Development of numerical methods for full aircraft crash simulation

- Understanding the aircraft response and crash performance during a crash landing
  - How is the aircraft crash performance affected by
    - Impact conditions, impact surface, occupant and cargo loading
  - Derivation of local loads from full aircraft crash simulation to be applied on a fuselage section simulation
    - Including effects such as pre-loading from aircraft rotation, combined horizontal/vertical loads, etc.
- Analysis and evaluation of future aircraft configurations
  - Need to consider full aircraft to understand and assess crash effects
  - E.g. hydrogen propulsion and LH2 tank integration





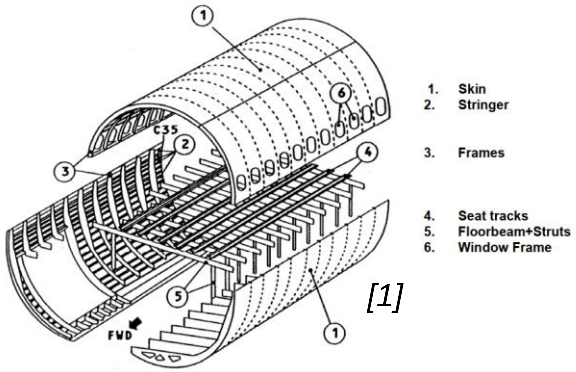
DLR project HYTAZER

1 Method development

Generic single-aisle aircraft design

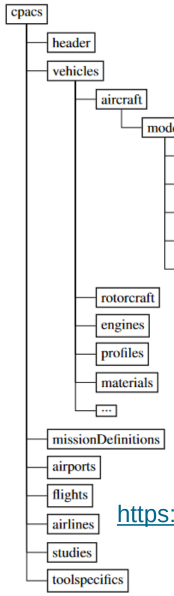
1 Method development
Approach

Process chain tool for full aircraft crash simulation



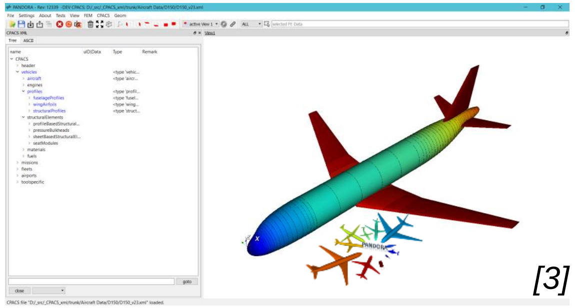
[1]

Aircraft design data



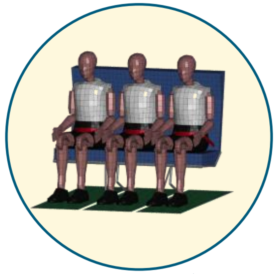
https://cpacs.de/ [2]

A) CPACS

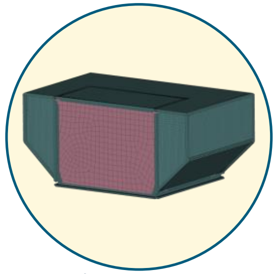

[3]

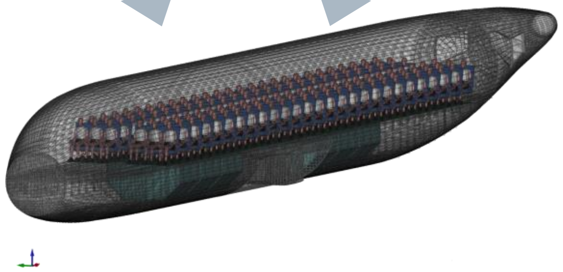
B) PANDORA

C) Occupants



D) Cargo





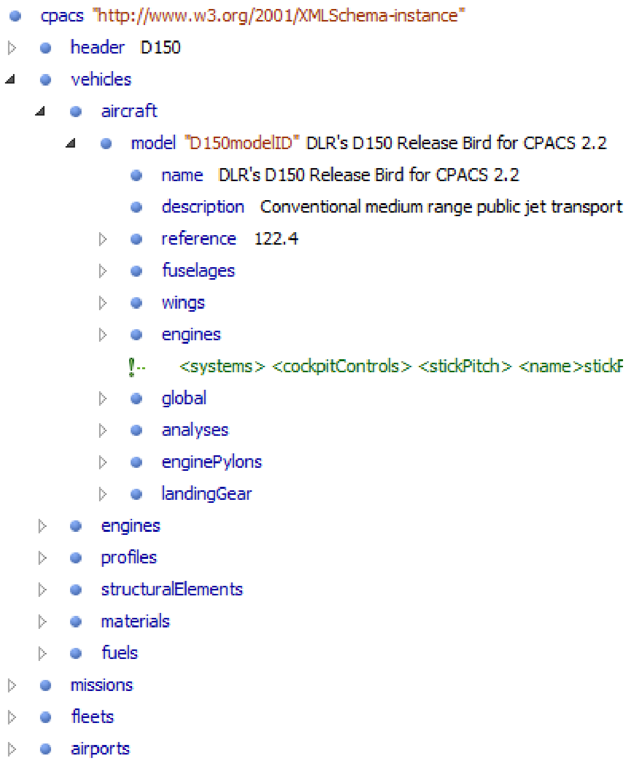
Aircraft FE model

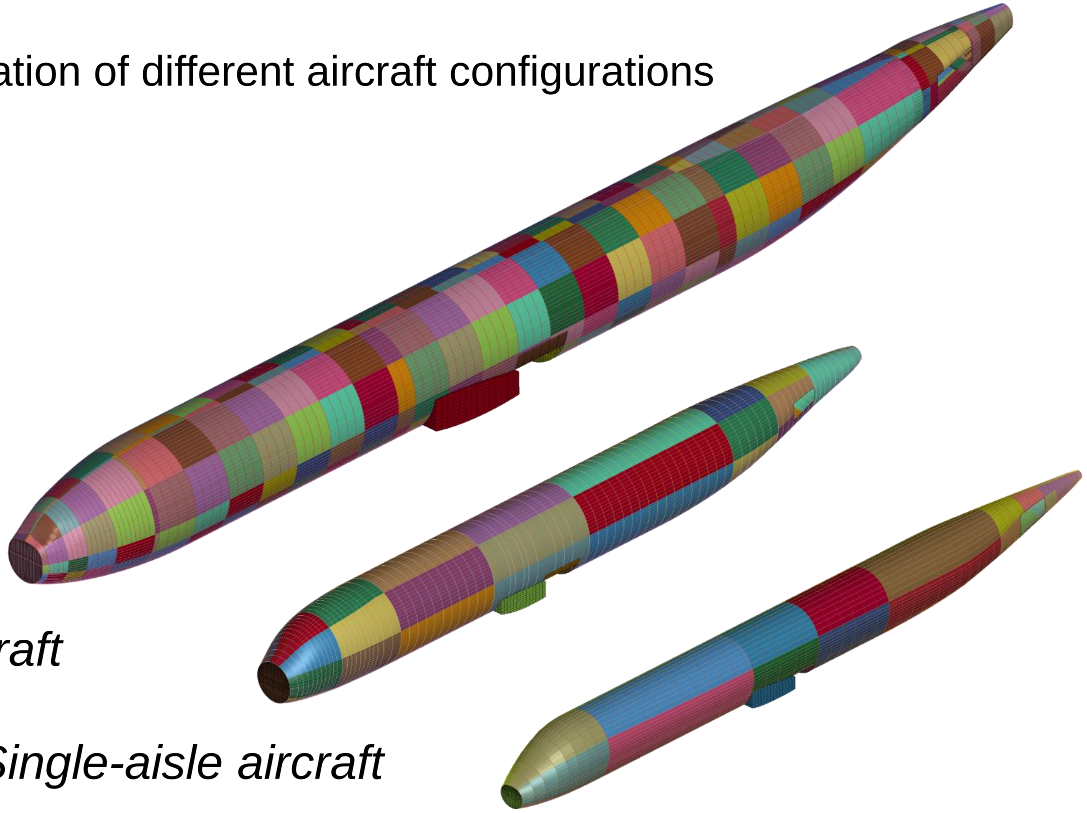
[1] K. Drechsler, P. Eyerer, and H. Dörner, "Fertigungstechnik und Bauweisen für Leichtbaukonstruktionen," Lecture material WS05/06, 2005.
[2] M. Alder, E. Moerland, J. Jepsen, and B. Nagel, "Recent Advances in Establishing a Common Language for Aircraft Design with CPACS," presented at the Aerospace Europe Conference 2020, Bordeaux, Frankreich, 2020. Available: https://elib.dlr.de/134341/
[3] M. Petsch, D. Kohlgrüber, and J. Heubischl, "PANDORA - A python based framework for modelling and structural sizing of transport aircraft," presented at the 8th EASN-CEAS International Workshop, Glasgow, Schottland, 2018. Available: https://elib.dlr.de/124181/

1 Method development
Approach

A) Aircraft structure description by CPACS [2]

- CPACS: Common Parametric Aircraft Configuration Schema (https://cpacs.de/)
- Enables parameterized and automated FE mesh generation of different aircraft configurations





Wide-body aircraft

Single-aisle aircraft

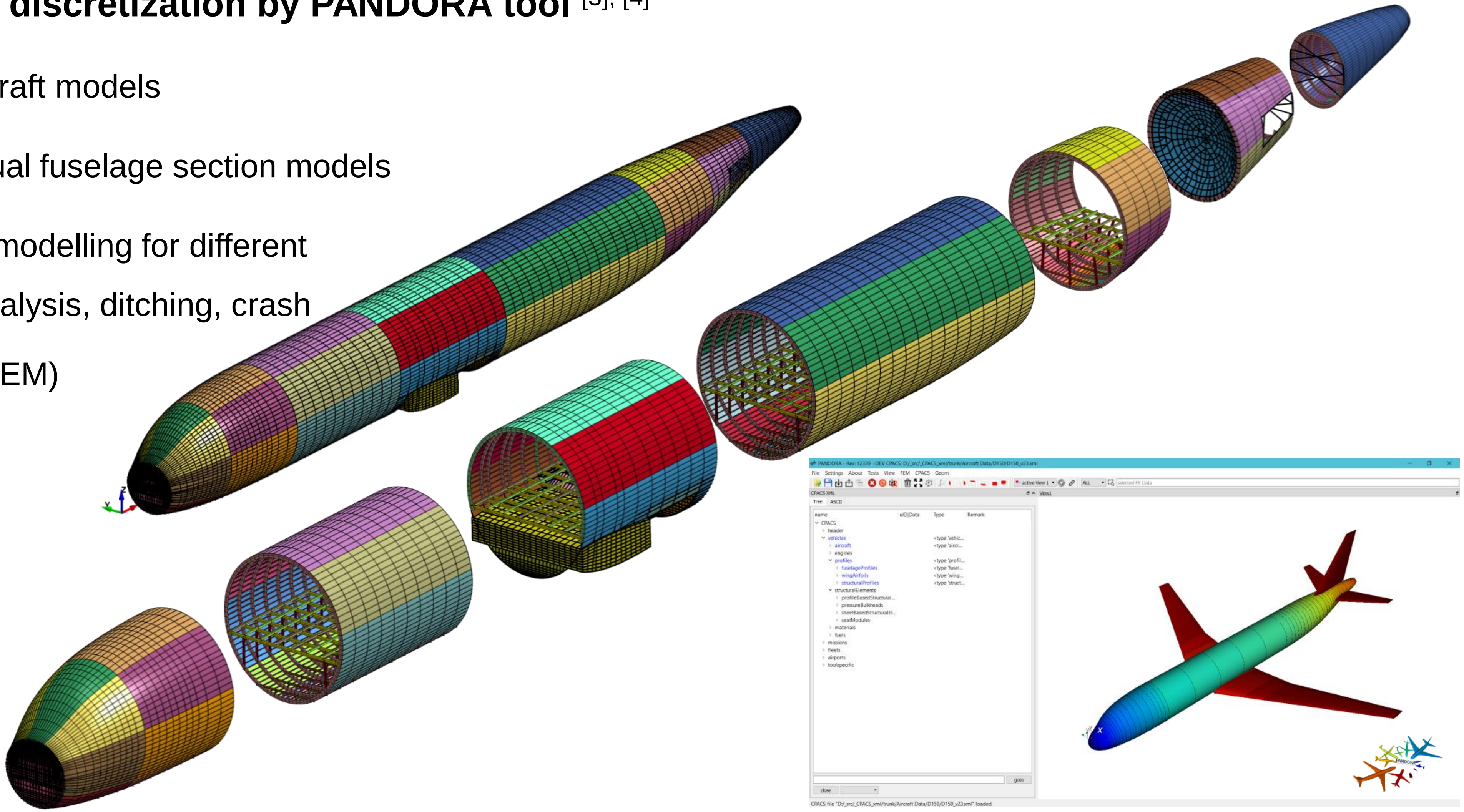
Regional aircraft

[2] M. Alder, E. Moerland, J. Jepsen, and B. Nagel, "Recent Advances in Establishing a Common Language for Aircraft Design with CPACS," presented at the Aerospace Europe Conference 2020, Bordeaux, Frankreich, 2020. Available: https://elib.dlr.de/134341/

1 Method development
Approach

B) Aircraft structure discretization by PANDORA tool [3], [4]

- Generation of full aircraft models
- Generation of individual fuselage section models
- Low and high fidelity modelling for different applications: static analysis, ditching, crash
    - Global FEM (GFEM)
    - Detailed FEM

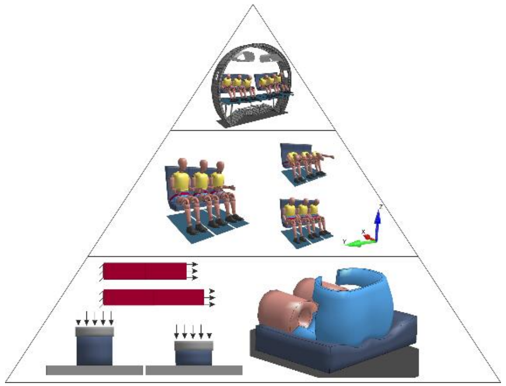


[3] M. Petsch, D. Kohlgrüber, and J. Heubischl, "PANDORA - A python based framework for modelling and structural sizing of transport aircraft," presented at the 8th EASN-CEAS International Workshop, Glasgow, Schottland, 2018. Available: https://elib.dlr.de/124181/
[4] C. Leon Muñoz and D. Kohlgrüber, "High Fidelity Simulations of Flexible Aircraft Structures Under Ditching Loads," presented at the Dynamic Modeling and Simulation (M&S) in Aircraft Ditching and Cabin Evacuation, FAA Virtual Workshop, 2022.

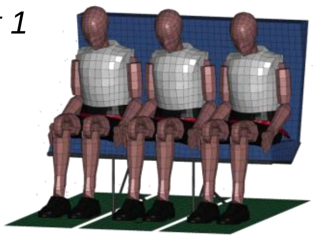
1 Method development
Approach

C) Occupant module [5], [6]

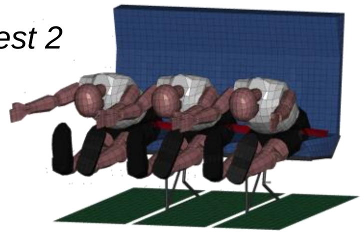
- Development according to the building block approach



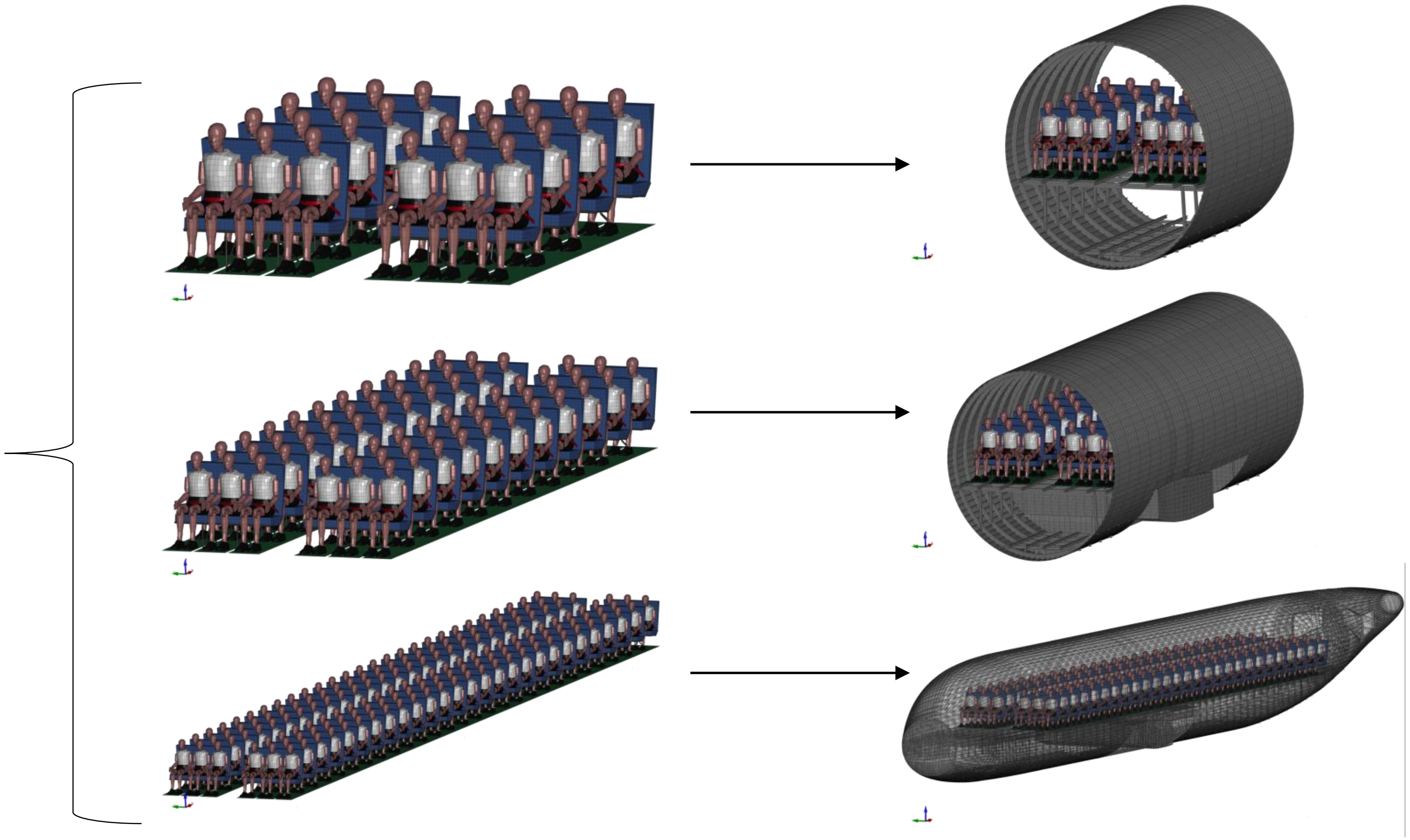
Test 1



Test 2



LSTC Hybrid 3 ATD FAST model

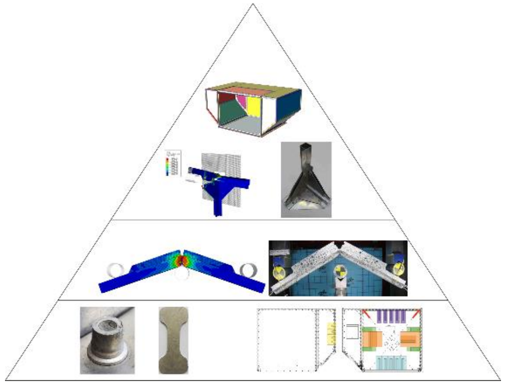


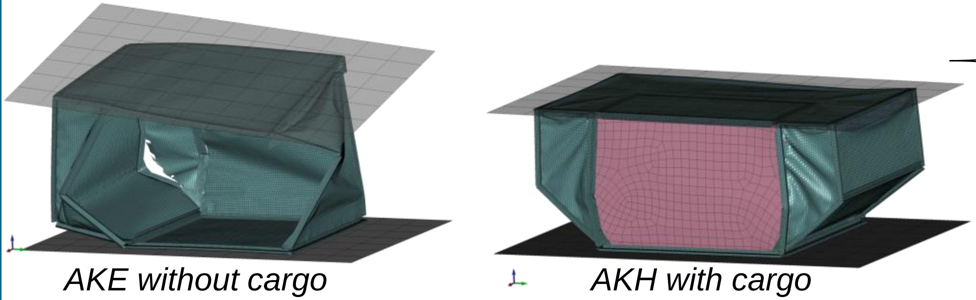
[5] T. Lehmann, "Entwicklung von Passagier-Sitz-Modellen für die Simulation von Flugzeugbruchlandungen," DLR-IB-BT-ST-2018-159, 2018
[6] N. Wegener, P. Schatrow, and M. Waimer, "Development of occupant-seat models for Fokker F28 crash test simulations," DLR-IB-BT-ST-2021-176, 2021.

1 Method development
Approach

D) Cargo module [7], [8]

- Development according to the building block approach

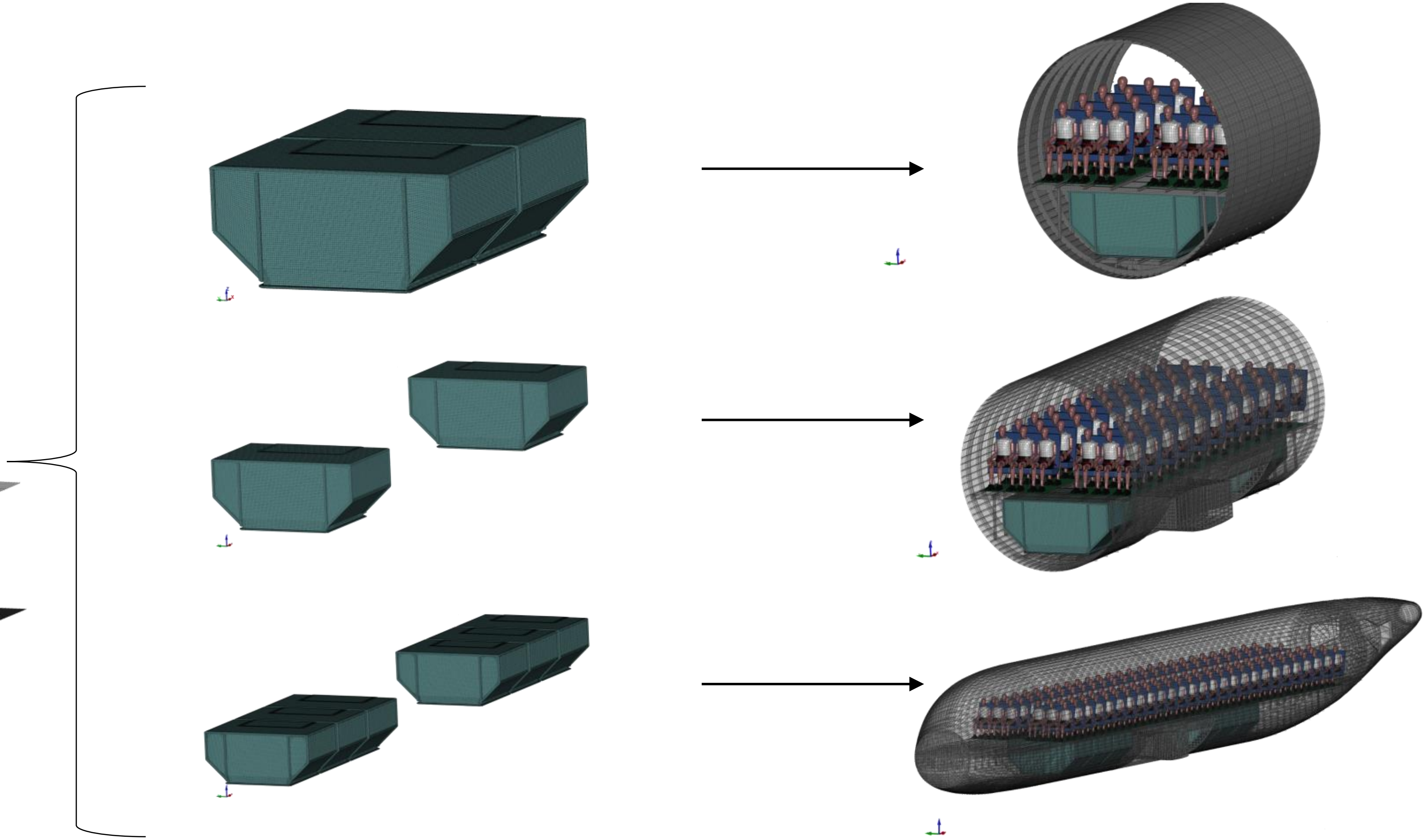




AKE without cargo
(Wide-body)

AKH with cargo
(Single-aisle)

Container model validation in progress



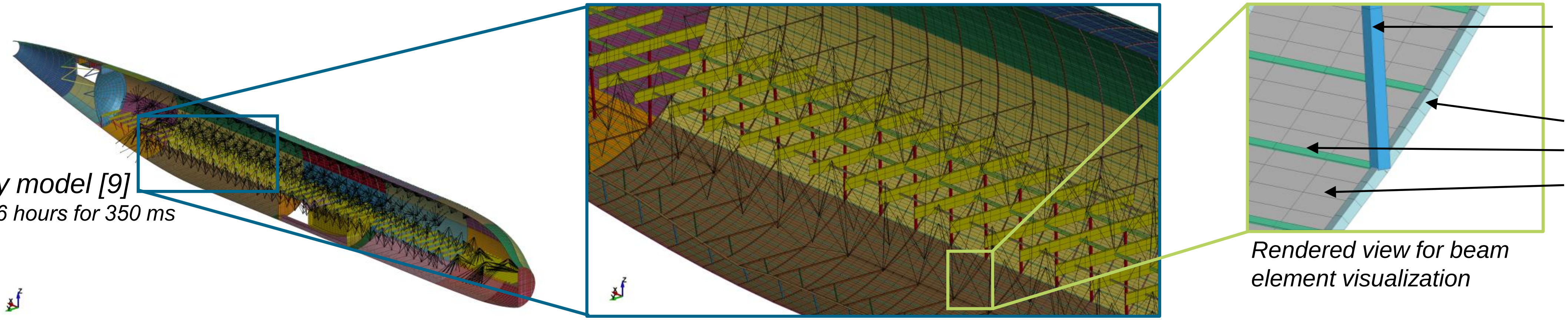
[7] M. Waimer and P. Schatrow, "Cargo Container Characterization for Airplane Crash Applications – Experimental Tests and Validation of Simulation Models," in Aerospace Structural Impact Dynamics International Conference, Madrid, Spain, 2019.
[8] M. Waimer and P. Schatrow, "Full-Scale Crash Testing of Cargo Containers - Experimental Characterization for Transport Airplane Crash Applications," in The Tenth Triennial International Fire & Cabin Safety Research Conference, Atlantic City, New Jersey, USA, 2022.

1 Method development
Approach

Process chain output

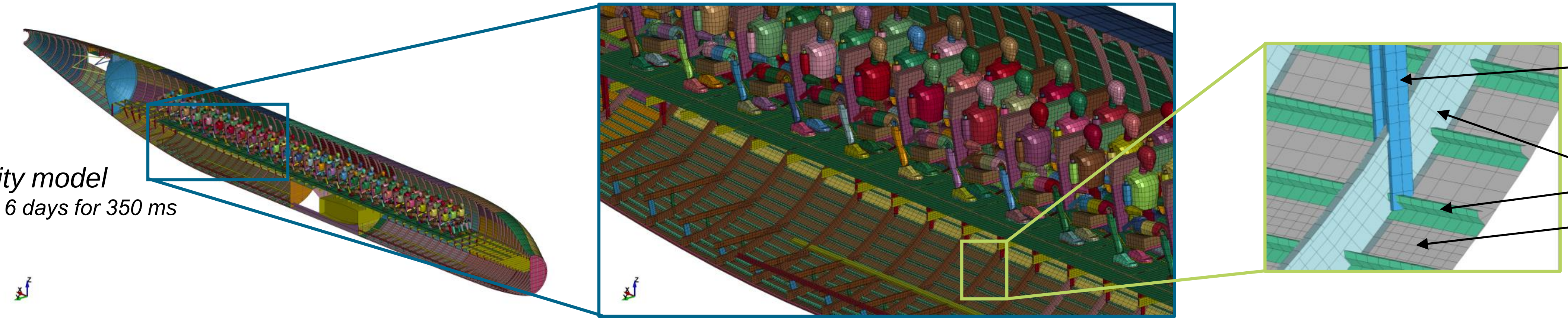
- Application-driven: suitable model fidelity for given application (global FEM, detailed FEM)

Low fidelity model [9]
CPU time: ≈ 6 hours for 350 ms



Rendered view for beam element visualization

High fidelity model
CPU time: ≈ 6 days for 350 ms

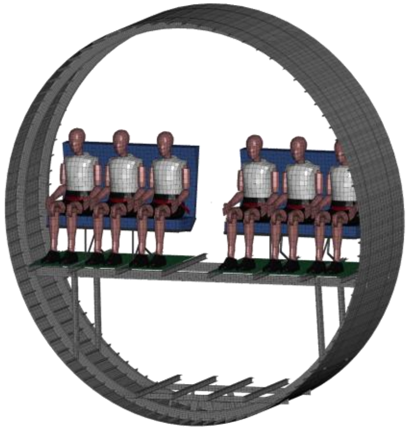


[9] P. Schatrow, M. Waimer, M. Petsch, C. Leon Muñoz, and D. Kohlgrüber, "Method development for full aircraft crash simulation at different levels of modeling detail," presented at the The Ninth Triennial International Fire & Cabin Safety Research Conference, Atlantic City, New Jersey, USA, 2019. Available: https://elib.dlr.de/130176/

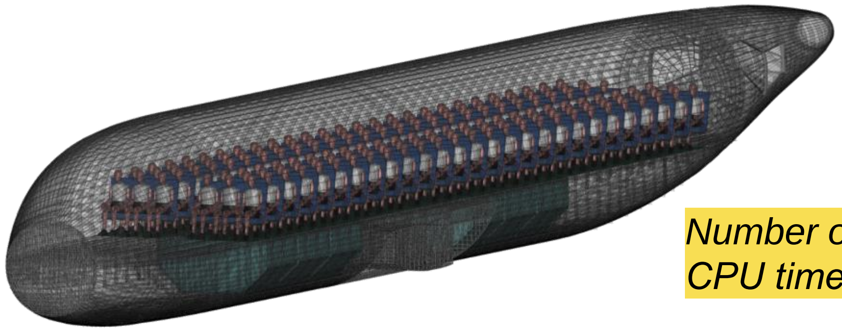
Current status of high fidelity full aircraft crash simulation

FE model overview (exemplary)

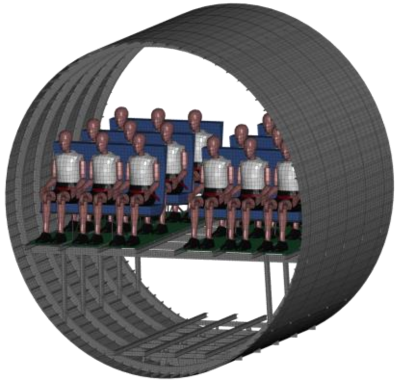
- Potential applications: configuration assessment, conceptual & preliminary design, determination of local loads, etc.

