A PARAMETRICAL TRANSPORT AIRCRAFT FUSELAGE MODEL FOR PRELIMINARY SIZING AND BEYOND

D. B. Schwinn, D. Kohlgrüber, J. Scherer, M. H. Siemann
German Aerospace Center (DLR), Institute of Structures and Design (BT),
Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

dominik.schwinn@dlr.de, tel.: +49 (0) 711 6862-221, fax: +49 (0) 711 6862-227

Abstract

Aircraft design generally comprises three consecutive phases: Conceptual, preliminary and detailed design phase. The preliminary design phase is of particular interest as the basic layout of the primary structure is defined. Up to date, semi-analytical methods are widely used in this design stage to estimate the structural mass. Although these methods lead to adequate results for the major aircraft components of standard configurations, the evaluation of new configurations (e.g. box wing, blended wing body) or specific structural components with complex loading conditions (e.g. center wing box) is very challenging and demands higher fidelity approaches based on Finite Elements (FE). To accelerate FE model generation in multi-disciplinary design approaches, automated processes have been introduced. In order to easily couple different tools, a standardized data format – CPACS (Common Parameterized Aircraft Configuration Schema) - is used. The versatile structural description in CPACS, the implementation in model generation tools but also current limitations and future enhancements will be discussed. Recent development in the progress of numerical process chains for structural sizing but also for further applications including crash on solid ground and ditching (emergency landing on water) are presented in this paper.
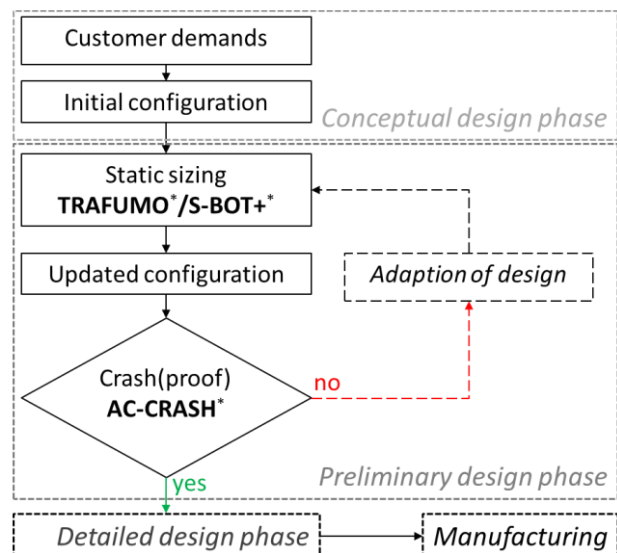
1. INTRODUCTION

Aircraft design is commonly divided into three major phases, i.e. conceptual, preliminary and detailed design. The conceptual design phase leads to basic design decisions based on the so-called 'Top Level Aircraft Requirements' (TLAR), such as requested missions, maximum fuel burn etc. In the subsequent preliminary design phase trade studies covering different disciplines are performed to define the configuration and general dimensions of the aircraft. Finally, all details of the aircraft are defined in the detailed design phase.

The present paper focuses on the preliminary design phase. Here, semi-analytical methods are widely used to estimate the structural mass. However, the evaluation of new configurations or specific structural components with complex loading conditions is very challenging. One solution to improve the preliminary sizing and mass estimation can be seen in the intensive use of high fidelity finite element (FE) based computations. With the increasing computational power nowadays, the application of complex FE models within trade studies is feasible. However, model generation and updating is still very time-consuming. To reduce the time spent on model generation and analyses, fully automated process chains for different applications in the preliminary design are developed at the German Aerospace Center (DLR).

Figure 1 shows the aircraft design process as it is used within the Institute of Structures and Design (BT) at DLR. The preliminary design phase requires the definition of an initial aircraft configuration. This initial airframe configuration is then statically sized according to specified

flight and ground load cases, e.g. +2.5g maneuver, gust crossing, etc. The objective in the sizing process is to find the optimal thickness distribution of the airframe. At the end of this process an updated aircraft configuration is generated. This new configuration is subsequently analyzed under crash load to investigate the energy absorption capability of the sized airframe. Ideally this configuration passes the crashworthiness proof so that the final, detailed design phase can be initiated.

Figure 1. Aircraft Design Process

In case the design does not pass the crashworthiness proof, the structural design has to be adapted and the static sizing has to be conducted again with the new design. This step has not yet been integrated in the process chain as indicated by the dashed lines in Figure 1.

The initial aircraft configuration may be defined using the tools VAMPZero [1] and F-DESIGN (Fuselage Design) that consider knowledge based global design rules and requirements. VAMPZero is a conceptual design tool to generate a basic aircraft layout and a first loft that fulfills the specified TLAR. An initial distribution of structural components (frames, stringers, crossbeams, struts, etc.) within this aircraft loft is generated using the tool F-DESIGN. Currently, frames and stringers are distributed with a constant pitch but first enhancements offer detailed positioning respectively distribution options. For instance, frames may be generated at specified cutout positions. The frame and stringer spacing may be varied as well as profiles/cross sections may change along their extrusion path. F-DESIGN is currently enhanced in a way that already existing aircraft configurations may be altered, e.g. existing frames may be adapted to match requirements from changes of the global configuration, e.g. wing position.

