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Parametric Occupant Safety Assessment into the Aircraft Preliminary Design Process Chain

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Abstract
Designing a new aircraft is a complex multidisciplinary process. The German Aerospace Center (DLR) has established a process chain for aircraft design, combining the expertise of its various institutes. This collaborative aircraft development relies on the Common Parametric Aircraft Configuration Schema (CPACS) to streamline the exchange of design data and results and increasingly detailed aircraft models within different institutions focusing on diverse aspects of aeronautics.
The Institute of Structures and Design plays a key role in the design process, contributing to crashworthiness and structural design. The internally developed Python tool PANDORA (Parametric Numerical Design and Optimization Routines for Aircraft) represents the interface with the design process chain, thanks to the generation of complex multi-fidelity Finite Element (FE) models based on the aircraft CPACS definition.
A novel challenge in aeronautic crashworthiness assessment emerges with non-conventional cabins. For such configurations, the passenger safety requirements may directly affect the structural design, urging to consider crashworthiness already in the preliminary design phase.
To meet this need, PANDORA is enhanced to automatically extend the generated FE fuselage models with the cabin environment and dummy models. As a result, a full-scale aircraft model can be rapidly generated based on its parametric CPACS definition and run in the dynamic solver LS-DYNA. Finally, injury criteria and outputs of interest can be automatically post-processed by PANDORA, enabling a flexible iterative procedure for crashworthiness assessment. The automatic strategy used to model primary structures is numerically validated, while the integration of dummies is based on an experimentally validated methodology. The newly established process chain is shown together with some preliminary results.
The modelling methodology is characterised by a fully parametric approach, to enable comprehensive parametric studies and optimisations typical of early design phases. In particular, the implementation is intended as a first step towards the development of a broader methodology for the Uncertainty Quantification (UQ) of occupant safety criteria. The outcome of the UQ methodology is expected to provide crucial safety insights and increase the design robustness, within the wide design space and inherent uncertainties of the pre-design phase. The ultimate goal is to accelerate the development of innovative aircraft configurations by fostering a deep understanding of their safety implications.

1. Introduction

Environmental sustainability is one of the top concerns of the global aviation industry, along with safety [1]. The sector aims for a net-zero CO_2 emissions goal by 2050 [2], incentivising the transition from traditional aircraft designs to innovative, sustainable solutions. This disruptive shift encompasses every discipline of aeronautics, ranging from electric propulsion and high-efficiency wings, to lightweight materials, high-density cabins and blended wing body configurations [3, 4].
Fuselage design combines several disciplines, impacting structural integrity, systems layout, manufacturing, and passenger comfort. For transport aircraft, the fuselage plays a central safety role by limiting dynamic loads experienced by occupants during emergency landings through specific structural deformation. Due to its significant implications and interdependencies, the crash load mitigation should be addressed in the early design of the cabin, to prevent costly modifications at a later, more detailed design phase [5].
Historically, occupant safety of traditional aircraft configurations has been addressed separately from the airframe structure, with a behaviour inferred from tests and accident data [6]. The certification processes for traditional aircraft

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require the application of standardised acceleration pulses to the seat structure (e.g., EASA CS-25.562) [7–10]. However, since 2017, the Certification Specifications for small aircraft (CS-23) have adopted a global approach, evaluating the combined crash performance of seats integrated with the airframe [11]. Similarly, new transport aircraft with unconventional features have to meet tailored certification requirements, known as Special Conditions. These conditions were created for innovative aircraft, such as Boeing B787-8 [12] and Airbus A350–900 [13], due to their composite fuselage structure, for which the applicable airworthiness regulation was not considered adequate. The regulator defined additional safety standards to establish a level of safety equivalent to the existing standards for traditional configurations [12, 13].
The need for advanced numerical tools to support the development and certification process becomes increasingly evident, considering the limited data obtainable from full-scale tests, and their prohibitive cost [14].
Ultimately, such a complex design process involves several conflicting objectives and requirements across different disciplines that need to be fulfilled. Structural topics, such as occupant safety requirements and structural weight goals, shall be integrated into this network to compute a solution that considers the overall system performance as well as all its interdependencies.
The DLR Institute of Structures and Design (BT) is developing advanced modelling techniques to simulate crash scenarios for transport aircraft, aiming to understand the unique crash dynamics of innovative configurations, including the emerging green aviation concepts. This paper describes the new features of the process chain for the automatic generation of full-scale finite element (FE) models of aircraft cabins, enabling global safety evaluations within the DLR preliminary design process chain.

