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Integrated process chain for crashworthiness assessment of innovative aircraft cabin layouts

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Abstract. Over the years, the German Aerospace Center (DLR) has developed a multidisciplinary process chain for aircraft design. This paper introduces a novel feature of this process chain, implemented in the Python tool called "Parametric Numerical Design and Optimization Routines for Aircraft" (PANDORA) developed at the Institute of Structures and Design (BT) featuring enhanced numerical tools for the fuselage structure analysis and sizing. The ongoing development focuses on achieving a high level of detail in the aircraft Finite Element (FE) modeling chain for crashworthiness evaluations, including a more detailed cabin description as well as advanced anthropomorphic test devices (ATDs). The aim is to study the dynamic behavior of novel cabin layouts and structures under crash conditions starting from their parametrical definition, and evaluate innovative design choices in terms of safety. Such a fully integrated process chain becomes necessary due to recent changes in aviation crashworthiness regulations, where the shift from prescriptive to performance-based requirements may significantly influence both the aircraft design and certification process.

Introduction

Crashworthiness in aviation is gaining increasing importance, as civil aviation is one of the fastest-growing sectors worldwide. In addition, the recent surge of interest in sustainable aviation paves the way for novel disruptive designs that may implicate an increased passenger density in the cabin, involving new safety problems to be explored. Since regulations prescribe that the structure must be designed to reduce loads acting on the occupants due to a crash to a tolerable level, the crash load mitigation will influence the overall design of a transport aircraft fuselage structure and hence it should be considered in an early phase of the design process [1].

Traditionally, the certification of seats and cabin is mainly considered independent of the structural behavior of the aircraft. In fact, the certification process requires the application of a standardized acceleration pulse directly to the seat structure. Nevertheless, statistics show a high influence of the aircraft structure on crash survivability [2]. From 2017, the certification authorities are starting to change the regulation to allow considering the combined crash performance of seats mounted to the airframe, rather than considering them separately [3].

As the aforementioned combined consideration in fully instrumented full-scale testing is prohibitive in terms of complexity and costs, extensive use of validated simulation techniques and the development of new modeling methodologies is of primary interest.

A Multidisciplinary Aircraft Design Framework

Plenty of subjects are involved in the design process of a new aircraft, such as aerodynamics, structural design, cabin concept, flight mechanics, costs and many others. This results in a complex Multidisciplinary Design Optimization problem demanding an efficient and accurate process chain to aim for the best pre-design solution and avoid expensive modifications at a later design stage.

An increasingly sophisticated aircraft predesign process chain was established as a result of the aggregation of the unique expertise of various DLR institutes specialized in different subjects. Such a collaborative process employs the Common Parametric Aircraft Configuration Schema (CPACS) data format [4] as a means of exchanging the aircraft description and analysis results.

The hierarchical CPACS data structure enables integration across disciplines and different levels of detail, ranging from simple statistical models to high-fidelity methods like FE analysis and computational fluid dynamics.

Within the DLR multidisciplinary process, PANDORA (Fig. 1) is an established tool for the automatic generation of global and detailed FE structural models for static and dynamic analysis (crash and ditching) and subsequent structural sizing [5]. A persistent effort is made to expand the modeling chain and achieve a higher level of detail. This paper introduces the new feature to integrate a realistic cabin environment (seats, luggage compartments, side panels, etc.) as well as ATDs into the FE model, with the final aim of evaluating under realistic crash scenarios.