Based on the initial structural description FE models are generated and subsequently statically analyzed and sized. Following this static sizing a preliminary crash computation is conducted with the objective to investigate negative crashworthiness influences caused by too high stiffness resulting from static dimensioning.

This paper presents the modeling approach for static sizing in the preliminary design phase. Moreover, applications beyond preliminary sizing like crash and ditching that make use of the same aircraft configuration description will be presented. Additionally, the common data format of the presented tools will be described and explained based on some generic examples.

2. AIRCRAFT DESCRIPTION DATA FORMAT

Multidisciplinary analyses or optimizations demand that a vast number of different disciplines with different analysis tools is combined to get consistent results or to find a global optimum for a given problem. To effectively use and combine the different tools, a common data format is required that overcomes issues like huge programming efforts and a high amount of maintenance due to the numerous tool interfaces involved within the optimization loop. Therefore, the Common Parameterized Aircraft Configuration Schema (CPACS) is used at DLR-BT.

CPACS is a *.xml (Extensible Markup Language) based data format featuring a hierarchical data structure to describe the air transport system including air- and rotorcraft. Its development began in 2005 in the TIVA (Technology Integration for the Virtual Aircraft) project and it is in use at almost all DLR aeronautical institutes down to the present day. The current version of CPACS is 2.2. It is published under open source and the schema can be downloaded from the CPACS homepage [2].

Its main advantages are the hierarchical structure that allows for good data mapping and the representation in

ASCII format (American Standard Code for Information Interchange) making it easy to handle. Furthermore, inheriting information by linking properties leads to prevention of redundancy which increases readability and clarity. Another advantage is the smaller file size which results in faster data access.

CPACS makes use of TIXI (TIVA XML Interface) [3] and TIGL (TIVA Geometric Library) [4] which are libraries that include specific functions for the calculation of geometries and data access (read operations) within CPACS.

All required parameters for any aircraft analysis are defined within a CPACS file, e.g. loft (outer geometry), load scenarios, flight mission/mission profiles, etc. Data sets can be validated with the corresponding *.xsd (XML Schema Definition) scheme to filter errors right away from the start of the selected process chain. The number of tool interfaces can be reduced by introducing a centralized data format with less tool interfaces. This, in turn, means less programming, code maintaining effort and error susceptibility.

Rizzi shows the advantage of using CPACS regarding the reduction of interfaces [5] in Figure 2. The figure on the left shows the approach without unified data featuring individual interfaces while the figure on the right shows the centralized CPACS approach with less tool interfaces.
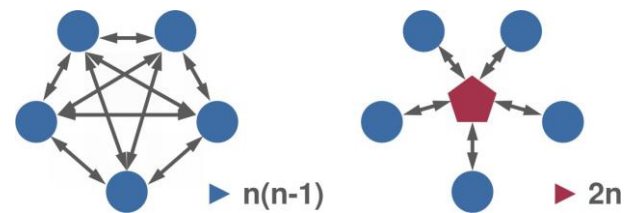

Figure 2.   CPACS: Reduction of tool interfaces [5]

It can be observed that the number of tool interfaces increases linearly with CPACS while the traditional approach shows quadratic increase. Table 1 demonstrates the savings of interface programming (shaded in green). It can be seen that the conventional approach requires less interfaces for two tools. For three tools both approaches require the same number of interfaces. But as soon as four or more tools are involved the centralized approach requires less interfaces. Consequently, the more tools are involved in the multidisciplinary optimization the higher the reduction of required interfaces.

Table 1. Reduction of tool interfaces with CPACS

Number of Tools	Standard Approach	Central Approach (CPACS)
2	**2**	4
3	6	6
4	12	**8**
5	20	**10**
10	90	**20**

The structural description of the aircraft components such as fuselage is based on global definitions of so-called structural profiles and structural elements (including material and thickness definitions).

Figure 3 shows an example of how one generic structural profile serves as geometrical base for three structural

elements. The structural elements (SE1, SE2, SE3) share the same structural profile (SP1) but different thickness of individual sheets (see Table 4). Thus, only SP1 has to be defined as structural profile in the corresponding CPACS file. Table 2 shows the definition of the structural profile SP1. The coordinates of the points (P1 – P6) refer to the profile coordinate system as shown in Figure 3 (highlighted in red). Moreover, the structural profile section determines how the sheets (S1 – S5) of a structural profile are defined.
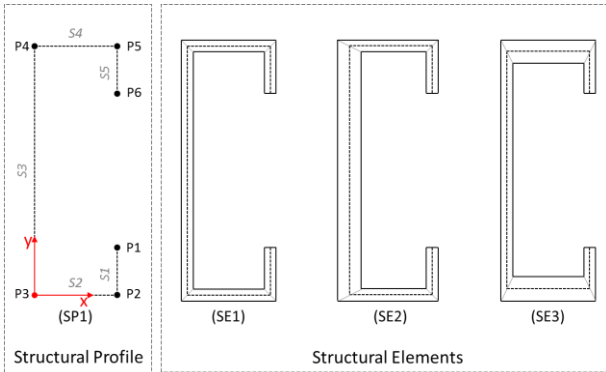

Figure 3. Structural profiles and structural elements

The geometric definition of the exemplary structural profile SP1 is given in Table 2. This definition is specified within the CPACS file under the structural profile node.