2. Process chain for aircraft design

The design of a novel aircraft is an interconnected multidisciplinary task, involving mutually dependent disciplines. The first step of this process, so-called conceptual design, is characterised by the study of a large number of design trade-off studies with tight multidisciplinary connections. Then, during the following preliminary design, more detailed calculations are performed to define the layout and general dimensions of the aircraft. Both the conceptual and preliminary phases are iterative processes, where the level of detail of the new concept increases at each iteration. Because of the strongly integrated nature of the aircraft design, potential improvements achieved in individual disciplines may be reduced or even eliminated by the effects of the integration between different fields. This interdependence increases the size and complexity of the design space, which is further affected by time and resource constraints. This challenge demands a radical digital transformation, based on highly automated tools integrated into a virtual design chain able to consider in parallel all aspects of the Multidisciplinary Design Optimisation (MDO) problem and aim for its optimal solution.
The Methodology described in the paper finds its application in the definition of a fuselage structure during the preliminary design phase. An aircraft design process chain is established at DLR, where various specialised institutes and external organisations work together to define novel configurations to fulfil ever-evolving missions, environmental and certification requirements. The Institute BT contributes with its expertise in structures and crashworthiness, designing lightweight fuselage structures capable of withstanding regular flight loads, as well as ensuring the safety of occupants in case of an emergency landing.
This work is part of the DLR initiative to bring together the disciplines involved in cabin design and develop the interconnected digital toolchain necessary for the design of modern, highly integrated cabins and the fulfilment of ever-evolving safety, comfort and environmental requirements. In this framework, the Institute of Structures and Design has enhanced its internal tool, named PANDORA (Parametric Numerical Design and Optimisation Routines for Aircraft) [15], towards the automatic generation of the fuselage structure, completed with the cabin environment.
The following section gives an overview of the PANDORA software, highlighting the current and future developments. In particular, concerning the automatic generation of FE models of fuselage primary structure, cabin environment (seats, dummies, overhead bins, etc.), as well as the possibility of being integrated into a data-driven iterative process (optimisations, sensitivity analysis, uncertainty quantification, etc.).
The aircraft models studied in this paper are developed by the DLR Institute of System Architectures in Aeronautics, with their knowledge-based FUGA tool (Fuselage Geometry Assembler) [16], which can interface with PANDORA for the generation of Finite Element models for structural and occupant safety analysis

3. PANDORA Design Environment

The Python-based software PANDORA has been developed to condense the department's tools and experience in the field of aeronautical structures, and it is now an integral part of the DLR design process chain. The PANDORA design environment plays a fundamental role in modelling, predicting and mitigating the hazards associated with newly proposed cabin layouts. The integration of PANDORA into the design process chain is visualised in Figure 1.

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The tool is integrated into the DLR process chain, thanks to the use of CPACS-structured data as the base for the generation of structural models of aircraft and rotorcraft fuselage structures. CPACS [17] represents the data format established by DLR to streamline the exchange of knowledge between the parties involved in the process chain, in a structured, unambiguous manner. It serves as the interface across various disciplines and levels of fidelity, ranging from simple statistical methods to high-fidelity Finite Element (FE) models. The aeronautic system description is stored in a hierarchical XML format, where parameters (e.g. materials, profiles, cabin environment layout, masses, etc.) are organised into branches based on the discipline.

PANDORA can then use this formatted information to create models of different fidelities for static analysis, sizing, or dynamic evaluations, such as drop tests or ditching. The model generation starts with the definition of a coarse full-scale model as a first numerical approximation, consisting of beam elements for the structural profiles (frames, stringers, crossbeams, struts, etc.) and shell elements for the skin. Then, the model can be enhanced to higher levels of detail thanks to the internal pre-processing functions. These functions include: mesh refinements, section cuts, transformation of beam elements into their 3D shell representation and inclusion of cargo or cabin environment, among others. PANDORA uses its native data format to store FE entities and results, and it can interface with various commercial solvers to compute the model. The selection of the solver is application-driven, since each methodology to convert the native data format into specific solver formats is purposefully tailored toward certain applications, to exploit the intrinsic strengths associated with each solver. In this work, LS-DYNA is used due to the availability of dummies and its widespread use in crashworthiness evaluations. The following chapters introduce the three steps implemented in PANDORA to automate and parameterise the modelling of the complete aircraft fuselage and its occupants.

