Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain

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German Aerospace Center (DLR e.V.) – Institute of Structures and Design (BT)
ESI Forum in Germany 2019

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DLR Deutsches Zentrum für Luft- und Raumfahrt

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Agenda

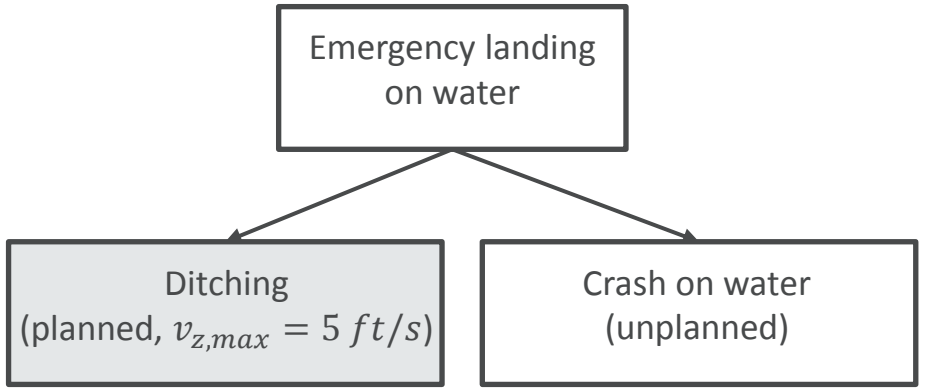
Motivation

Aircraft Ditching Simulation

Multidisciplinary Aircraft Design

Summary and Outlook

Ditching



Ditching

Initial conditions:
- Low speeds
- Nose-up positions
- Retracted landing gear
- …

Highest hydrodynamic loads:
- Structural integrity
- Local deformations
- Failure of the structure

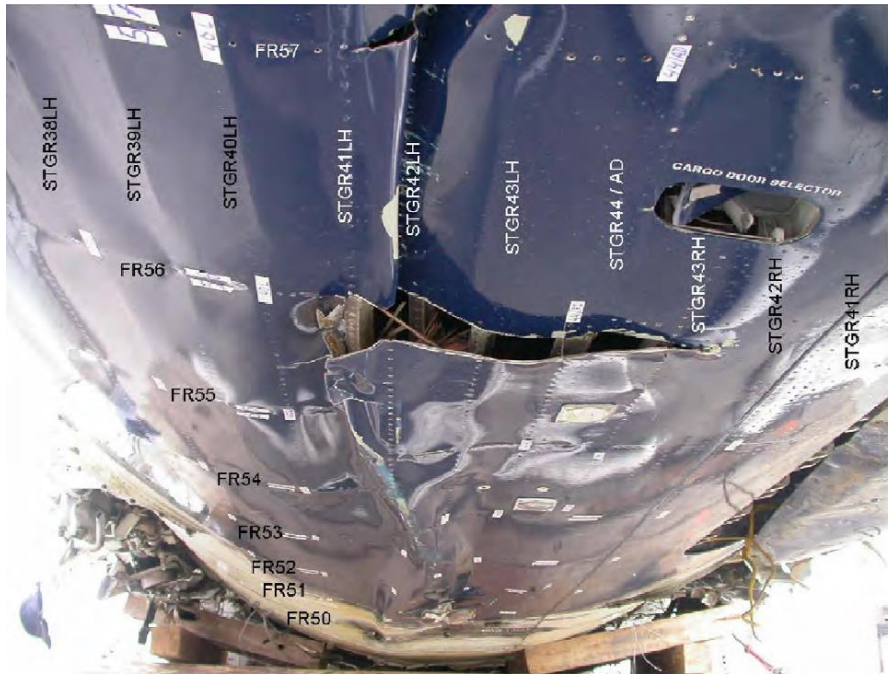
Hydrodynamic phenomena:
- Suction
- Overpressure
- Cavitation

Evacuation:
- Time
- Structural fractures
- Water ingress

Hudson River Accident

[1]

[2]



US Airways A320, Januar 2009, Hudson River, New Jersey, USA

[1] http://img.planespotters.net/media/photos/original/076000/PlanespottersNet_076460.jpg, Accessed 15.06.2016
[2] NTSB, Structures Group Chairman's Factual Report, Attachment 2, Photos, SA-532 7-F, Technical Report Addendum 1, NTSB, Washington DC, USA, 2009.