Table 2. Point definition of a structural profile

Points (SP1)	(x, y)
P1	(3.0, 1.5)
P2	(3.0, 0.0)
P3	(0.0, 0.0)
P4	(0.0, 10.0)
P5	(3.0, 10.0)
P6	(3.0, 8.5)

Every structural profile definition comprises of a point list with 2D coordinates and a sheet list with connections between the defined points. The sheet list for the structural profile SP1 is presented in Table 3.

Table 3. Sheet definitions of a structural profile

Sheets (SP1)	Start point – end point
S1	P1 – P2
S2	P2 – P3
S3	P3 – P4
S4	P4 – P5
S5	P5 – P6

In order to define a closed profile an additional sheet to close the profile has to be defined within the structural profile section. In the presented example of SP1 this would be a sheet from P6 to P1.

Structural elements in a CPACS file are defined within the structural element node. Each structural element needs an entry that refers to a structural profile. Furthermore, each sheet of the used structural profile requires a material and thickness definition. The material is defined using a reference to the corresponding material definition node in the CPACS file. In Table 4 exemplary structural element definitions are shown.

Table 4. Sheet thicknesses [mm] of structural elements

structuralElements / sheets	S1	S2	S3	S4	S5
SE1	1.0	1.0	1.0	1.0	1.0
SE2	1.0	1.0	**2.0**	1.0	1.0
SE3	1.0	**2.0**	1.0	**2.0**	1.0
SE4	1.0	1.0	1.0	1.0	1.0

Note that the structural elements SE1 to SE3 defined in Table 4 refer to structural elements made of the same material. The bold printed values show the differences compared to SE1 that require the definition of a new structural element. It is also possible to define another structural element (e.g. SE4) that shares the same structural profile (SP1) and sheet thickness distribution but comprising a different material. In Table 4 the green shaded cells represent material M2 while the non-shaded ones represent material M1. The option to use identical thickness with different material definitions (or lay-ups) is of particular interest when dealing with composite materials.

On account of the parametric approach CPACS offers another advantage which is the huge variety of positioning and aligning of structural members (extruded structural elements) within the fuselage. Exemplary applications are shown and described subsequently.

Figure 4 shows how points on the loft are defined respectively positioned within CPACS and calculated by TIGL. The whole aircraft within a CPACS file is related to the aircraft reference axis. In Figure 4 it is represented by the red dot and runs along the aircraft longitudinal axis. Within the aircraft yz-plane at a defined x-position the two parameters *referenceY* and *referenceZ* define a local reference point. Using the *referenceAngle* parameter, a line from this reference point is drawn within the given plane until it intersects with the loft geometry, resulting in a point on the fuselage hull where a frame or stringer may be positioned.
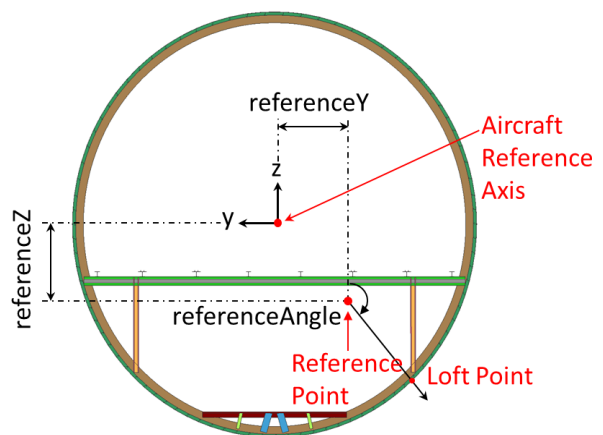

Figure 4. CPACS: Loft Points

Based on the principle given in Figure 4 all stringers and frames in the fuselage are defined respectively their positions are calculated. The bays formed by their intersections are defined as skin segments. Each segment may have its own unique thickness and material assigned.

Stringers are defined by an arbitrary number of so-called stringer position points that comprise a x-position

(*positionX*), a reference point, a reference angle and a structural element uID[1]. The stringer position points at frame positions that are not defined are interpolated from adjacent positions.

Analogously, frames are defined by an arbitrary number of frame position points which are defined by a x-position, a reference point, a reference angle and a structural element uID. Contrary to the stringers, the frame position points of one frame usually differ in circumferential position instead of x-position.

Due to the need of a proper load transfer into the fuselage shell, crossbeams and struts are always coupled to frame/stringer intersections.

The crossbeams for the cabin and the cargo floor are defined by a frame uID, the parameter *positionZ* (see Figure 5) a structural element uID and some alignment options that orient the structural profile. The x-position of the crossbeam is taken from the x-position of the frame to which it is linked. Alignment parameters may be used to slightly adjust the crossbeam in local y- and z-direction (*translationLocY* and *translationLocZ*), along its extrusion path (*offset1LocX* and *offset2LocX*) or to rotate it around its extrusion path (*rotationLocX*). The parameters *offset1LocX* and *offset2LocX* at the start and end point of the crossbeam are similar to those described for the strut definitions below and are exemplarily shown in Figure 5 while the parameters *translationLocY* and *translationLocZ* are exemplarily depicted in Figure 6.

