Federal Aviation Administration

Dynamic Modeling and Simulation (M&S) in Aircraft Ditching and Cabin Evacuation

High Fidelity Simulations of Flexible Aircraft Structures Under Ditching Loads

Virtual Workshop. August 10, 2022

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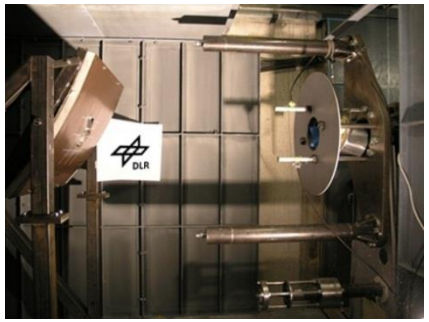
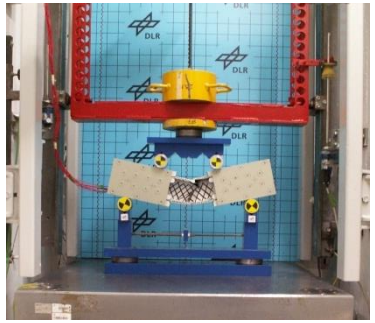
DLR

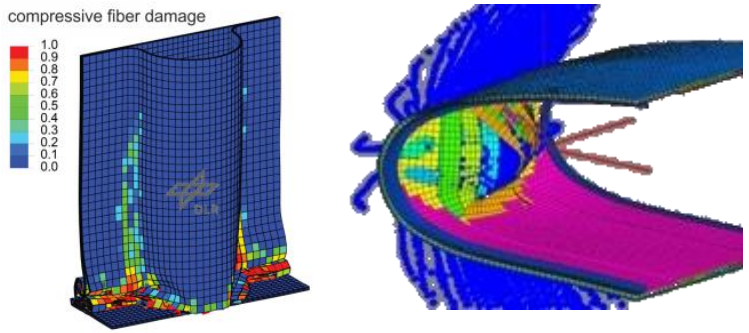
German Aerospace Center (DLR) – Institute of Structures and Design (BT)

Department: Structural Integrity





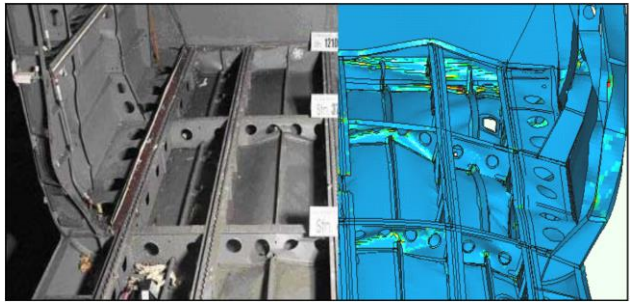
Development of energy absorbent structural concepts (incl. Crash & Impact Tests)



Modeling & analyze of aircrafts and components (quasi-static & transient dynamic)

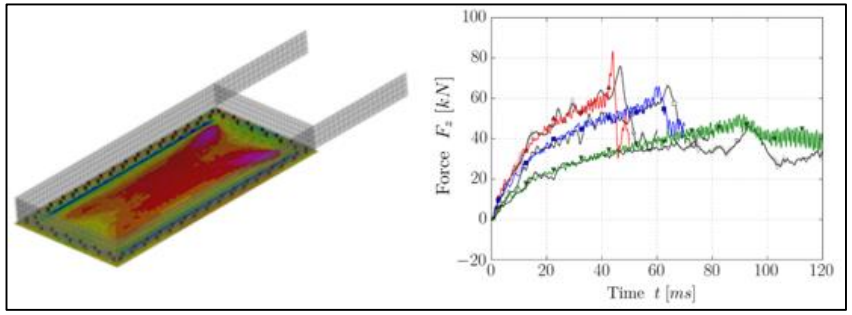
- Large experience with Hi-Fidelity (Hi-Fi) Fluid-Structure Interaction (FSI) simulations
  - Since 2003: several dissemination activities, 2 PhDs (Toso 2009, Siemann 2016)
  - Mainly SPH-FE with VPS software

[1]



EU-CAST (WG30-Vertical Drop, 2004)

[2]



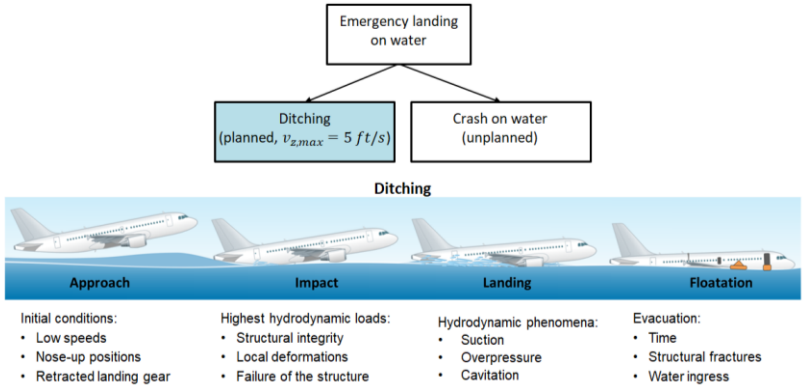
Influence of local deformations on hydrodynamic loads (SMAES/ADAWI, ~2016)

[1] N. Toso, Contribution to the Modelling and Simulation of Aircraft Structures Impacting on Water, Stuttgart, University of Stuttgart, 2009
[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016

Motivation: Contribution to Crashworthiness Requirements

- Certification Specification e.g. CS-25: Large Aeroplanes
  - §563 - Structural ditching provisions
  - §801 - Ditching
  - §807(i) - Ditching emergency exits for passengers

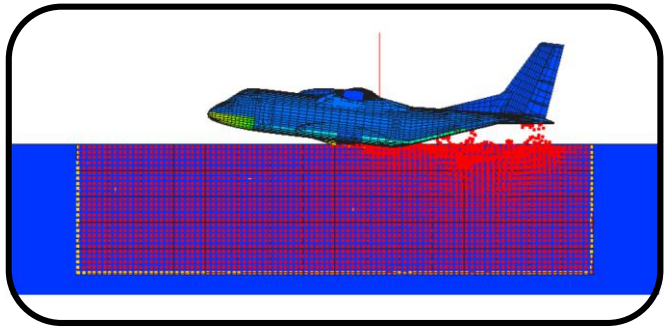
  - ➢ **After-crash structural failures do not lead to immediate injuries**
  - ➢ **Emergency exits operative after landing**
  - ➢ **Sufficient time for evacuation**



[3]

Computational methods:

- Lo-Fidelity: analytical / semi-analytical approach
  - Simplified flow theory: very fast approach
  - Analysis of the global deformation
- **Hi-Fidelity: advanced numerical methods**
  - 2-way (fluid and structure) computation
  - Analysis of the global kinematic behavior
  - <u>Analysis of the local structural response to hydrodynamic loads</u>
  - <u>Parametric variation: attitude, velocities, mass, etc.</u>



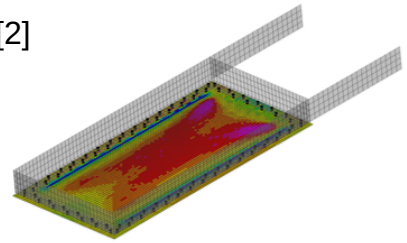
[4]

[3] NTSB, Accident Report: Loss of Thrust in Both Engines after Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, Washington, 2009
[4] L. Benítez Montañez, H. Climent Máñez, M. Siemann and D. Kohlgrüber, Ditching Numerical Simulations: Recent Steps in Industrial Applications, Aerospace Structural Impact Dynamics International Conference, 2012

Ditching activities at DLR

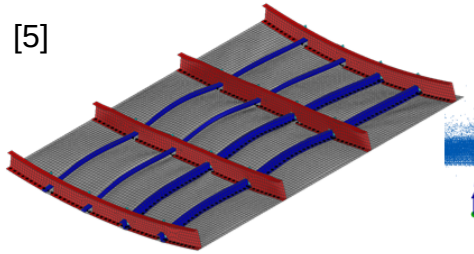
1. Ditching methods development at DLR

[2]

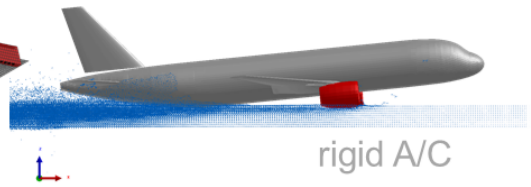


- Simple flex. structure (generic panels)
- Prescribed motion
- Validated FE-SPH approach

[5]



- Complex flex. structure (generic reinforced panels)
- Prescribed motion



- Rigid structure (Generic aircraft)
- Free motion

2. DLR ditching pre-design process chain

Data Set for aircraft definition

Modelling of generic aircraft (Focus on fuselage)

[6]

Generic flexible aircraft (Focus on fuselage)

3. Integration of complex models into ditching analyses

[3]

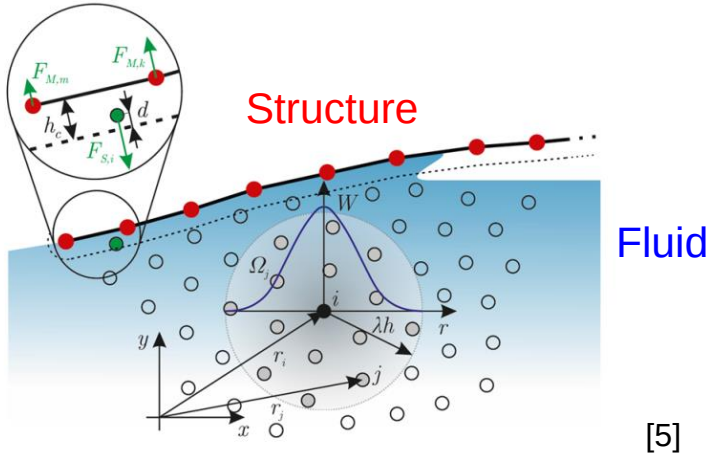
- Highly complex, flexible structure (generic aircraft)
- Free motion

[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016
[3] NTSB, Accident Report: Loss of Thrust in Both Engines after Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, Washington, 2009
[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017
[6] C. Leon Muñoz, D. Kohlgrüber, M. Petsch, Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain, ESI-Forum 2019, Berlin, 2019

Fluid-Structure Interaction (FSI): methods considered

- Efficient approach for a multi-model problem with nonlinear structural behavior and large fluid displacements

Coupled Smoothed Particle Hydrodynamics (SPH) - Finite Element (FE)