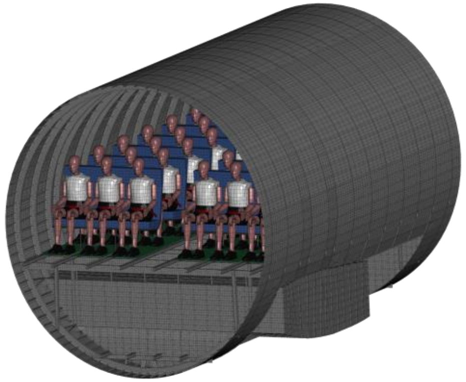


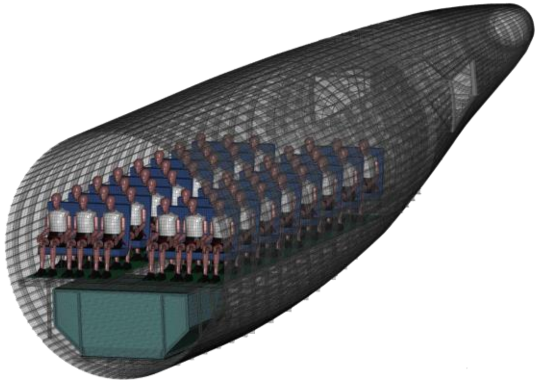
Number of nodes: 95,000
CPU time: ≈ 50 min for 250 ms



Number of nodes: 3.3 M
CPU time: ≈ 8 days for 350 ms







Linux cluster
LS-Dyna 13.1.0
16 core processor

2 Method validation

Specific aircraft design Fokker F28

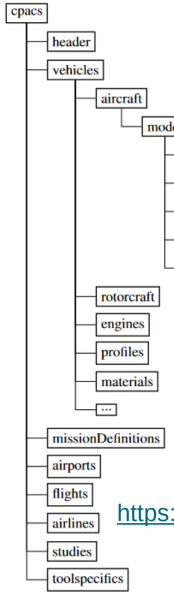
2 Method validation

Current status

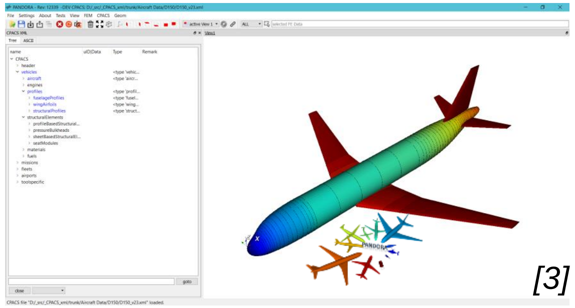
FE model generation

Design data provided by Fokker Services

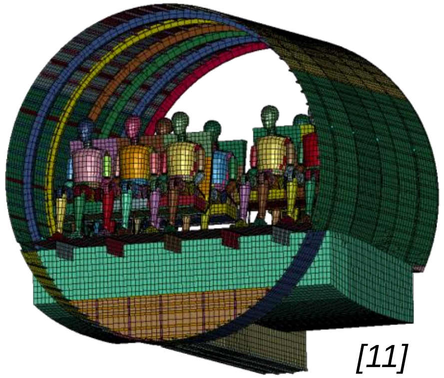
[10]



https://cpacs.de/ [2]



[3]



[11]

Aircraft design data → *CPACS* → *PANDORA* → *Aircraft FE model*

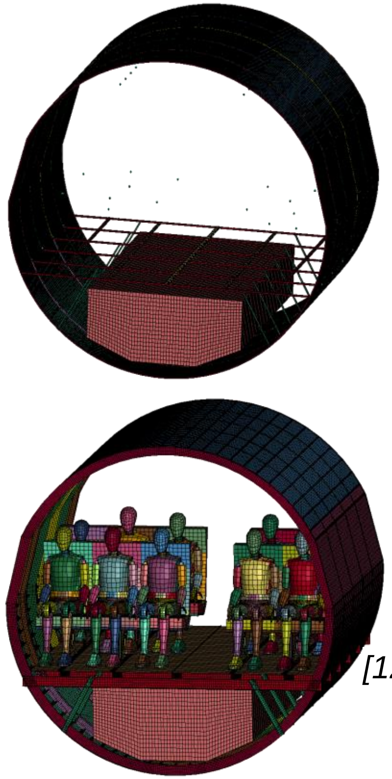
[10] J. D. Littell, "A summary of results from two full-scale Fokker F28 fuselage section drop tests," NASA/TM–2018-219829, 2018.
[11] E. Wegener, "Numerical Simulation of a Crash Test on a Fokker F28 Center Fuselage Section with Wing Box and Oblique Impact Surface," DLR-IB-BT-ST-2021-148, 2021.

2 Method validation
Current status

Definition of F28 CPACS data set and generation of two fuselage section models with PANDORA

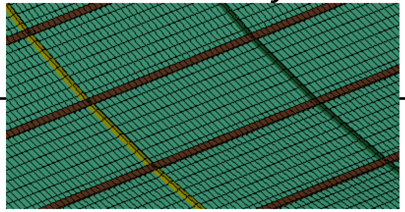
FAA/NASA Test 1:
F28 fuselage section with cargo door and luggage

FAA/NASA Test 2:
F28 fuselage section with wingbox

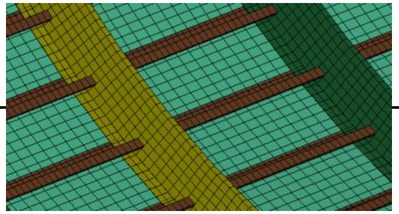


[12]

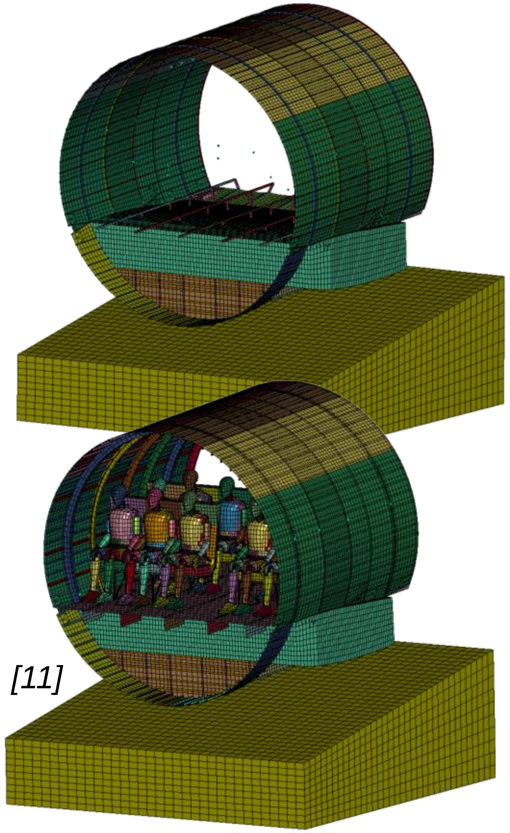
Low-Fidelity



High-Fidelity



[11]



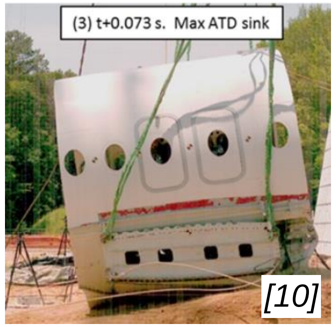
[12] J. Birk, "Numerical Simulation of a Crash Test on a Fokker F28 Typical Fuselage Section with Cargo Door and Bulk Loading," DLR-IB-BT-ST-2021-147, 2021.

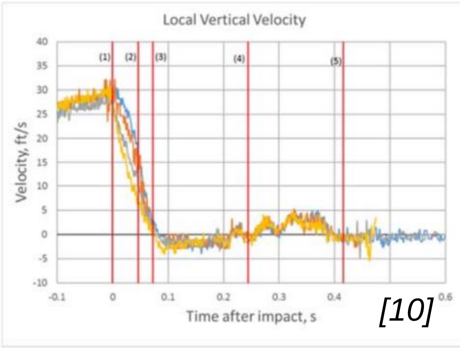
2 Method validation

Current status

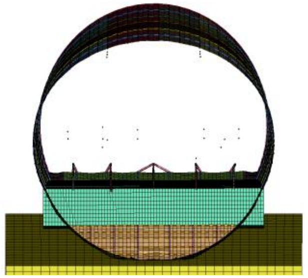
Partial validation of simulation methods on the basis Fokker F28 full scale crash test data

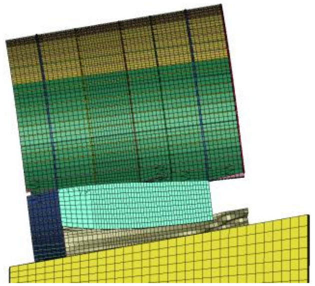
Experiment

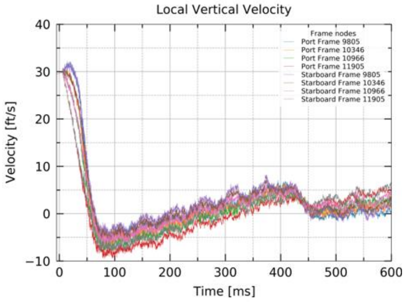




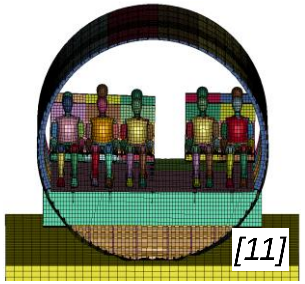
Low-Fidelity

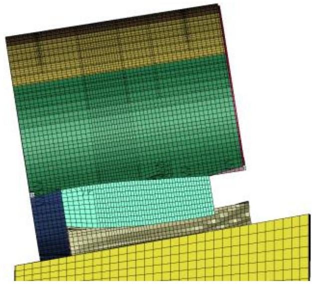


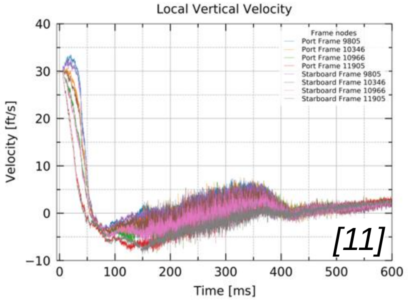




High-Fidelity

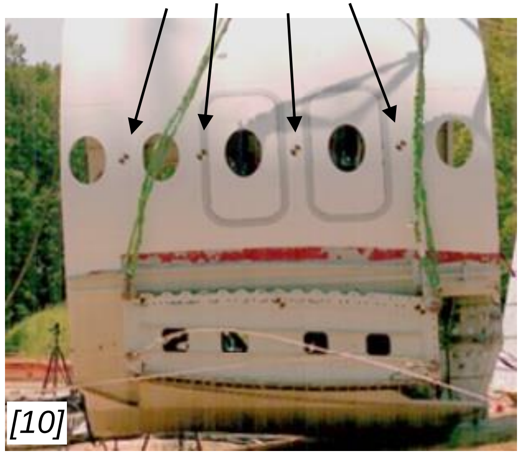






t = 60 ms
ATD maximum sink position

Velocity measurement



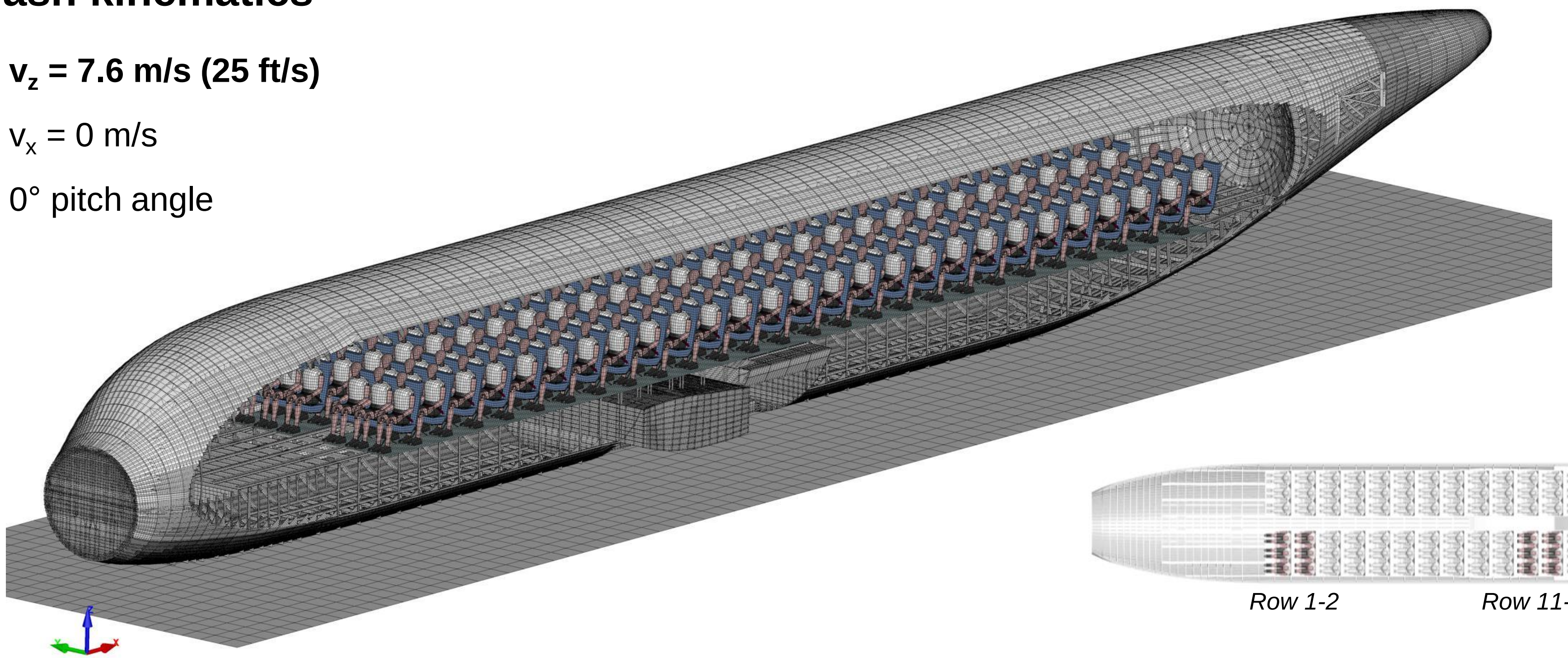
3 Method application

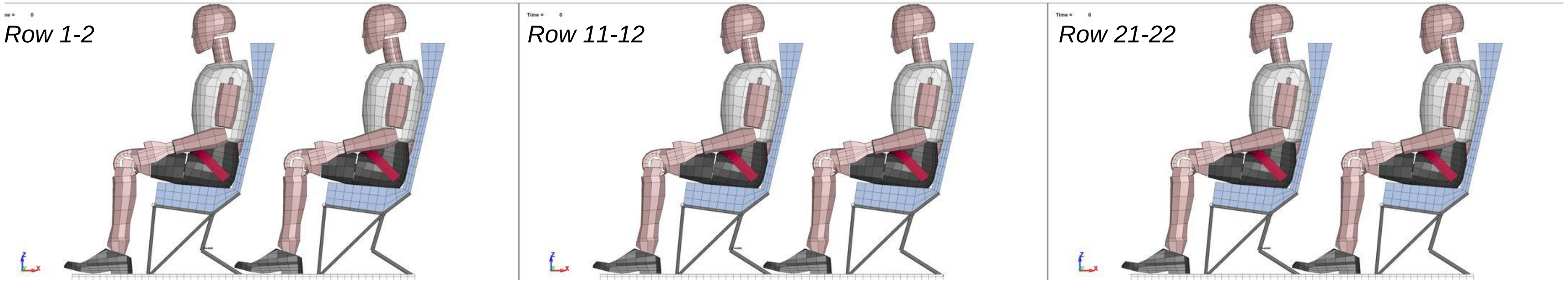
Examples (generic single-aisle aircraft)

3 Method application (examples)
I) Vertical drop of full aircraft model

Crash kinematics

- **v_z = 7.6 m/s (25 ft/s)**
- v_x = 0 m/s
- 0° pitch angle





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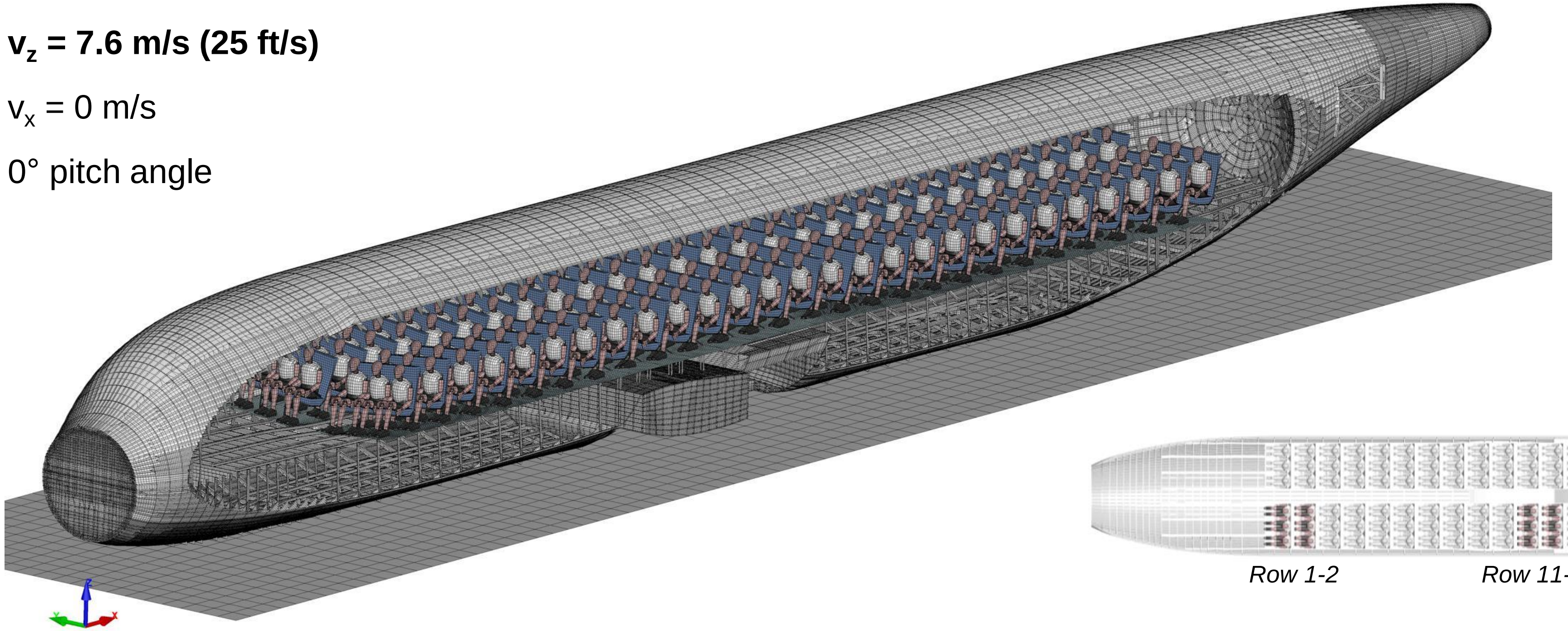

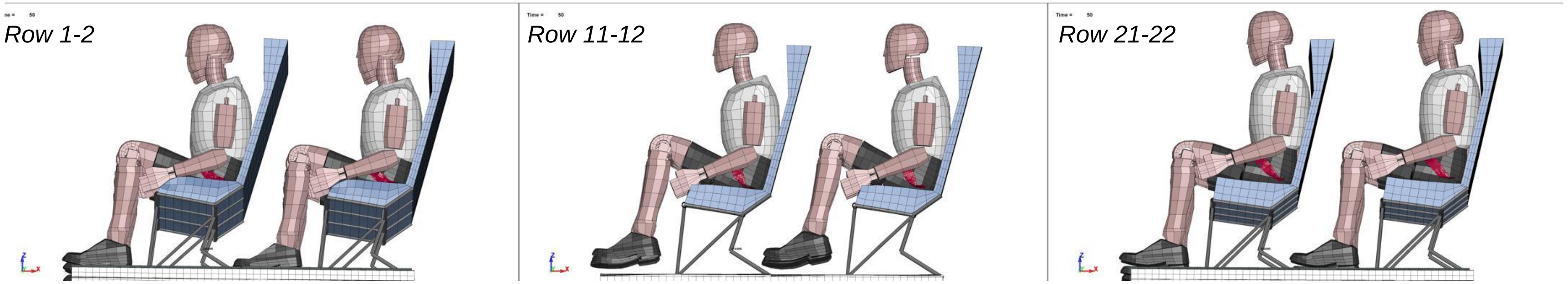

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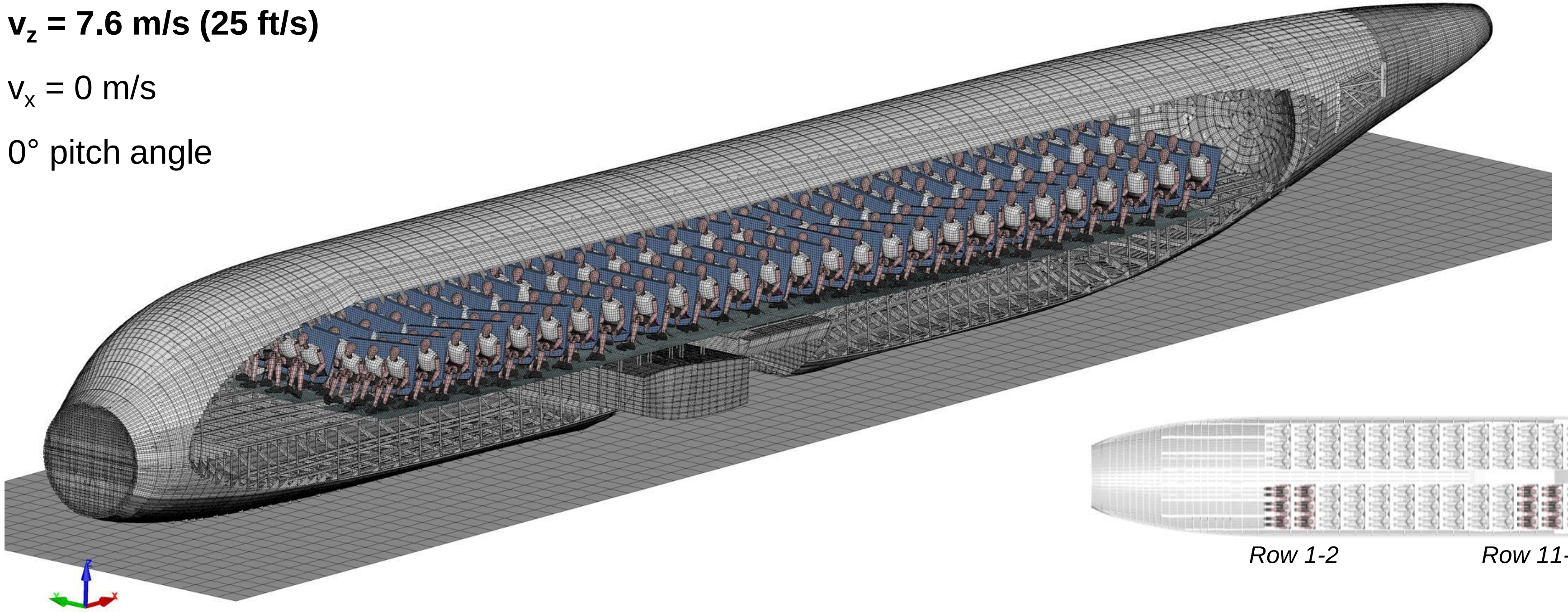

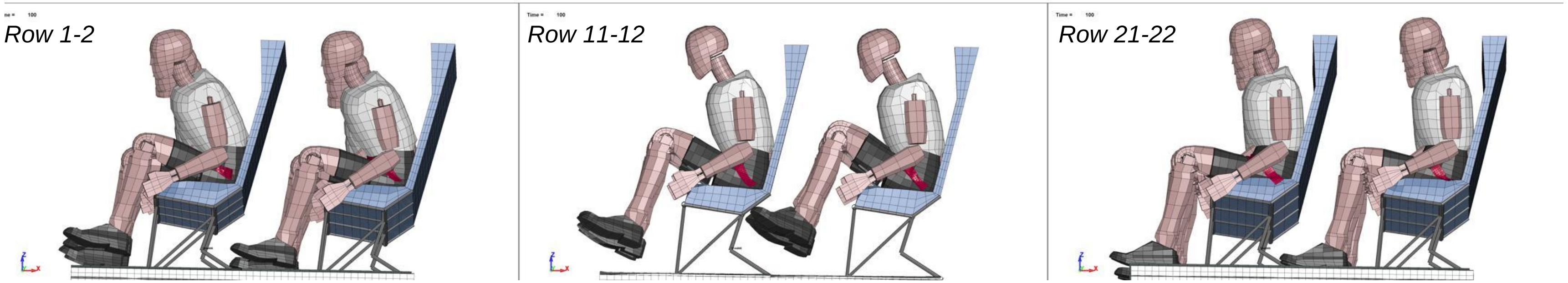

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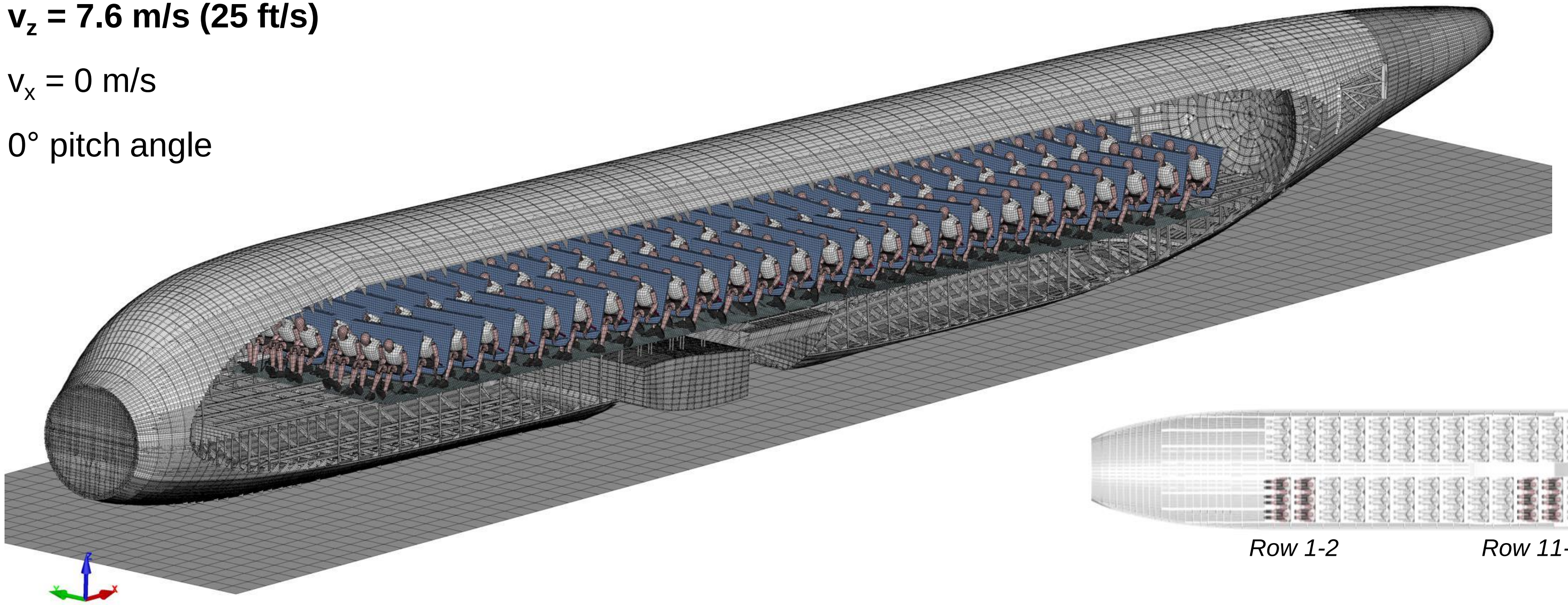
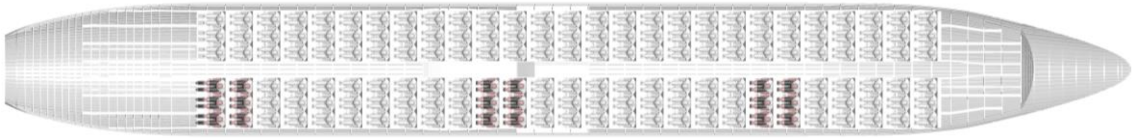
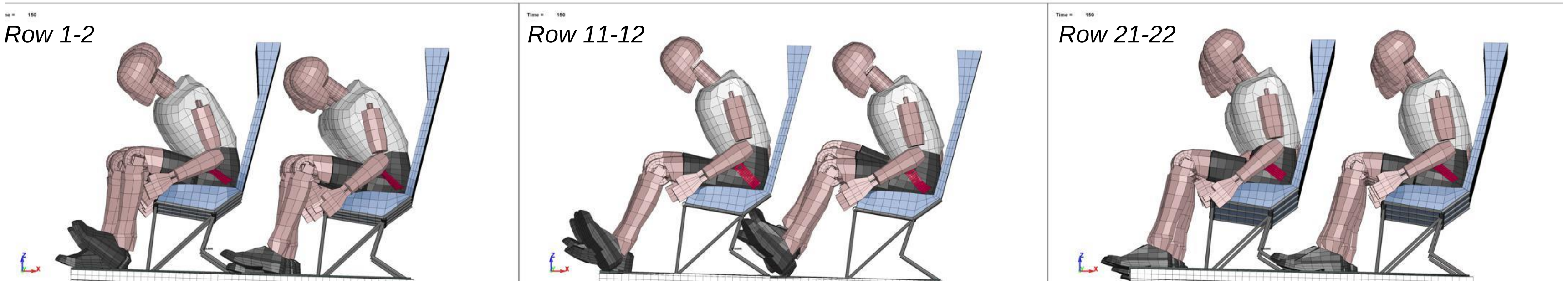