Support struts for the cabin and cargo floor structure are defined in CPACS using a frame uID (that in turn defines the x-position), a crossbeam uID (that defines the z-position), a structural element uID and the two parameters *positionYAtCrossbeam* and *angleX* (see Figure 5). The parameter *positionYAtCrossbeam* is measured relative to the reference point (taken from the frame uID) and defines the y-position where the strut begins. Using an extrusion direction defined by the *angleX* parameter an intersection point with the fuselage skin is calculated by the use of TIGL functions defining the end point of the support strut. To connect the end point of the support strut to the airframe structure, the nearest stringer-frame intersection point is calculated and the end point of the strut is shifted to this position. Additionally, the alignment options (as introduced above) are available for the support struts.

Some exemplary positioning options that have been mentioned are presented in Figure 5. Based on the aircraft reference axis the parameter *positionZ* is used to position the passenger crossbeams. The parameter *positionYAtCrossbeam* is used to define the vertical passenger crossbeam support strut along the lateral aircraft axis y. Using *angleX* the orientation of the strut can be defined. As each crossbeam strut has an own uID and, therefore, an own entry in the CPACS file, each crossbeam strut may be positioned differently. The parameters *offset1LocX* and *offset2LocX* are defined to either extend or shorten the extruded structure along its extrusion path.

---

[1] uID = unique Identifier. uIDs are used to distinguish between individual entries which have been defined previously.

Additional information about the main functionalities of the CPACS fuselage structure description and about the use of structural profiles and structural elements is given by Scherer [6].
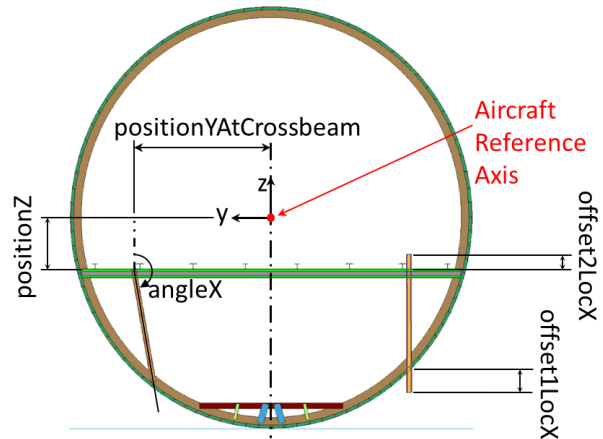

Figure 5. CPACS: Local Positioning Options

An application of the two alignment parameters *translationLocY* and *translationLocZ* is exemplarily presented in Figure 6. The figure shows the course of three stringers and two frames, composing two fuselage skin panels. The structural element SE1 represents stringer 2 being placed along its course.
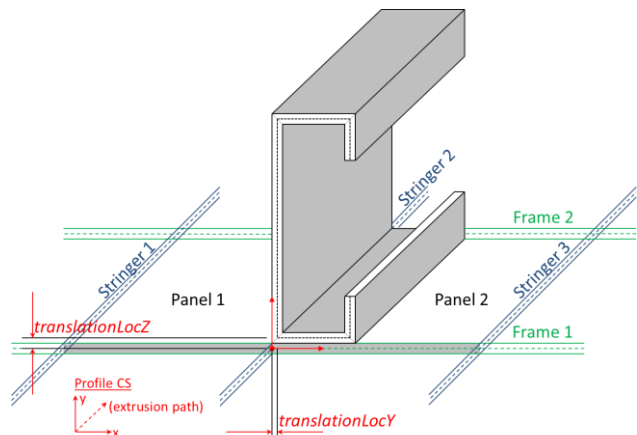

Figure 6.   CPACS: Profile alignment

The profile coordinate system (3D, denoted in red) in this example corresponds to the profile coordinate system as used for the definition of the profile SP1 (see Figure 3). Note, that the coordinate denotation changes ($x_{profile} \rightarrow y_{alignment}$ and $y_{profile} \rightarrow z_{alignment}$) as the x-direction here corresponds to the direction of extrusion. The structural element is positioned on the intersection of the frame and the stringer (denoted by the red point in Figure 6). The two offset parameters can now be used to slightly adjust the structural element relative to its original position. These alignments can be used to account for e.g. varying skin thicknesses.

3. STRUCTURAL ANALYSIS

To evaluate aircraft fuselage structures, fully automated and parameterized process chains have been developed

at DLR-BT. These process chains are written in the Python programming language. Modeling is controlled using the APDL (ANSYS Parametric Design Language) based PROSHAPE toolbox [7]. They use CPACS as central data input format, thus, benefitting multi-disciplinary approaches.

Aircraft models are generated in ANSYS file format (*.db, *.cdb). An in-house converter can be used to transfer the mesh into other solver formats, e.g. VPS/PAM-CRASH (see section 4).

Engineering constants of the structural elements (e.g. cross section area, moments of inertia, center of gravity) are computed automatically by ANSYS and applied to the corresponding elements.