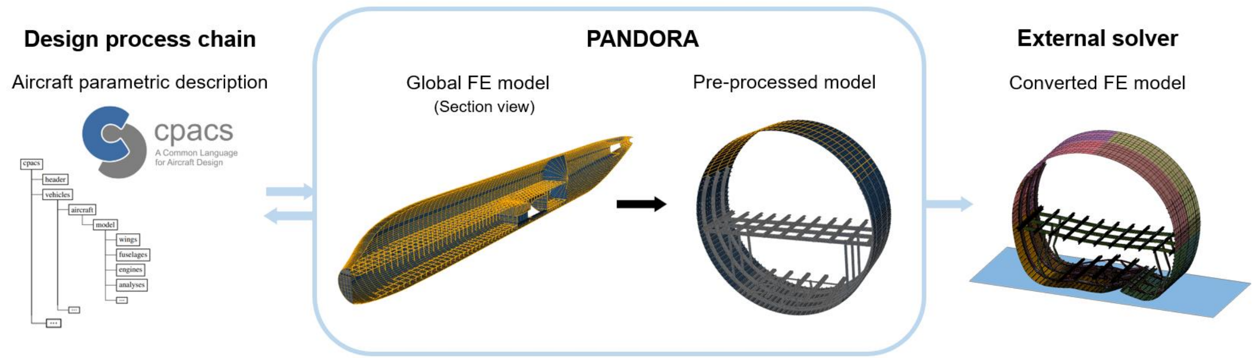

Figure 1: Workflow for primary structure generation, from CPACS to LS-DYNA

3.1 Primary structure

The first step of the implementation involves the capability to automatically generate parametric FE models of the cabin primary structure and convert them into LS-DYNA format. To ensure the reliability of the automated methodology in handling complex FE models, the outcomes are compared with existing modelling approaches in use at the Institute. Given the wide range of possible approximations and mathematical formulations when defining a cabin model, various levels of modelling detail are studied to characterise their strengths and appropriate application domains.

The methodology is implemented with a bottom-up approach. A series of structural benchmarks with progressive levels of complexity is defined in either PANDORA or CPACS and solved in LS-DYNA, from the single element scale to the fuselage barrel (Figure 2). This way, observations and problems encountered in each step are understood and implemented in the modelling methodology prior to the following, more complex benchmark. Each benchmark represents a brick composing a typical aircraft FE model, and its output must be consistent with well-established standard strategies in use at the Institute to define structural models with an implicit (for static analysis) and explicit (for dynamic analysis) time integration schema, such as the one used for ditching studies [18]. Two discretisations are considered for the structural profiles. Through beam elements with stiffness properties calculated by PANDORA according to the cross-section, or through their 3D shell element representation. The interpolation element formulation used to connect lumped masses to the structure is also evaluated. Shell and beam discretisations, modelled through both new and existing methodologies (solved by different solvers), show a good agreement in kinematics, for all quasi-static cases up to the fuselage barrel section.

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Finally, the crash analysis of a generic fuselage section is used to assess the modelling capability of PANDORA and its stability in the intended field of application. The tool is specialised for this application, being able to define the typical crash scenarios of fuselage sections, including initial conditions, constraints, loads, impact surfaces, tie connections, and contacts in an automatic and customizable manner. A 30ft/s drop test simulation highlights the good comparability between the modelling strategies and the inadequacy of the PANDORA-defined beam discretisation to simulate the vicinity of the impact zone. It shows substantial differences in contact forces, failure and buckling, even though it requires 96% less CPU time. This efficient formulation must be confined to the upper cabin structure, far from areas undergoing plastification, buckling or contacts, as the absence of a cross-section representation may lead to unrepresentative contact and structural responses [19].

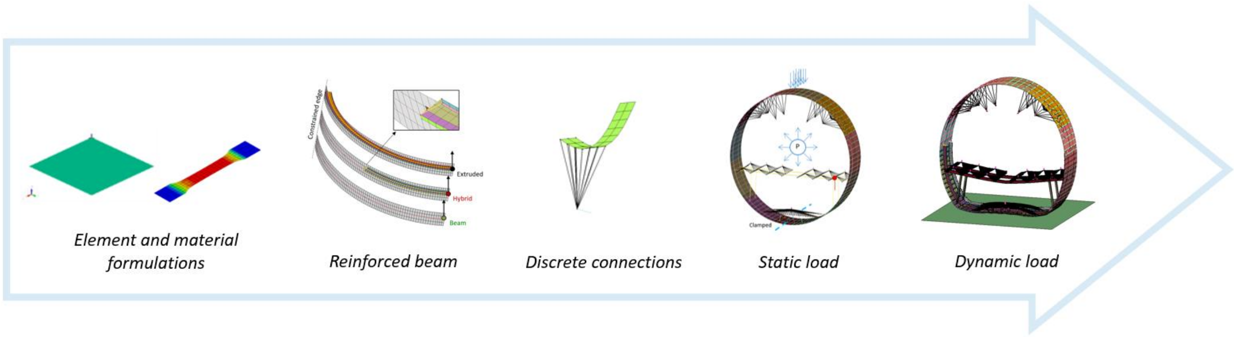

Figure 2: Hierarchical numerical benchmarks of increasing complexity

As part of the development of a methodology to define primary structure models, the floors and cargo compartment are also added to the automatic generation, as defined by CPACS or parametrically by the user. The cargo compartment, lying under the passenger floor, is defined by PANDORA using the external open-source GMSH module for the mesh generation. The mechanical properties and geometry of the luggage are based on a previous study, which, however, highlights the inherent difficulty in modelling this area [20]. Two main reasons are behind the need to include the cargo section in the model. Firstly, it may directly affect the extent of crushing of the bottom fuselage area, which is the main contributor to energy absorption in transport aircraft. Secondly, the discrete connections between cargo lumped masses and primary structure may create fictitious constraints between the nodes of the bottom longerons, causing an unrealistic stiffening when they undergo high deformations.