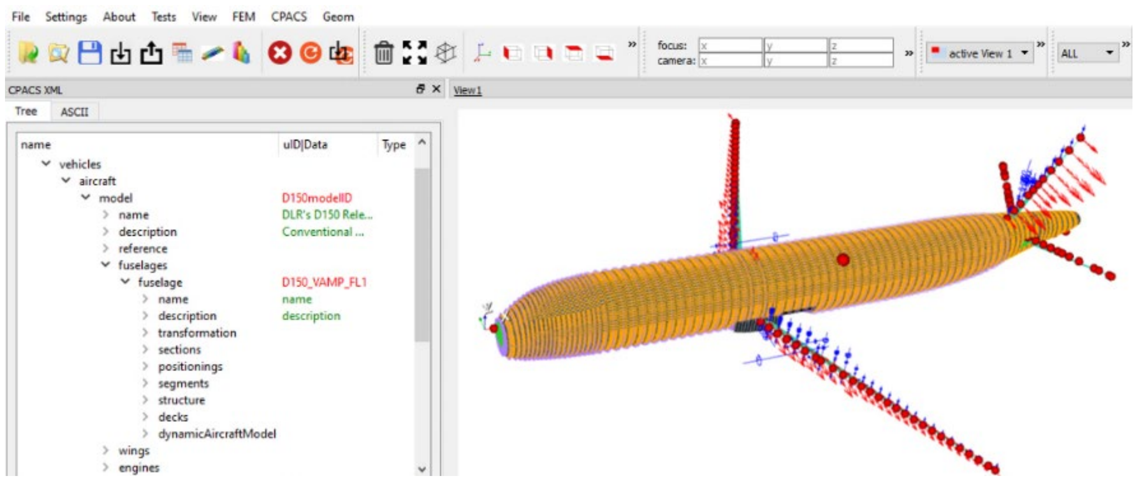

Figure 1. *PANDORA graphical user interface. Visualization in PANDORA of CPACS data and resulting aircraft Global FEM*

Crash Analysis of FE Parametric Models

The finite element model is automatically generated based on geometric and structural data in a CPACS file and stored in the general FE format of PANDORA. Pre-processing is possible directly in PANDORA through plenty of dedicated functions to create models in a wide range from low complexity to high fidelity. Within this process, the portion of fuselage to be analyzed can be selected, the mesh can be locally refined and each structural profile cross-section can be extruded in arbitrary zones, to achieve both, an accurate and cost-effective simulation.

After the model generation, the internal FE database is converted to the selected solver's format, according to the type of application. Currently, PANDORA features interfaces to standard structural solvers such as ANSYS, and NASTRAN as well as the dynamic solvers VPS and LS-DYNA with an explicit time integration schema. The integration of the passenger dummies shall be conducted in LS-DYNA due to its availability of dummy models representing a wide range of passengers, from light (5th percentile female) to heavy people (95th percentile male).

Two main topics were addressed prior to the integration of the dummies. The first topic (left side in Fig. 2) concerns the new capability of PANDORA to create LS-DYNA models. The validation of LS-DYNA modeling methodology was carried out with a bottom-up approach, though several numerical benchmarks, starting from simple static models up to the fuselage barrel crash. The results are compared with validated test runs in VPS, with its well-established modeling strategy previously used for ditching studies [6].

The second topic (right side in Fig. 2), involves the development of the methodology for modeling ATDs, belts, and seats. This is defined and validated in a parallel study [7]. A first simple seat model originating from studies performed in the 1990s is used in this first part of the project, but shall be replaced in later stages of the research project.

Currently, the integration of the dummy in the seat requires specialized manual work. Hence, to fit ATDs into an automatic process chain, a library single seat-ATD assembly is created for different ATD types, using the previously developed methodology. The single-seat-ATD models are then combined to simulate the different specific seat configurations defined in CPACS.

The automatic generation of a full-integrated cabin is sought as a result of this implementation (top image in Fig. 2, manually implemented previous department's model [8]). This will allow the creation of full-scale aircraft models in a matter of seconds, rather than days of manual work.