Detailed description of the process chain and how the different modules (inter-) act is given in [8–10]. Detailed benchmark is also available. Coding is under steady development - not only to enhance the features involved but also to reduce the model generation time in the process.

The so-called tool specific nodes in each CPACS file allow the definition of further controlling options for each individual tool. Therefore, it is possible to control different tools using a single CPACS file. The geometric and material data of the aircraft configuration are tool independent.

In the following paragraphs selected applications of further tools developed at DLR-BT are introduced and described.

3.1. Static Sizing

Static sizing based on flight and ground load cases (e.g. pull up maneuvers, gust crossing, etc.) is the dominant task during aircraft design evaluation. Static load cases call for small deformations and linear elastic behavior. Therefore, comparably coarse meshes are applicable.

The tool TRAFUMO (Transport Aircraft Fuselage Model) is used to generate the FE model for static analyses and sizing. Static analyses and sizing are conducted using the ANSYS solver featuring an implicit time integration scheme and the in-house developed routine S-BOT+ that iteratively sizes the fuselage structure according to specified static load cases.

3.2. TRAFUMO model generation

The structural reinforcements are discretized using elastic beam elements (ANSYS Beam 188) that feature arbitrary cross section predestining them for the use with CPACS. The fuselage skin is discretized with elastic shell elements (ANSYS Shell 181).

The generated mesh is of so-called GFEM (Global FEM) quality. The skin segments (formed by a bay between two adjacent frames and stringers) as described above form one shell element each.

For sizing purposes the fuselage can optionally be coupled to wing structures for aerodynamic load introduction. Wing

and empennage are generated by the ELWIS (Finite Element Wing Structure) tool [11]. Loads are computed on the undeformed lifting surfaces by the use of the external tool AVLloads [11, 12] which is based on the freeware vortex-lattice code AVL (Athena Vortex Lattice).

Secondary loads (e.g. fuel, engine and landing gear loads) are computed by the tool ESEL (Finite Element Secondary Loads) [11, 12]. Then, the fuselage structure is coupled with the wing and empennage structure. Eventually, the combined model is used to size the fuselage airframe according to the specified aerodynamic and inertia loads.

Added masses like fuel or passengers are modelled by single mass points that are connected to the airframe by the use of constraint equations (RBE3).

Generic short (D150) and long (D250) range aircrafts as generated by TRAFUMO/ELWIS are shown in Figure 7.
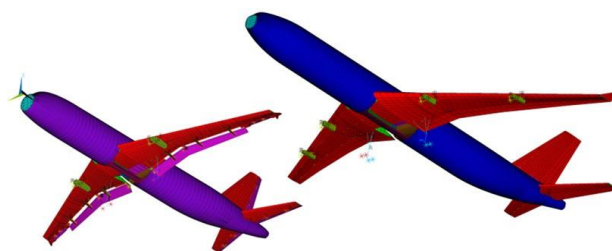

Figure 7. D150 and D250 models for static sizing

Details on modeling of the center wing box area in the fuselage, including keel beam and main landing gear bay, as well as load introduction framework for the empennage structure is presented in [6, 10].

3.3. S-BOT+

Static sizing is conducted with S-BOT+ (Sizing Robot+), an enhancement of the S-BOT (Sizing robot) tool that was originally developed at the DLR Institute of Composite Structures and Adaptive Systems (FA) for sizing of wing structures [13].

Strength evaluation is based on fully stressed design principles: For each specified load case the minimum required sheet thickness is computed by the ratio of actual and maximum acceptable stress. After analysis of all defined load cases the maximum required sheet thickness for each element is stored. This method grants an optimum material utilization.

For isotropic structures S-BOT+ uses the maximum stress criterion. For anisotropic shell structures one can choose between the maximum stress, the Puck and the Tsai-Wu criterion. Stability failure is also considered. Shell structures are sized to resist local compressive and shear buckling according to methods proposed by Bruhn [14]. More information on the sizing processes in general is given in [10].

An exemplary fuselage sizing result is presented in Figure 8. It can be seen that the highest skin thicknesses are located around the center wing box where high aerodynamic forces are introduced into the fuselage.

Lowest skin thicknesses are required at the cockpit section. The fuselage model is clamped at the empennage structure. Reaction forces lead to high skin thicknesses in this region. Forces decline behind the mounting, therefore, the required skin thickness is minimum.
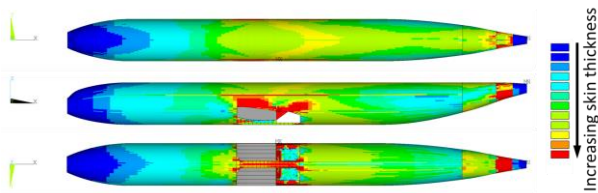

Figure 8.   Exemplary D250 fuselage sizing (seen from top, side, bottom)

4. APPLICATIONS BEYOND STATIC SIZING

As shown in Figure 1, the crashworthiness proof follows the static sizing. The proof that the structure features sufficient energy absorption in case of survivable emergency crash landings is a request given by the airworthiness authorities for the certification of new aircrafts.