Row 1-2 Row 11-12 Row 21-22



3 Method application (examples)

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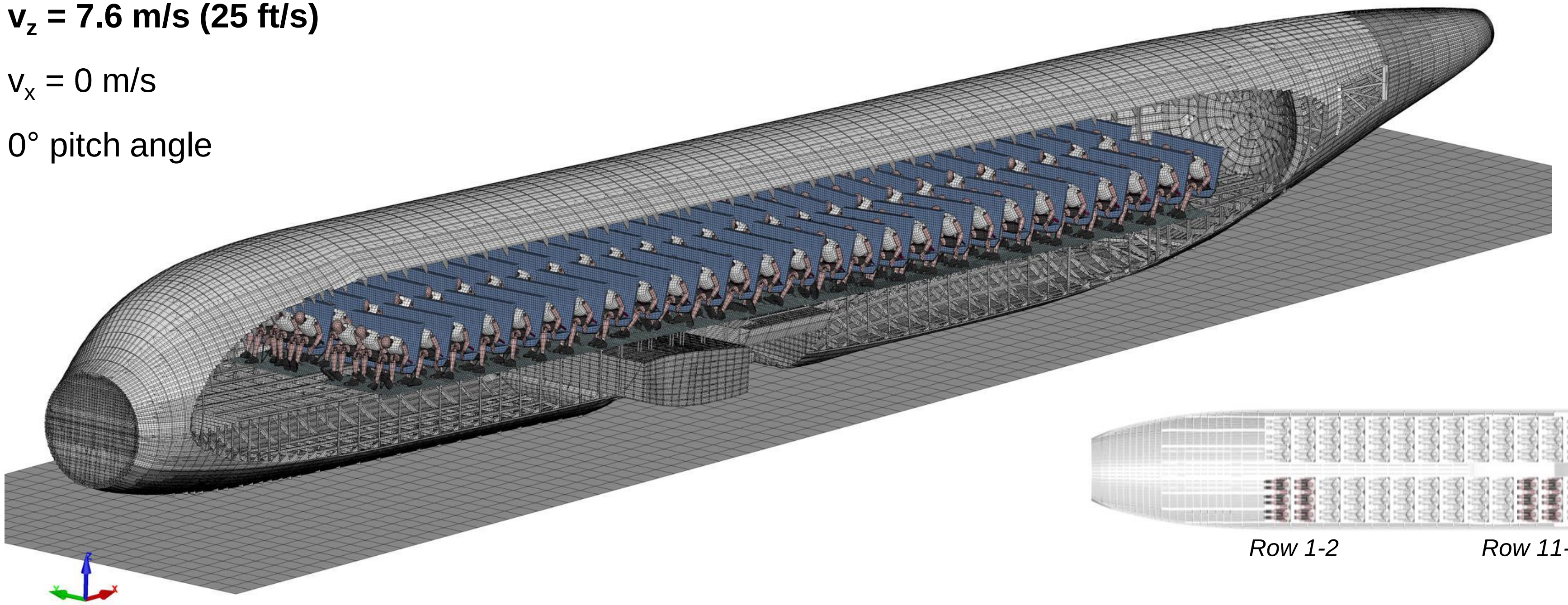

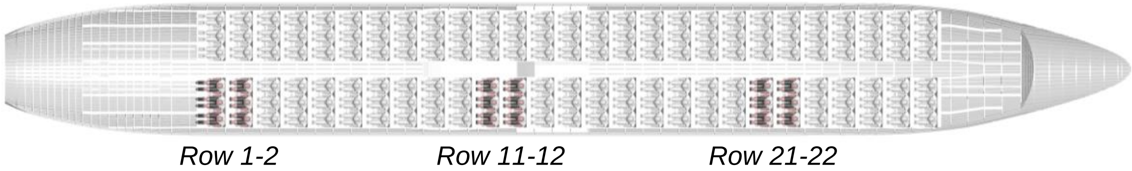

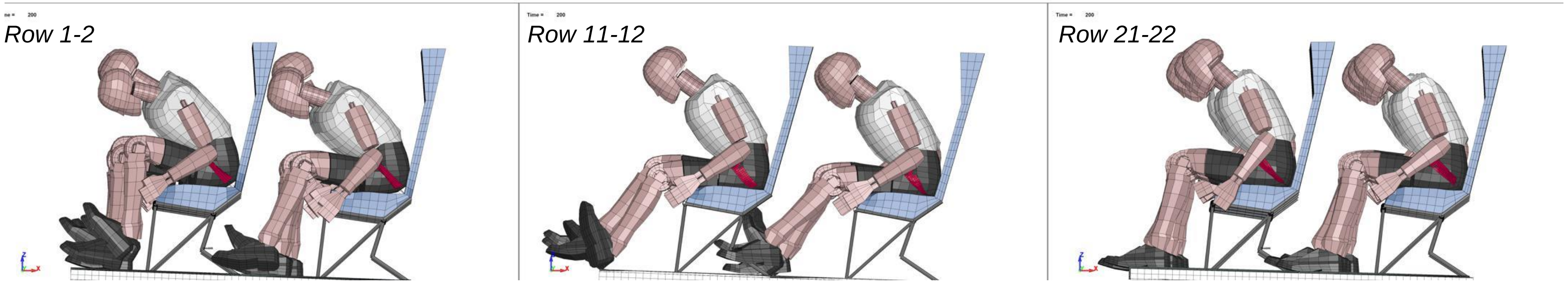

3 Method application (examples)

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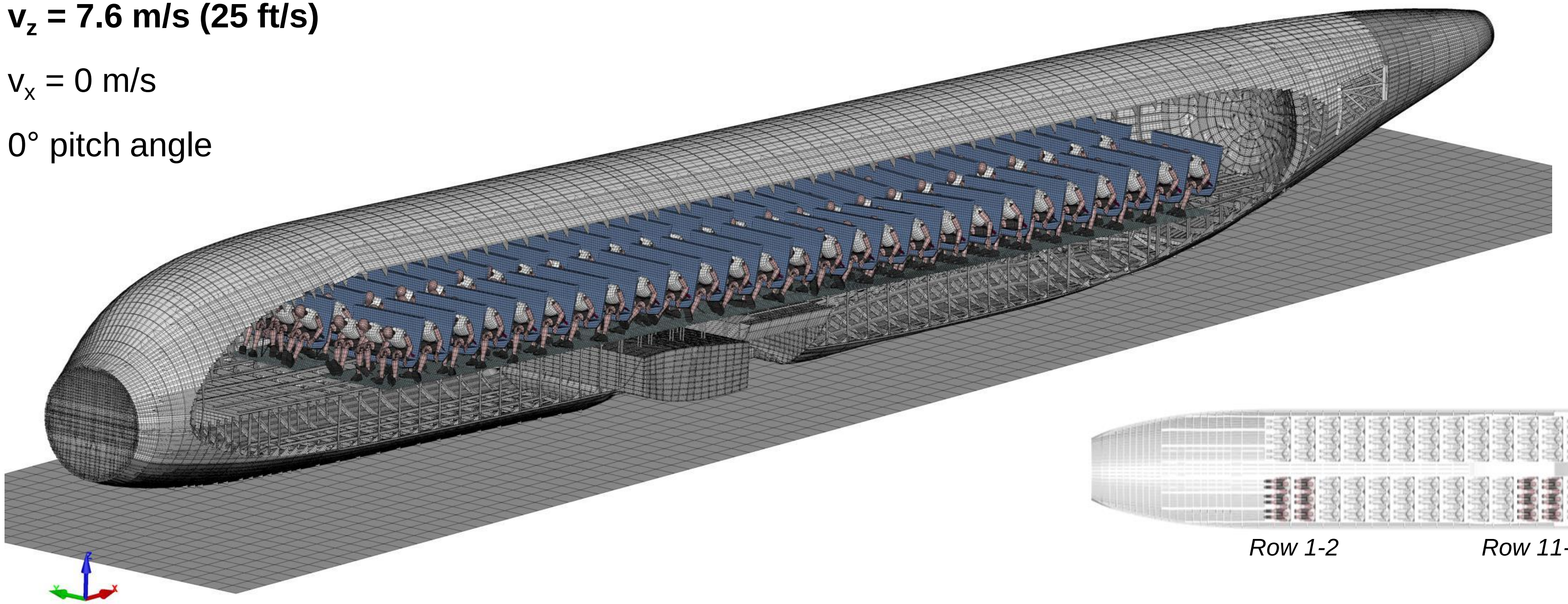
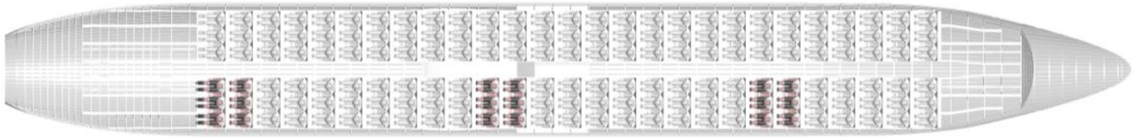
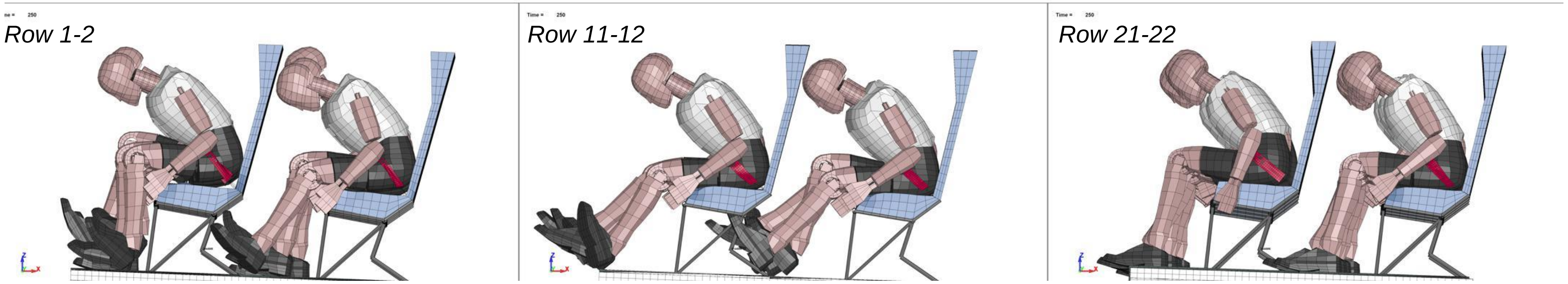




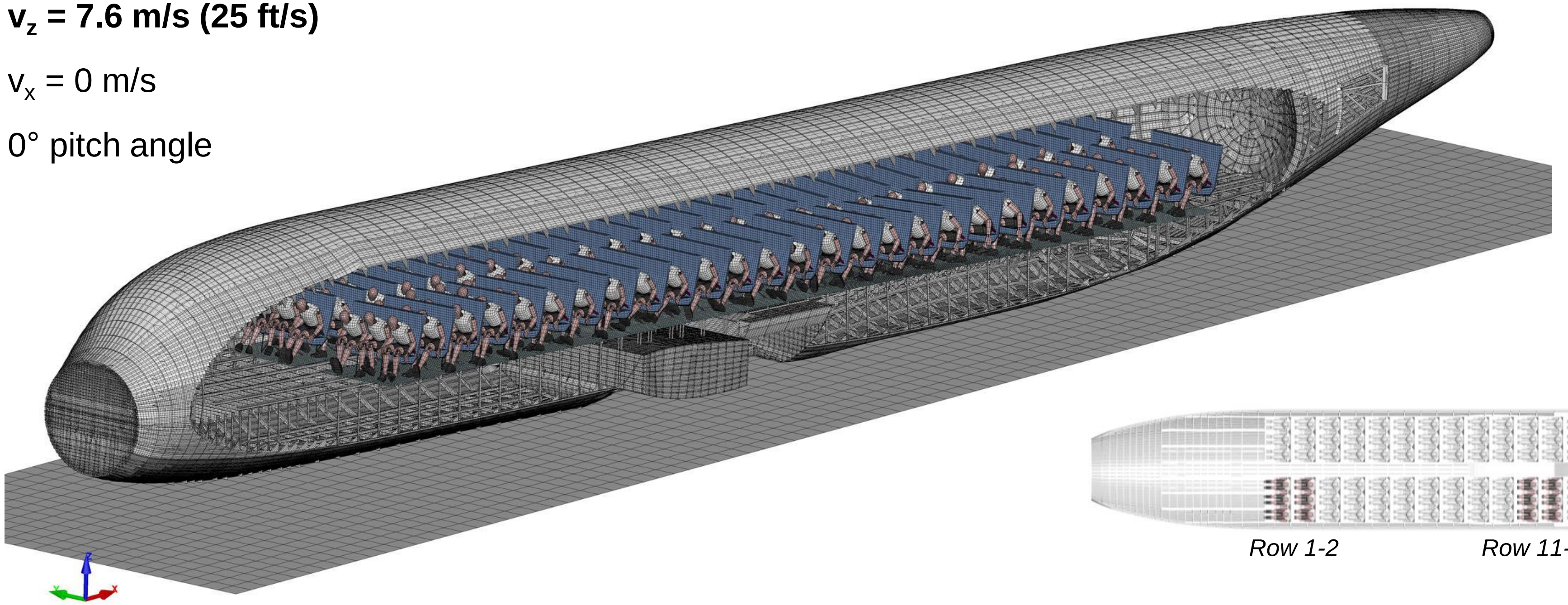
Row 1-2 Row 11-12 Row 21-22

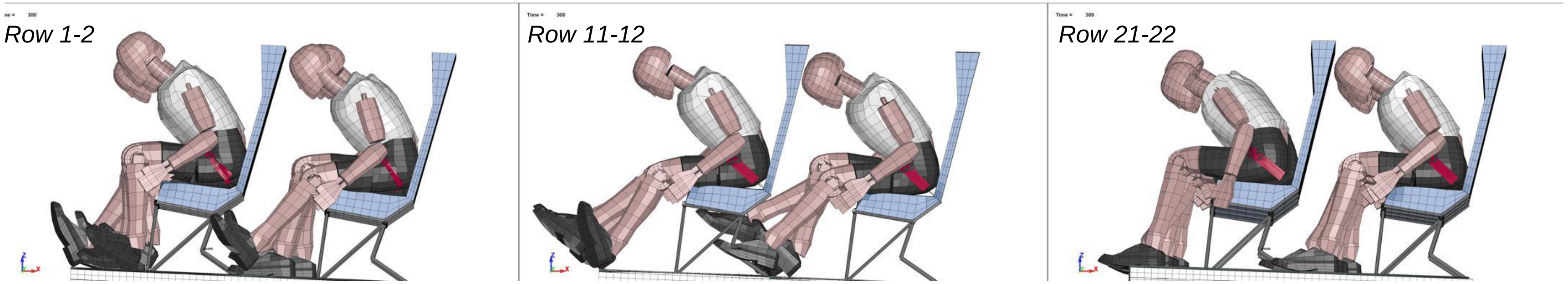


3 Method application (examples)
I) Vertical drop of full aircraft model

Crash kinematics

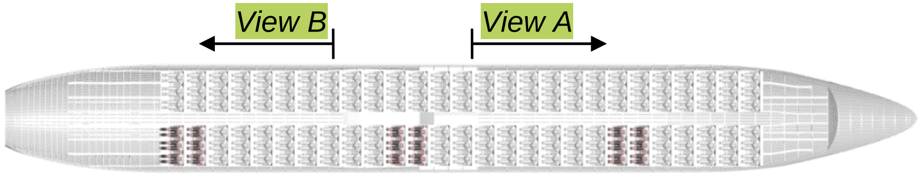
- **v_z = 7.6 m/s (25 ft/s)**
- v_x = 0 m/s
- 0° pitch angle





3 Method application (examples)

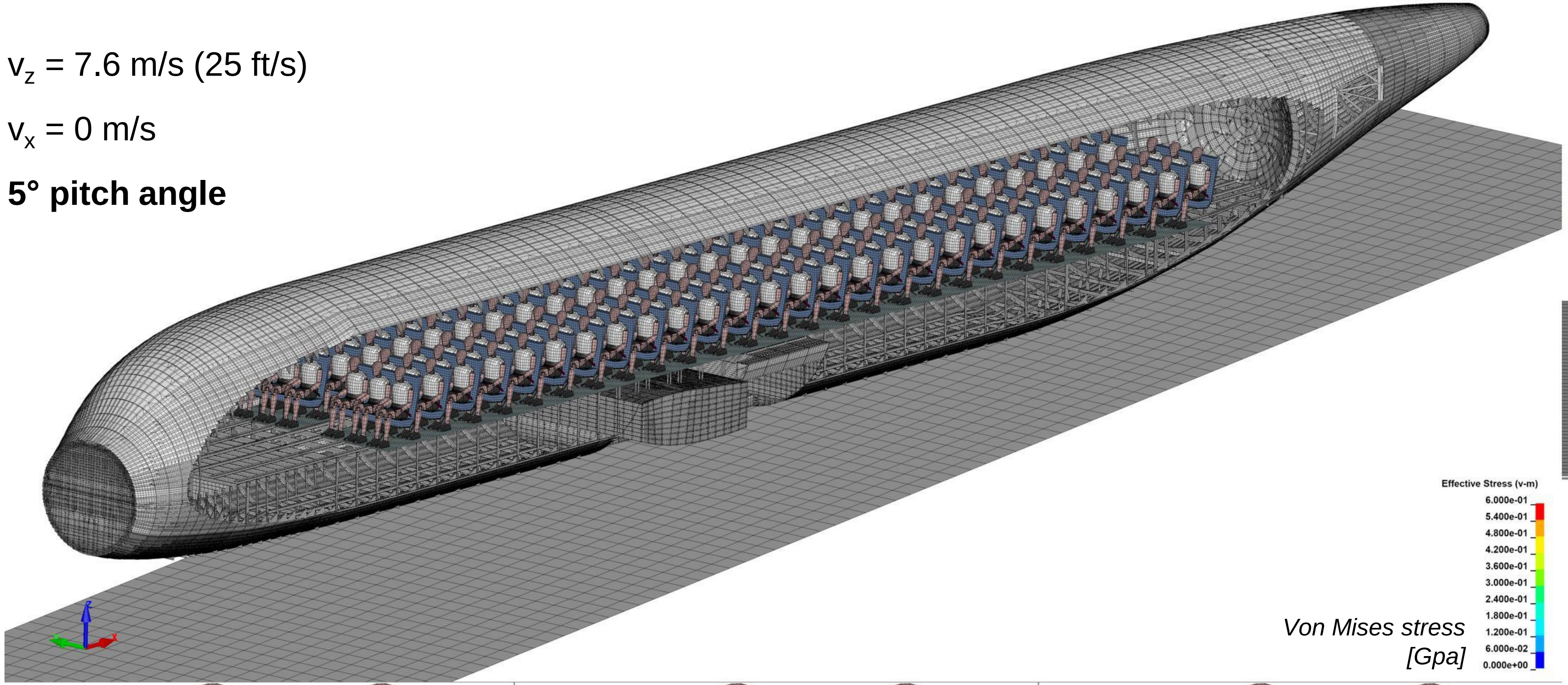
II) Vertical drop with pitch angle



DLR

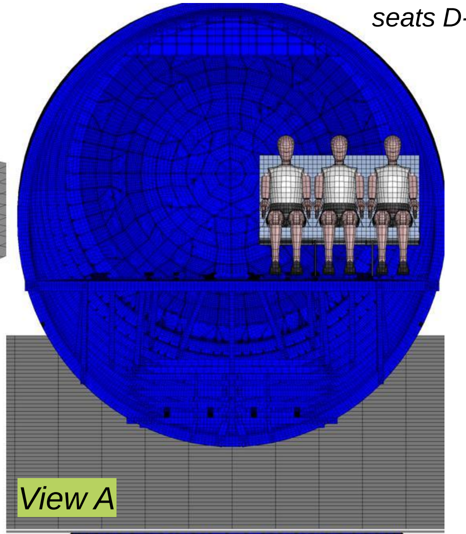
Crash kinematics

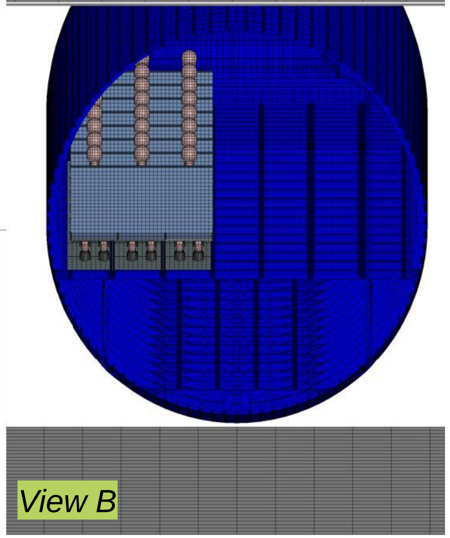
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

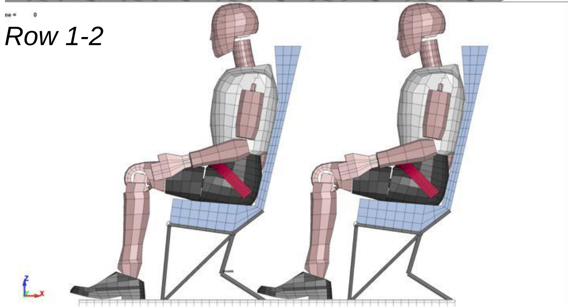


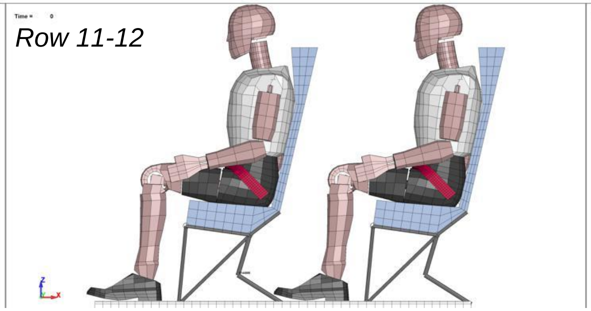
Von Mises stress [Gpa]

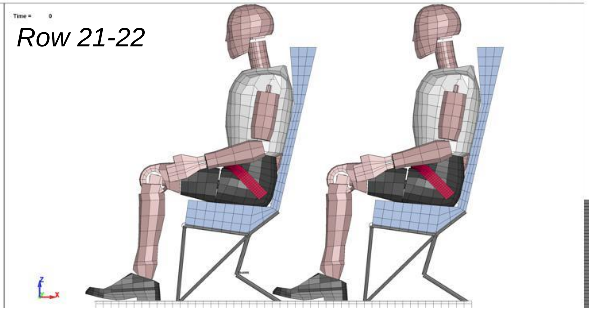
In view A and view B seats A-C displayed, seats D-F hidden





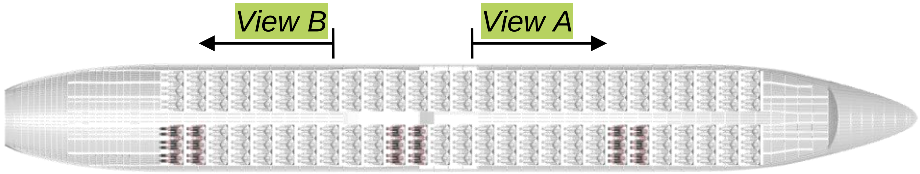






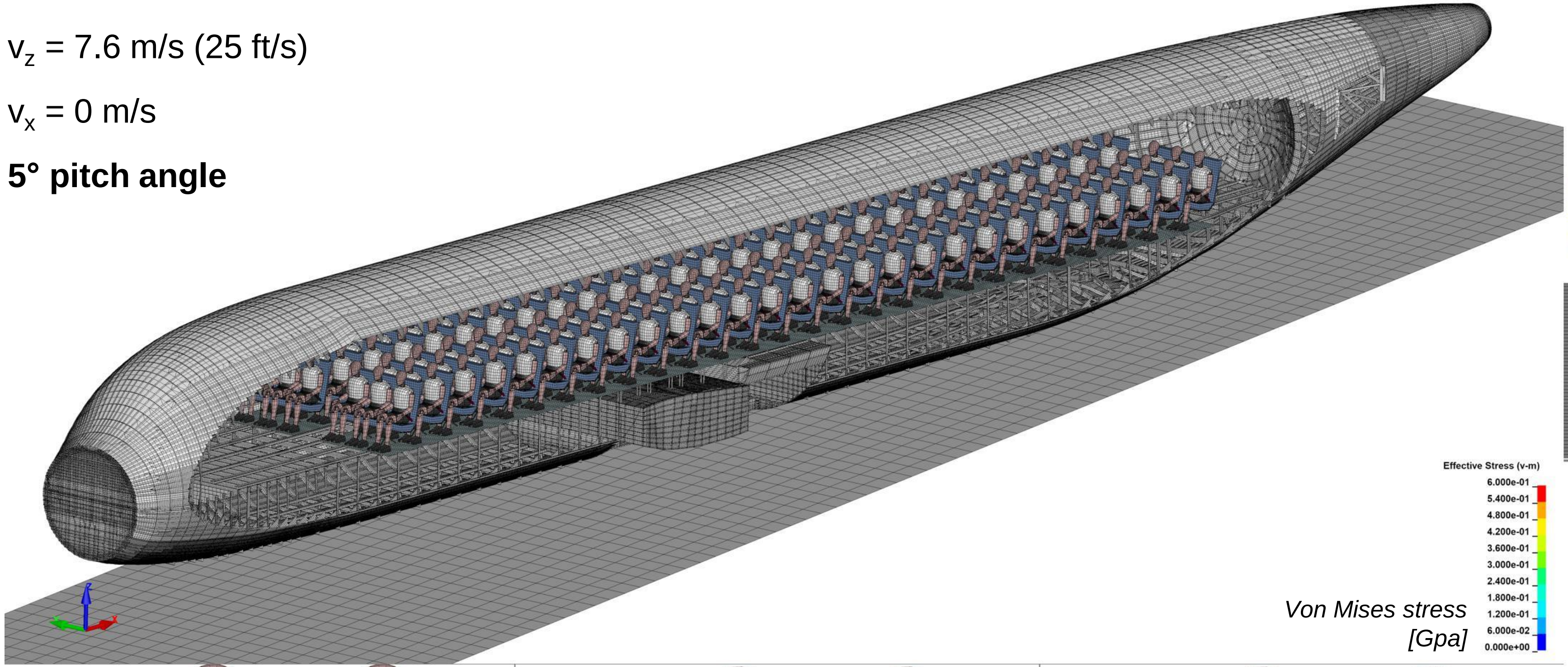
3 Method application (examples)