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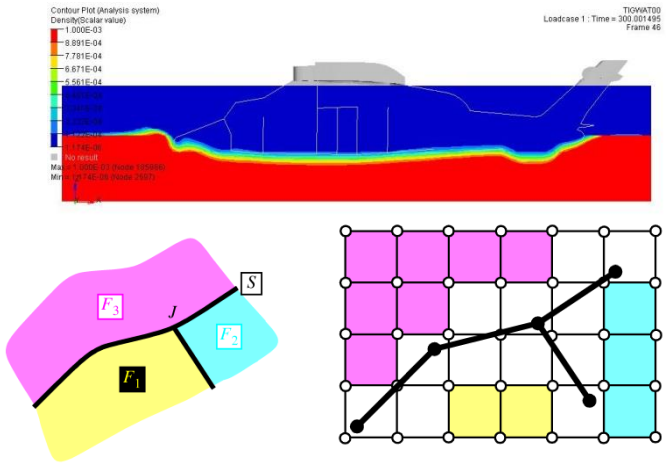
- Structure discretized using a mesh-based discretization (FE)
- Fluid modelled with the mesh-free Lagrangian method SPH
- Coupling of models using a penalty contact formulation

Arbitrary Lagrangian Eulerian (ALE)



[7]

- Combines Lagrangian and Eulerian formulations
- Arbitrary motion of the mesh nodes independently of the material
- Coupled approach: structure mesh embedded in the fluid domain

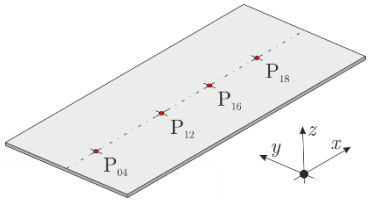
[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017
[7] B. Langrand, M. H. Siemann, D. Kohlgrüber, C. Leon Munoz, Full aircraft ditching simulation by advanced fluid structure interaction computational methods: a comparative analysis, ASIDIC 2019, Madrid, 2019

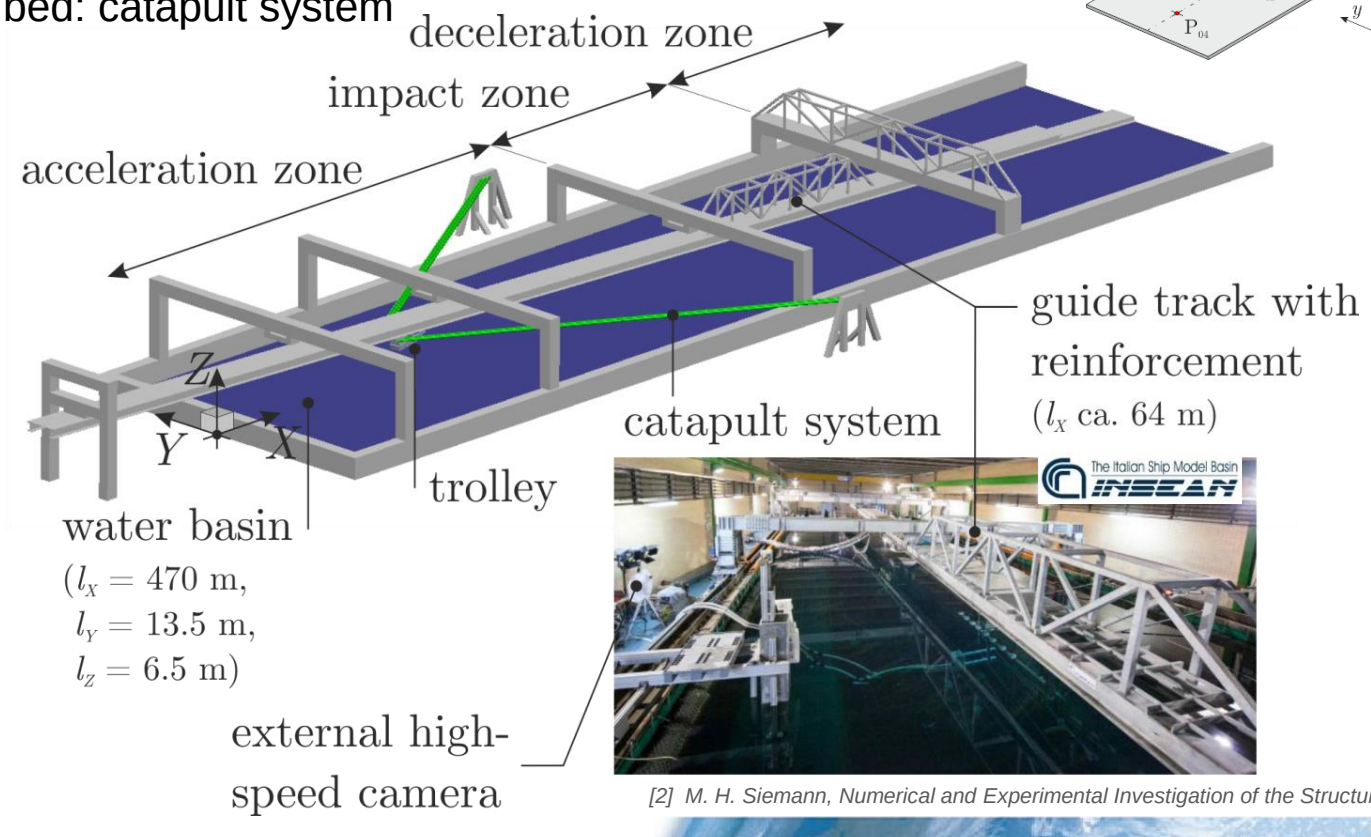
SMAES
Smart Aircraft in Emergency Situations

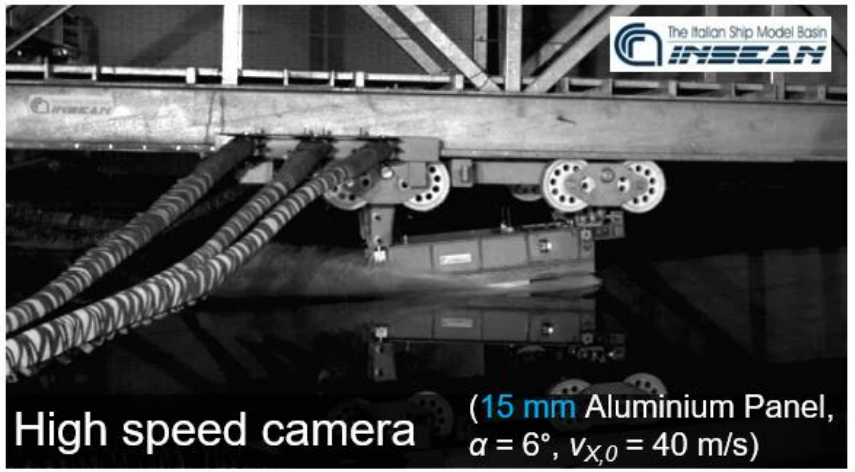
Ditching Methods Development

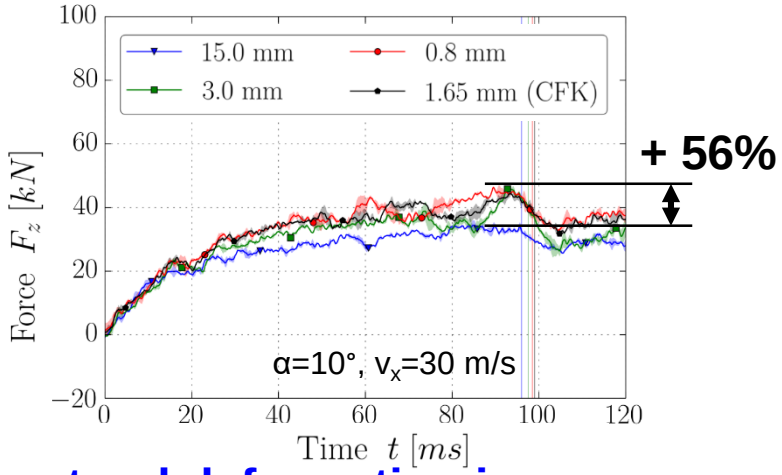
Generic Panel – Guided Ditching Tests (CNR-INSEAN, Rome 2014)

- Experimental campaign to investigate flexible structures and to validate the SPH-FE method at CNR-INSEAN
- Guided ditching test using generic flexible flat panels
- Test bed: catapult system









[2]

➔ **Structural deformation increases hydrodynamic loads significantly**

[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016

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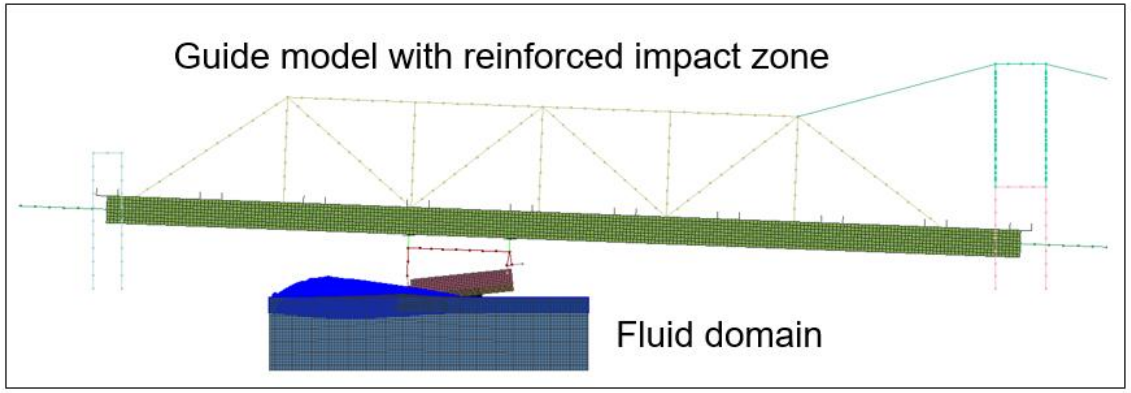
SMAES
Smart Aircraft in Emergency Situations