To evaluate aircraft crashworthiness the tool AC-CRASH (Aircraft-Crash) has been developed at DLR-BT. Like the TRAFUMO model generator, described in section 3.2, it is based on CPACS. The current version is V3.

Unlike the static sizing, crash computations are generally conducted using an explicit time integration scheme. At DLR-BT it was decided to use VPS/PAM-CRASH (v2011.0 and newer) as solver for AC-CRASH. However, the integration of other explicit solvers is under development.

AC-CRASH which will be introduced subsequently generates flexible aircraft fuselage models for the use in aircraft crash analyses. However, for the investigation of fluid-structure interaction, flexible models lead to excessive computation times. Therefore, several approaches have also been developed to conduct ditching simulations efficiently. These approaches will be presented following the introduction of AC-CRASH.

4.1. Crash simulation using AC-CRASH

The evaluation of crashworthiness of aircraft designs is usually conducted using vertical drop tests because real full-scale tests would be very expensive, highly time-consuming and very sensitive to boundary conditions and outer influences which may influence reproducibility.

Therefore, aviation authorities usually accept the crashworthy evaluation of vertical drops in the certification process. New aircraft types are numerically analyzed and their crash behavior must not be worse compared to existing ones.

An overview of section drop tests conducted at the NASA Langley facility is given by Jackson [15]. It shall be mentioned here that full-scale drop tests may be conducted in case the aircraft is not too big.

According to what is defined in the tool specific node of the CPACS file AC-CRASH either generates a section model for vertical drop analyses or a full fuselage model for crash scenarios with a horizontal velocity component.

A typical generic model used for the vertical drop test simulation scenario is presented in Figure 9. It shows a rear section of a generic aircraft. For visibility reasons some fuselage skin panels have been removed.
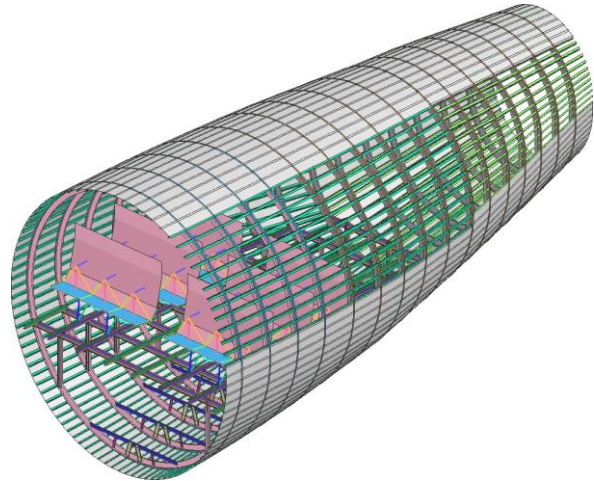

Figure 9. Rear section for vertical drop simulation

Section drop scenarios are suited for evaluating the vertical acceleration response of occupants in a crash load case. The vertical load case is a potential risk for the spine as well as inner organs of the occupants as these are captured within the thorax.

However, horizontal acceleration threatens the head of the occupants as the inertia accelerates them towards the seat mounted in front. For evaluation the so-called Head Injury Criteria (HIC) is applied. As this scenario is hardly investigative in full structural tests, the HIC is usually evaluated by the use of sled tests with seat/occupant combinations.

To evaluate crash scenarios with horizontal velocities, e.g. ditching or nose landing gear failure, AC-CRASH can be used to generate full fuselage models. Generic examples of a short and long range aircraft are presented in Figure 10.
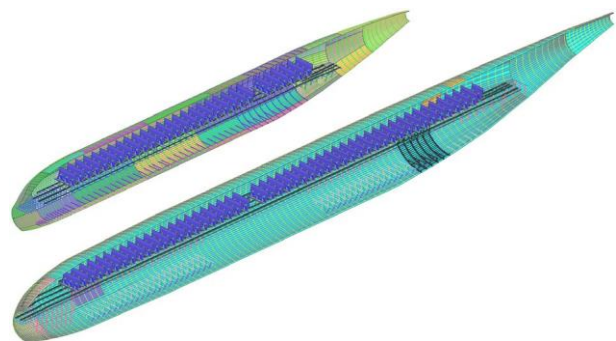

Figure 10.   D150 and D250 for crash simulations (volume cut models)

Contrary to static design, large deformations to absorb kinetic impact energy are expected in the crash case. Highly non-linear behavior is expected in that load case. Therefore, aspects like plastification (in case of metallic constructions) and damage initiation/progress (in case of composite materials) need to be represented adequately.