3.2 Cabin environment and occupants

In the following step, the cabin environment is integrated into the structural model. This includes the numerical model of passengers and cabin elements (e.g. seats, overhead bins, cabin linings). Occupants are simulated using commercial v-ATD (virtual Anthropomorphic Test Devices) models of varying cost and accuracy, which enable the computation of injury indexes. The integration of v-ATD into the fuselage model is based on a prior validation study [21] of the methods for passenger safety simulations, such as dummy positioning, seatbelt materials and contracts. As briefly described in Chapter 3, the cabin layout is described in CPACS through the parametric information of each component, such as position, orientation or structural connections [22]. However, the geometry of each cabin component is given through a reference to a library of common geometries.

To create FE models from the CPACS description, a library of FE models is made in PANDORA for each component. The FE component is based on the CPACS-referenced geometry, which is defeatured, meshed and completed with contacts and mechanical properties. The so-defined library FE sub-models can be included in the main fuselage model according to the position and connections defined in CPACS.

Contrary to the other cabin elements, derived directly from the CPACS geometry library, the seats necessitate a different, more specific treatment. The definition of a numerical seat model and its integration with the v-ATD is a complex task with significant influence on simulation outcomes, in terms of occupant safety indexes. Given its importance, the large variety of seats defined in conceptual design (first to economy class, 1 to 4 people seat, central or side position in the fuselage) is modelled as a combination of a single modular numerical seat representing one seat and its dummy. These single-seat sub-models, as well as representative seat legs, are positioned according to the aircraft description and adaptively connected reciprocally or with the primary structure through contact, rigid or discrete definitions. The simplified numerical seat is sourced from an aircraft OEM, and the dummy is positioned following the SAE guidelines [23].

DOI: 10.13009/EUCASS2025-014

The positioning steps, including pre-simulations, are performed manually for different license-free v-ATD types. In particular, four “Hybrid III” dummies by LSTC are integrated and available for use in PANDORA. The dummies differ in their accuracy level and body weight (5th percentile female, 50th percentile male, and 95th percentile male), as displayed in Figure 3.
These dummies are designed for automotive crash testing, and their curved spine may affect the result under vertical load. Furthermore, the seat from the 1990s in use at DLR-BT features outdated design and modelling methods. The introduction of aerospace-certified dummies and high-fidelity numerical seats in the crashworthiness assessment chain is presented in Chapter 4.

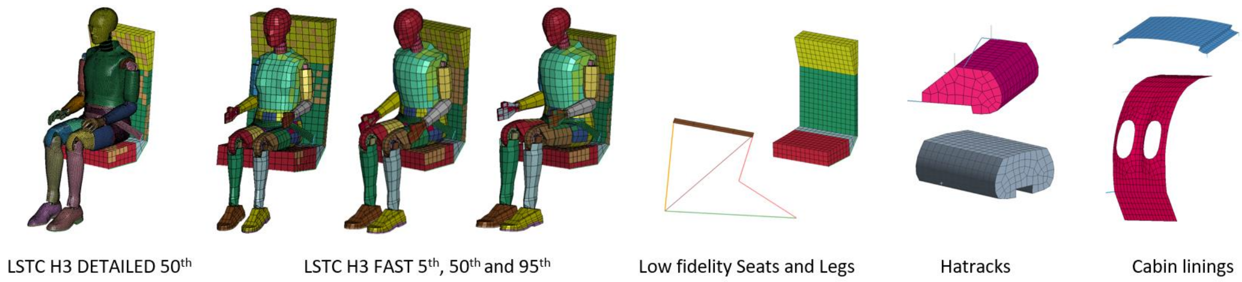

Figure 3: ATD types and cabin elements currently available in the FE sub-model library of PANDORA

The modular approach allows the definition of library components with varying degrees of complexity that can be selected in PANDORA according to the specific model application, from simple lumped masses to detailed meshed models. Similarly, while the seat layout is defined in CPACS, the dummy-type distribution within the cabin can be chosen at will during the model generation.
The FE sub-modules (seats, hatracks, legs, etc.) and the primary structure components (floor, longerons, frames, etc.) are connected according to their class through simple tie contacts, guaranteeing a flexible and robust trade-off at such an early design phase where the information on individual connections (bolts, rivets, welding) is not yet available.
The full-scale FE model of a novel LH2-propelled concept from DLR [24] is displayed in Figure 4 to show an application case of the procedure presented in this chapter, which is already in use at DLR [25]. The resulting model, ready to run, is created in a matter of minutes according to the CPACS description and a set of parameters of the PANDORA's pre-processing chain, which tunes its level of detail, loads, boundary conditions, etc.