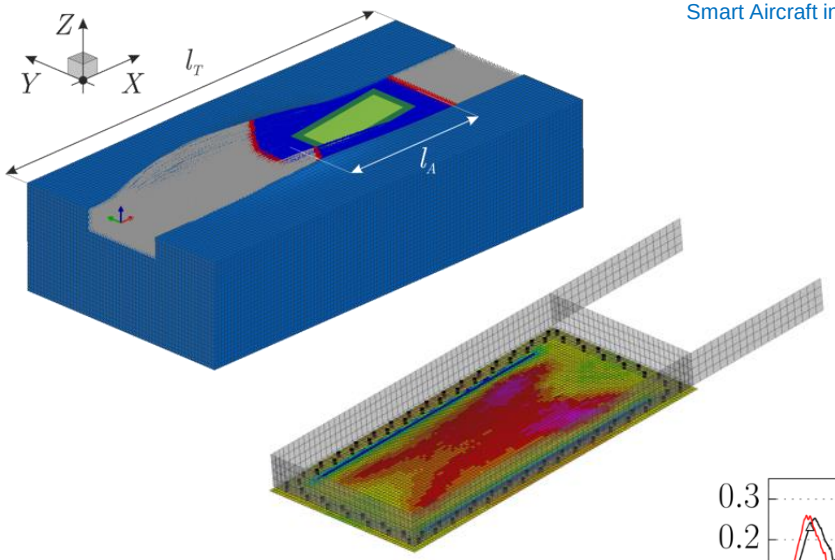
Ditching Methods Development

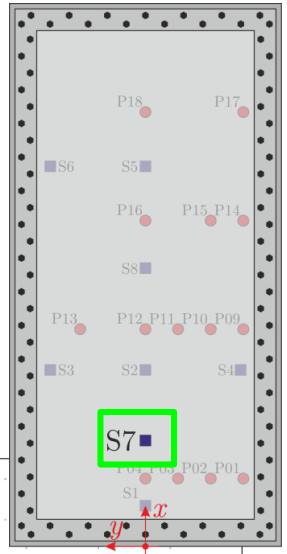
Generic Panel – Guided Ditching Simulation

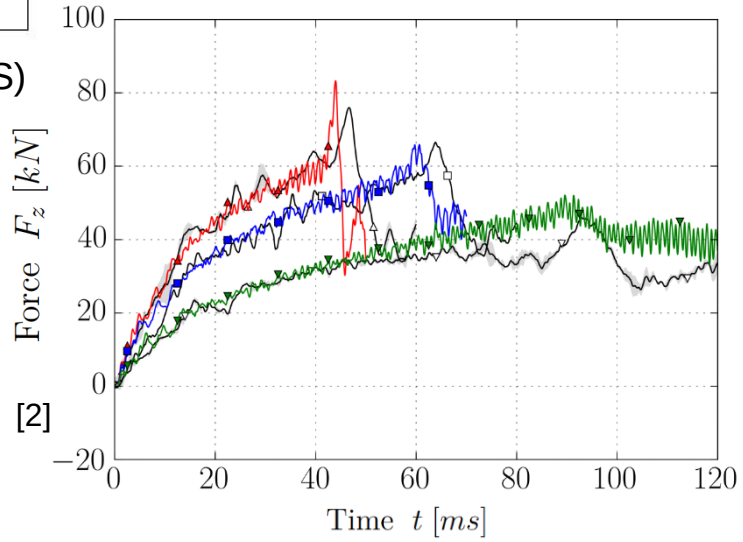
- Experimental campaign provided valuable data for validation



SPH-FE model (Code: VPS)







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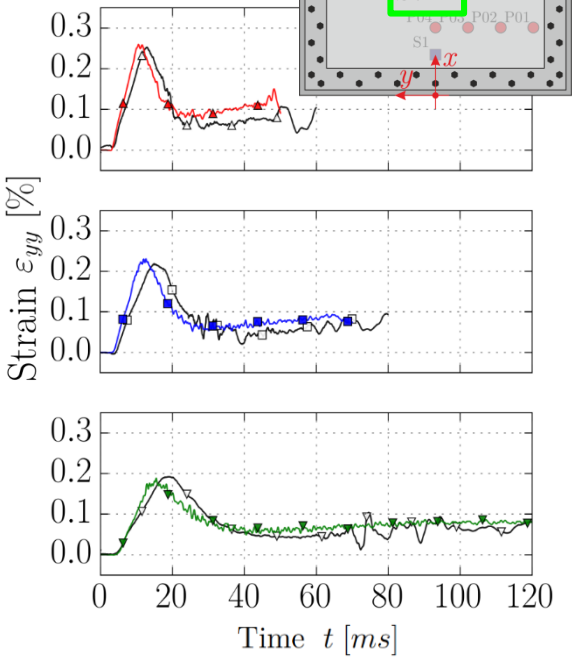

➔ **Guided ditching simulation using SPH-FE method validated with simple flexible panel**

[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016

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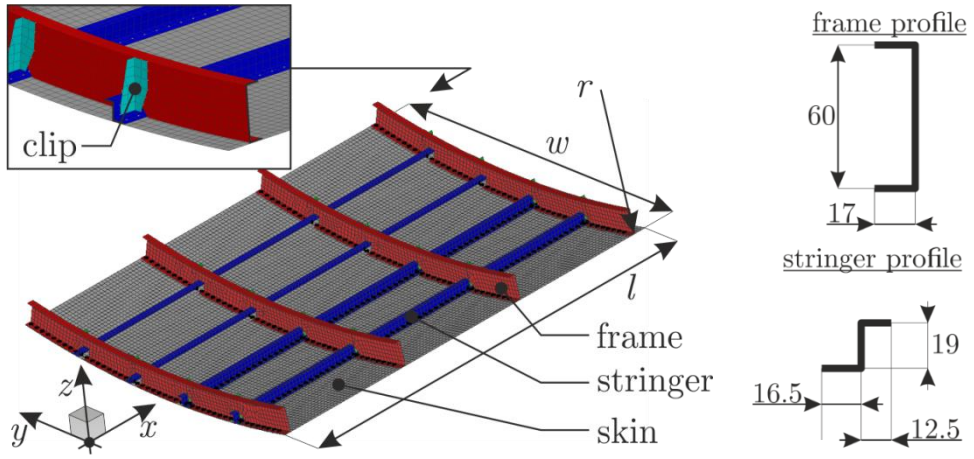
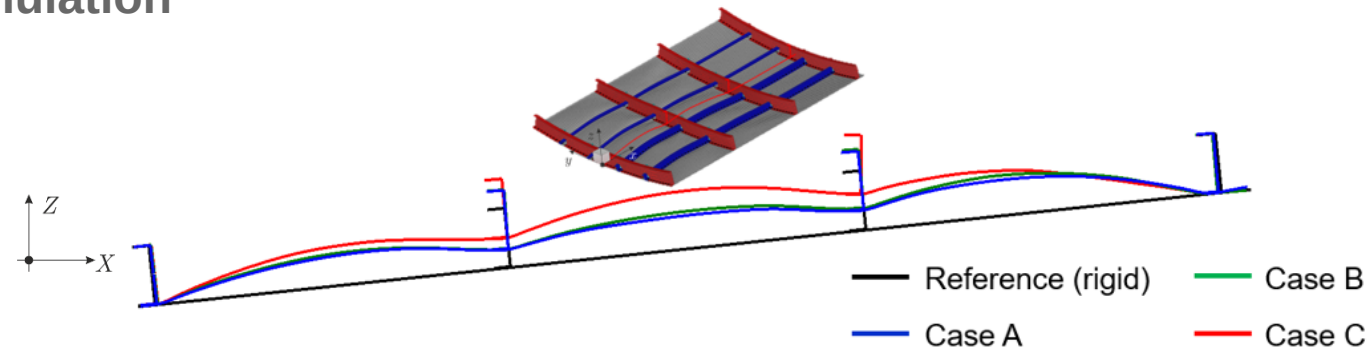
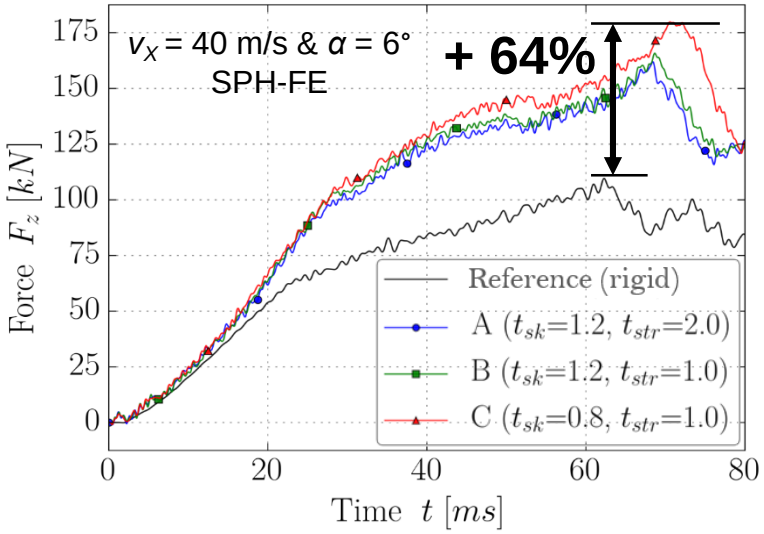
Ditching Methods Development

Generic Fuselage Panel – Guided Ditching Simulation







[5]

- Extension of study on deformable panel tests from SMAES
- Numerical simulation with SPH-FE parameters (validated on SMAES)
- Qualitatively similar normal force time histories compared to guided ditching simulation with unstiffened panels

➔ **Influence of flexibility: structural deformation increases hydrodynamic loads significantly**

➔ **In line with SMAES´ results on simple flexibel panel**

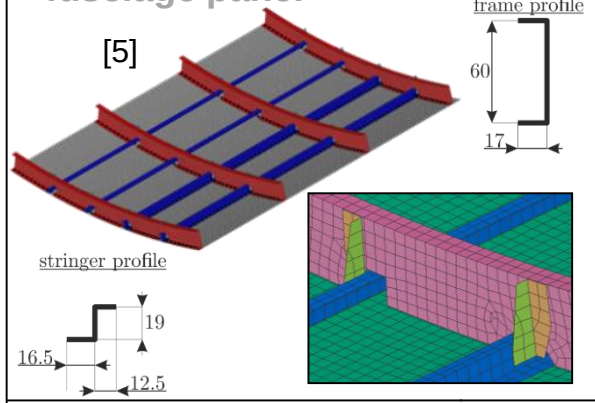
➔ **However, not feasible to transfer to full aircraft model**

[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017

Ditching Methods Development

Generic detailed lower fuselage panel

[5]

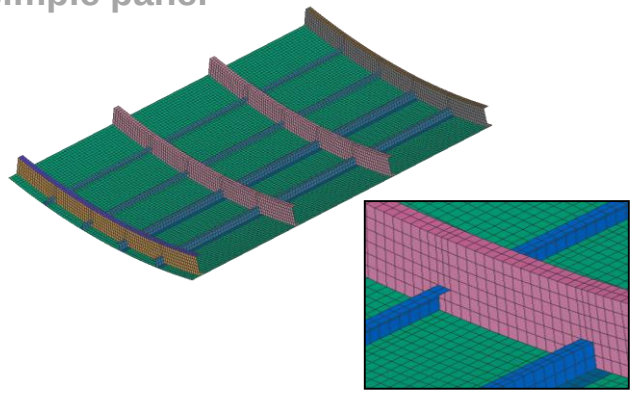


Skin, stringers, frames modeled individually

- Connect. via rivets, tied interfaces
- Clips, mouseholes

→ Too complex to model for different methods and codes

Extension of study on deformable simple panel



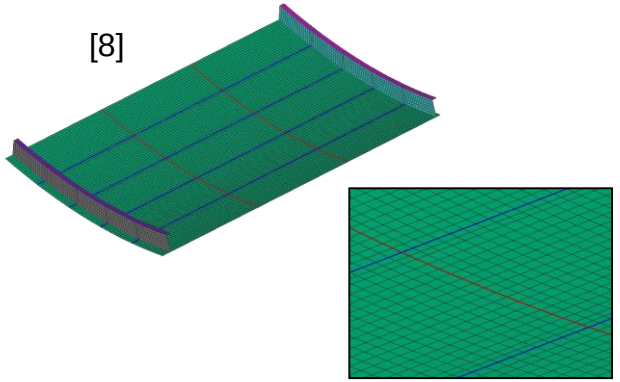
Skin, stringers, frames modeled with common nodes