This requirement led to the development of so-called detailed regions. Under the tool specific node in the CPACS file areas can be defined where the fuselage is discretized much finer using, for instance, extruded shell elements instead of beams for all reinforcements. Each detailed region may be provided by an individual element size definition, thus, allowing versatile meshing options. An exemplary detailed region is shown in Figure 11. The area depicted in this figure represents the area of first impact in a ditching scenario. In the detailed region the frames, stringers as well as the cargo subfloor structure are modeled by shell elements with typical element edge length of about 10–30 mm. So-called transition areas around the detailed regions are used to gradually adapt the element size of the fuselage skin to the global element size which comprises one bay of two frames and two stringers. This step is required to avoid large element gradients which may cause numerical instabilities during explicit crash simulation. Also observable is that outside the detailed region, structural components are discretized using beam elements (e.g. passenger crossbeam vertical support struts and cargo subfloor structure).
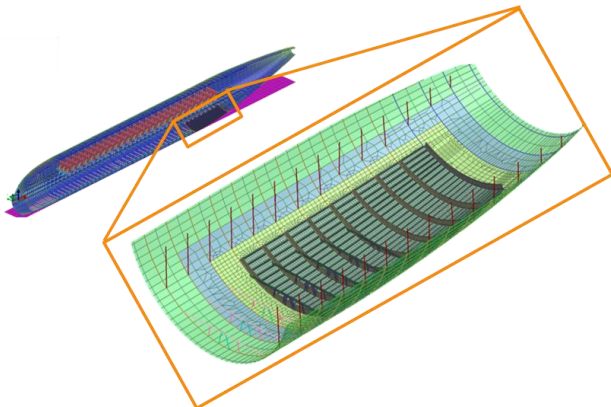

Figure 11. Detailed region of first impact zone

The coupling of the shell elements in the fine meshed extruded beam sections and the corresponding beam elements in the coarsely meshed regions is realized using the MTOCO (Multiple Nodes To One Node Constraint) element in VPS/PAM-CRASH. AC-CRASH automatically detects the interfaces between the two discretization approaches, selects the corresponding nodes and elements at each interface and generates the input deck for VPS/PAM-CRASH. The MTOCO method ties all translational and rotational degrees of freedom of the dependent nodes to those of the independent node, acting like a rigid body.

Recently, dummy modeling for a more realistic passenger load introduction has been integrated. An exemplary full-scale emergency landing of a generic single aisle aircraft is presented in [16].

4.2. Ditching simulations

In addition to studies of crash impact on hard ground, aircraft design also addresses the investigation of controlled emergency landing on water, known as ditching, in order to proof compliance with airworthiness regulations.

The high forward velocity of fixed-wing aircraft typically causes hydrodynamic effects which may affect the global kinematics of the aircraft. Moreover, complex fluid-structure interaction determines the structural behavior.

This impact environment is significantly more complex which requires specific numerical methods to handle large fluid deformations and complex free surface shapes. Therefore, the fluid domain is modeled using the mesh-free Smoothed Particle Hydrodynamics (SPH) method. Due to its Lagrangian formulation, the SPH water model may easily be coupled to FE aircraft models within one solver.

Main challenges arise from the combination of flexible aircraft models, which determine the critical time step of the explicit simulation, and the large amount of particles necessary to discretize a sufficiently large water domain. Applying state-of-the-art modeling techniques such as translating periodic boundary conditions and non-uniform particle distributions [17], both significantly reducing the CPU effort, have recently enabled detailed ditching analyses.

In order to assess the capabilities and limitations with respect to efficiency and accuracy, aircraft modeling approaches with different level of detail have been developed to be studied in ditching analyses:

- Rigid aircraft model: Computationally fastest model; may be used to investigate global aircraft kinematics during ditching. (Focus on hydrodynamic effects)

- Stick aircraft model: Slightly increased computational effort; represents the global stiffness of the airframe while local deformations are not allowed. (Focus on influence of global flexibility)

- Coarse/detailed full FE models: Computationally very demanding; portray global as well as local structural behavior including deformation, failure etc. (Focus on the influence of local deformations on fluid-structure interaction)

Exemplary, the generation of a dynamic aircraft model (stick aircraft modeling approach) is described below. This model represents a combination of the global finite element and the rigid body aircraft models (Figure 12). Consistency is ensured as all data is based on one CPACS input file. The global FE model, which has been generated by AC-CRASH after being statically sized by S-BOT+, is used to determine the global stiffness distribution of the fuselage. For each frame bay the stiffness of the airframe is computed and subsequently condensed on a beam element located at the aircraft reference axis. In addition, the fuselage skin of the rigid body model is cut at each frame position and resulting sections are connected to the respective beam elements using rigid body

constraints (see Figure 12, center). This procedure results in the final model which represents a flexible fuselage structure with locally rigid sections used to model the contact between the aircraft structure and the water particles.
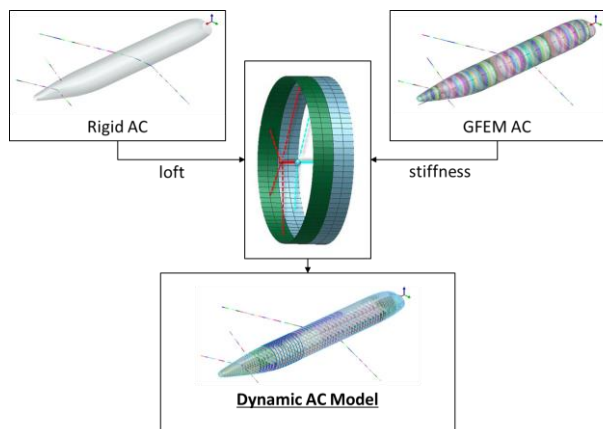

Figure 12. Dynamic aircraft model

5. CONCLUSION AND OUTLOOK

In this paper the work of DLR-BT in the field of preliminary aircraft design has been summarized. The description of the fuselage structure in the unified data format CPACS that serves as basis for all applications in the field of multi-disciplinary aircraft design within DLR has been presented. Options that are required for the definition, positioning and alignment of structural components have been presented and explained.