Ditching Analysis

Crashworthiness requirements: Certification Specifications (CS)

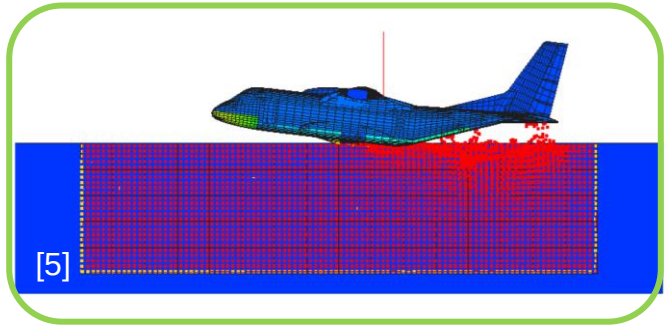
- CS-25: Large Aeroplanes
  - §563 - Structural ditching provisions
  - §801 - Ditching
  - §807(i) - Ditching emergency exits for passengers

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


[3]


[4]

Ditching analysis	Accident investigations & comparisons	Experiments with sub-scale models	Computational methods
Time & Costs	✓	✗	✓
Kinematic behaviour	✓	✓	✓
Structural response	✗	✗	✓
Hydrodynamic loading	✗	✓	✓
Accredited by authorithies	✓	✓	✗


[5]

[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] H. Climent, L. Benitez, F. Rosich, F. Rueda and N. Pentecote, "Aircraft Ditching Numerical Simulation," in 25th International Congress of the Aeronautical Science, Hamburg, Germany, Sept. 2006
[5] L. Benítez Montañez, H. Climent Máñez, M. Siemann and D. Kohlgrüber, "Ditching Numerical Simulations: Recent Steps in Industrial Applications," in Aerospace Structural Impact Dynamics International Conference, 2012