- Simple intersection w. updated skin thk.
- No mouseholes

→ Simplified for harmonization in different methods and codes

Integration of representative beam FE in skin reinforcements

[8]

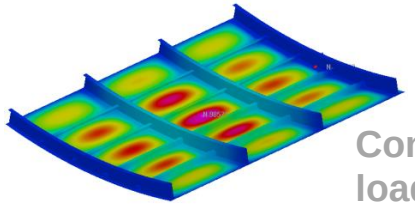


Stringers and inner frames replaced by beam elements

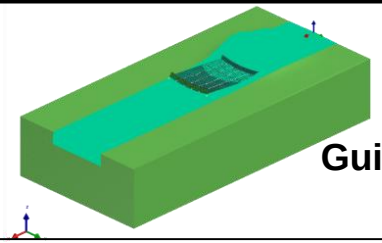
- Flanges included in beam properties
- Standard skin thickness

→ **Step to reach affordable calculations with full aircraft model**

Loading Conditions investigated



✓ Constant pressure loading



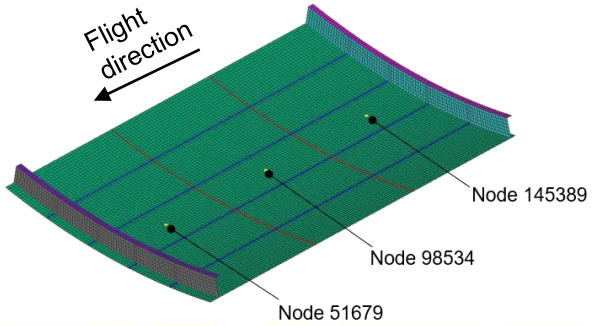
Guided Ditching

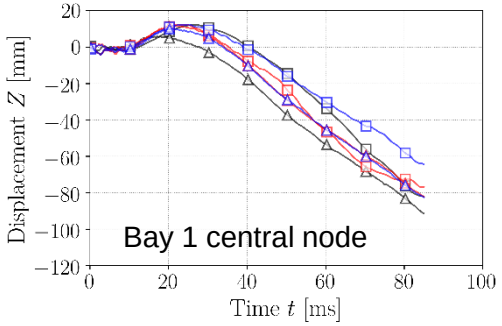
[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017
[8] C. Leon Muñoz, D. Kohlgrüber, B. Langrand, Analysis of fuselage skin reinforcements with beam element models in flexible aircraft panels for ditching simulations, IOP Conf. Ser.: Mater. Sci. Eng. 1024 012054, 2021

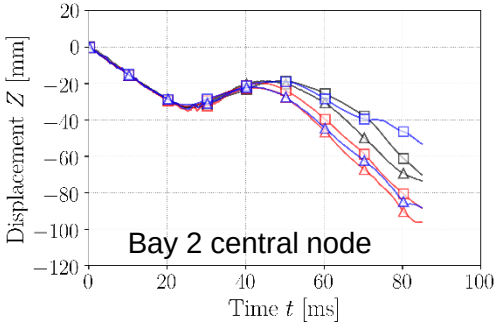
Ditching Methods Development

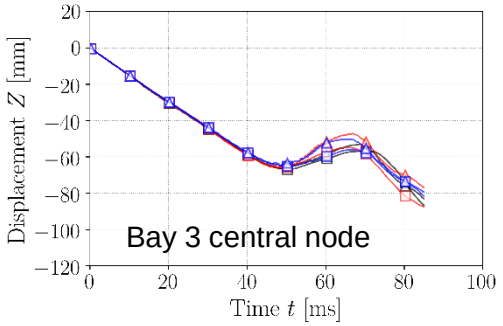
Generic Fuselage Panel with Beam Reinforcements – Guided Ditching Simulation

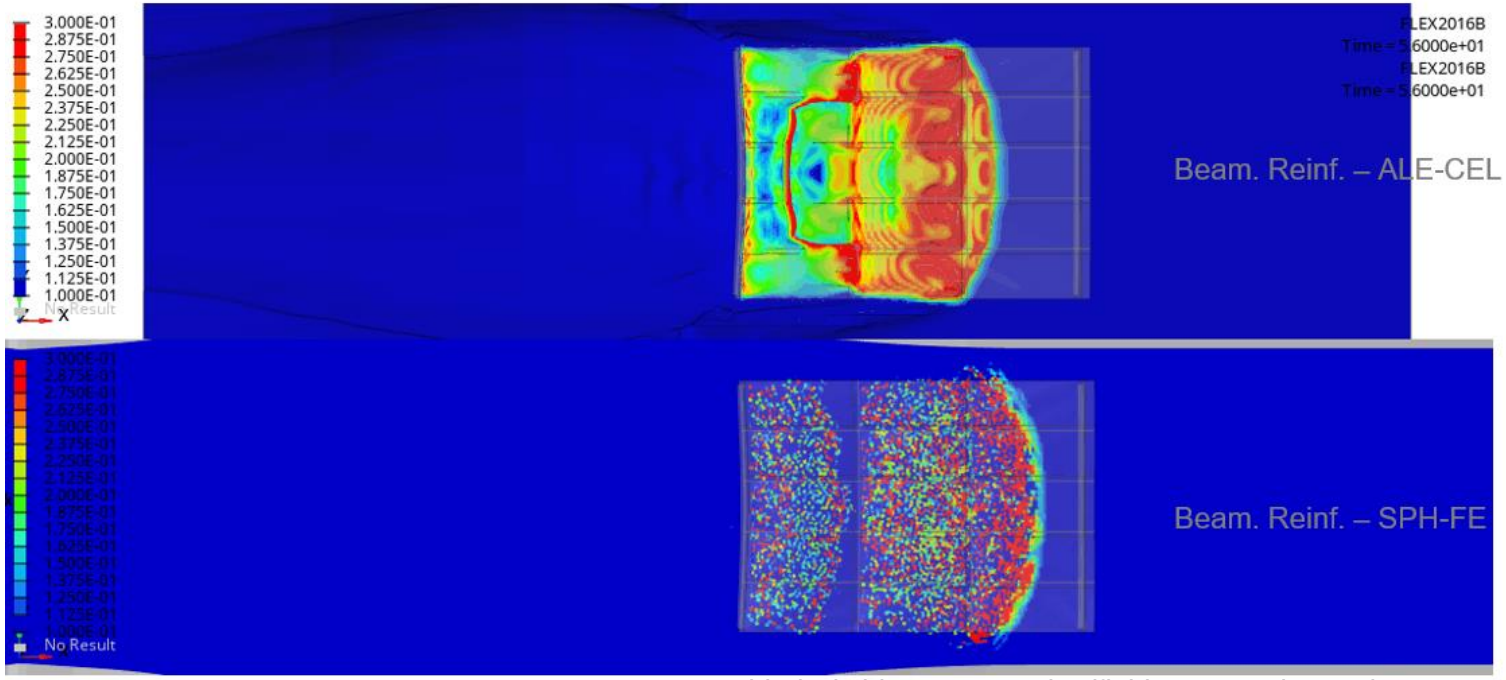
Initial conditions:
Sink rate = 1.5 m/s
Velocity Vx = 40 m/s
Pitch angle = 6°



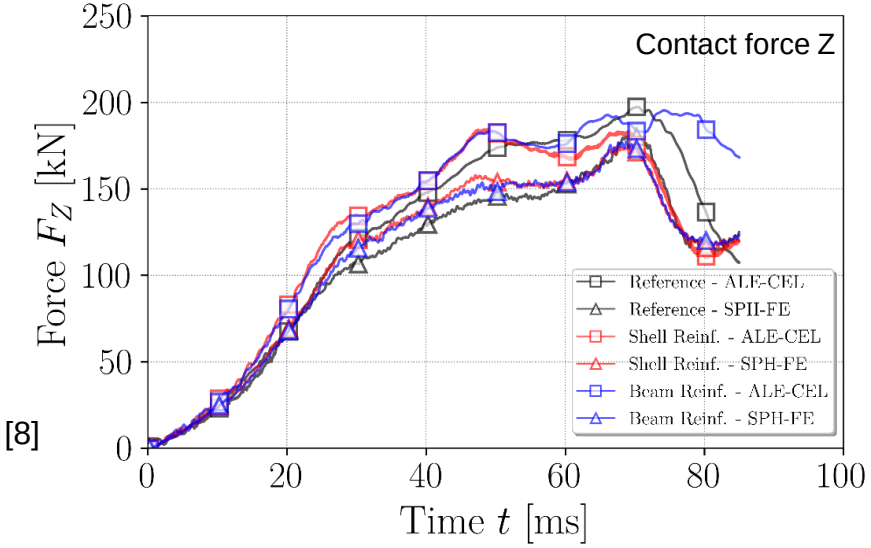








Guided Ditching contour plot (fluid pressure in MPa)



[8]

➔ Comparable behavior using beam FE

[8] C. Leon Muñoz, D. Kohlgrüber, B. Langrand, Analysis of fuselage skin reinforcements with beam element models in flexible aircraft panels for ditching simulations, IOP Conf. Ser.: Mater. Sci. Eng. 1024 012054, 2021