II) Vertical drop with pitch angle

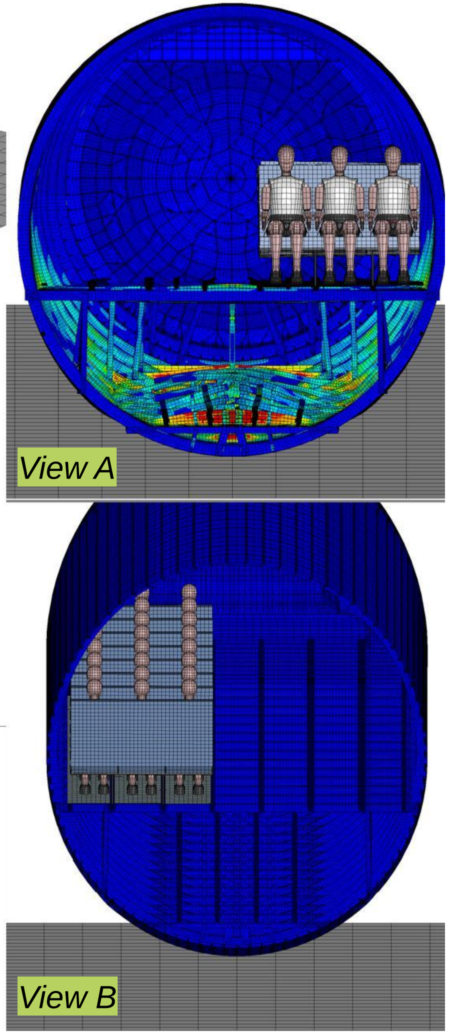


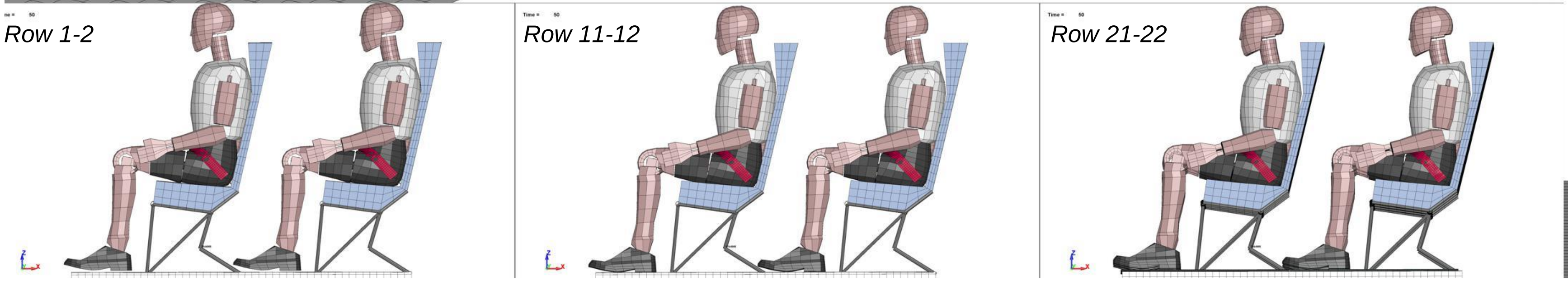
Crash kinematics

- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**



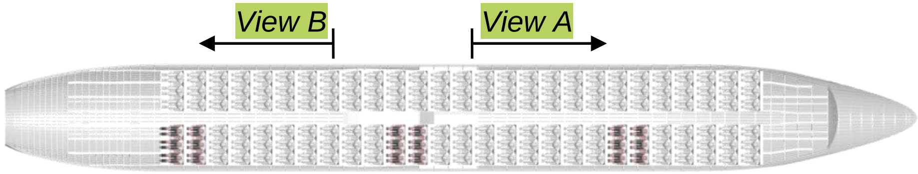
In view A and view B seats A-C displayed, seats D-F hidden





3 Method application (examples)

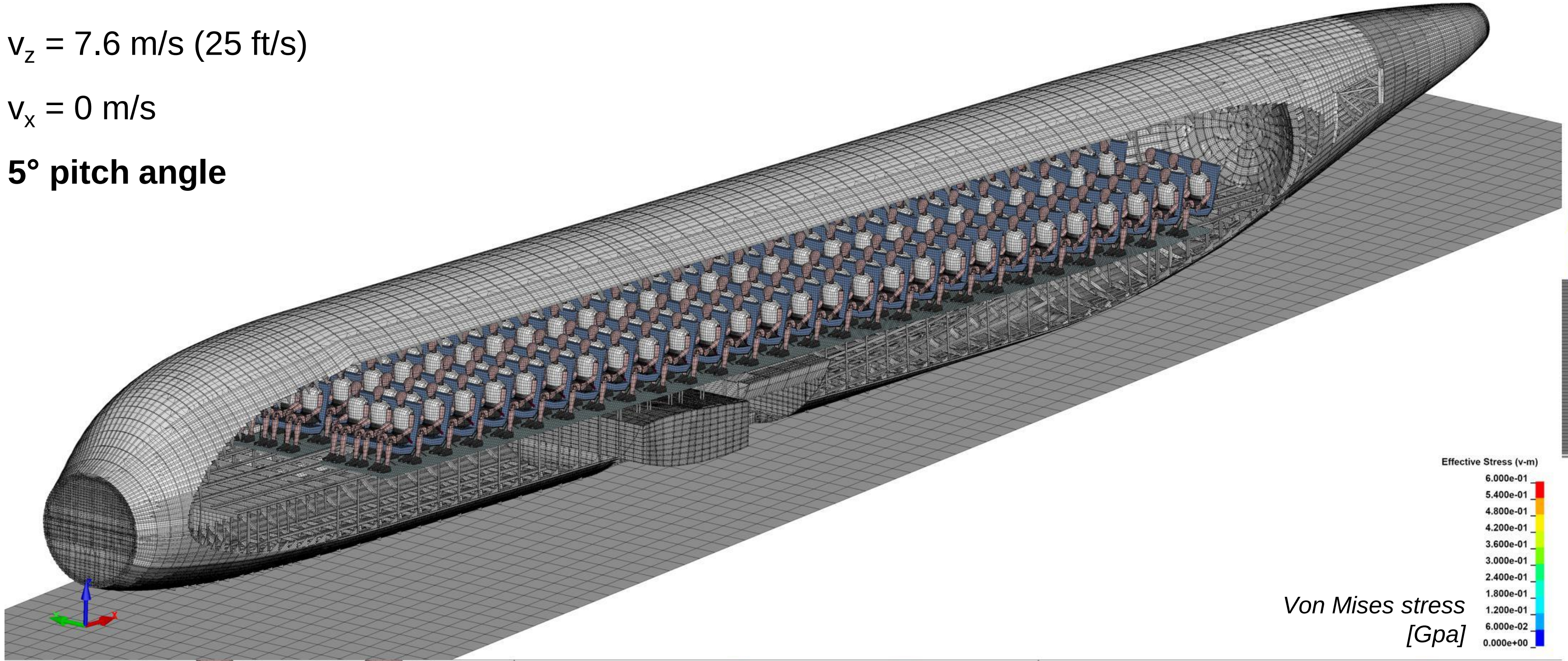
II) Vertical drop with pitch angle



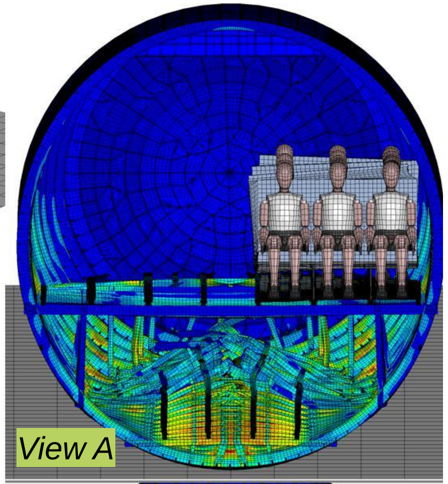
In view A and view B seats A-C displayed, seats D-F hidden

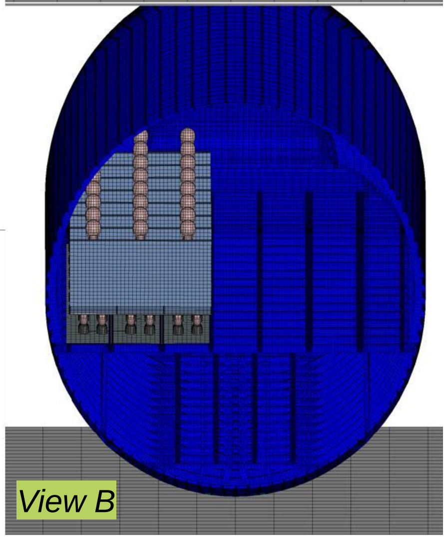
Crash kinematics

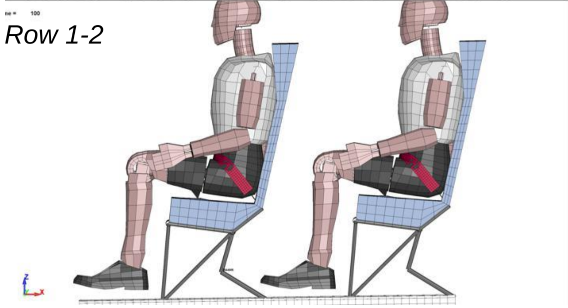
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

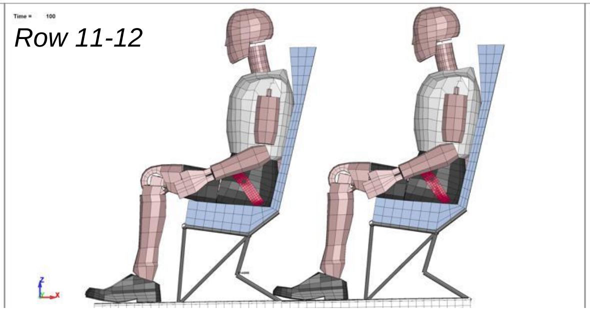


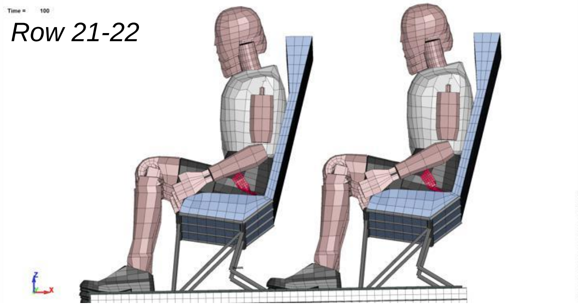
Von Mises stress [Gpa]





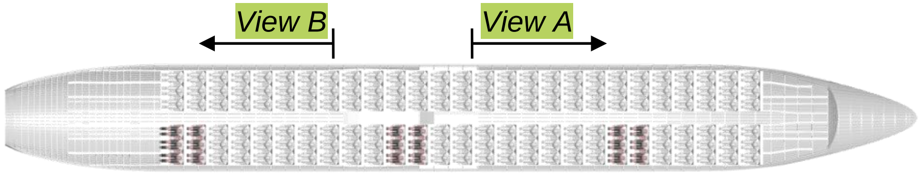






3 Method application (examples)

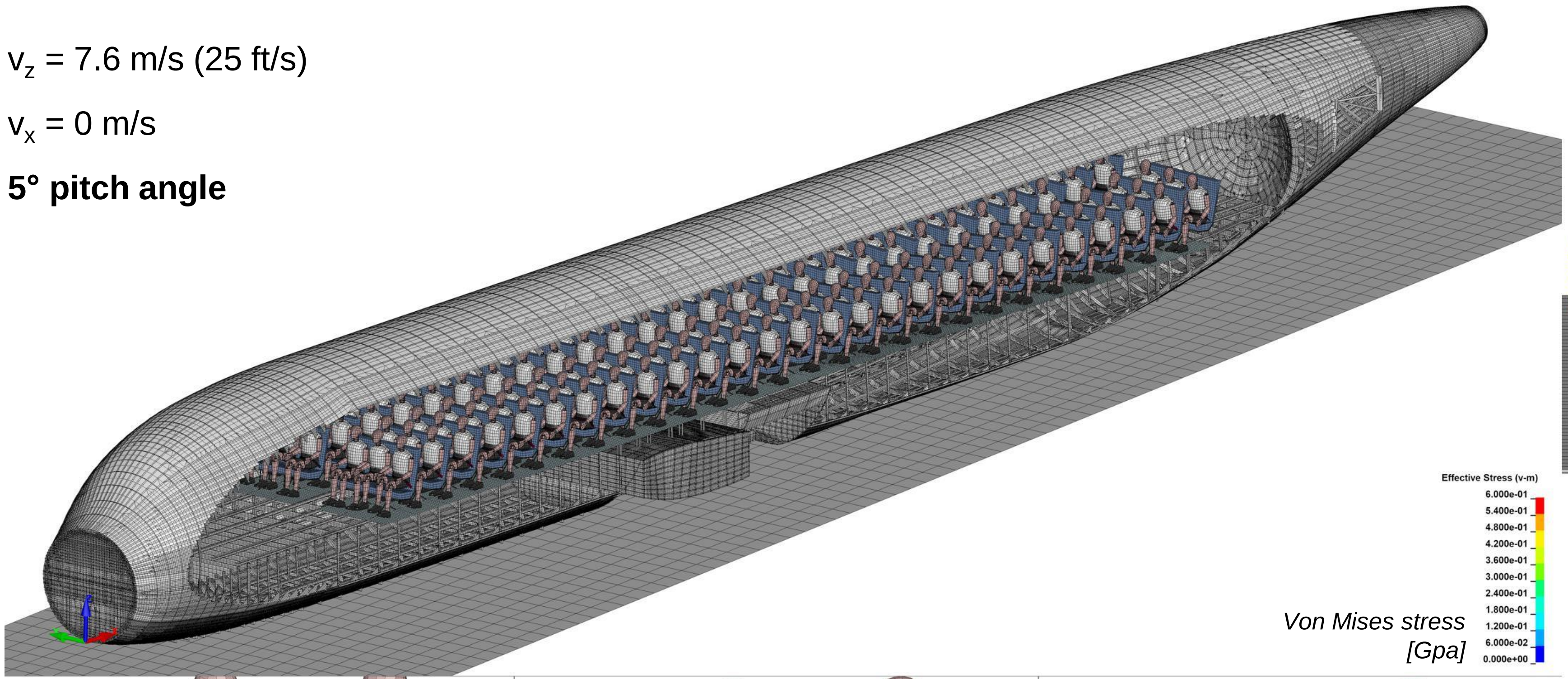
II) Vertical drop with pitch angle



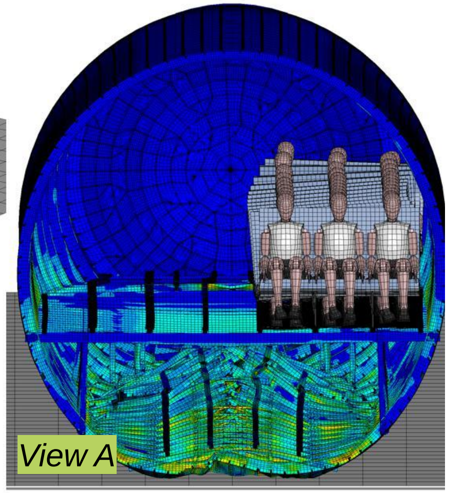
In view A and view B seats A-C displayed, seats D-F hidden

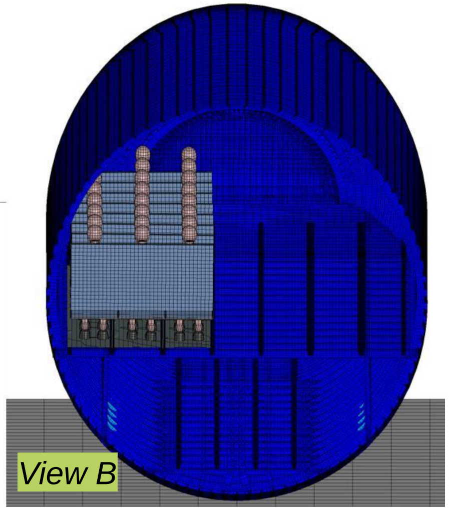
Crash kinematics

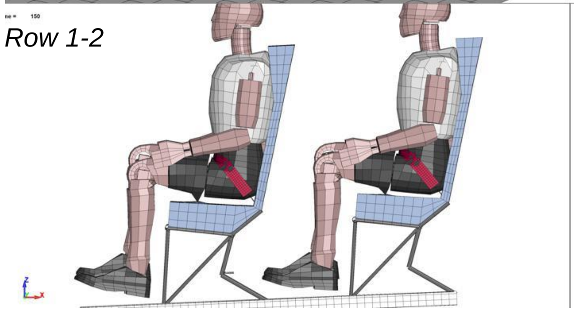
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

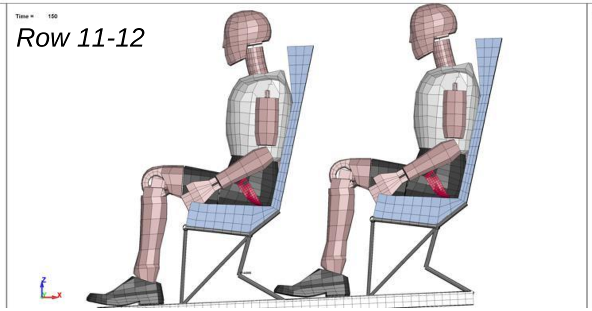


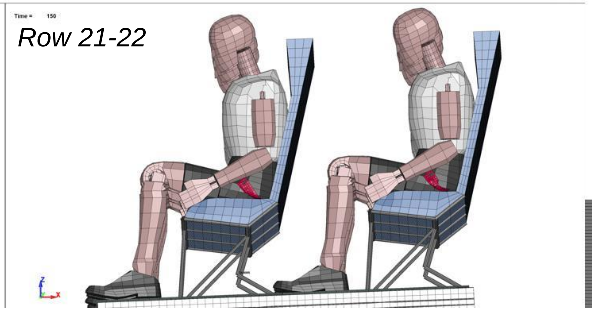
Von Mises stress [Gpa]





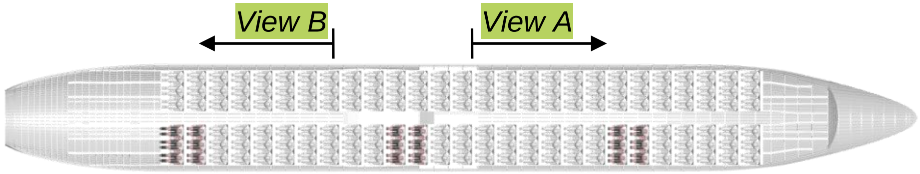






3 Method application (examples)

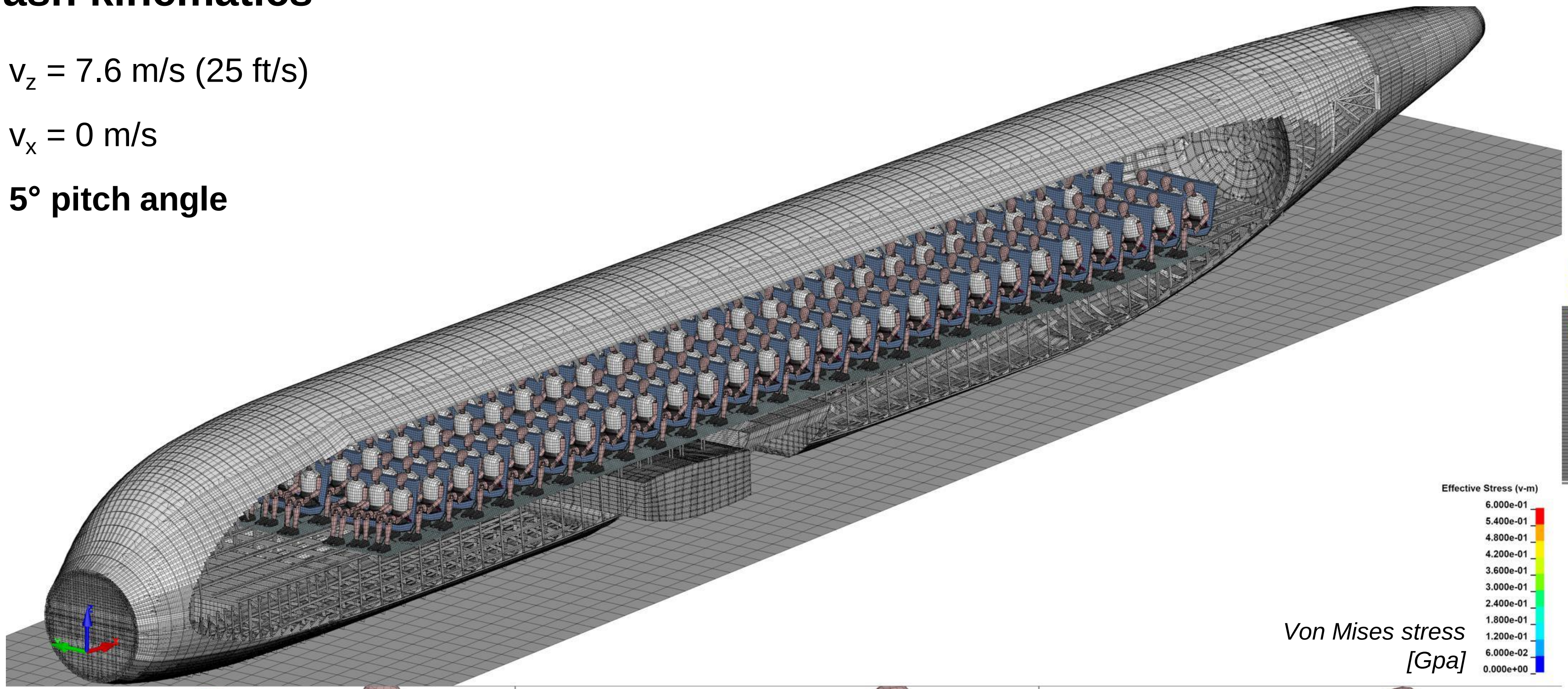
II) Vertical drop with pitch angle



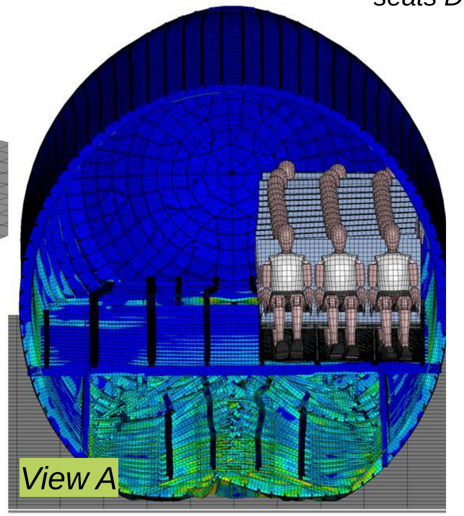
In view A and view B seats A-C displayed, seats D-F hidden

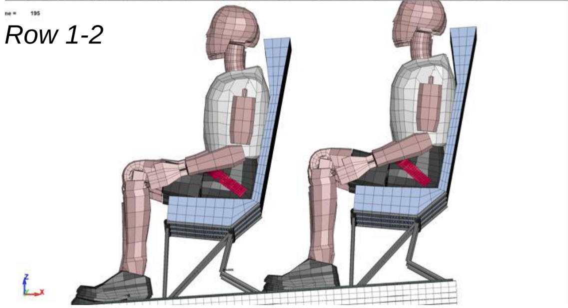
Crash kinematics

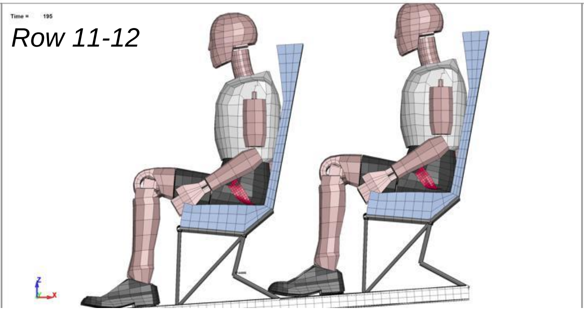
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

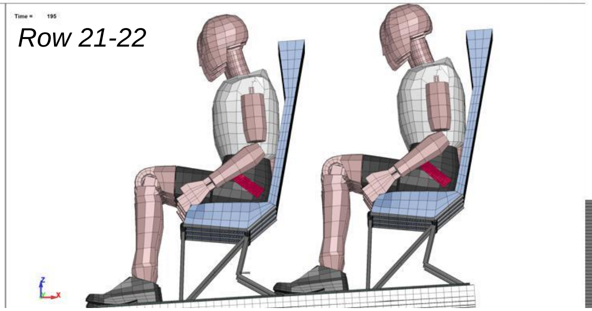


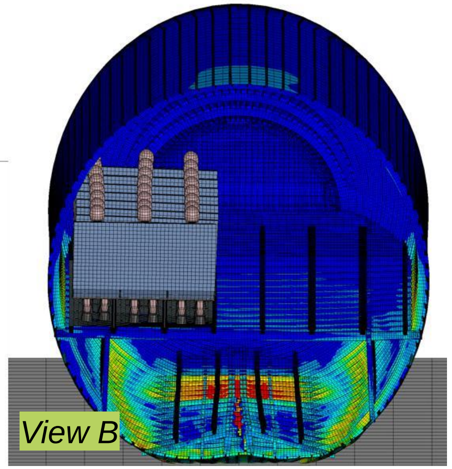
Von Mises stress [Gpa]





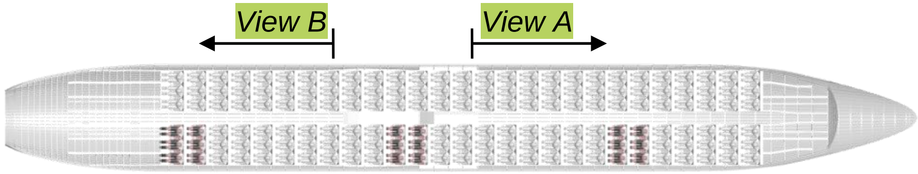






3 Method application (examples)

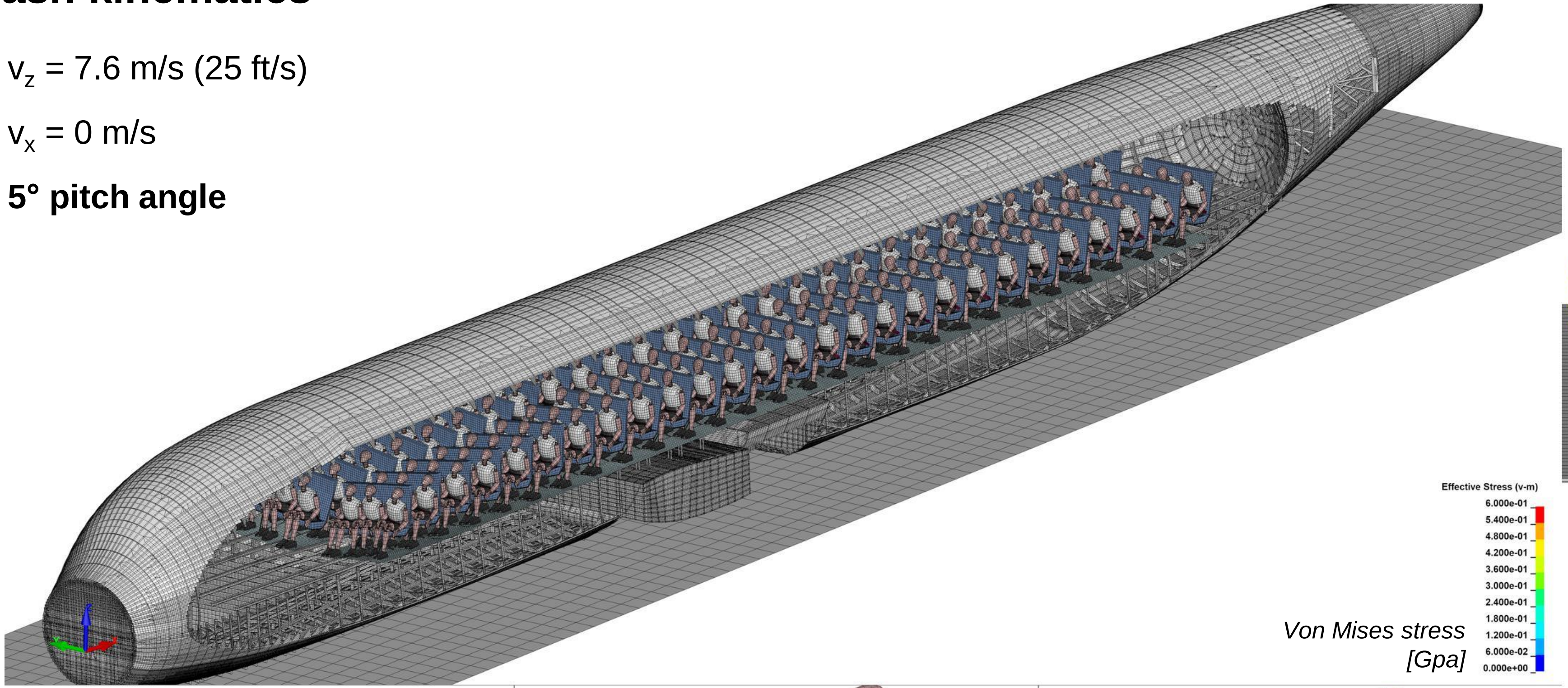
II) Vertical drop with pitch angle



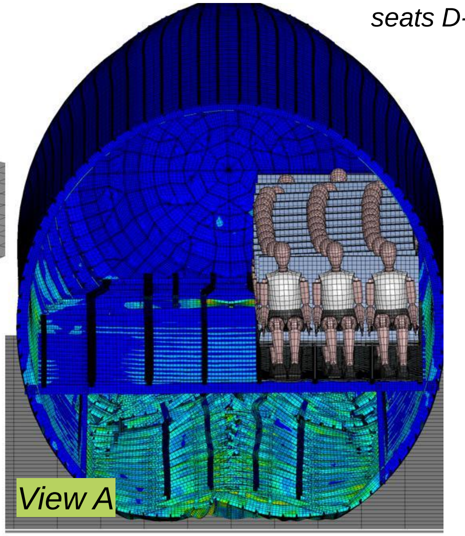
In view A and view B seats A-C displayed, seats D-F hidden