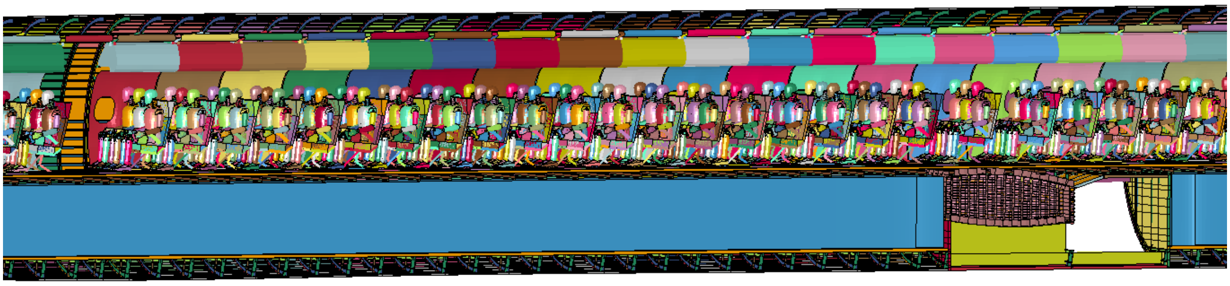

Figure 4: Section view of a full-scale FE model generated by PANDORA, with cargo and cabin environment.

3.3 Data-driven process chain

The implementations presented in the paper close the process chain loop within PANDORA, by enabling the automatic model generation, simulation, data post-processing, and eventually, the definition of new analysis cases starting from the newly computed results, as shown in the flowchart in Figure 5.
PANDORA can create models based on the CPACS-formatted description, which can be tuned within dedicated pre-processing functions to vary countless parametric definitions, including geometry, material or mechanical properties, initial or boundary conditions, among many others. The parametric definitions ease the handling of different fidelities within the model, as well as features that shall be assessed under different conditions for a robust analysis of the design, such as load cases or cargo models.

DOI: 10.13009/EUCASS2025-014

After the models are created, they can be automatically run in parallel on clusters and finally post-processed. The evaluation of safety criteria defined by the regulation for emergency landing conditions [26], follows the guidelines for v-ATD evaluation provided by the Aerospace Recommended Practice 5765B [23].
At the current status, the PANDORA environment may be paired with any iterative external logic able to interpret the outputs of a simulation with given inputs and define the input for the following iterations. This may enable optimisation routines or sensitivity analysis to be conveniently integrated into the design environment. The capability of running iterative analysis within the broad and adaptable PANDORA framework for fuselage analysis paves the way to comprehensive data-driven occupant safety studies.
The final objective of this work, besides providing a powerful tool for the development of new concepts, is to enhance the robustness of the safety evaluation for new aeronautical designs. This is envisioned to be achieved through the augmentation of deterministic simulation results with the inherent uncertainty of both the physical event and its numerical counterpart. Sources of uncertainty can emerge from discretisation, mechanical properties, load cases, occupant models [27] and other real-case aspects of primary importance for certification. A thorough Uncertainty Quantification study is deemed necessary [28], considering the extended domain of possible load scenarios and the broad design of the aircraft at its preliminary stage.

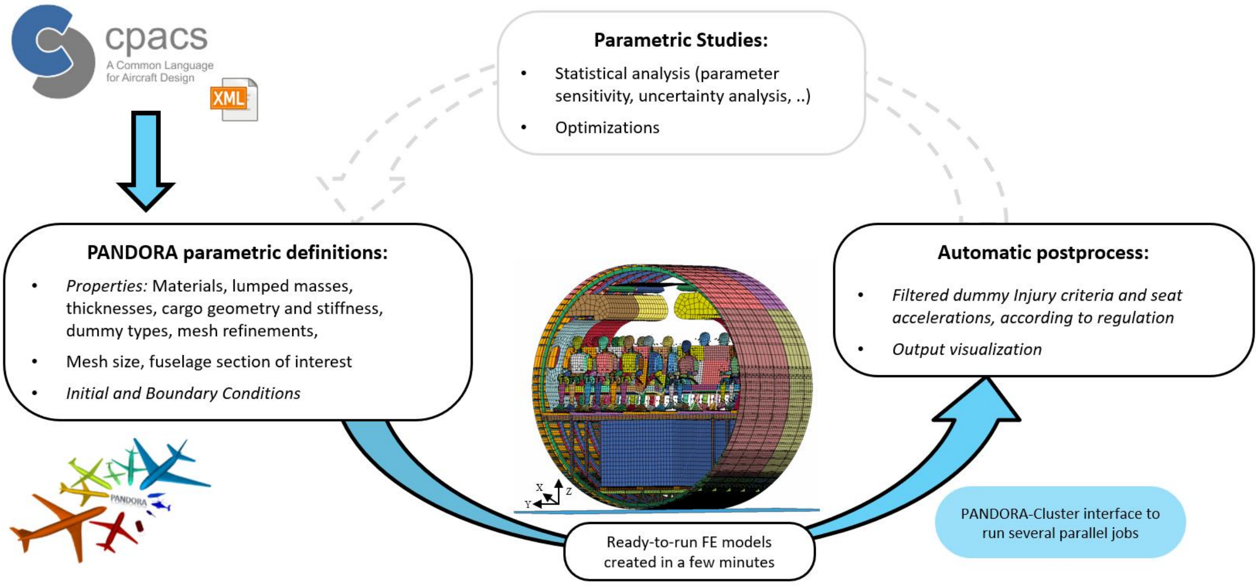

Figure 5: PANDORA closed-loop process chain for parametric analysis of aircraft cabins crashworthiness