Ditching Methods Development

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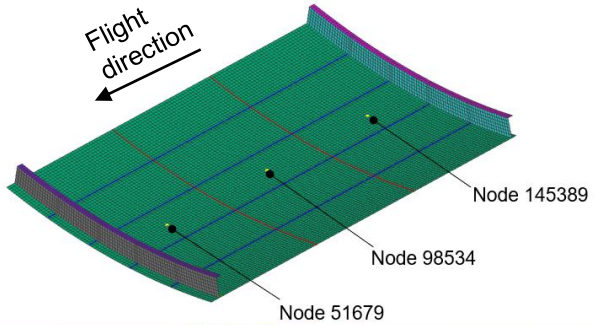
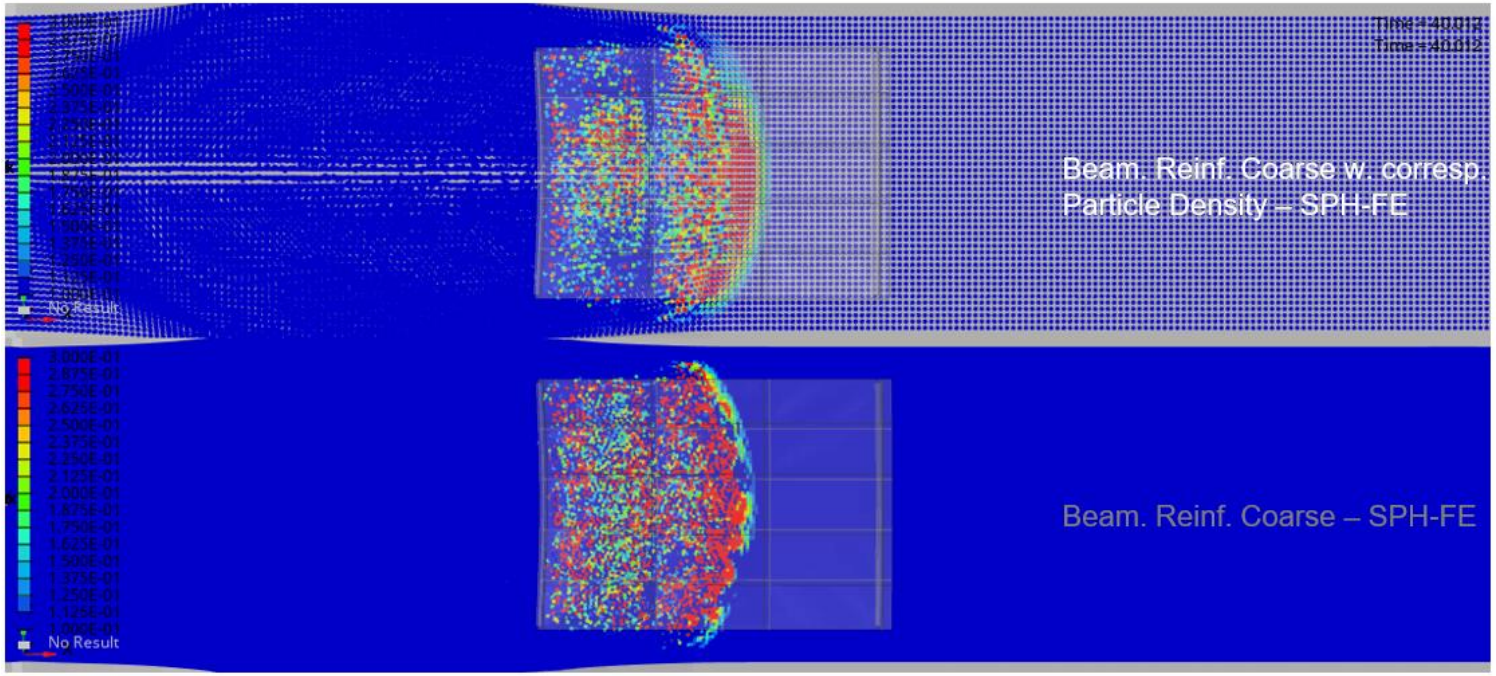


Elapsed times:
Beam reinf. standard mesh (10 mm): ~3h15min
Beam reinf. coarse mesh (20 mm) (corresp. particle density): ~12min30s



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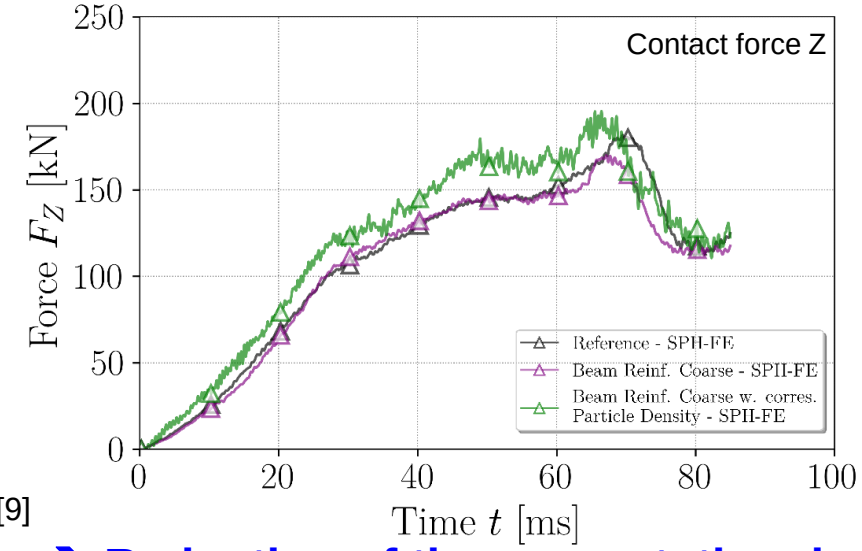


[9]

➔ Reduction of the computational effort by factor 15 possible

[9] C. Leon Muñoz, B. Langrand, D. Kohlgrüber, Analysis of the application of fuselage skin reinforcements with beam element representations in flexible full aircraft models for ditching simulations, IOP Conf. Ser.: Mater. Sci. Eng. 1226 012042, 2022

Ditching activities at DLR

1. Ditching methods development at DLR

[2]

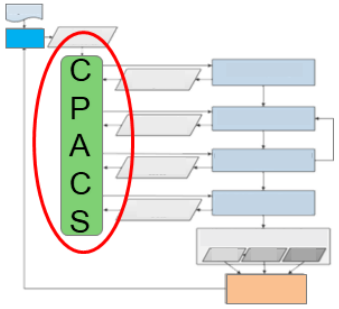
- Simple flex. structure (generic panels)
- Prescribed motion
- Validated FE-SPH approach

[5]

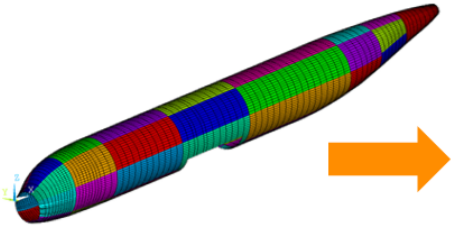
- Complex flex. structure (generic reinforced panels)
- Prescribed motion

- Rigid structure (Generic aircraft)
- Free motion

2. DLR ditching pre-design process chain

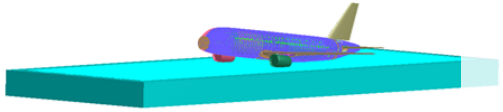


Data Set for aircraft definition



Modelling of generic aircraft (Focus on fuselage)

[6]



Generic flexible aircraft (Focus on fuselage)

3. Integration of complex models into ditching analyses

[3]

- Highly complex, flexible structure (generic aircraft)
- Free motion

[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016
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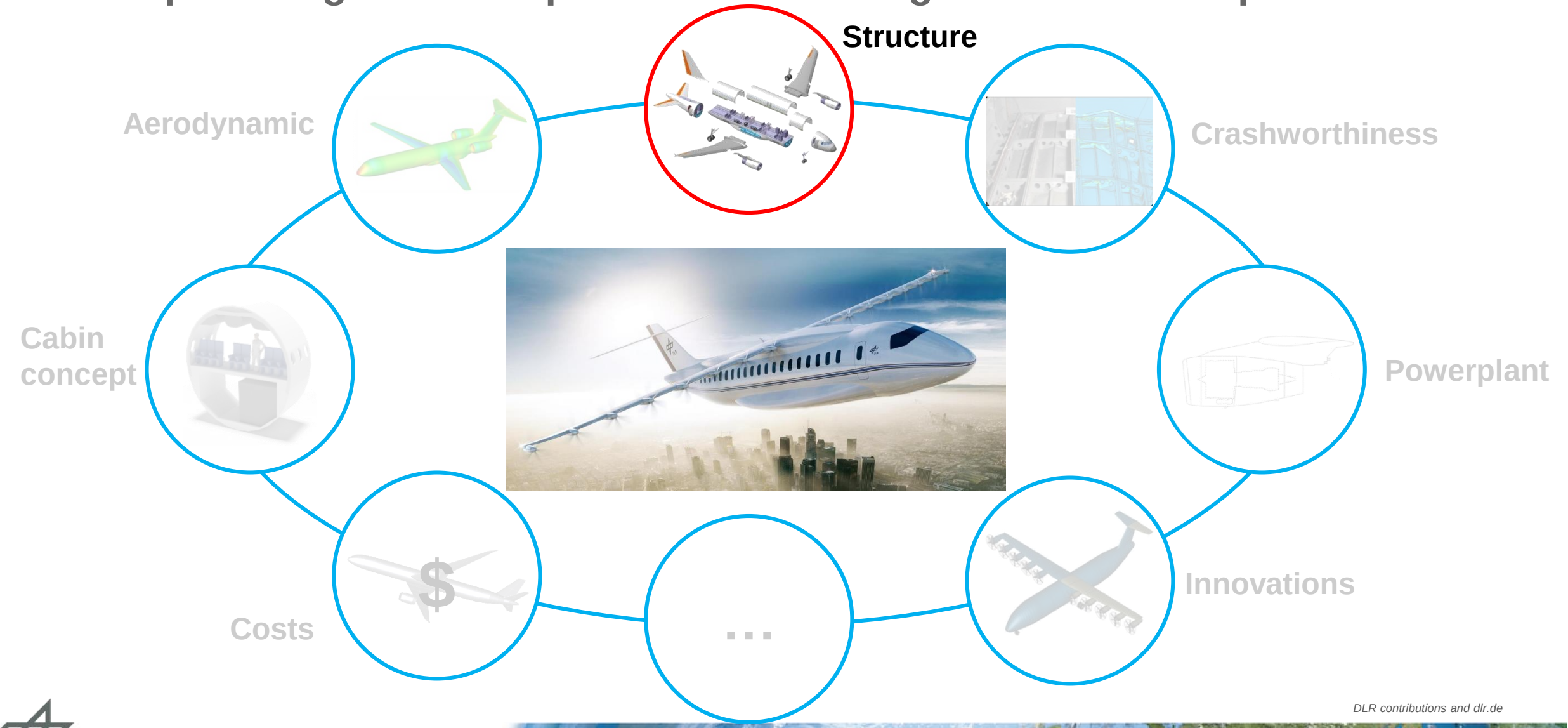
[6] C. Leon Muñoz, D. Kohlgrüber, M. Petsch, Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain, ESI-Forum 2019, Berlin, 2019