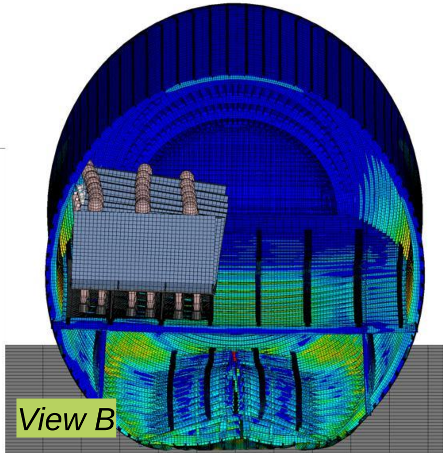
Crash kinematics

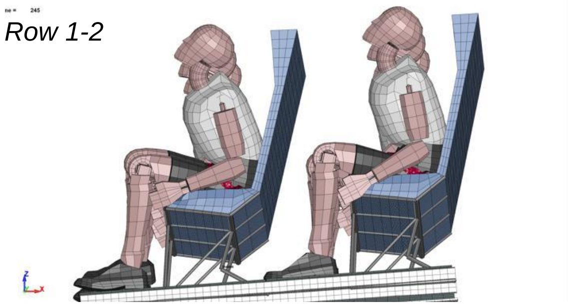
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

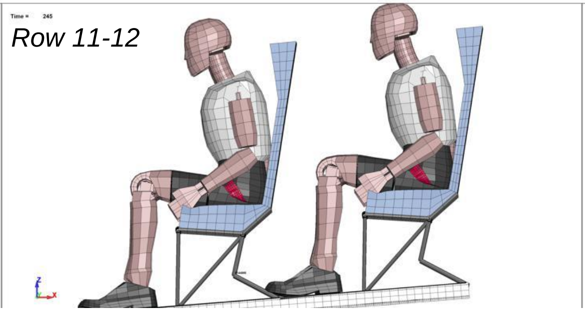


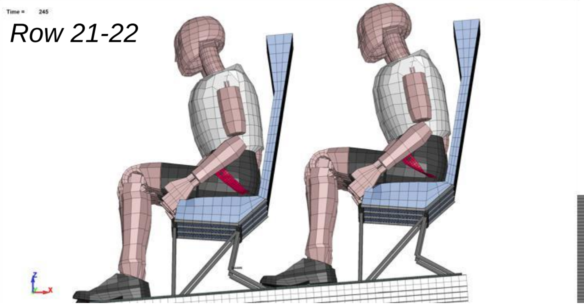
Von Mises stress [Gpa]





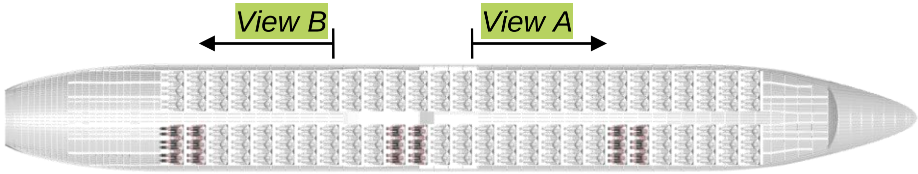






3 Method application (examples)

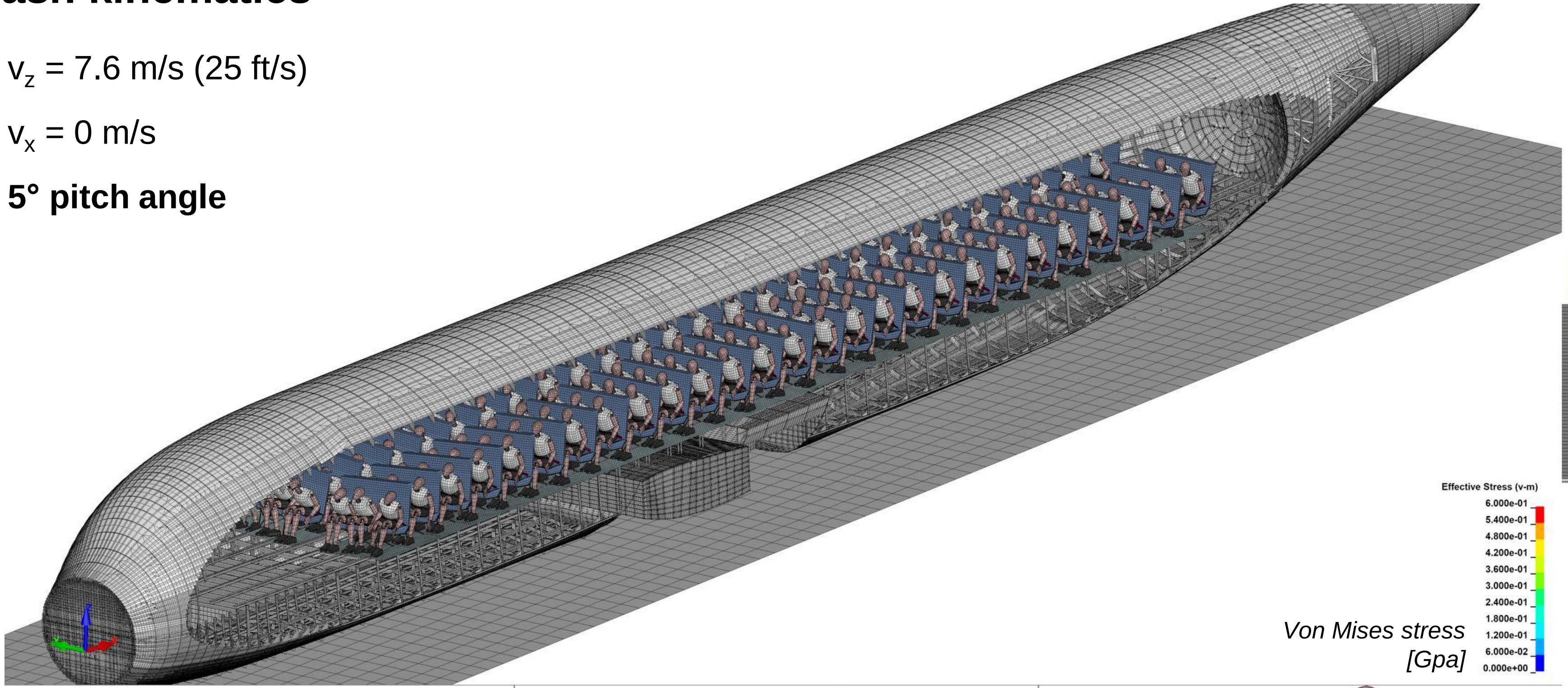
II) Vertical drop with pitch angle

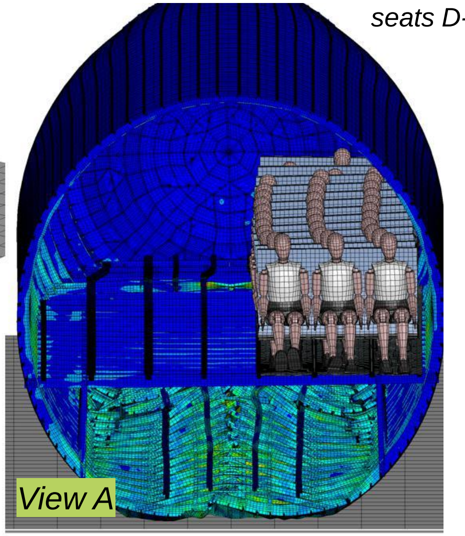


In view A and view B seats A-C displayed, seats D-F hidden

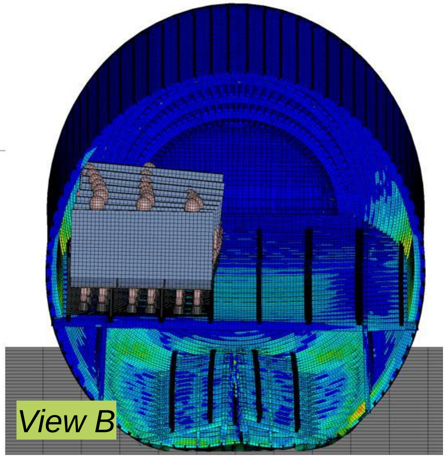
Crash kinematics

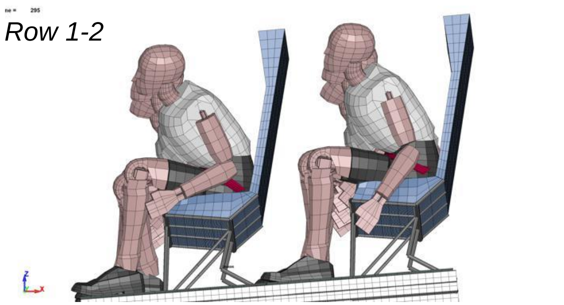
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

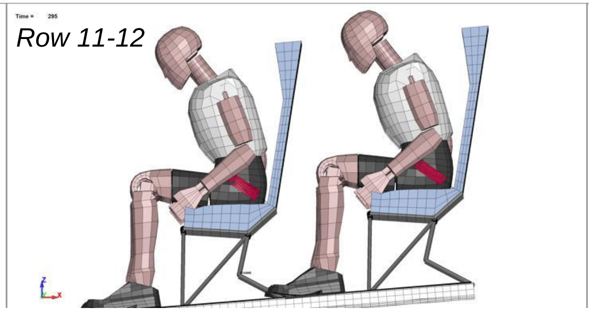


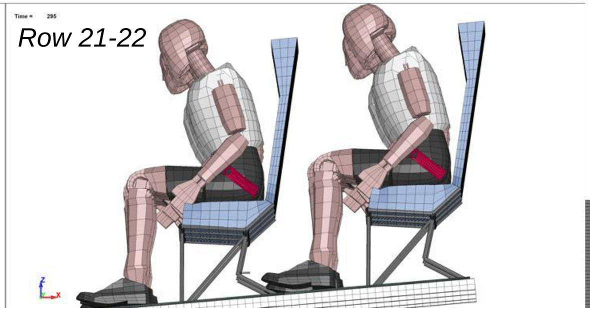


Von Mises stress [Gpa]



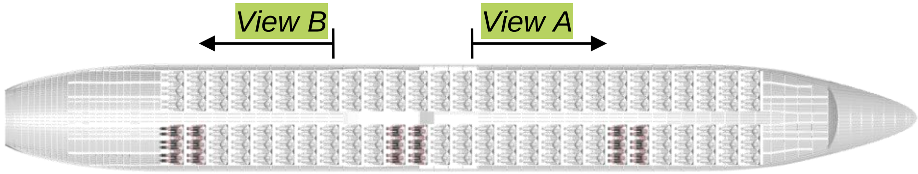






3 Method application (examples)

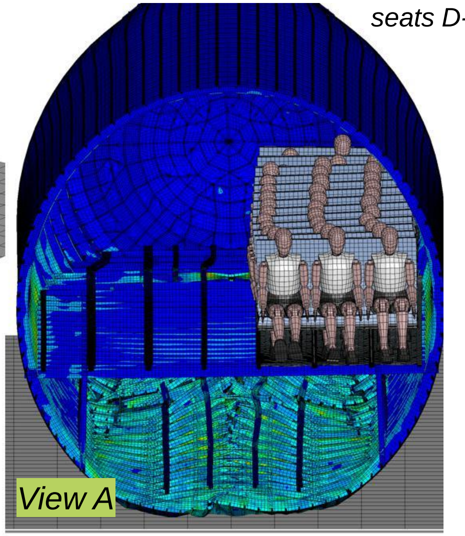
II) Vertical drop with pitch angle

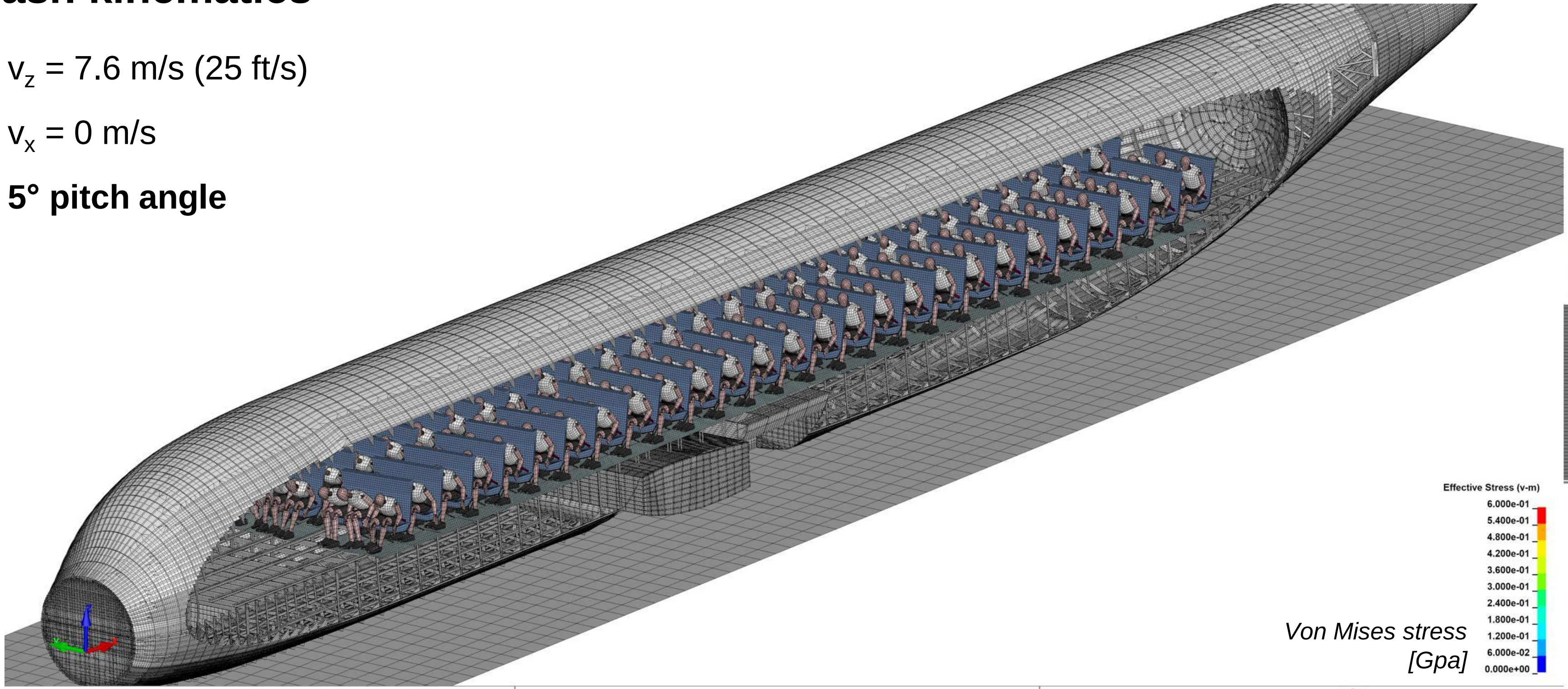


In view A and view B seats A-C displayed, seats D-F hidden

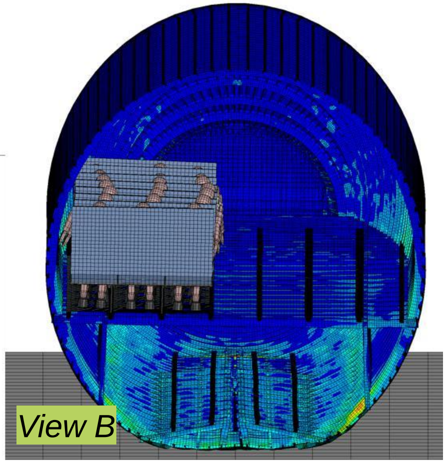
Crash kinematics

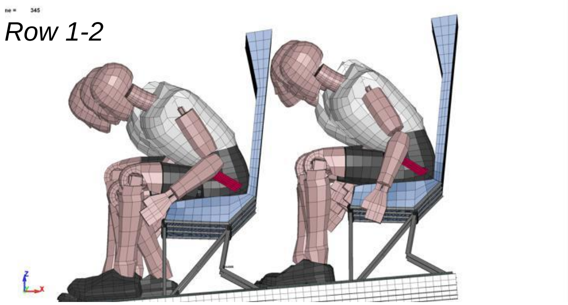
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- **5° pitch angle**

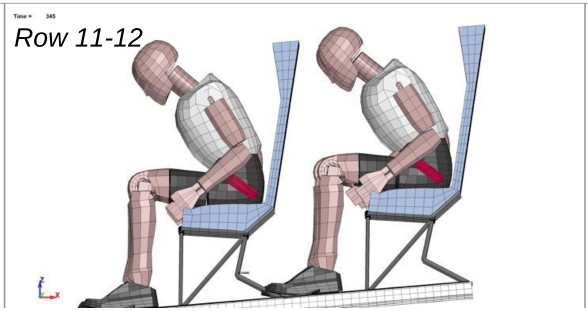


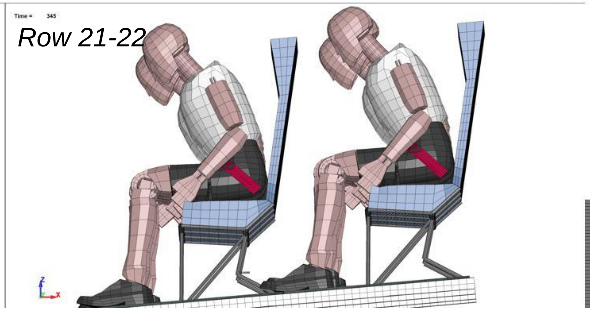


Von Mises stress [Gpa]



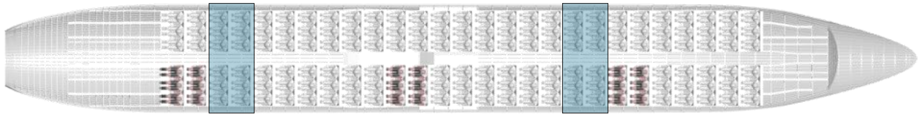






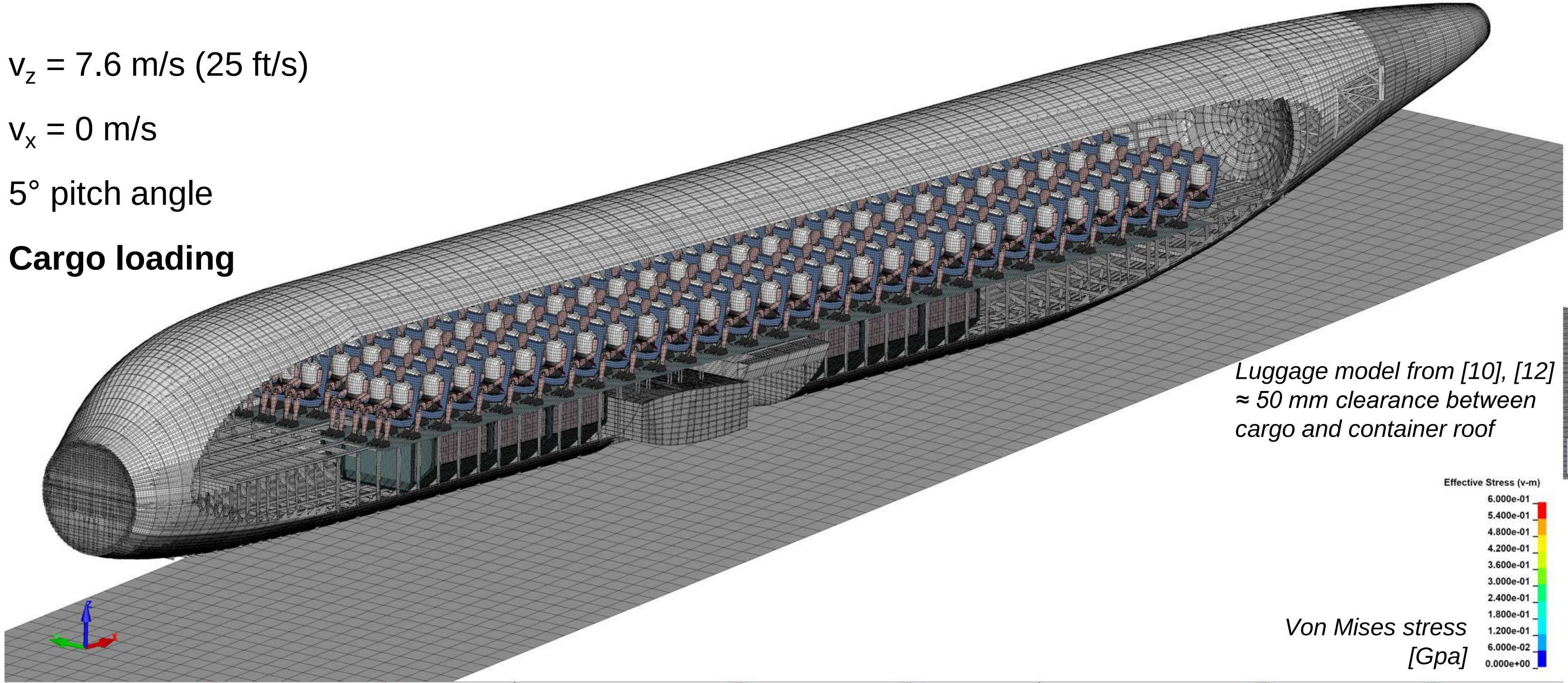
3 Method application (examples)

III) Vertical drop with pitch angle and cargo loading



Crash kinematics

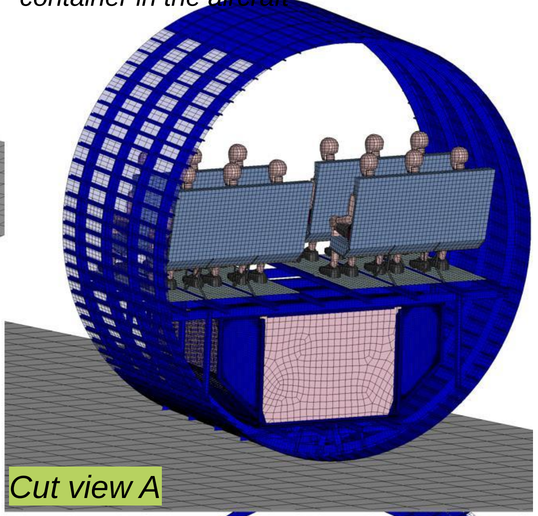
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**



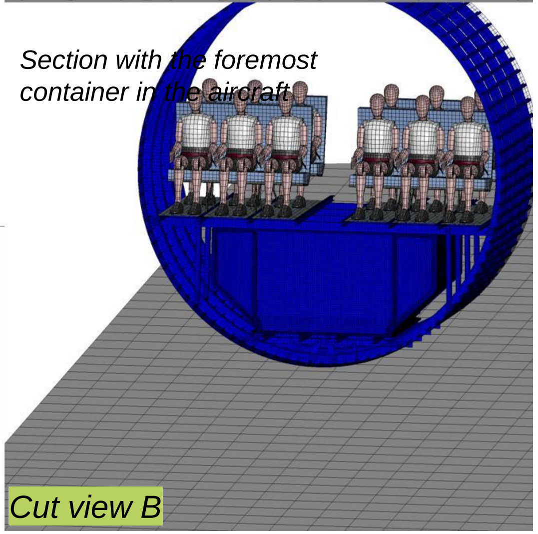
Luggage model from [10], [12]
≈ 50 mm clearance between cargo and container roof

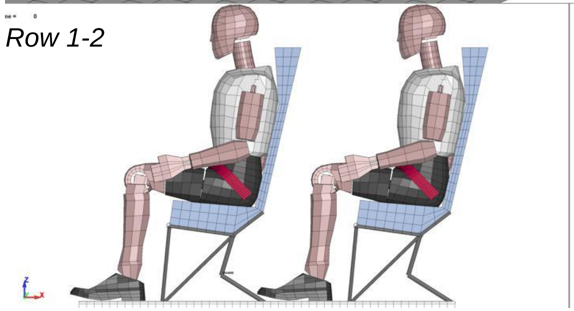
Von Mises stress [Gpa]

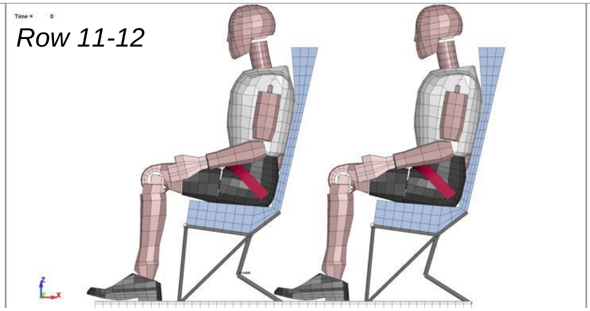
Section with the rearmost container in the aircraft

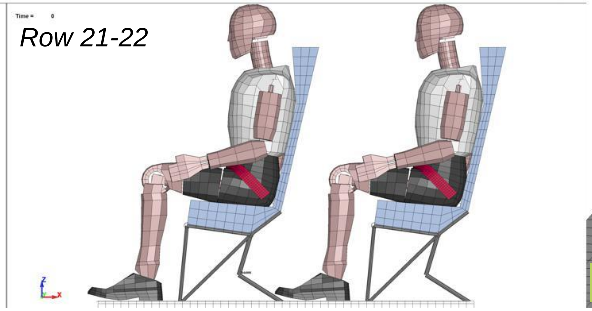


Section with the foremost container in the aircraft







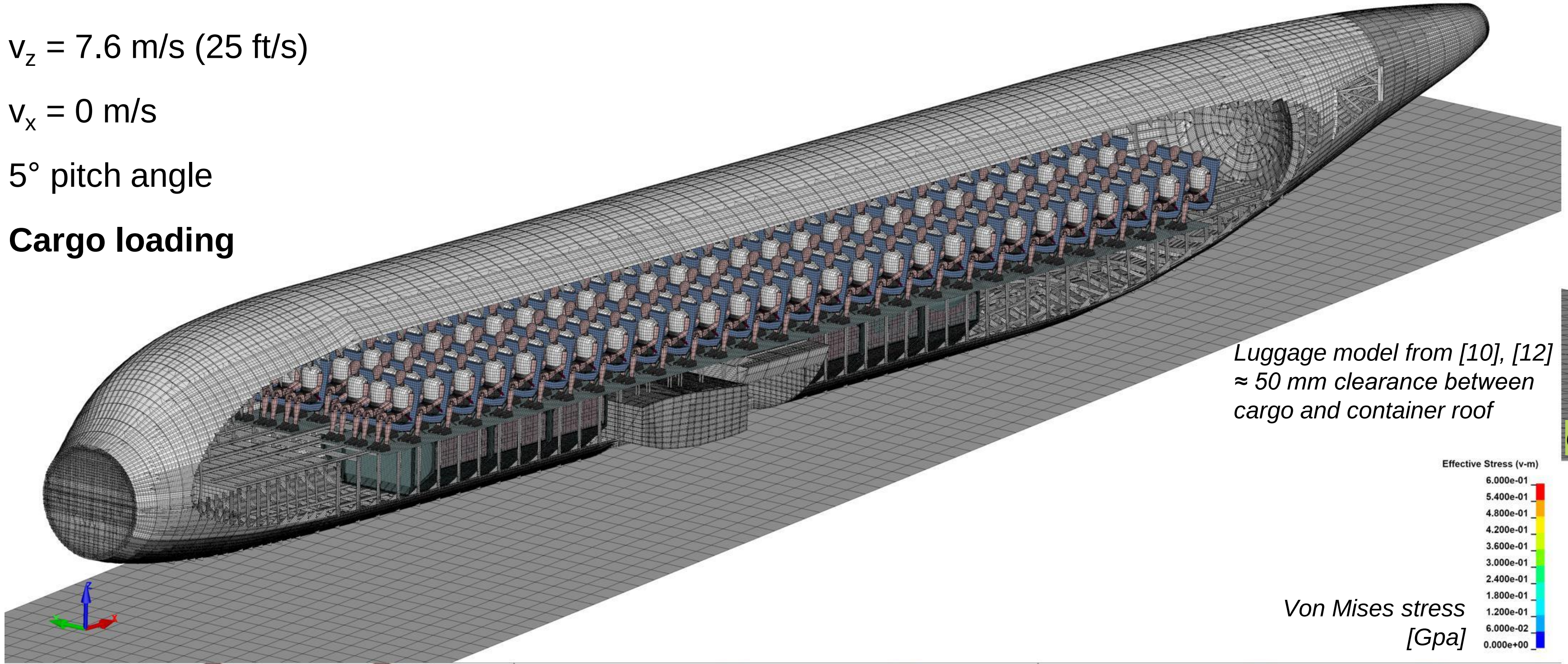


3 Method application (examples)

III) Vertical drop with pitch angle and cargo loading

Crash kinematics

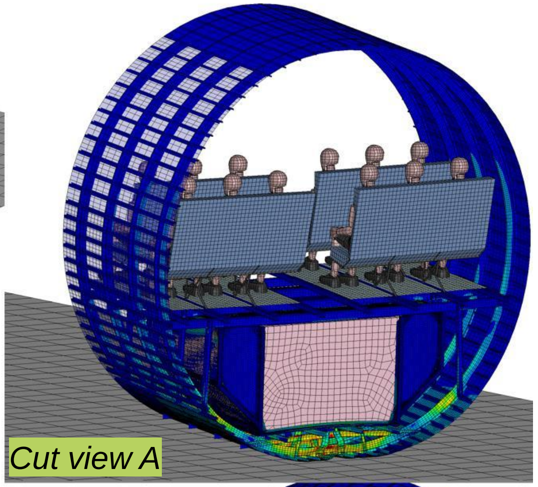
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**