Tools for static sizing and preliminary crashworthiness evaluation including ditching have been presented. Exemplary models that are based on the same CPACS data set have been shown giving an idea of the versatile possibilities available with CPACS.

Currently modeling approaches to cover alternative aircraft configurations, such as strut braced wing aircraft, are under development.

F-DESIGN is under permanent development to automatically generate initial CPACS files according to given loft geometries based on predefined design rules. Moreover, the range of F-DESIGN options is under steady development and shall soon cover, for instance, the automatic generation of door definitions within CPACS.

Future enhancements of AC-CRASH comprise integration of structural components like center wing box and wing integration.

6. ACKNOWLEDGEMENTS

This conference article is a pre-print of an article published in the CEAS Aeronautical Journal. The final peer-reviewed version of this article is available online at https://doi.org/10.1007/s13272-016-0193-4.

7. REFERENCES

[1] D. Böhnke, B. Nagel, and V. Gollnick, "An Approach to Multi-Fidelity in Conceptual Aircraft Design in Distributed Design Environments," in *IEEE Aerospace Conference*, Big Sky, USA. 2011.

[2] CPACS, "CPACS - A Common Language for Aircraft Design," 2011. [Online]. Available: https://code.google.com/p/cpacs/. [Accessed: 05-Nov-2013].

[3] TIXI, "TIXI Homepage." [Online]. Available: https://code.google.com/p/tixi/. [Accessed: 17-Jan-2014].

[4] TIGL, "TIGL Homepage." [Online]. Available: https://code.google.com/p/tigl/. [Accessed: 20-Aug-2014].

[5] A. Rizzi, M. Zhang, B. Nagel, D. Böhnke, and P. Saquet, "Towards a Unified Framework using CPACS for Geometry Management in Aircraft Design," in *50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, Nashville, USA. 2012.

[6] J. Scherer and D. Kohlgrüber, "Overview of the versatile options to define fuselage structures within the cpacs data format," in *4th EASN Association International Workshop on Flight Physics & Aircraft Design*, Aachen, Germany. 2014.

[7] K. Harbig, "Entwicklung eines parametrisierten Netzgenerators zur automatisierten Crashsimulation von Flugzeugrumpfstrukturen," DLR-IB 435-2010/22, 2010.

[8] D. B. Schwinn, D. Kohlgrüber, K. Harbig, and J. Scherer, "Development of a Fully Parameterized Process Chain to Evaluate the Crash Behaviour of Transport Aircraft in the Preliminary Design Phase," in *Aerospace Structural Impact Dynamics International Conference*, Wichita, USA. 2012.

[9] D. B. Schwinn, J. Scherer, D. Kohlgrüber, and K. Harbig, "Development of a Multidisciplinary Process Chain for the Preliminary Design of Aircraft Structures," in *NAFEMS World Congress*, Salzburg, Austria. 2013.

[10] J. Scherer, D. Kohlgrüber, F. Dorbath, and M. Sorour, "A Finite Element Based Tool Chain for Structural Sizing of Transport Aircraft in Preliminary Aircraft Design," in *Deutscher Luft-*

und Raumfahrtkongress, Stuttgart, Germany. 2013.

[11] F. Dorbath, B. Nagel, and V. Gollnick, "Implementation of a Tool Chain for Extended Physics-Based Wing Mass Estimation in Early Design Stages," in *71th Annual Conference of Society of Allied Weight Engineers, Inc.*, Bad Gögging and Manching, Germany. 2012.

[12] F. Dorbath, B. Nagel, and V. Gollnick, "Extended physics-based wing mass estimation in early design stages applying automated model generation," *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, vol. 228, no. 7, pp. 1010–1019, Apr. 2013.

[13] B. Nagel, M. Kintscher, and T. Streit, "Active and Passive Structural Measures For Aeroelastic Winglet Design," in *26th International Congress of the Aeronautical Sciences*, Anchorage, USA. 2008.

[14] E. F. Bruhn, *Analysis and Design of Flight Vehicle Structures*. Tri-State Offset Company, 1973.

[15] K. E. Jackson, R. L. Boitnott, E. L. Fasanella, L. E. Jones, and K. H. Lyle, "A History of Full-Scale Aircraft and Rotorcraft Crash Testing and Simulation at NASA Langley Research Center," in *4th Triennial International Aircraft and Cabin Safety Research Conference*, Lisbon, Portugal. 2004.

[16] D. B. Schwinn, "Integration of Crashworthiness Aspects into Preliminary Aircraft Design," *Applied Mechanics and Materials*, vol. 598, pp. 146–150, 2014.

[17] M. H. Siemann and P. H. L. Groenenboom, "Modeling and validation of guided ditching tests using a coupled SPH-FE approach," in *9th International SPHERIC Workshop*, Paris, France. 2014.