Aircraft pre-design is a complex task consisting of several disciplines



Ditching Pre-Design Process Chain

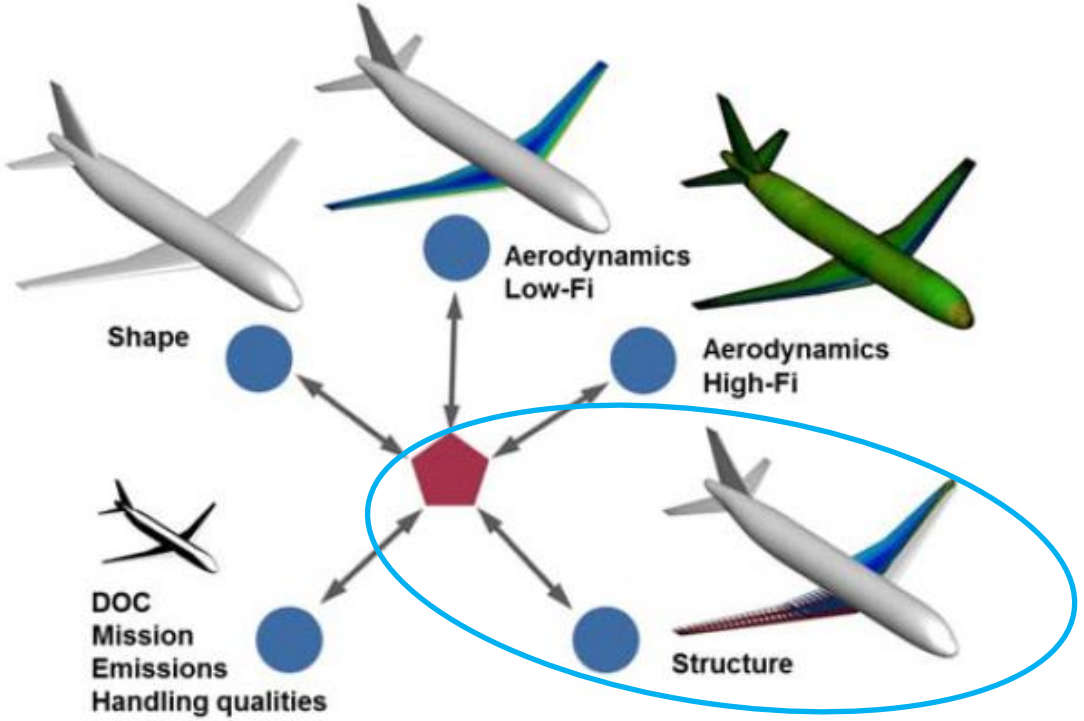
Data exchange

CPACS (Common Parametric Aircraft Configuration Schema)

- Standardized format for description of aircraft / air traffic system
- Hierarchical organized xml-file
- https://www.cpacs.de & https://github.com/DLR-SL/CPACS

[10]

CPACS Data format



Disciplines:

- Aerodynamics
- **Structure**
- Aero-elasticity
- Flight dynamics
- Cabin layout
- Costs
- Noise
- **Crash / Ditching**
- ...

Fuselage description:

- Geometry (Surface)
- Structure (Definition)
- Profiles
- Loads
- Materials
- …

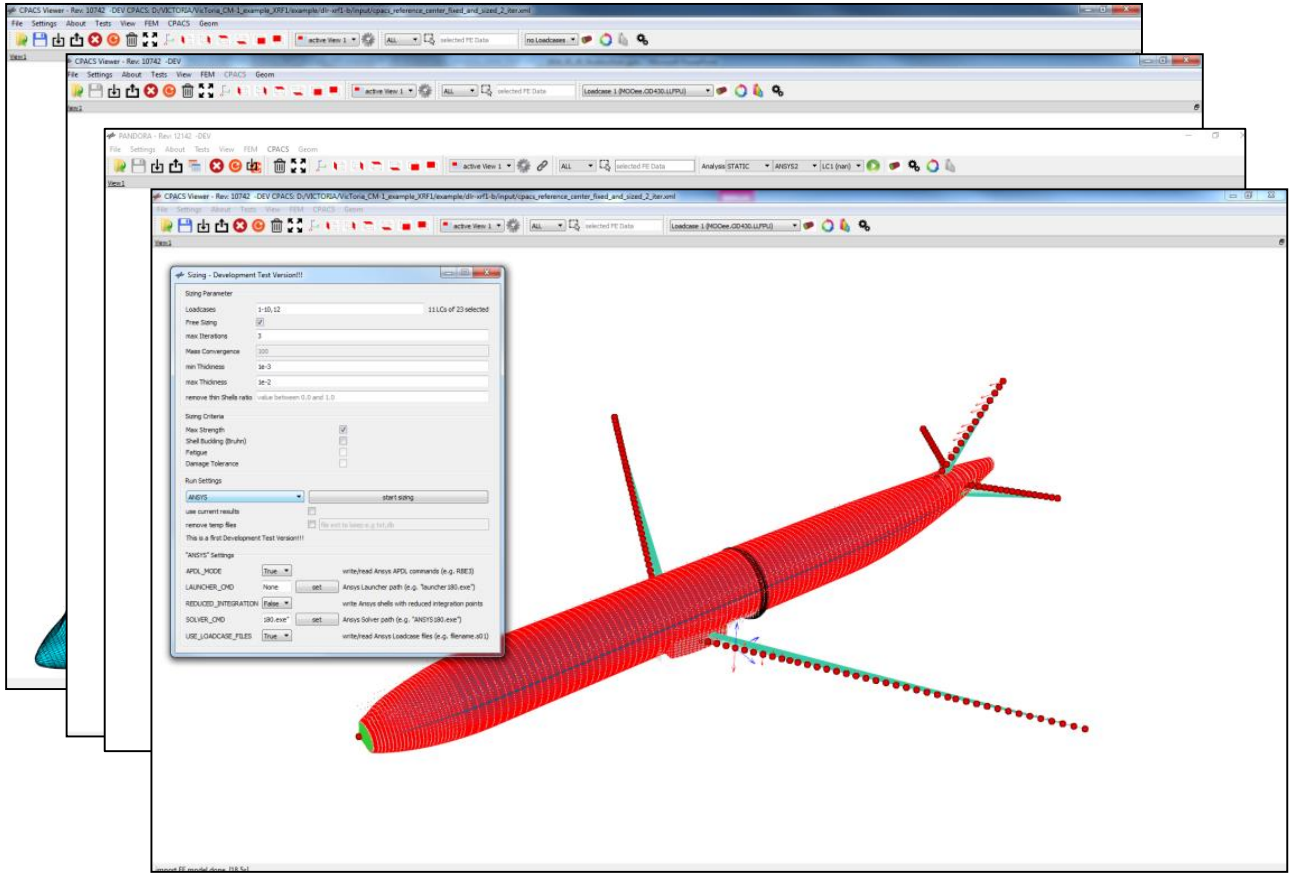
[10] B. Nagel, D. Böhnke, V. Gollnick, P. Schmollgruber, A. Rizzi, G. La Rocca and J. J. Alonso, Communication in Aircraft Design: Can we establish a Common Language?, ICAS, Brisbane, 2012

Ditching Pre-Design Process Chain

Fuselage model generation in the DLR pre-design process chain

PANDORA (Parametric Numerical Design and Optimization Routines for Aircraft)

[11]



PYTHON based modelling and sizing tool:

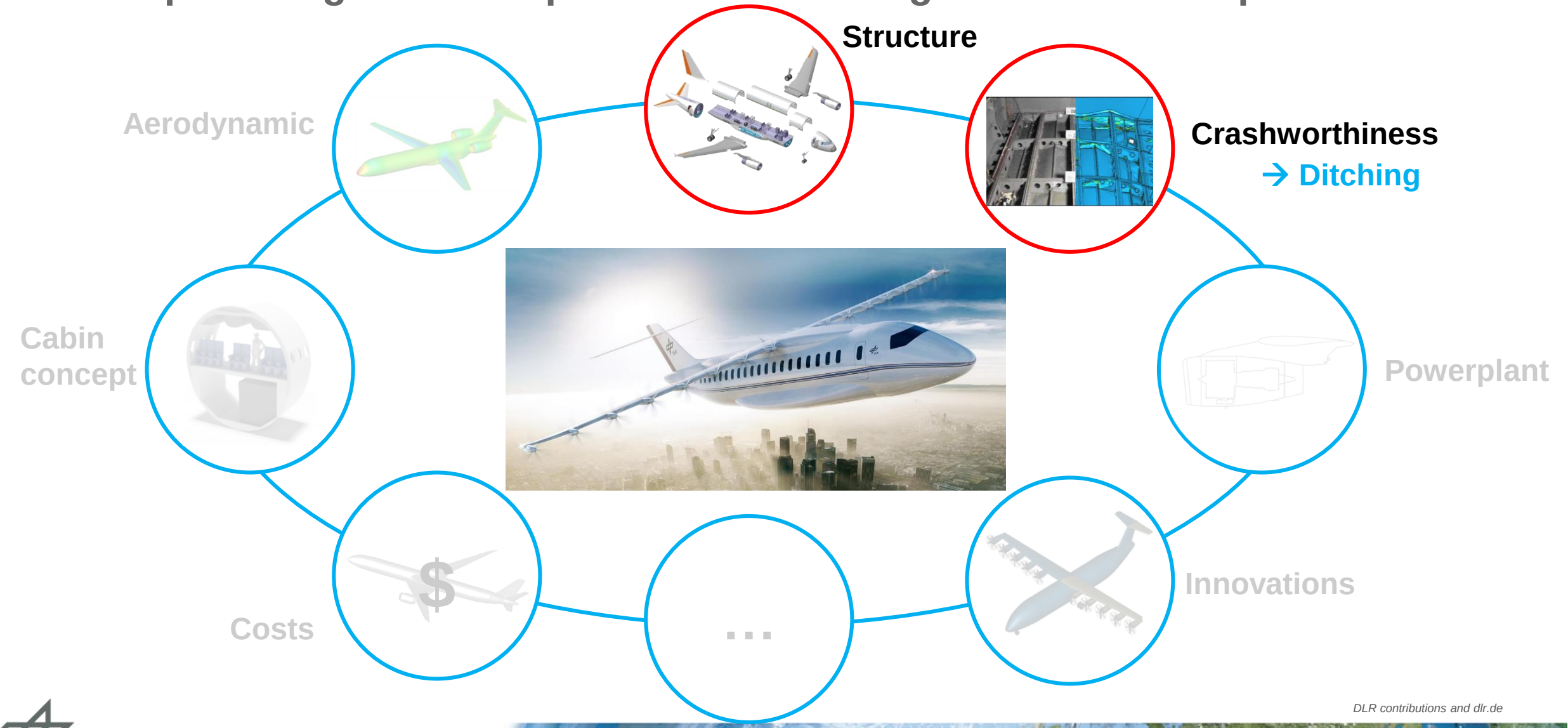
- Integrates various individual tools
- Modular architecture
  - Different packages for a certain function
  - Possible to implement new options (e.g. failure criteria)
- Integrated GUI