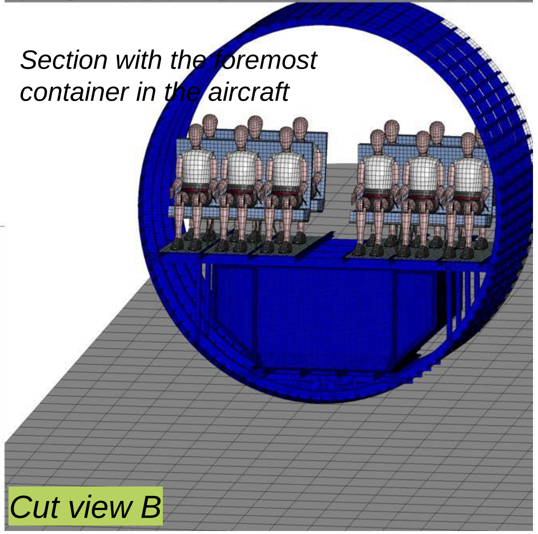
Luggage model from [10], [12]
≈ 50 mm clearance between cargo and container roof

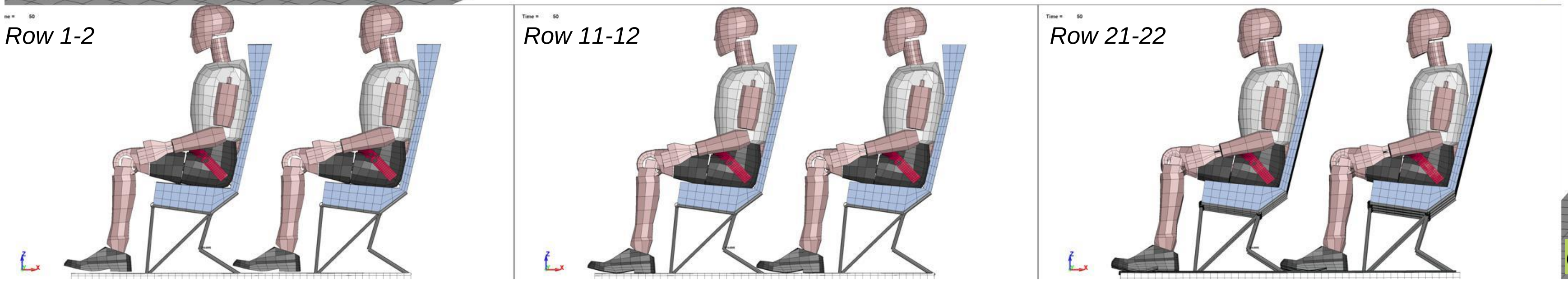
Von Mises stress [Gpa]

Section with the rearmost container in the aircraft



Section with the foremost container in the aircraft



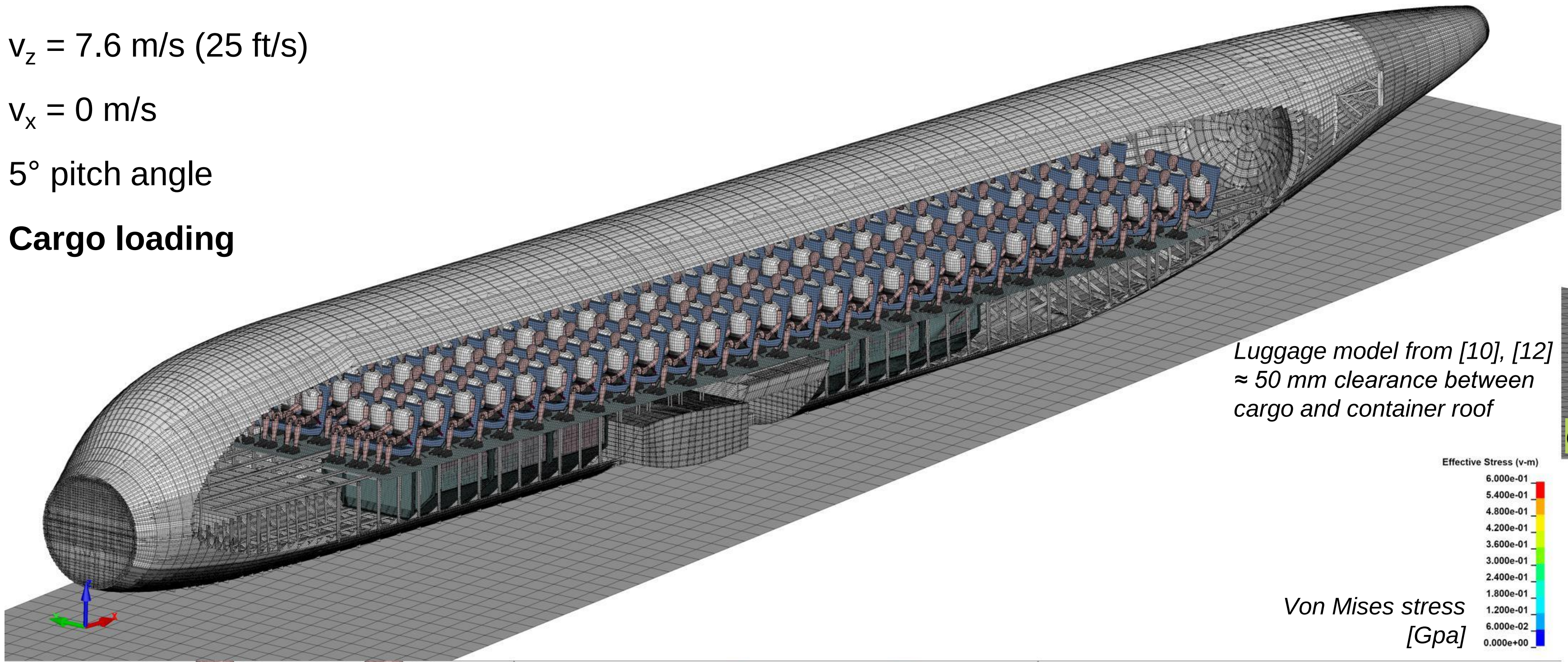


3 Method application (examples)

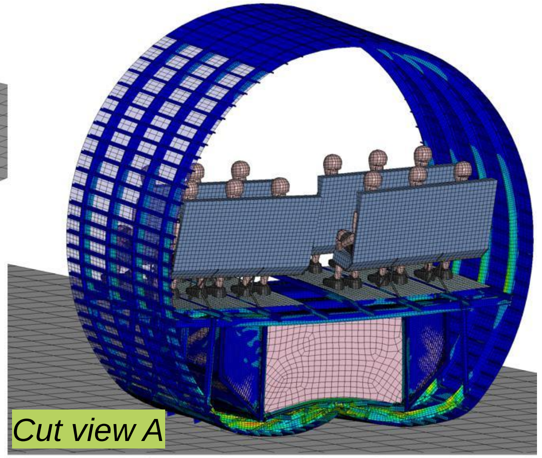
III) Vertical drop with pitch angle and cargo loading

Crash kinematics

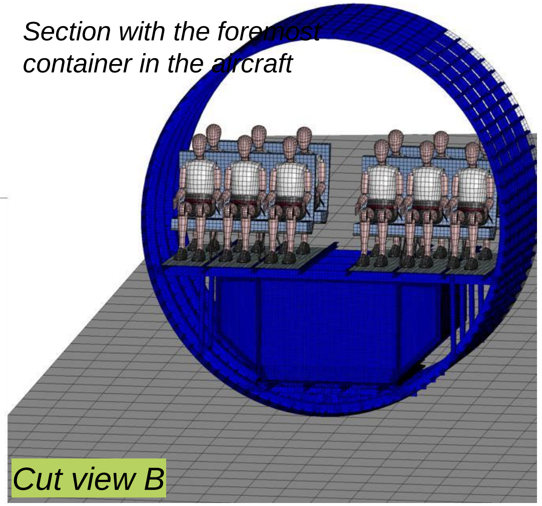
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**

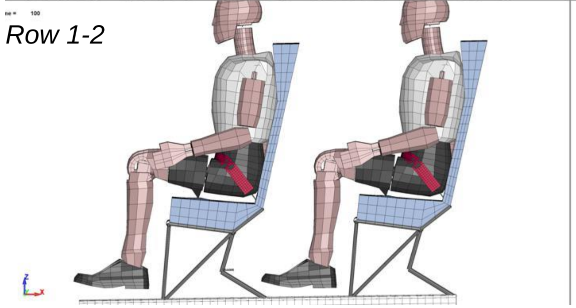


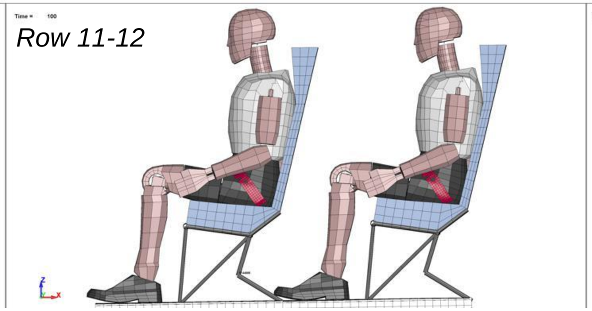
Section with the rearmost container in the aircraft

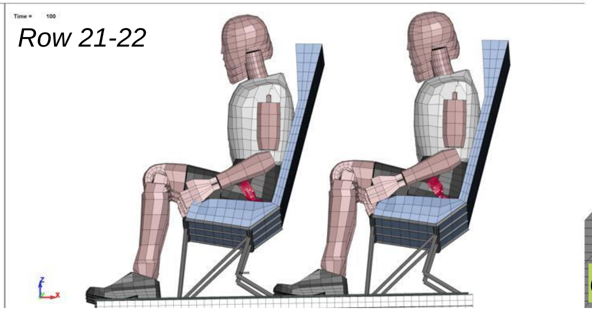


Section with the foremost container in the aircraft



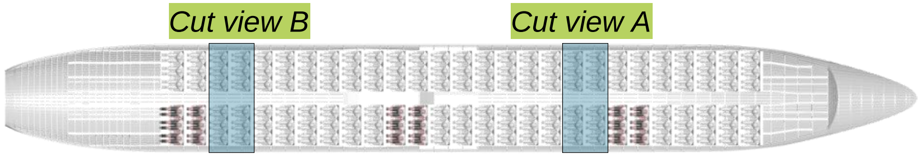






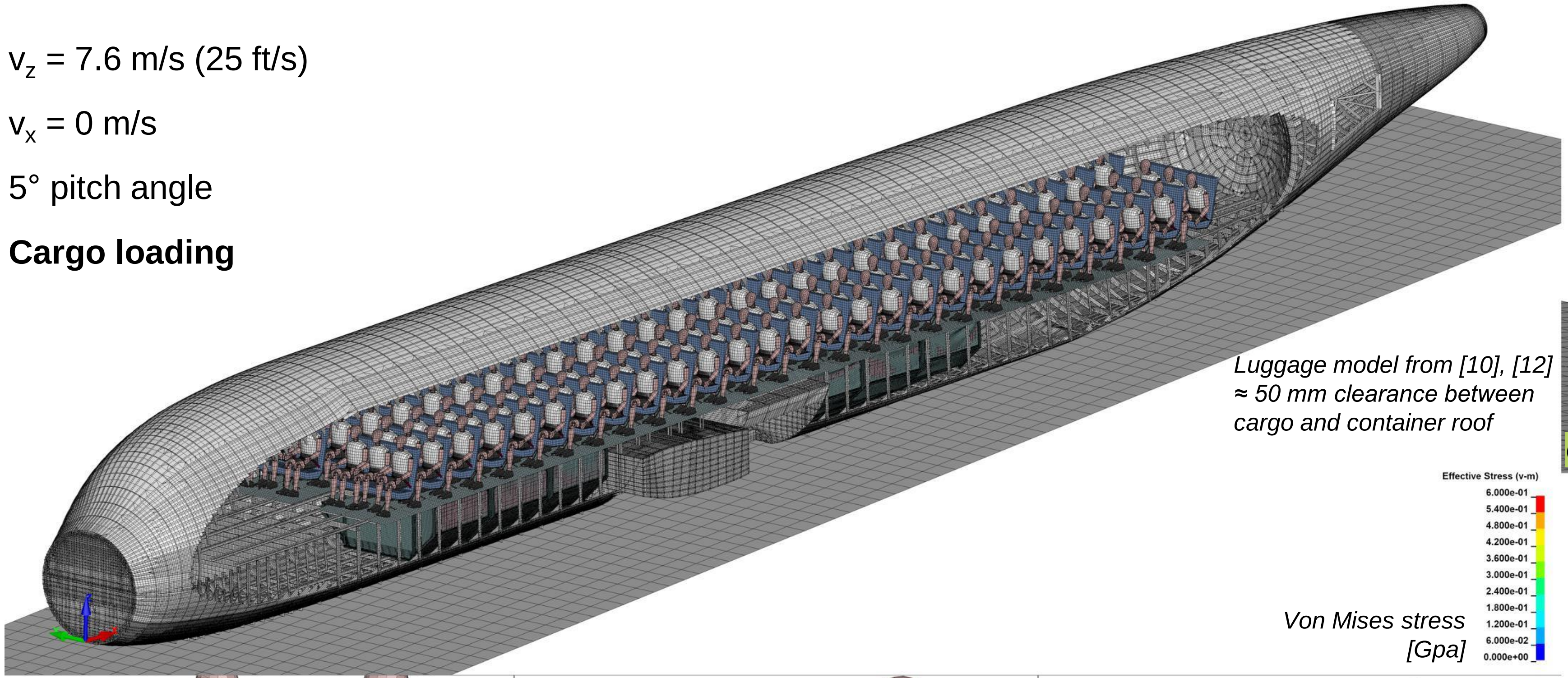
3 Method application (examples)

III) Vertical drop with pitch angle and cargo loading



Crash kinematics

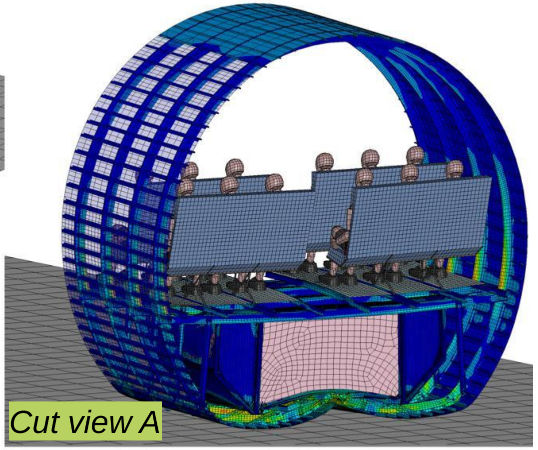
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**



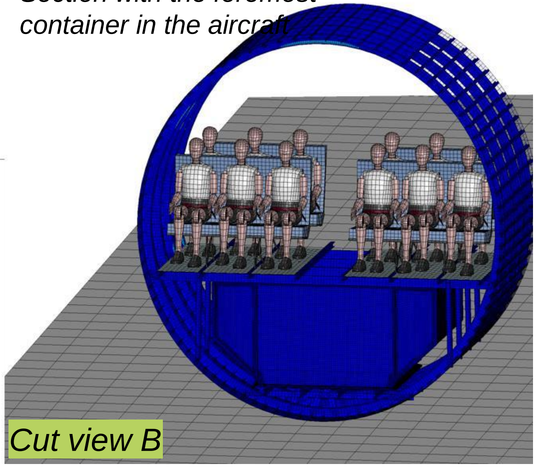
Luggage model from [10], [12]
≈ 50 mm clearance between cargo and container roof

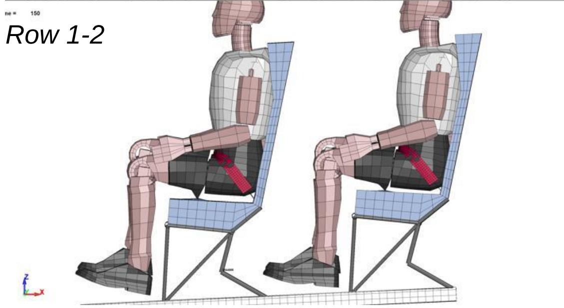
Von Mises stress [Gpa]

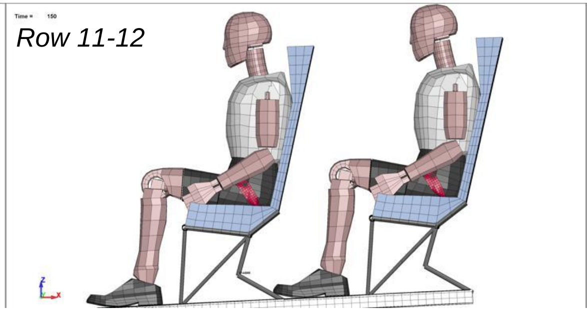
Section with the rearmost container in the aircraft

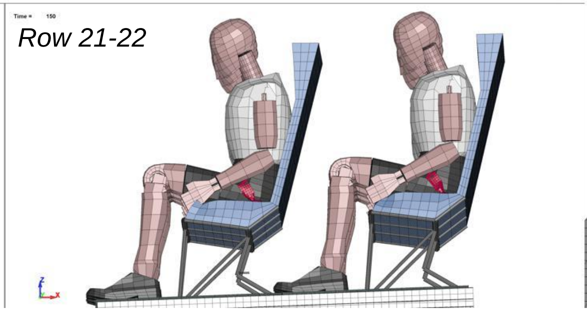


Section with the foremost container in the aircraft



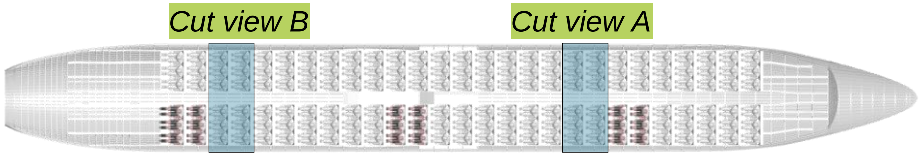






3 Method application (examples)

III) Vertical drop with pitch angle and cargo loading



Crash kinematics

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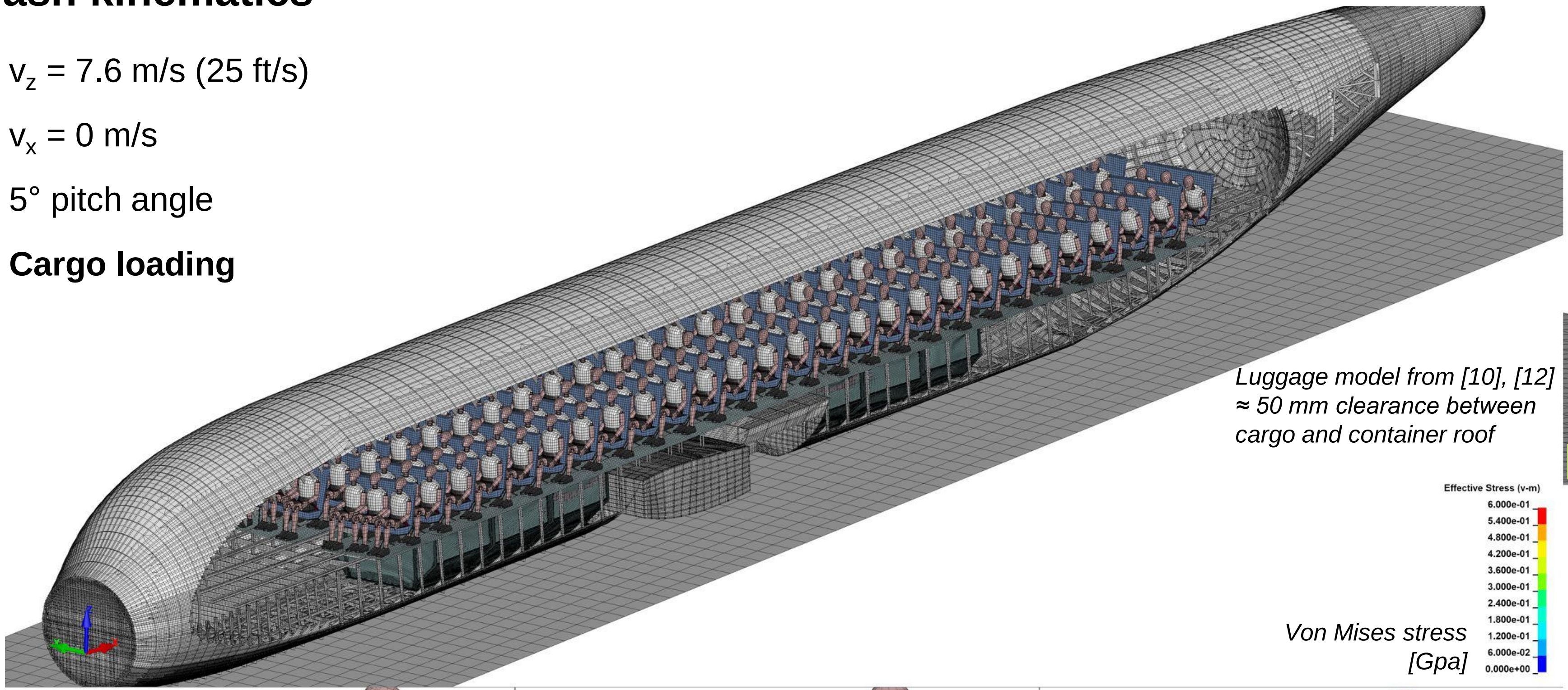
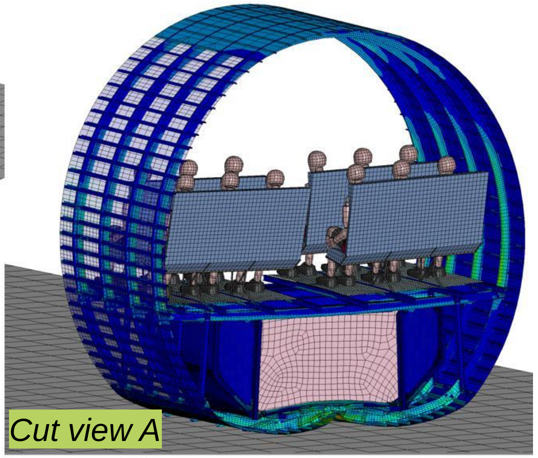
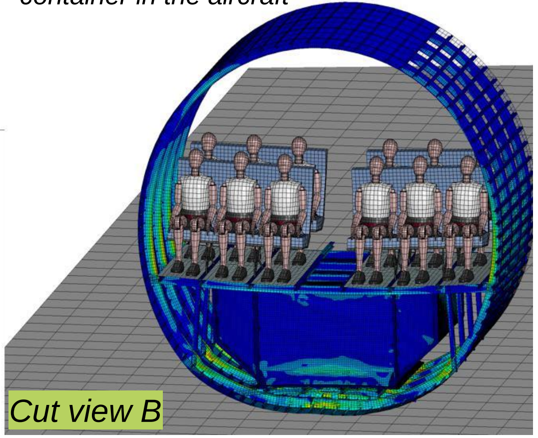
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**

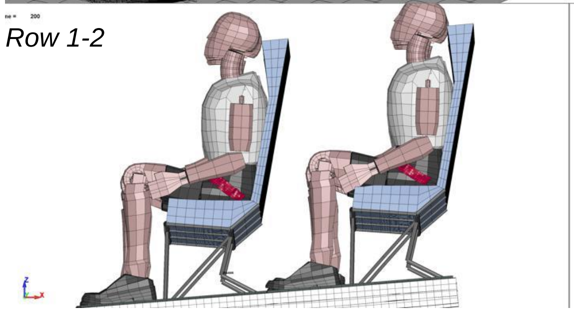


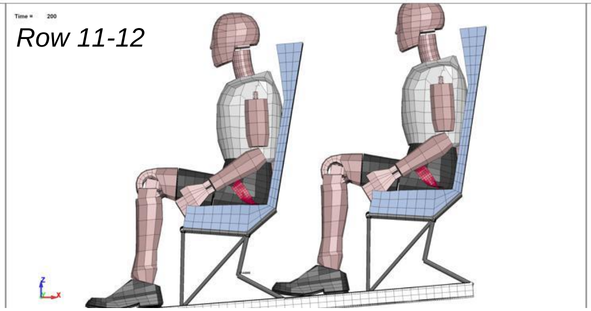
Section with the rearmost container in the aircraft

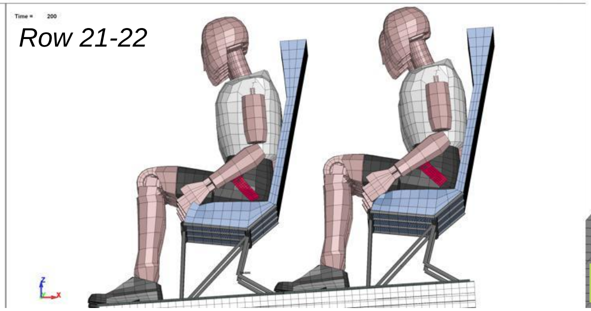


Section with the foremost container in the aircraft



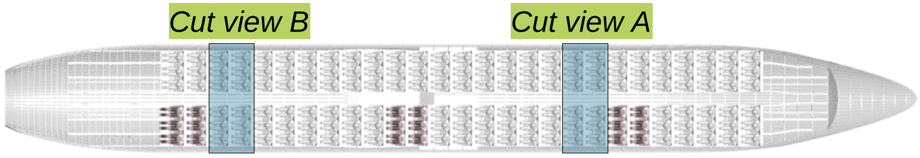






3 Method application (examples)

III) Vertical drop with pitch angle and cargo loading



Crash kinematics

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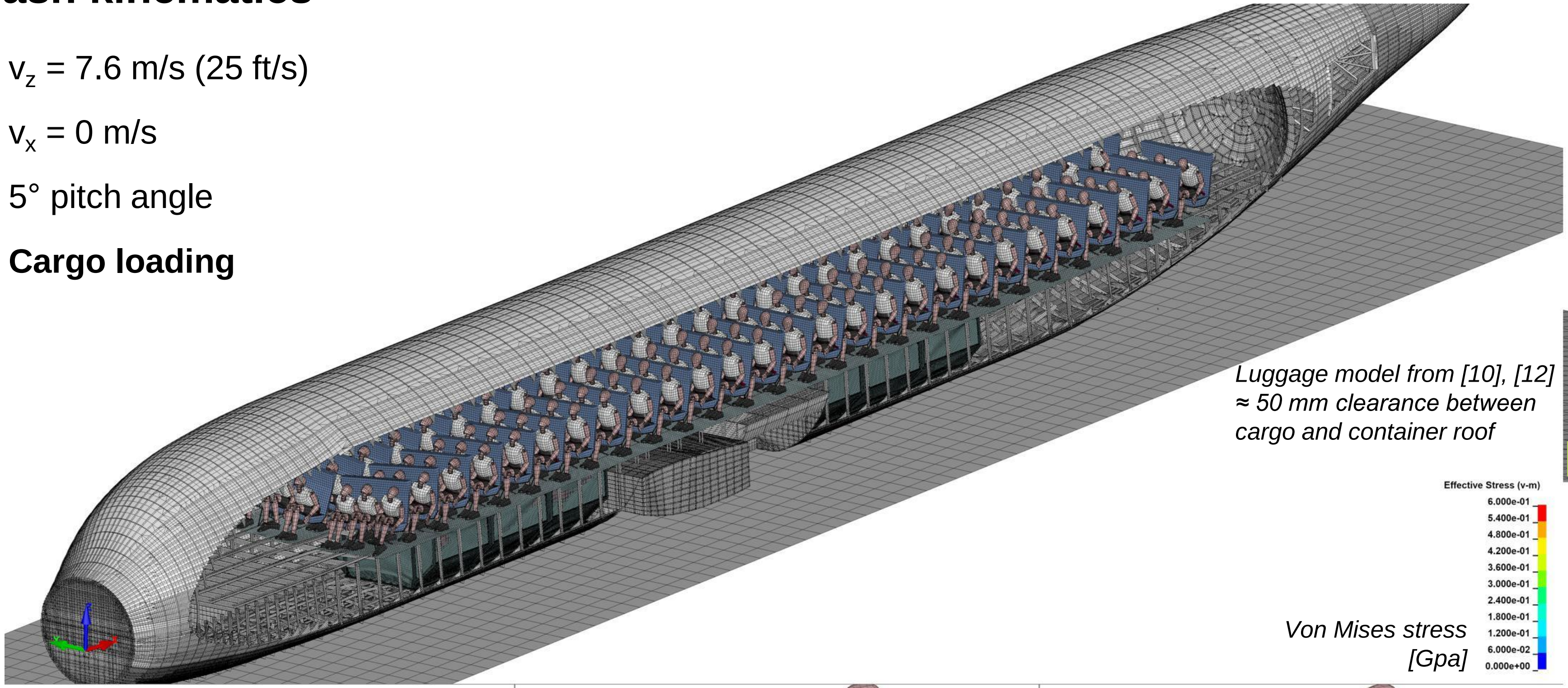
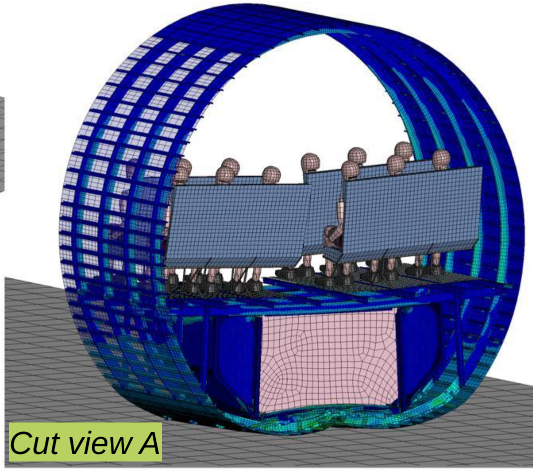
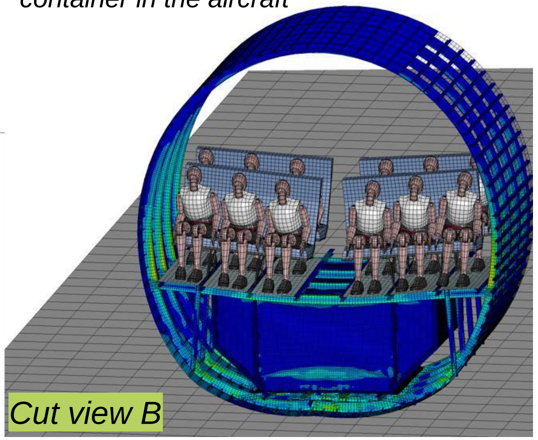
- 5° pitch angle
- **Cargo loading**