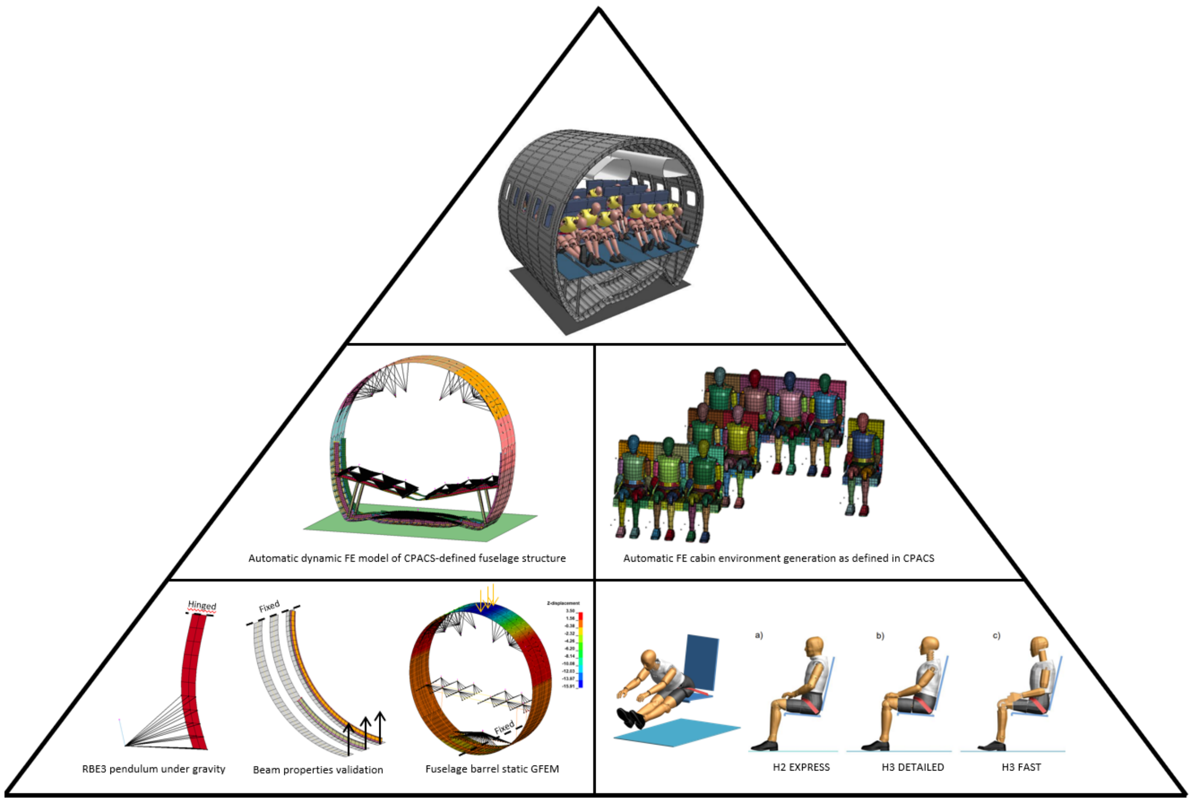

Figure 2. *Integration pyramid in three steps from simple benchmarks to full-cabin model*

Conclusion and Future Works

The DLR Institute of Structures and Design has extensive experience in creating FE models for aircraft crash analysis, which however requires a long integration work, with limited possibilities to modify the model. The knowledge of the institute in aircraft and ATD modeling is condensed into a novel PANDORA implementation, which paves the way to fully parametrized crashworthiness studies of full-scale aircrafts. This new capability represents a powerful tool to understand the outcomes of pioneering designs in terms of occupant safety, for innovative cabin layouts (Fig. 3), seat configurations, and their connection to the structure (Fig. 4).

This shall accelerate the development of innovative aircraft concepts, while aiding designers to improve aircraft safety, by considering crashworthiness from the first stages of the predesign phase. In particular, the emphasis is on addressing the safety challenges of emerging designs such as zero-emission configurations and high-density cabin layouts in which the design space is yet to explore and a means for parametric analysis is of fundamental importance.

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Future developments of PANDORA include the integration of advanced ATDs and human body models, and the investigation of up-to-date seat structures to include in the structural model.

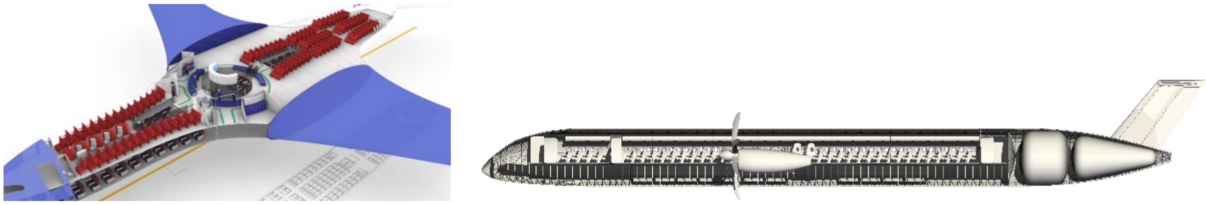

Figure 3. *Examples of novel cabin design and zero-emission aircrafts developed by DLR Institute of System Architectures in Aeronautics (SL)*

Figure 4. *Reconfigurable (left DLR SL) and high-density seat configurations (right [9])*

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