Functionalities:

- CPACS based model generation
  - Surface models (e.g. rigid aircraft)
  - Global FE fuselage model
- Data conversion to different solver formats
  - Static: ANSYS, NASTRAN, B2000++,…
  - Dynamic: VPS, LS-DYNA,…
- Starting of numerical analyses (static & dynamic analyses, static sizing)

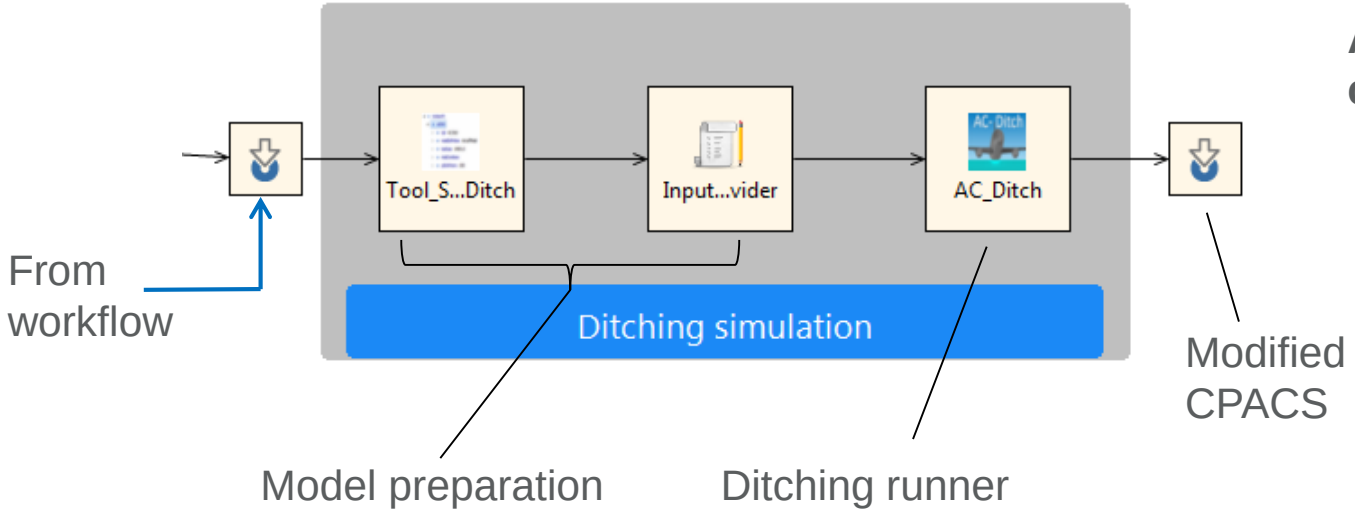
[11] M. Petsch, D. Kohlgrüber, J. Heubischl, PANDORA – A python based framework for modelling and structural sizing of transport aircraft, EASN-CEAS 2018, 2018, Glasgow

Aircraft pre-design is a complex task consisting of several disciplines

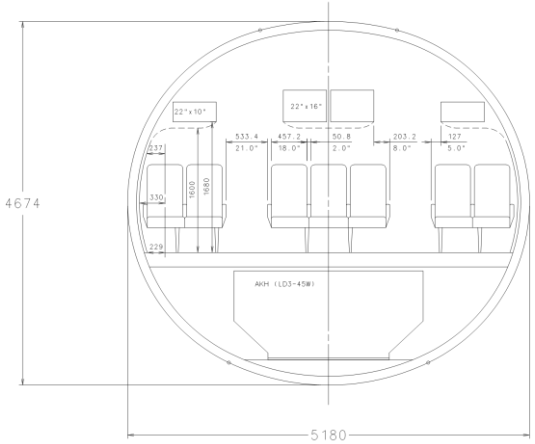


Ditching Pre-Design Process Chain

Integration into a DLR multidisciplinary aircraft design process chain



Application on a widebody medium range aircraft configuration



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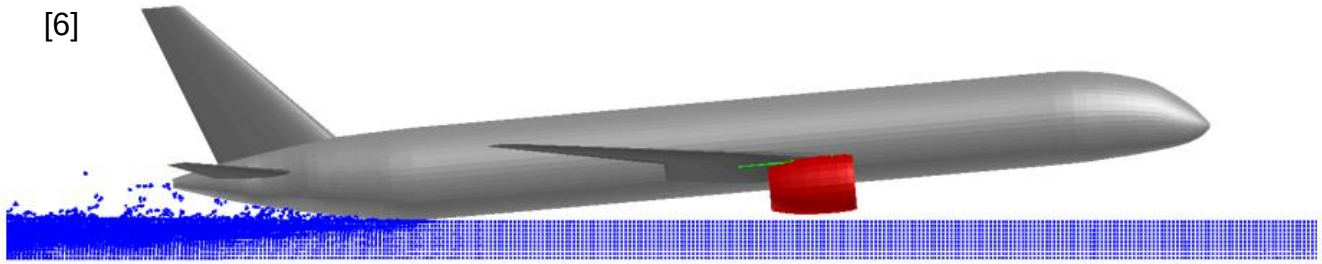


Flight direction

Exemplary ditching simulation (rigid, t=1000ms)

Total mass and inertia at predefined COG

Simulation characteristics:

- Surface mesh generation using PANDORA framework
- Full ditching model generation using the pre-processing ditching tool (~10min)
- Running of ditching simulation on local cluster (~8h)

➔ **Possible to integrate ditching in an aircraft pre-design process chain**

Rigid fuselage

[6] C. Leon Muñoz, D. Kohlgrüber, M. Petsch, Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain, ESI-Forum 2019, Berlin, 2019

Ditching activities at DLR

1. Ditching methods development at DLR

[2]

- Simple flex. structure (generic panels)
- Prescribed motion
- Validated FE-SPH approach

[5]

- Complex flex. structure (generic reinforced panels)
- Prescribed motion

- Rigid structure (Generic aircraft)
- Free motion

2. DLR ditching pre-design process chain

Data Set for aircraft definition

Modelling of generic aircraft (Focus on fuselage)

[6]

Generic flexible aircraft (Focus on fuselage)

3. Integration of complex models into ditching analyses

[3]

- Highly complex, flexible structure (generic aircraft)
- Free motion

[2] M. H. Siemann, Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water, Stuttgart, University of Stuttgart, 2016
[3] NTSB, Accident Report: Loss of Thrust in Both Engines after Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, Washington, 2009
[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017
[6] C. Leon Muñoz, D. Kohlgrüber, M. Petsch, Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain, ESI-Forum 2019, Berlin, 2019

Integration of Complex Models into Ditching Analysis

Flexible aircraft ditching simulation using beam elements

Structures modelled using beam elements:
- Frames, stringers, floor structures, etc.

Beam element properties: described in CPACS
- Bending moments of inertia, cross-area, material

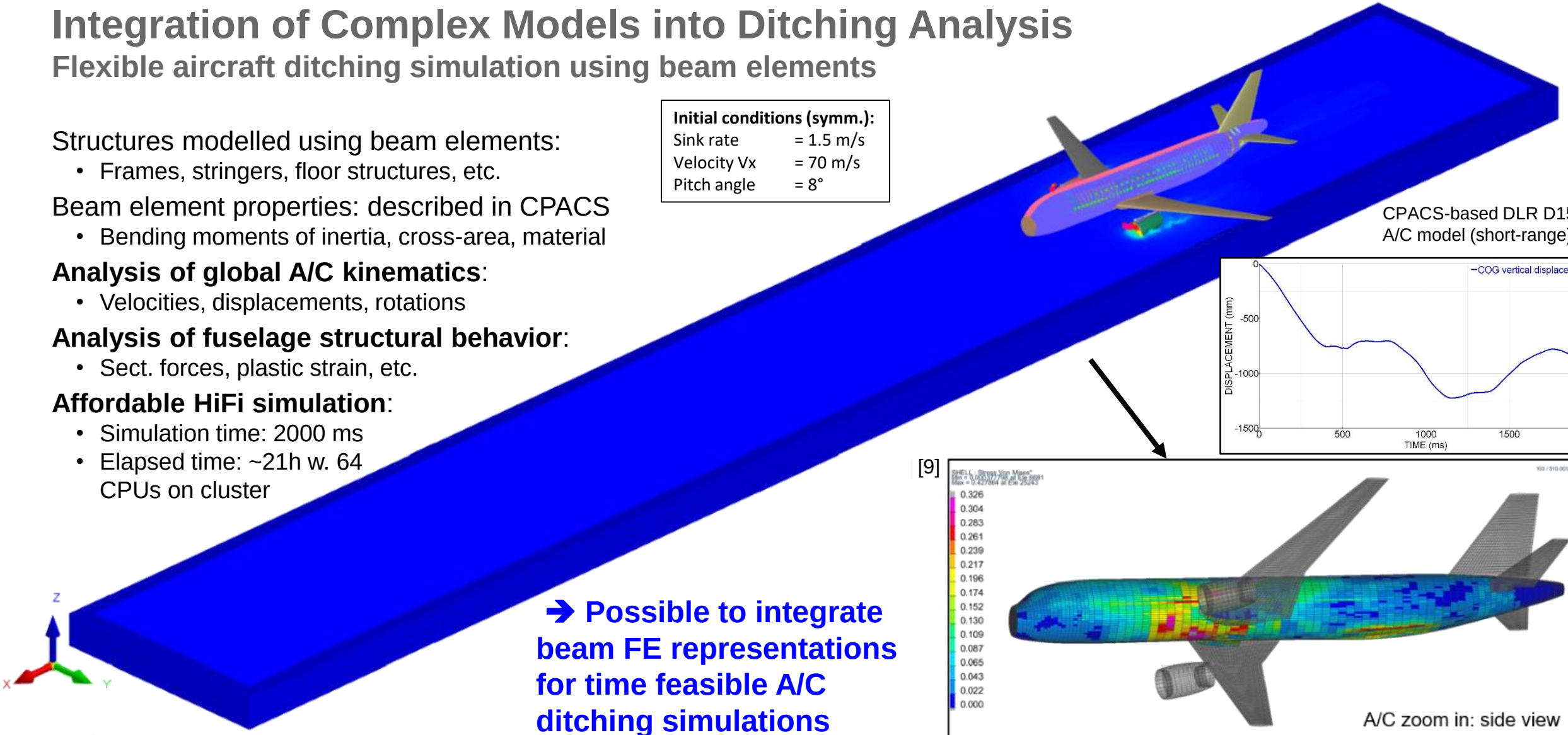
Analysis of global A/C kinematics:
- Velocities, displacements, rotations

Analysis of fuselage structural behavior:
- Sect. forces, plastic strain, etc.