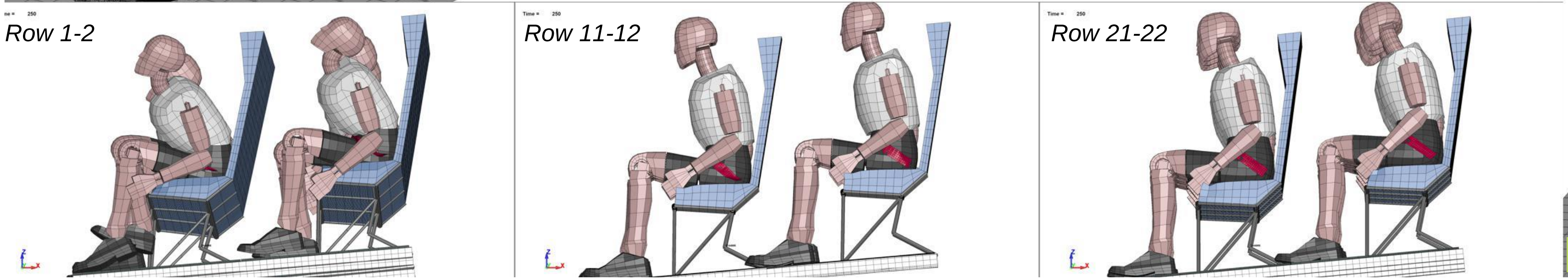


Section with the rearmost container in the aircraft



Section with the foremost container in the aircraft



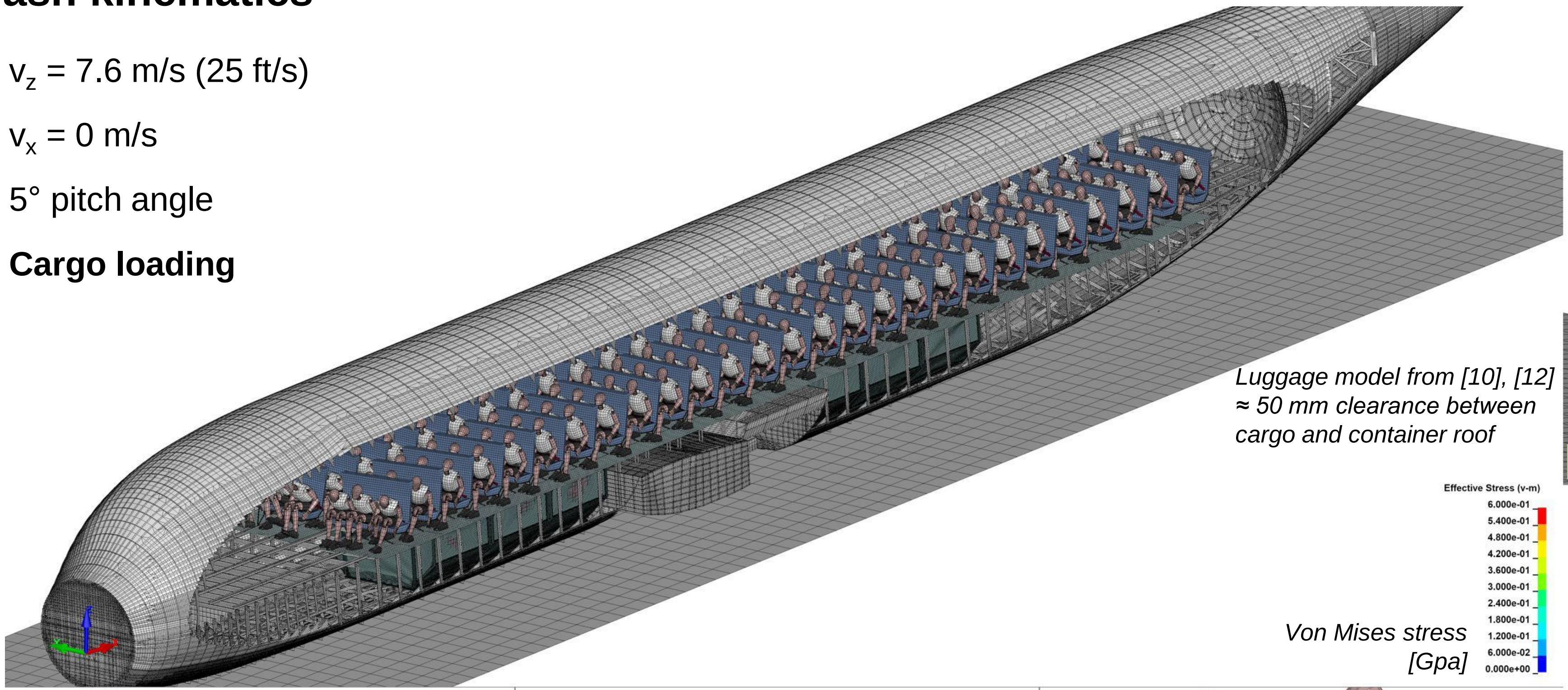


3 Method application (examples)

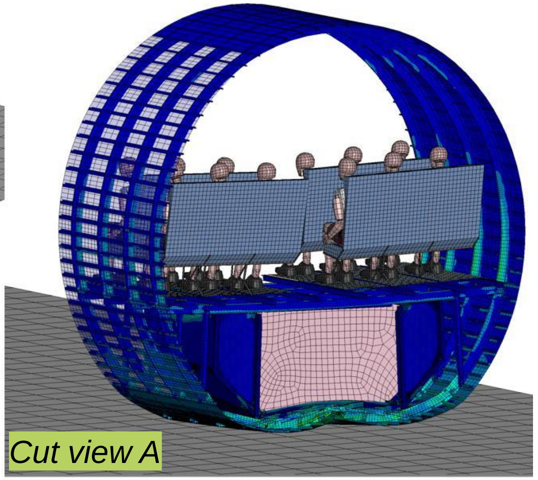
III) Vertical drop with pitch angle and cargo loading

Crash kinematics

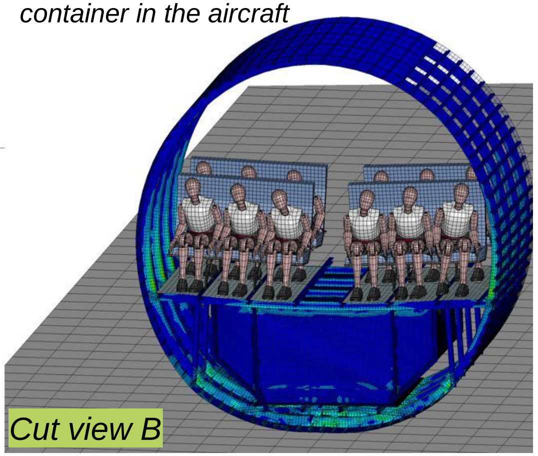
- v_z = 7.6 m/s (25 ft/s)
- v_x = 0 m/s
- 5° pitch angle
- **Cargo loading**

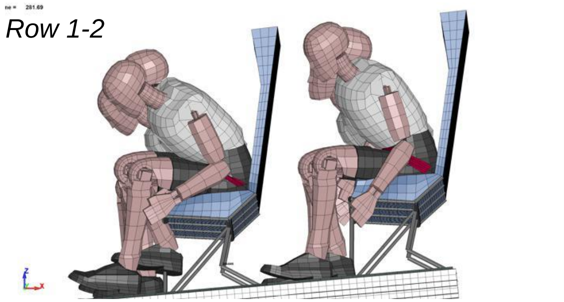


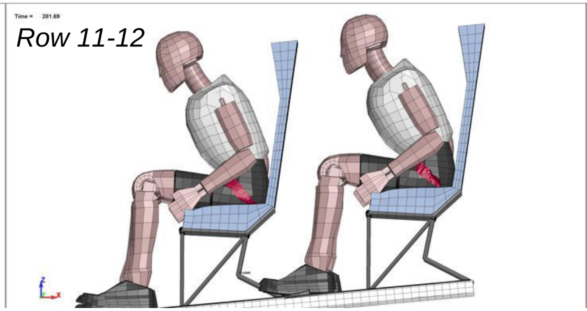
Section with the rearmost container in the aircraft

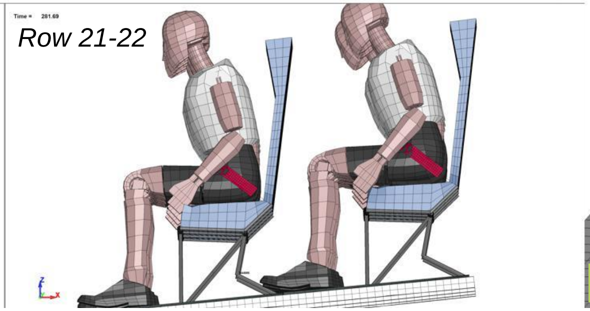


Section with the foremost container in the aircraft



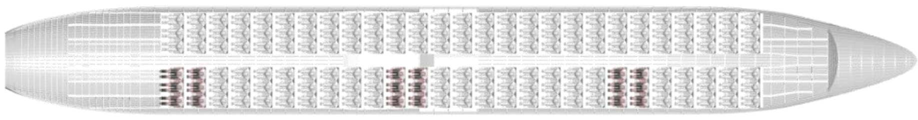






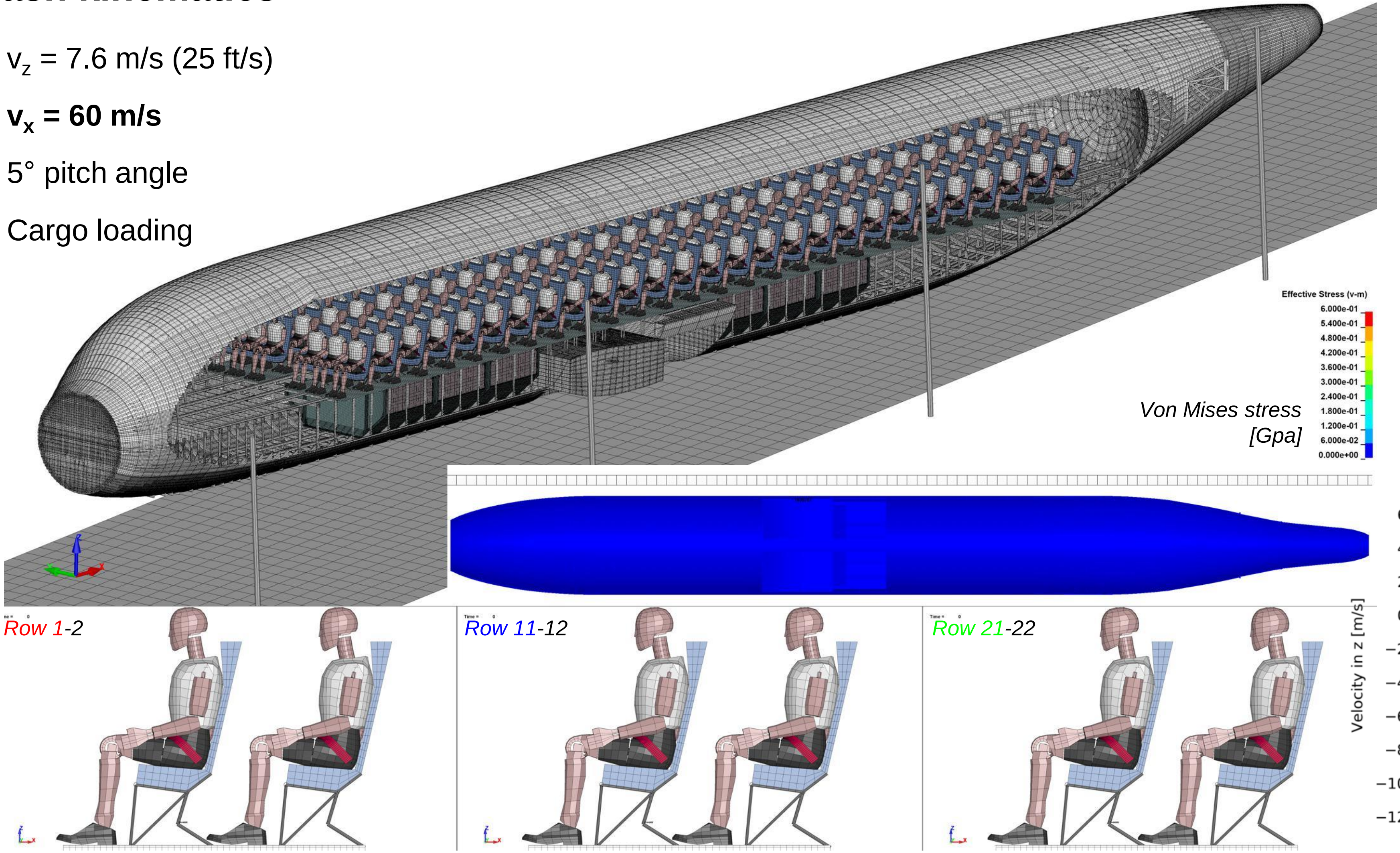
3 Method application (examples)

IV) Full aircraft xz-crash

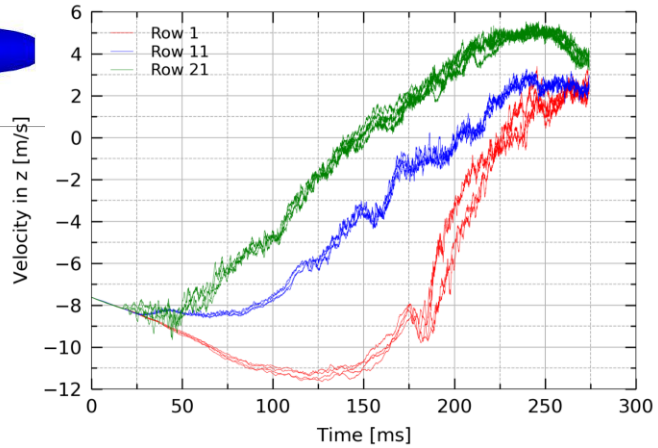


Crash kinematics

- v_z = 7.6 m/s (25 ft/s)
- **v_x = 60 m/s**
- 5° pitch angle
- Cargo loading

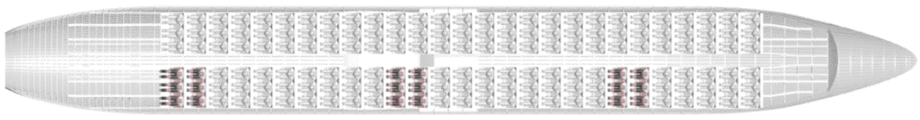


Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



3 Method application (examples)

IV) Full aircraft xz-crash



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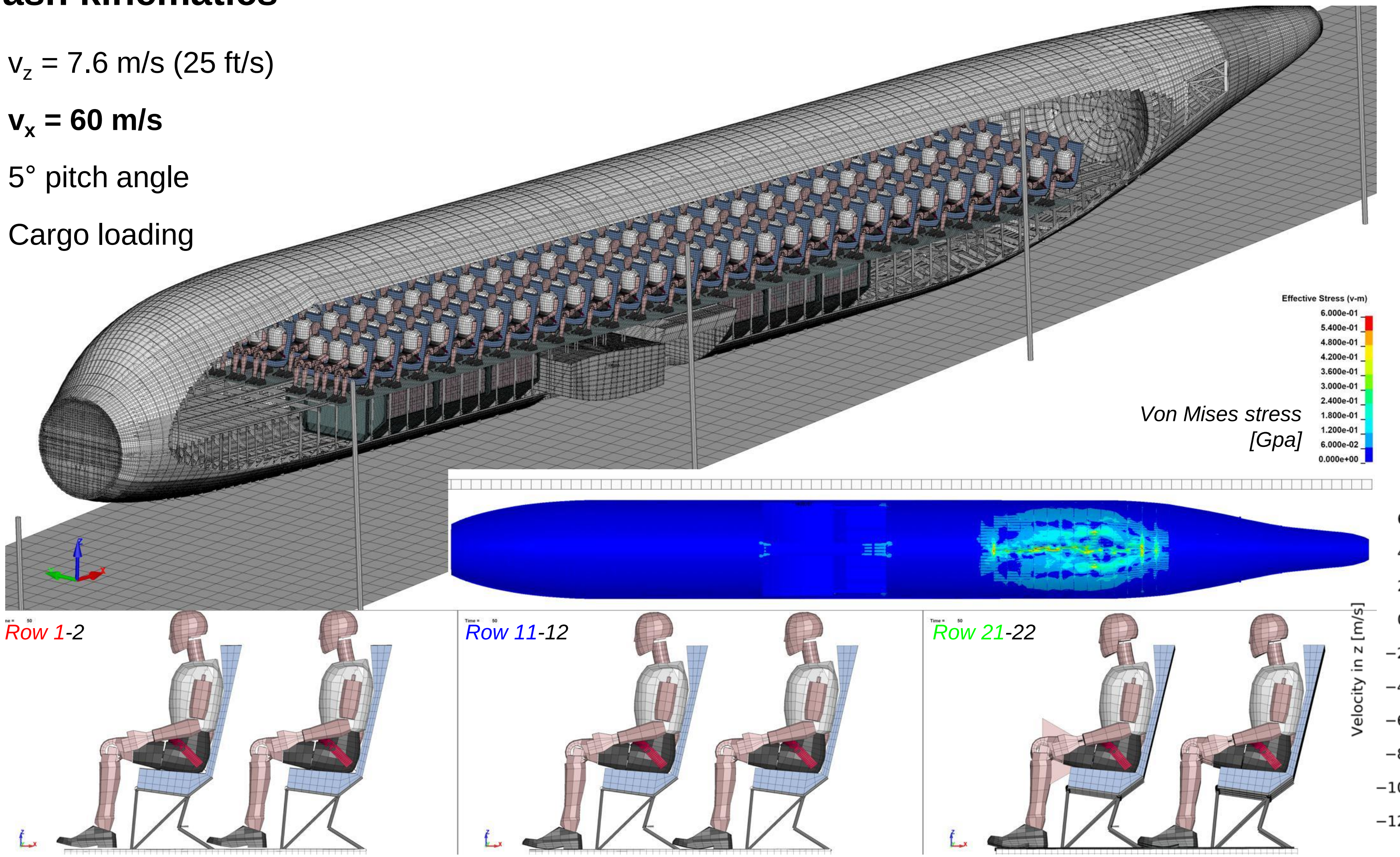
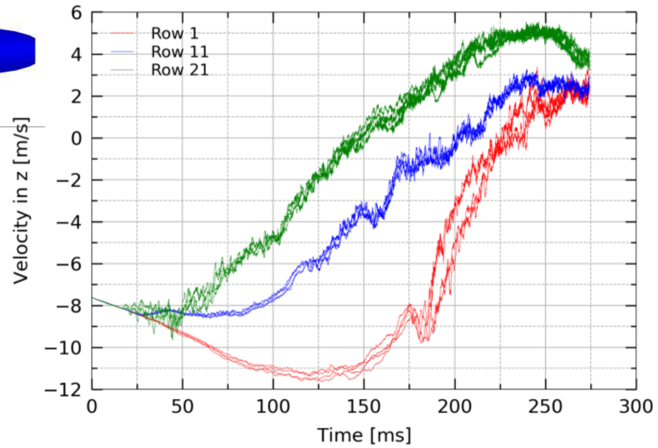


Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



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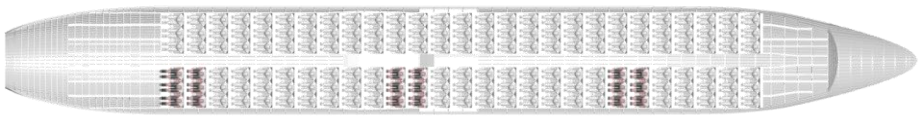

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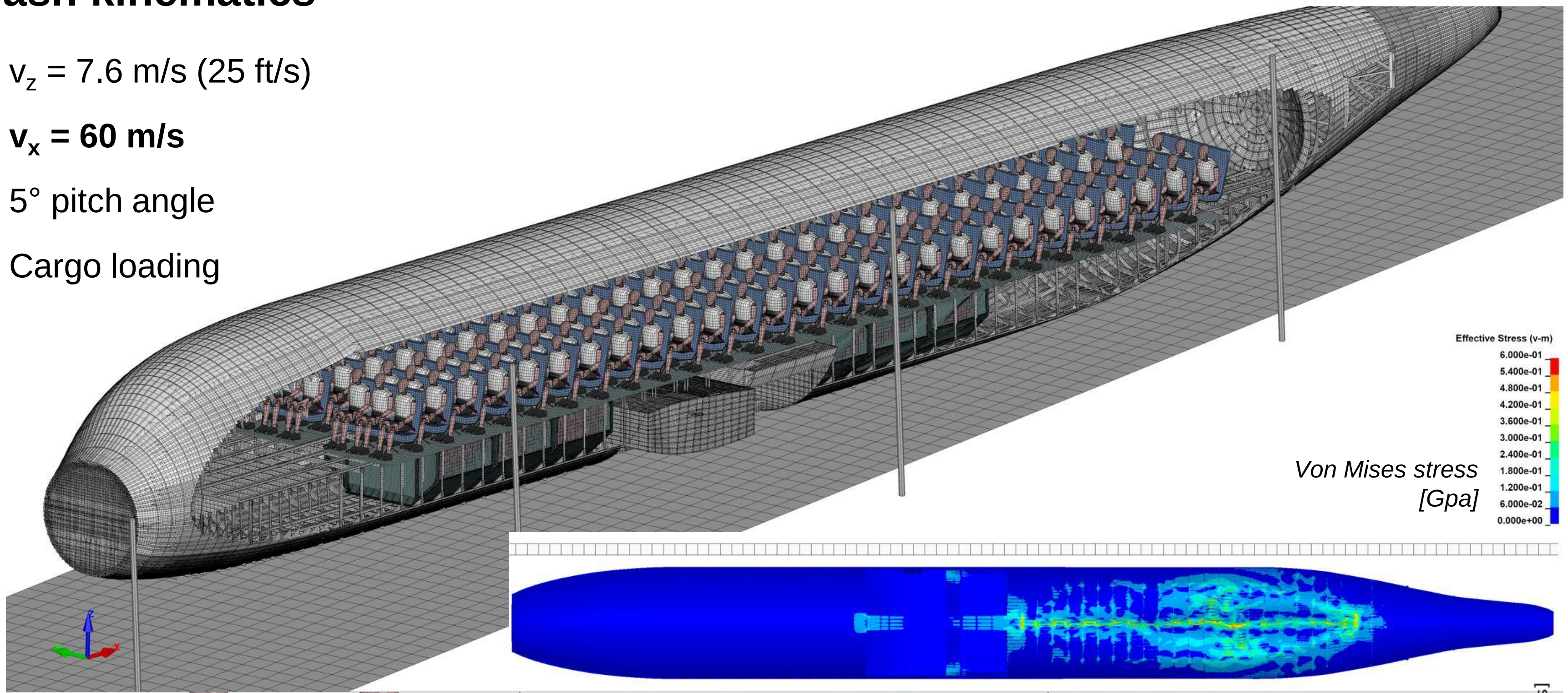

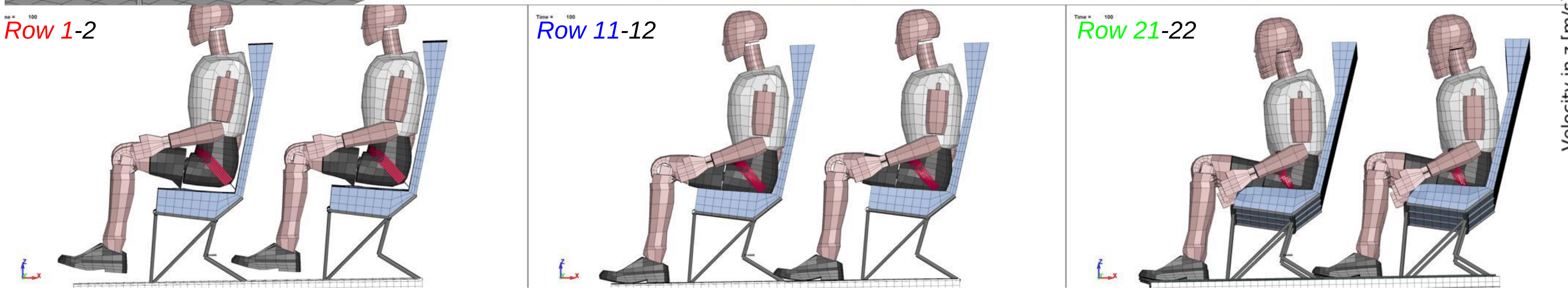

Seat foot local velocity
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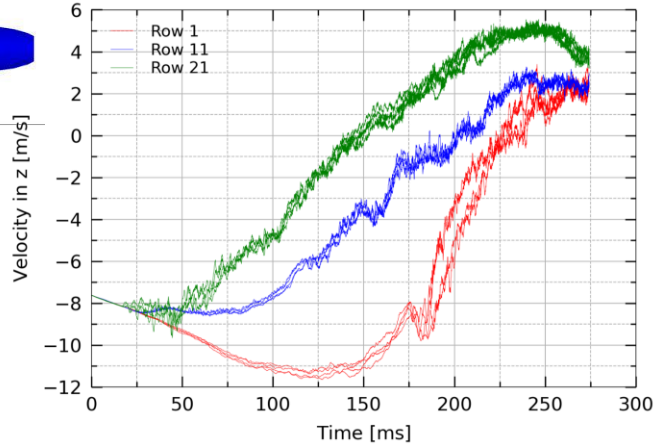
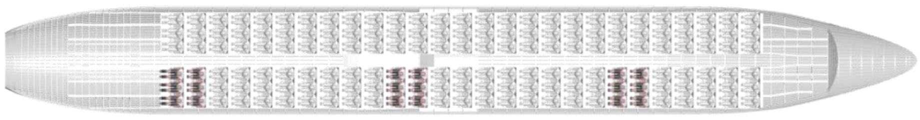