4. Fuselage section study

This paragraph shows a preliminary evaluation of the forward section of a DLR hydrogen-propelled aircraft concept during an emergency landing. The new features of the PANDORA process chain described in this paper are used to generate the numerical model. The vertical impact load case is defined automatically by PANDORA, including symmetry conditions, rigid impact surface, gravity and an initial vertical velocity. The initial velocity of 30 ft/s, quoted in the A350-900 special conditions [13], is incremented by 25% to consider the increased impact velocity of the forward fuselage section due to the slap-down effect during a typical nose-up pitch emergency landing [29].
The fuselage's mesh is increasingly refined in areas closer to the impact surface, where plastification, buckling and failure are expected, while a coarse discretisation is used for the upper cabin structure, overhead bins and linings.
The fuselage model with occupants of different body weights, and the numbering of seats and occupants referred to in this chapter, are visible in Figure 6. Six seats are in the model, referred to as ABC (left side) or DEF (right side). The three DEF seats accommodate nine 50th percentile weight dummy types, while ABC seats have a randomised distribution of occupants: 4 ATD of 95th, 3 ATD of 5th percentile weight, and 2 empty seats. All dummies are LSTC H3 FAST from the PANDORA library shown in Figure 3.
Four FE models are analysed to evaluate the influence of seats and dummies of varying fidelities in terms of acceleration at the cabin floor and the resulting loads on seats and dummies. In fact, aeronautic passenger seats play a main safety role, as they are designed to guarantee the survivability of the occupant under a prescribed domain of vertical and horizontal loads.

DOI: 10.13009/EUCASS2025-014

The four models are identical, except for the 2nd seat row DEF, where different seat-dummy models replace the PANDORA-defined model:

- Base Model ("a" in Figure 6): The original PANDORA model featuring the simple elastic seat and LSTC H3 FAST 50-percentile dummies.
- Mass Model ("b" in Figure 6): The seat is replaced by a lumped mass replicating the inertia of the dummy-seat assembly, rigidly connected to the four seat-leg attachment points, to evaluate the effectiveness of this simple approximation.
- The Low-Fi. Model ("c" in Figure 6): Introduces an efficient numerical seat model with a beam-based structure representative of a certified seat geometry, integrated with LSTC H3 FAST 50-percentile dummies.
- The High-Fi. Model ("d" in Figure 6): Employs a numerical seat with fine shell-discretised structure derived from a certified seat geometry and integrated with aerospace-certified FAA H3 50-percentile v-ATD from Humanetics to ensure a high level of detail and reliable results.

The four models are tied to the primary cabin floor structure at the same four points (seat legs attachment points), where accelerations, velocities and loads are calculated. The Base Model is created by PANDORA in 2 minutes, and it can run without manual adjustments on 32 cores of a small DLR cluster. The 200-ms-long simulation runs within 5 hours for all models except the High-Fi. Model which needs 48 hours on 96 cores.

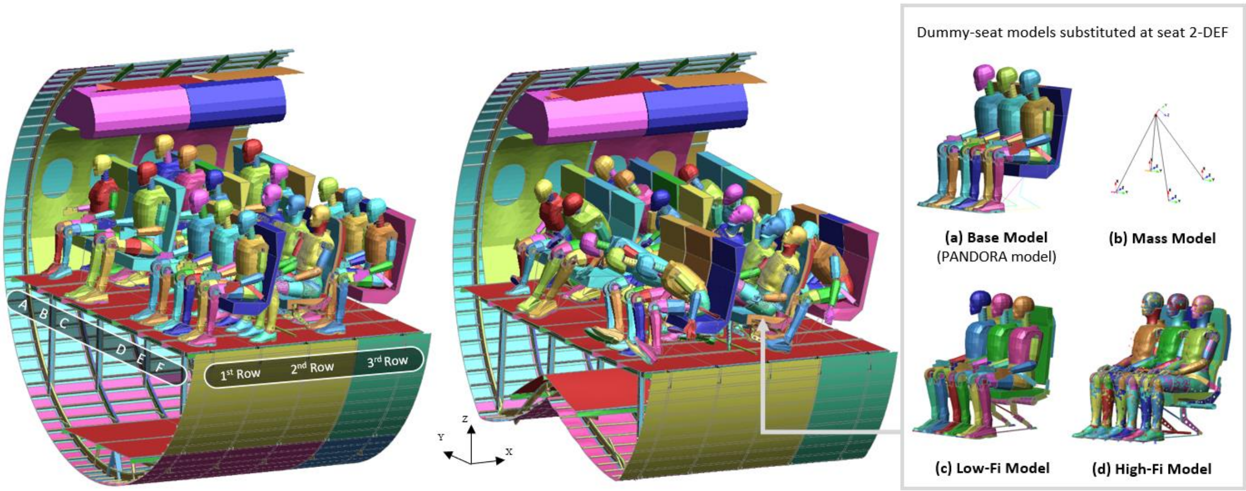

Figure 6: Section view of cabin in the High-Fi. Model, before (left) and after the emergency landing (right)