Affordable HiFi simulation:
- Simulation time: 2000 ms
- Elapsed time: ~21h w. 64 CPUs on cluster

Initial conditions (symm.):

Sink rate	= 1.5 m/s
Velocity Vx	= 70 m/s
Pitch angle	= 8°



CPACS-based DLR D150 A/C model (short-range)

[9]

➔ Possible to integrate beam FE representations for time feasible A/C ditching simulations

[9] C. Leon Muñoz, B. Langrand, D. Kohlgrüber, Analysis of the application of fuselage skin reinforcements with beam element representations in flexible full aircraft models for ditching simulations, IOP Conf. Ser.: Mater. Sci. Eng. 1226 012042, 2022

InSiDE
Industrialisierte Simulation von Ditching-Ereignissen

Federal Ministry for Economic Affairs and Climate Action

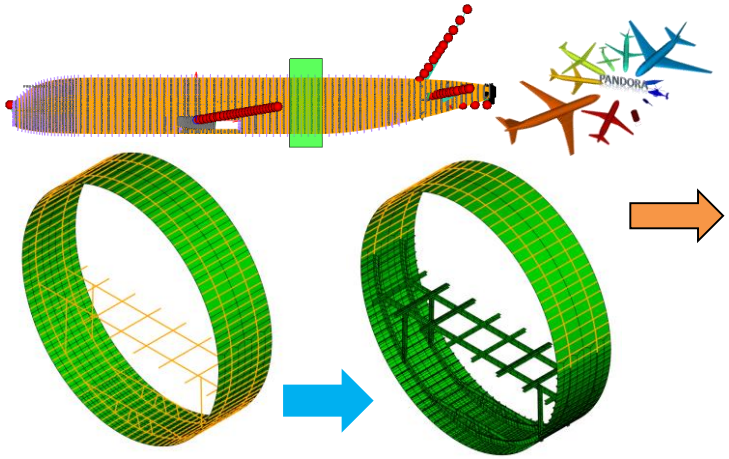
Integration of Complex Models into Ditching Analysis

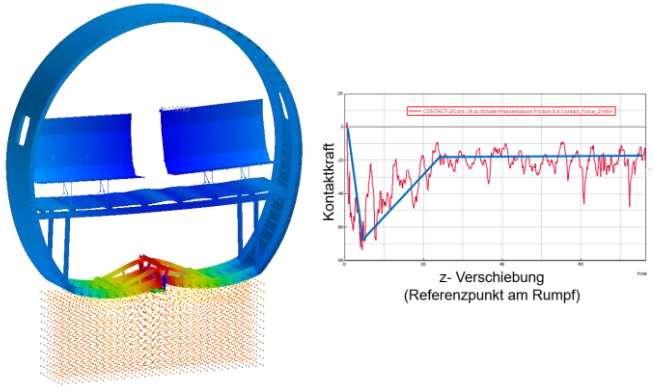
Industrialization aspects

Objective of current InSiDE project (Industrialized Simulation of Ditching Events, -05/2024)

- Combination of advantages of Lo-Fi and Hi-Fi processes: add structural effects to fast analytical process (ML methods)
- Development of methods for a fast generation of representative structural models (simplifications vs. accuracy)
- Consideration of local deformations in a robust industrialized process
- Validation of the process chain using test data and reference models

cpacs
A Common Language for Aircraft Design





Training of Lo-Fidelity process (machine learning)

Aircraft data

Model generation and processing

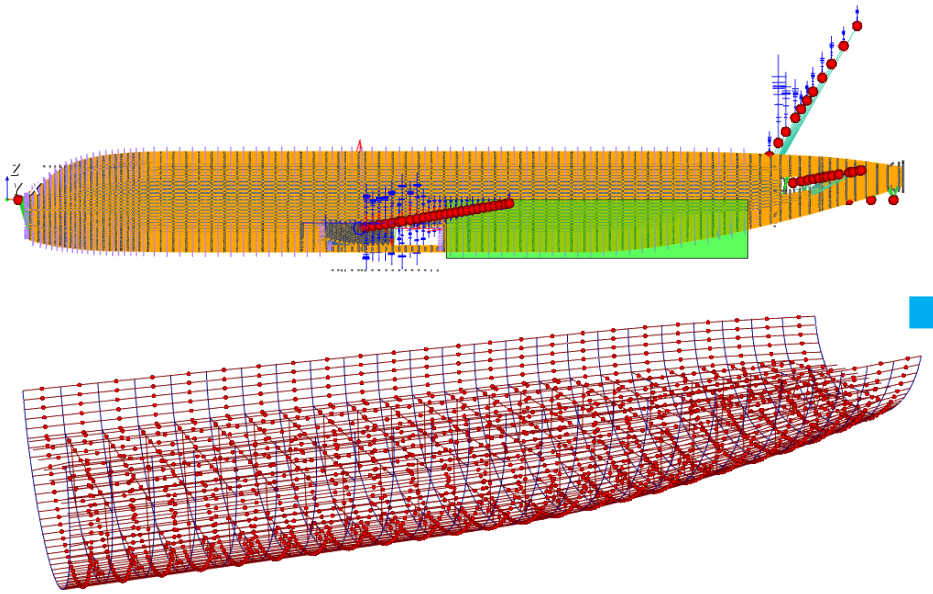
Water impact simulation with representative fuselage section, assessment

Data transfer of results to partners in the consortium

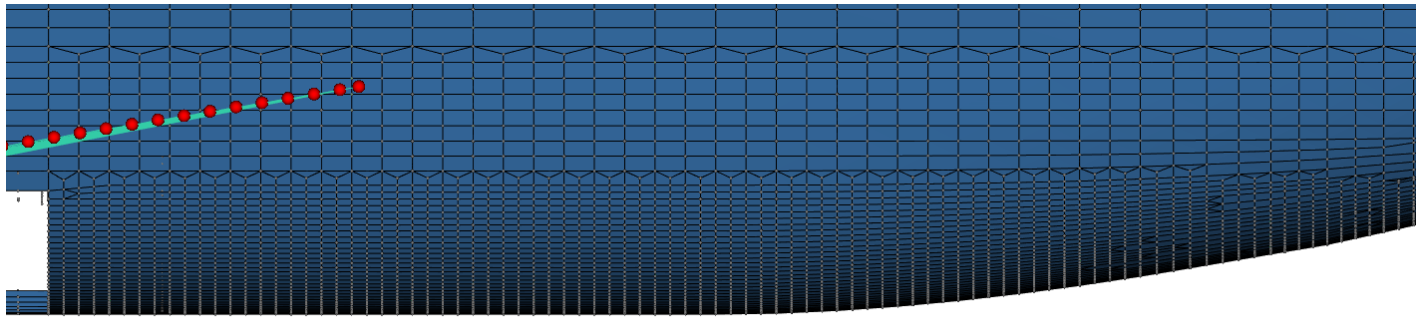
Integration of Complex Models into Ditching Analysis

Integration of local refinements into full aircraft

- Application via script foreseen for fully automatic refinement of a user-defined section
- Refinement in extended fuselage sections: rear bottom fuselage zone
- Initial approach using purely beam reinforcements → later with extruded shell representations for verification



Selected fuselage zone



Final refinement

➔ Full model generation for VPS and LS-DYNA application <3 min

Summary and Outlook

Conclusions:

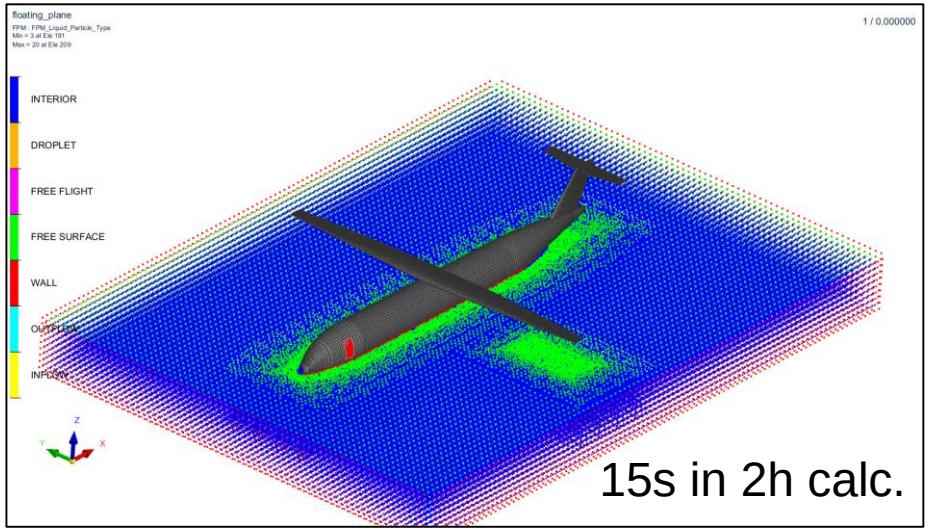
- Structural deformations may lead to a relevant increase of the hydrodynamic loads
- Generally good agreement between investigated FSI approaches
- Feasibility to integrate simpler beam representations also with coarser mesh sizes: reduction of calculation time
- Feasibility to transfer modelling technique to a full aircraft ditching: kinematics, structural response and parametric variations

Scientific challenges:

- Establish best practice ditching modelling process as compromise between computational time and accuracy of results
- Transfer of scientific results into a real aircraft certification process

Next steps:

- Further comparison between models with different discretization options (simplified beam application vs extruded shell representations)
- Ditching simulations with refinements in extended fuselage sections
- Extend method evaluation to Finite Pointset Method in VPS (some potential advantages in terms of accuracy and timestep)
- Extension of the ditching simulation process chain to floatation phase (mainly with FPM method)



High Fidelity Simulations of Flexible Aircraft Structures Under Ditching Loads

Thanks for your attention. Questions?

Virtual Workshop. August 10, 2022

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DLR

Sources

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[3] NTSB, Accident Report: Loss of Thrust in Both Engines after Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, Washington, 2009

[4] L. Benítez Montañez, H. Climent Máñez, M. Siemann and D. Kohlgrüber, Ditching Numerical Simulations: Recent Steps in Industrial Applications, Aerospace Structural Impact Dynamics International Conference, 2012

[5] M. H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, 2017

[6] C. Leon Muñoz, D. Kohlgrüber, M. Petsch, Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain, ESI-Forum 2019, Berlin, 2019

[7] B. Langrand, M. H. Siemann, D. Kohlgrüber, C. Leon Munoz, Full aircraft ditching simulation by advanced fluid structure interaction computational methods: a comparative analysis, ASIDIC 2019, Madrid, 2019

[8] C. Leon Muñoz, D. Kohlgrüber, B. Langrand, Analysis of fuselage skin reinforcements with beam element models in flexible aircraft panels for ditching simulations, IOP Conf. Ser.: Mater. Sci. Eng. 1024 012054, 2021

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