3 Method application (examples)

IV) Full aircraft xz-crash



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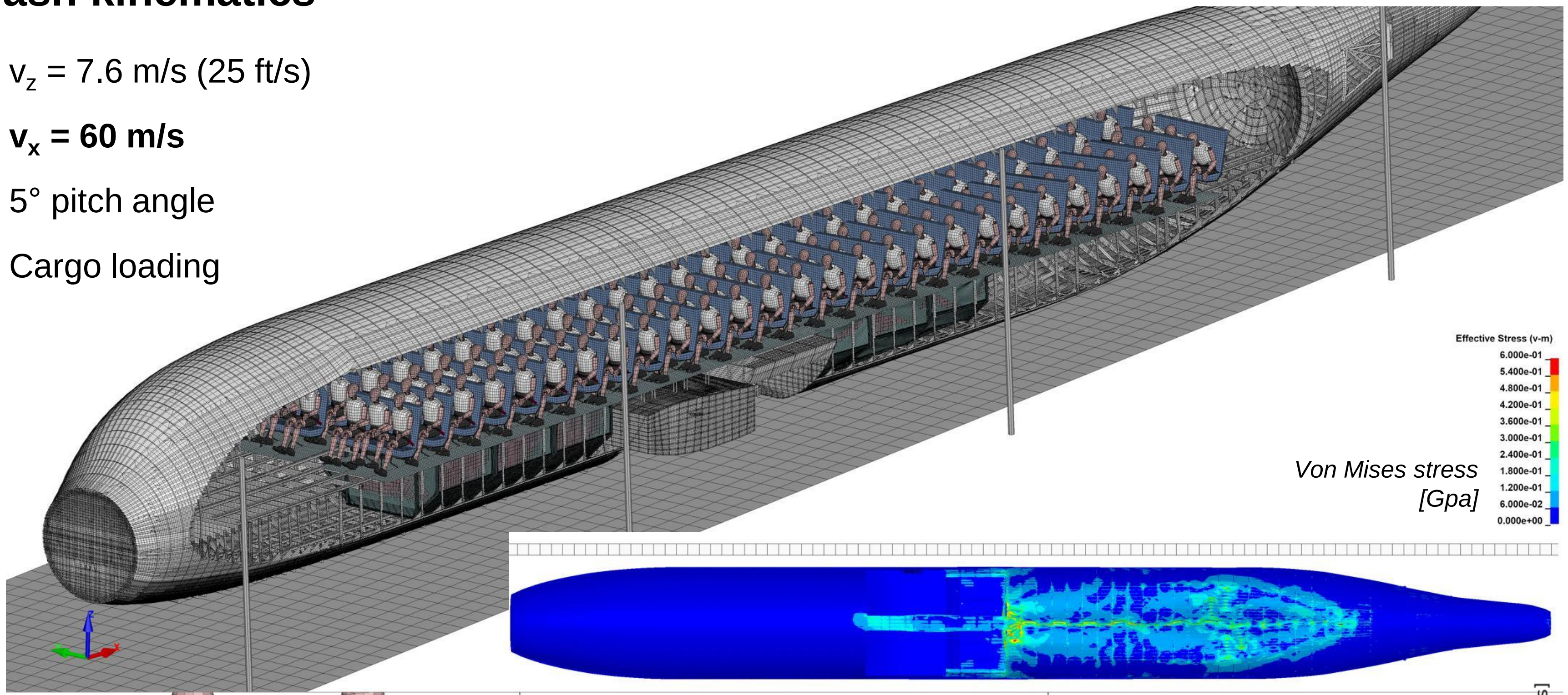
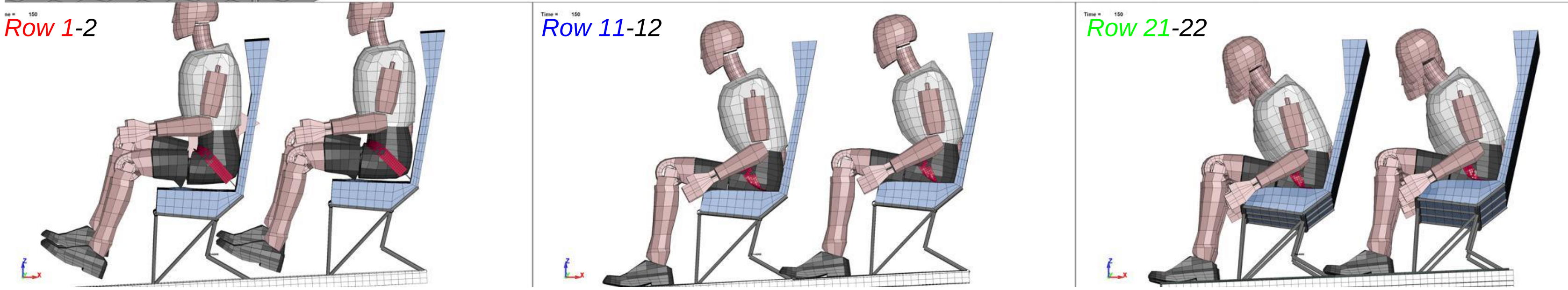
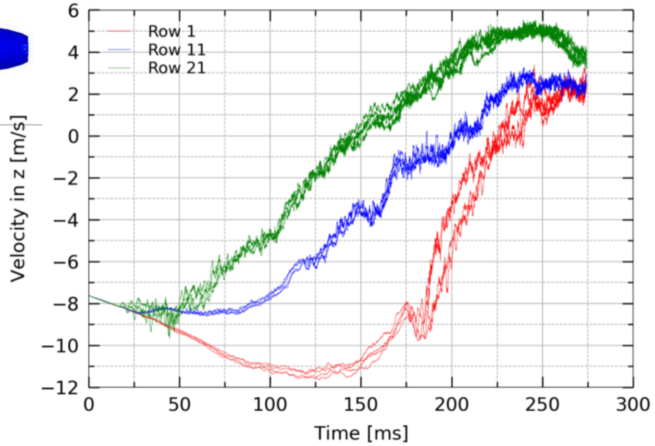


Von Mises stress [Gpa]



Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



3 Method application (examples)

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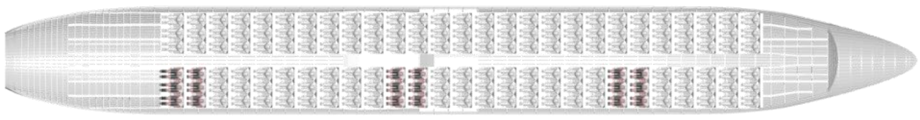

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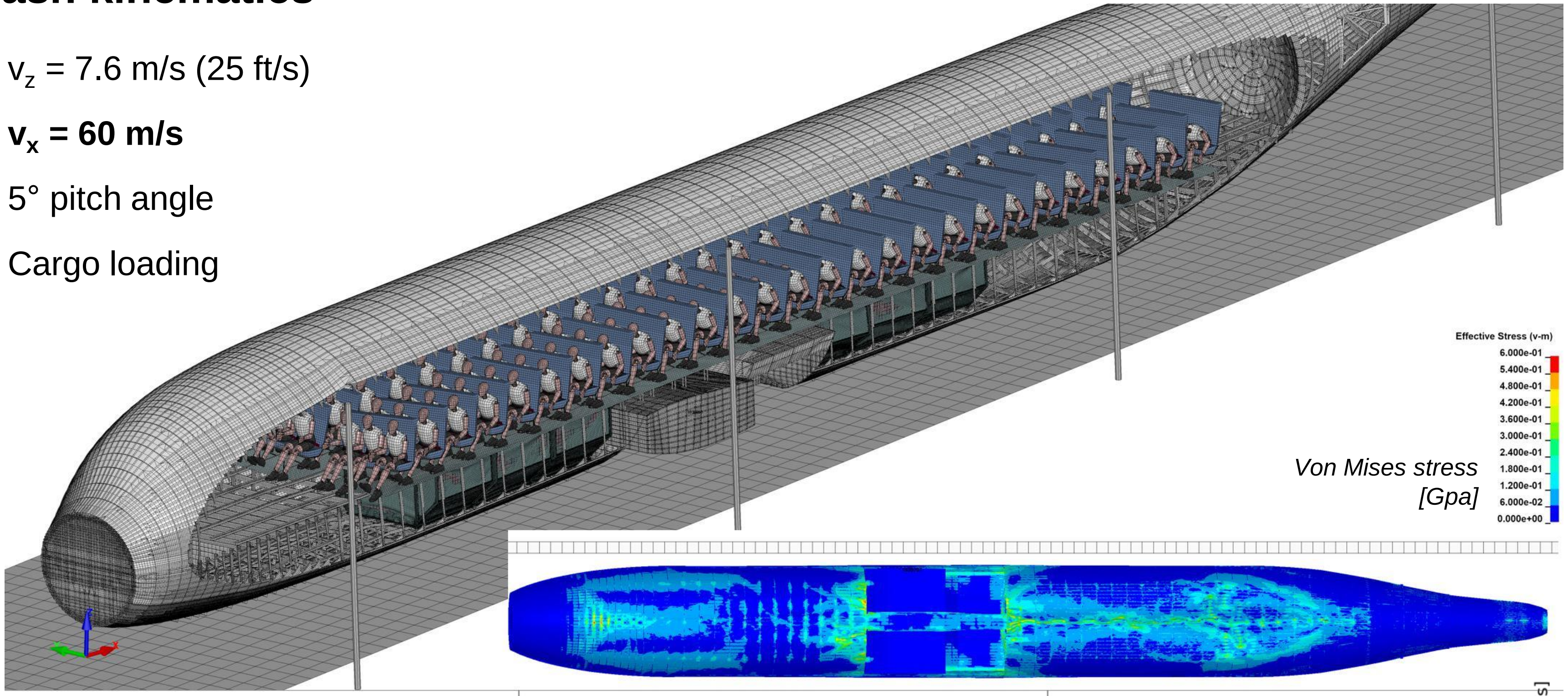
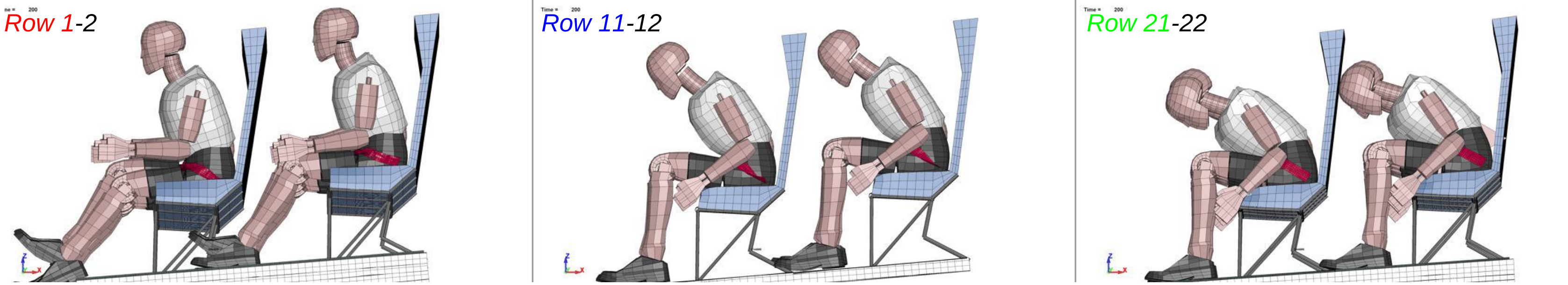
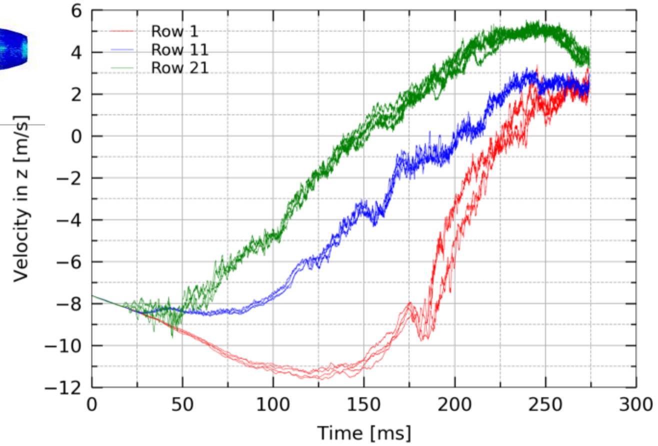


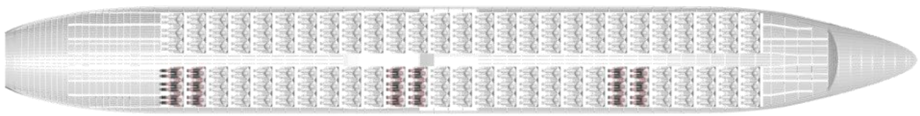


Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



3 Method application (examples)

IV) Full aircraft xz-crash



Crash kinematics

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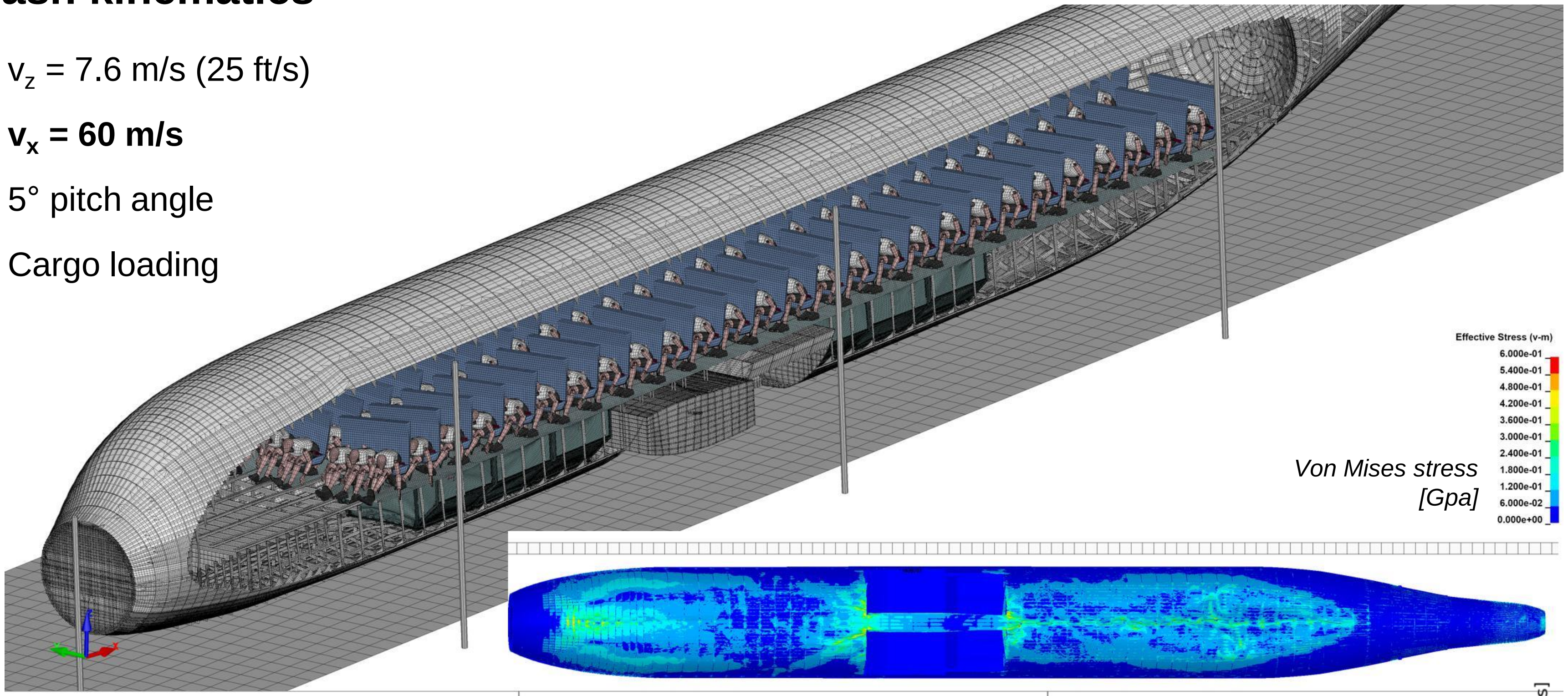
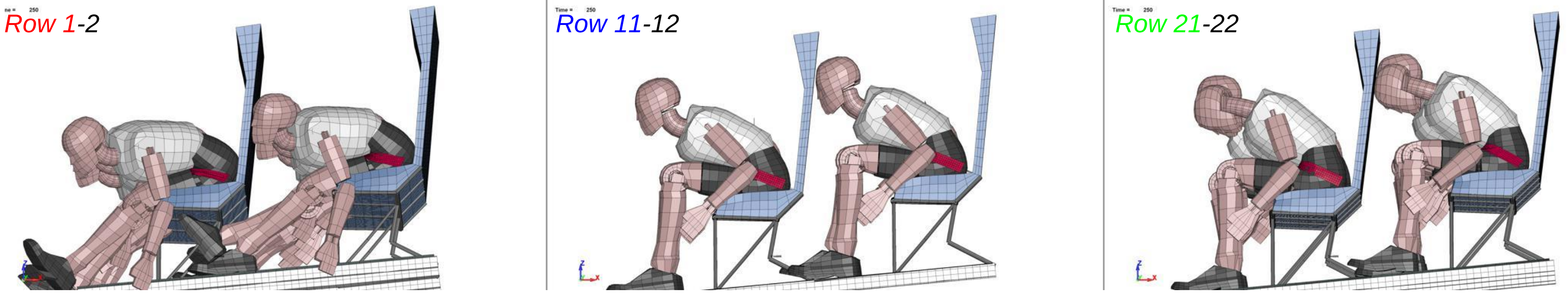
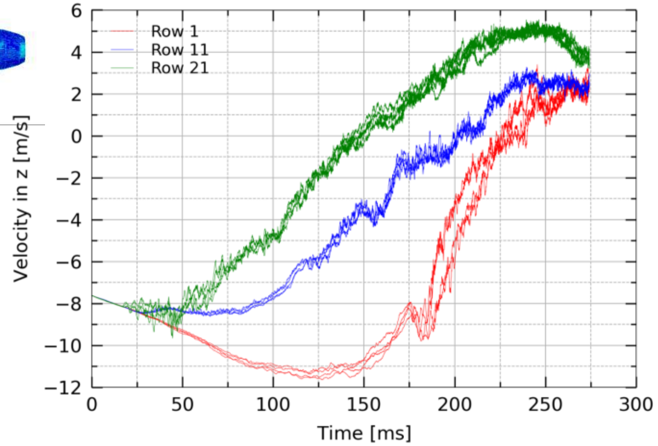
- Cargo loading



Von Mises stress [Gpa]

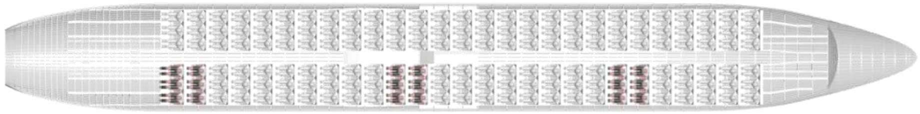


Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



3 Method application (examples)

IV) Full aircraft xz-crash



Crash kinematics

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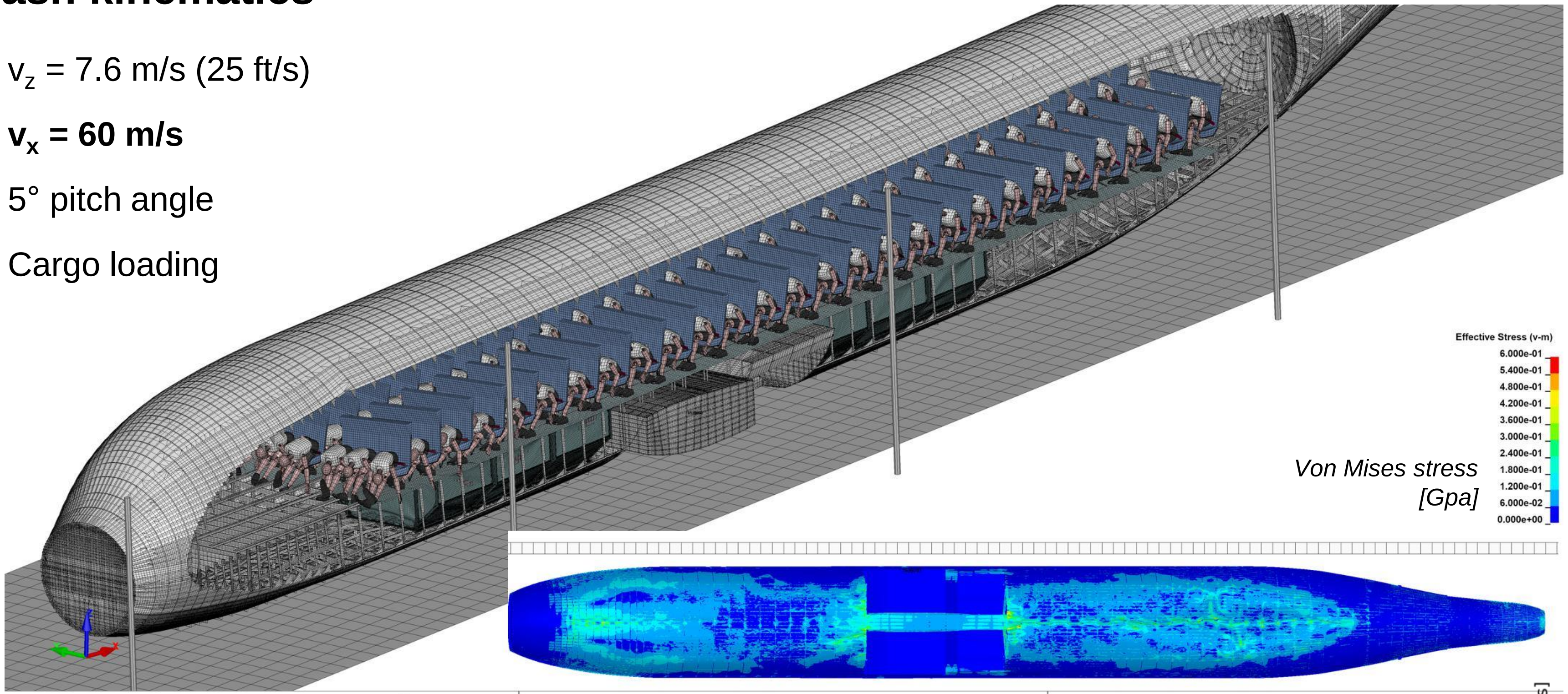
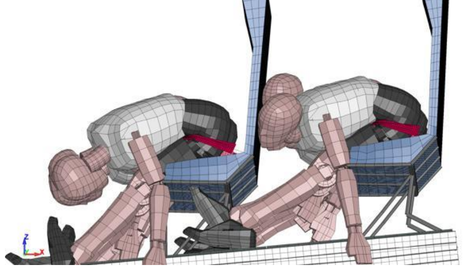
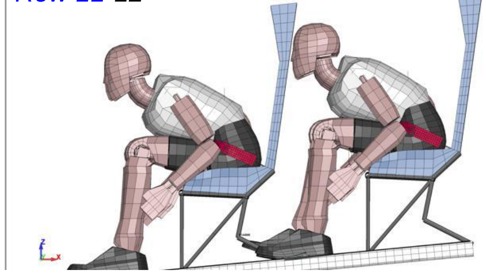


Von Mises stress [Gpa]

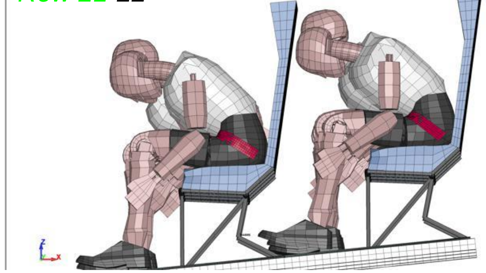
Row 1-2



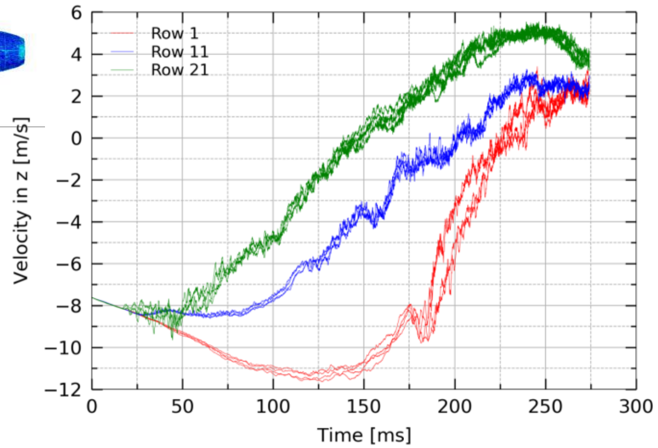
Row 11-12



Row 21-22



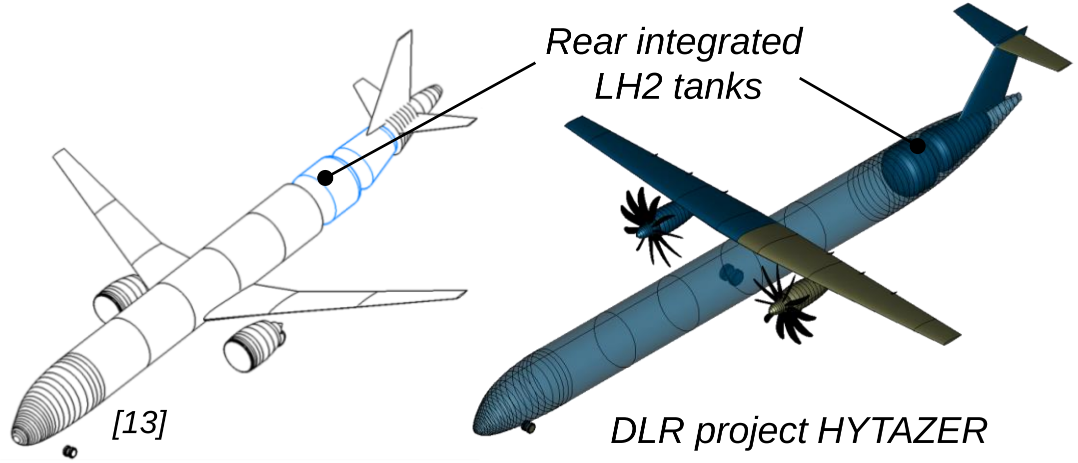
Seat foot local velocity
Row 1, Row 11, Row 21
Left side in flight direction



3 Method application (examples)
V) Crashworthiness assessment of novel aircraft configurations

Crashworthy LH2 tank integration

- Assessment of LH2 tank installation locations with respect to real-world crash loads and effects
  - Fuselage break
  - Retention of tank mass
- Assessment of LH2 tank integration with respect to real-world crash loads and effects
  - Crashworthy tank mounts
- Determination of local crash loads from full aircraft crash simulation
  - Detailed development of crashworthy LH2 tank integration
  - Iteration of full aircraft crash simulation and more detailed local analysis (e.g. fuselage section or structural detail)

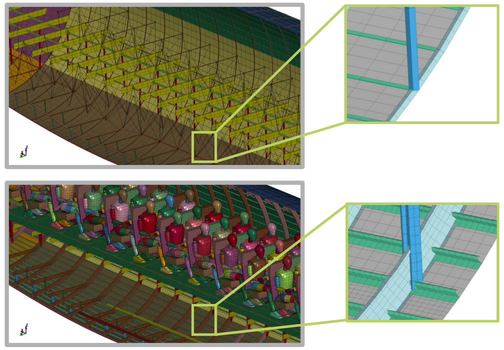


[13] D. Silberhorn, G. Atanasov, J.-N. Walther, and T. Zill, "Assessment of Hydrogen Fuel Tank Integration at Aircraft Level," presented at the Deutscher Luft- und Raumfahrtkongress 2019, Darmstadt, Deutschland, 2019. Available: https://elib.dlr.de/129643/

Summary

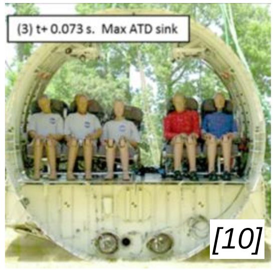
Motivation: Full aircraft crash simulation as a research goal at DLR

1 Method development

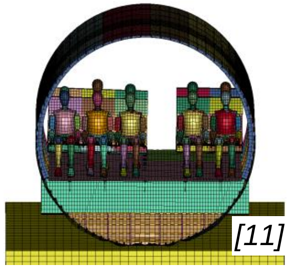


- Aircraft structure description by CPACS file format (https://cpacs.de/) [2]
- Aircraft structure generation at different levels of model fidelity by PANDORA tool [3]
- Development of individual modules for occupants [5], [6] , cargo [7], [8], masses, impact terrains, etc.

2 Method validation



[10]

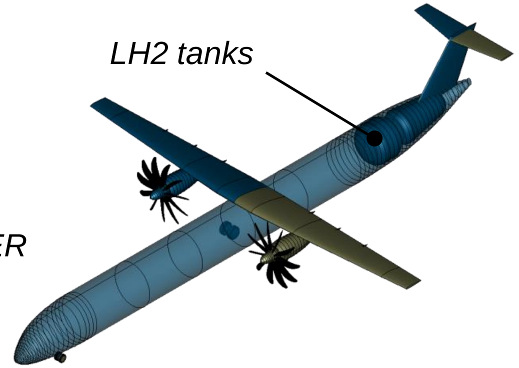

[11]

- Ongoing method validation based on available experimental data [11], [12]

3 Method application

- Crash simulation of a generic single-aisle aircraft at different levels of model fidelity: low fidelity modeling [9] and high fidelity modeling
- Future work: Assessment of new aircraft configurations such as aircraft with rear integrated LH2 tanks

LH2 tanks



DLR project HYTAZER

Thank you for your attention!

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