The four simulations exhibit overlapping energy balance and ground reaction forces. The kinematics of the interface nodes between seat legs and longerons also align closely, thus loading the four models in a comparable manner.
Due to the impact, the cargo crossbeams and struts fail at 20 ms, causing a sharp drop in the initially high reaction force against the rigid floor. Subsequently, the frames fail near the cabin strut attachment, leaving the latter in contact with the impact surface. At this point, the struts bypass the crushing area represented by the cargo compartment and transmit the load directly to the passenger's floor. The contact generates a second reaction force peak at 70ms. The two events are highlighted in the plots in Figures 7 and 8. It is interesting to notice that a triangular acceleration pulse with an acceleration peak of 21g and a duration of 120 ms (Figure 7), would result in a comparable velocity curve, except for the two acceleration spikes. The pulse has a higher peak but a shorter duration, resulting in a similar change of velocity to that defined by the regulation for seat certification, which shall be representative of survivable emergency landing events.
Plastic deformation is observed in the seat structures of the low- and high-fidelity models, potentially reducing the load transmitted by the seat, as visible in Figure 8. The second acceleration peak even buckles the rear legs of the high-fidelity model, further reducing its reaction force.
On the contrary, the Mass Model, although replicating the initial inertia matrix of the seat-dummy model, it induces high forces and moments on the primary structure due to its rigid behaviour, which is not representative of the multi-body problem. The use of rigidly connected lumped masses to represent the occupants may therefore result in an unrealistic loading of the primary structure.
The lumbar load injury criteria remain below the limit for all occupants, with the highest loads observed in the window seat positions due to the underlying reinforcement strut. The Base and Low-Fidelity Model feature the same ATD type, however, on the purely elastic Base seat, the dummy bends forward, reducing its lumbar load and at the same time,

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hitting the head on the forward seat row, increasing a second injury criterion, the Head Injury Criteria (HIC). On the Low-Fidelity seat, the seat legs compression keeps the dummy straight. Finally, a large difference is observed in Lumbar Load and vertical force on the seat attachments between the Low- and High-Fidelity Model. Nevertheless, the FAST H3 LSTC v-ATD is meant for automotive applications, and a discrepancy in lumbar load and kinematics can be expected due to their curved spinal column and coarse discretisation.
The filter CFC60 is used for accelerations and velocities, and CFC60 for forces [23].

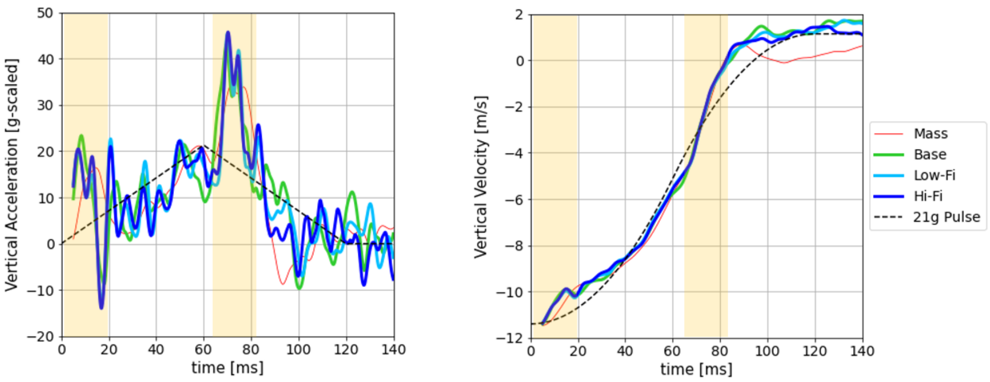

Figure 7: Acceleration (left) and velocity (right) of seat 2-DEF averaged over its four leg-to-floor attachments. The timespan of the two reaction force peaks is highlighted.

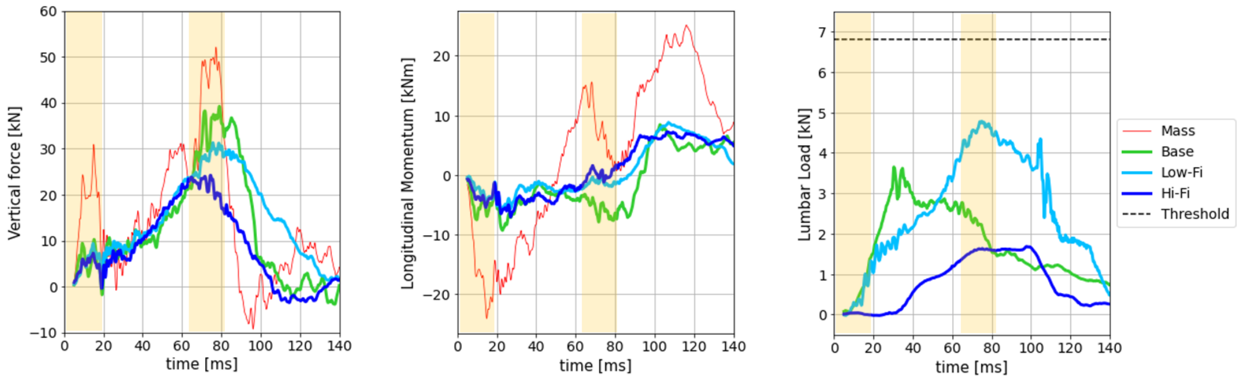

Figure 8: Force (left) and moment reaction (centre) of seat 2-DEF averaged over its four leg-to-floor attachments. Lumbar Load (right) averaged over the three Dummies of the 2-DEF seat.

5. Conclusions

5. Results

The process chain described in this paper enables a comprehensive crashworthiness and occupant injury assessment within the DLR's aircraft design process chain using the Finite Element method. The safety evaluation of emergency landings is integrated into the preliminary design thanks to the design environment PANDORA, which enables the generation of numerical models of the fuselage concepts defined within the DLR design chain. The design features of these concepts are described in the standardised CPACS format, which can be interpreted by PANDORA and used to define parametric structural models of varying levels of detail.
This paper describes the current state of PANDORA for occupant safety evaluations, which is enhanced in three main points: Generation of primary structure, integration of cabin environment and definition of iterative analysis.
Initially, the tool is expanded to generate FE models of the fuselage primary structure for the commercial solver LS-DYNA. The generated models are then compared with well-known modelling methods in use at the Institute, through a series of numerical tests, to validate their comparability and robustness.
Subsequently, a modular process is defined for the integration of the numerical cabin environment. This brings the automatic process chain together with manual modelling procedures, such as the v-ATD integration into the seat or the defeaturing of CPACS's cabin geometries, as they require engineering judgment or pre-simulations. A library of pre-

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built FE models is integrated in PANDORA, which can assemble these FE sub-modules to simulate practically any cabin layout defined within the preliminary design.
Finally, the process chain is extended to enable data-driven analysis within the design environment. The iterative process is based on the fuselage FE models, resulting from the CPACS description together with a set of parametric definitions for the pre-processing. The interface with the internal cluster and LS-DYNA enables running parallel simulations, post-processing relevant results, and potentially managing iterative procedures. The control logic of the iterative procedure is currently under development, however, the PANDORA parametric framework already represents a powerful and versatile tool for future data-driven applications, such as statistical studies and optimisations.
To give an overview of the new features introduced in the paper, the FE model of a DLR-concept fuselage section drop test is created, run and evaluated. The load case is set to simulate the vertical impact velocity quoted by the Special Conditions for non-traditional fuselages. The simulation of the PANDORA-generated model containing 16 v-ATD of various body weights is modelled in 2 minutes and runs within 5 hours. The simulation is used as a test bench for evaluating improved seat models, designed to replace the simple elastic seat model currently integrated in PANDORA. As a result, while accelerations at the seat leg attachment to the cabin floor remain fairly unchanged, a large variation is observed in the loads acting on seats and occupants, which strongly affect the estimation of the injury criteria needed to assess the safety of the design. The novel capabilities of the PANDORA environment open the way to an automatic data-driven process for the occupant safety evaluation, with the final objective to facilitate the development and certification process of upcoming innovative aircraft and cabin concepts.

5. Future works

Future enhancements of PANDORA will cover the development of a more representative numerical seat model, as well as a methodology for the Uncertainty Quantification (UQ) of the numerical model. The novel numerical seat model is under development to replace the current elastic seat model of PANDORA. The high-fidelity FE model is modelled and experimentally validated, based on a certified seat hardware. However, the computational cost associated with the high model resolution needed to simulate the human and seat leg non-linear behaviour during a crash makes the application of such a model impractical on a full-scale aircraft simulation in all seat rows. Therefore, a modular lower-fidelity model is derived from the high-fidelity reference to be integrated in PANDORA, as a trade-off between accuracy, robustness and computational efficiency.
Lastly, plenty of uncertainty sources and modelling approximations may affect the reliability of the numerical results, in turn, undermining the effectiveness of the safety assessment.
The UQ statistical evaluation will leverage PANDORA’s capabilities to manage iterative analysis, to quantify the effects of varying parameters related to the model, the design and the load case, on the safety of the aircraft concept under investigation. Within this framework, the next step will involve the development of a surrogate model of the seat to efficiently enhance the injury prediction of the simplified seat model. The AI-driven surrogate will be trained on the detailed seat and dummy model’s outcome, and designed to account for the inherent sources of uncertainty arising from the seat-occupant assembly.

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