Agenda

Motivation

Aircraft Ditching Simulation

Multidisciplinary Aircraft Design

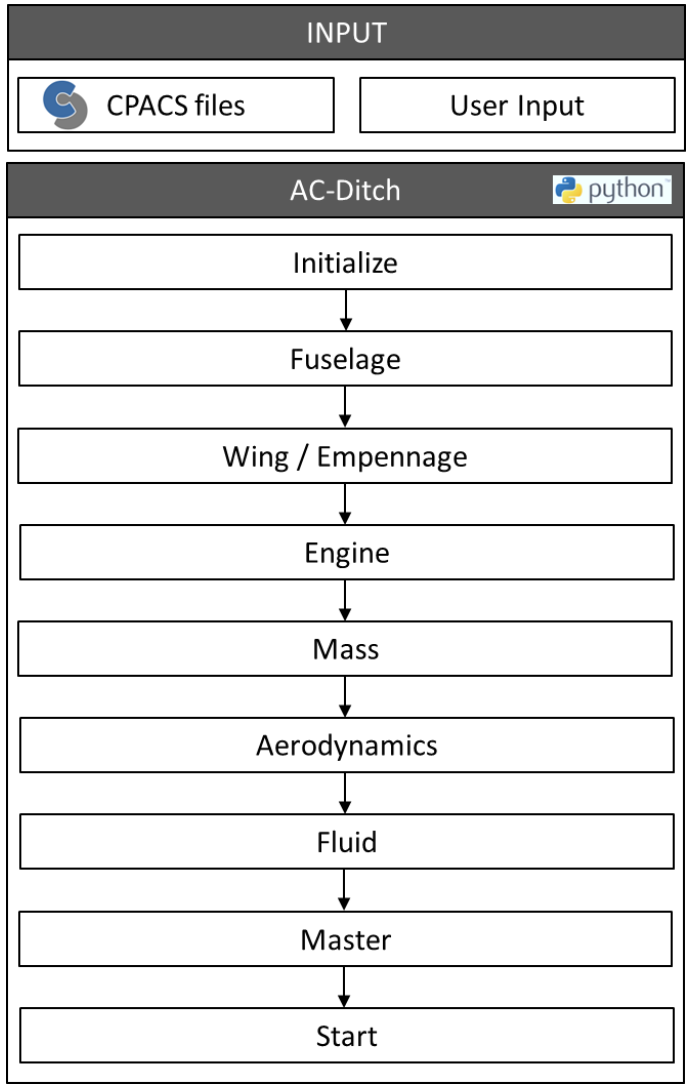
Summary and Outlook

Tool: AC-Ditch

AC-Ditch : DLR Tool for Numerical Ditching Analysis

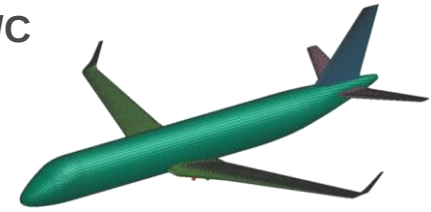
- In-house development
- Fully automated (Python)
- Modular architecture
- Coupled SPH-FEM
- Solver : Virtual Performance Solution

Virtual Performance Solution



Generic long range A/C
- size similar to A330
- approx. 250-400 PAX

Generic medium range A/C
- size similar to A320
- approx. 150 PAX



Generic short range A/C
- Similar size to E190
- approx. 100-115 PAX

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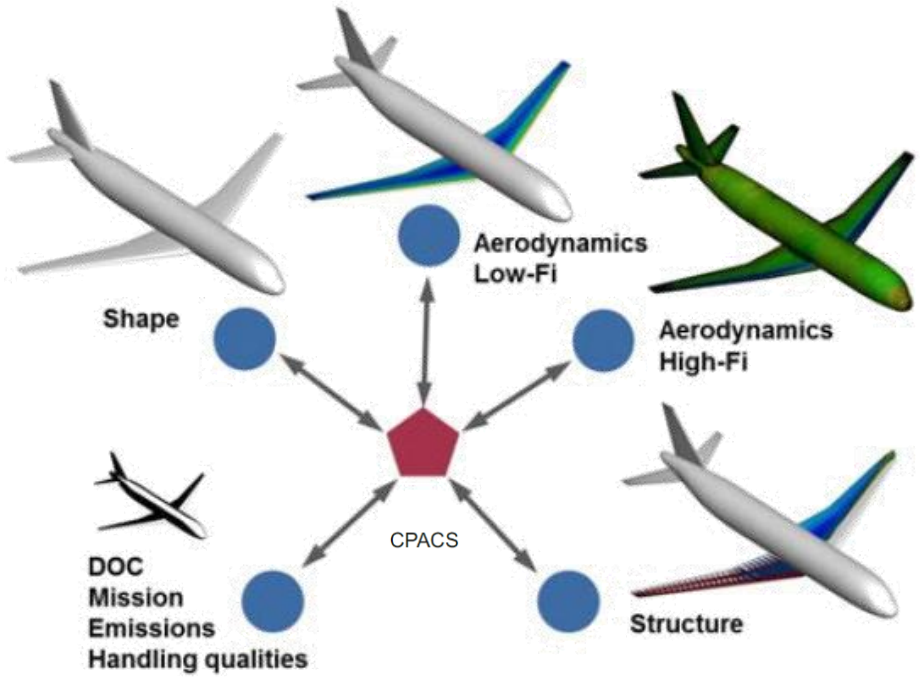
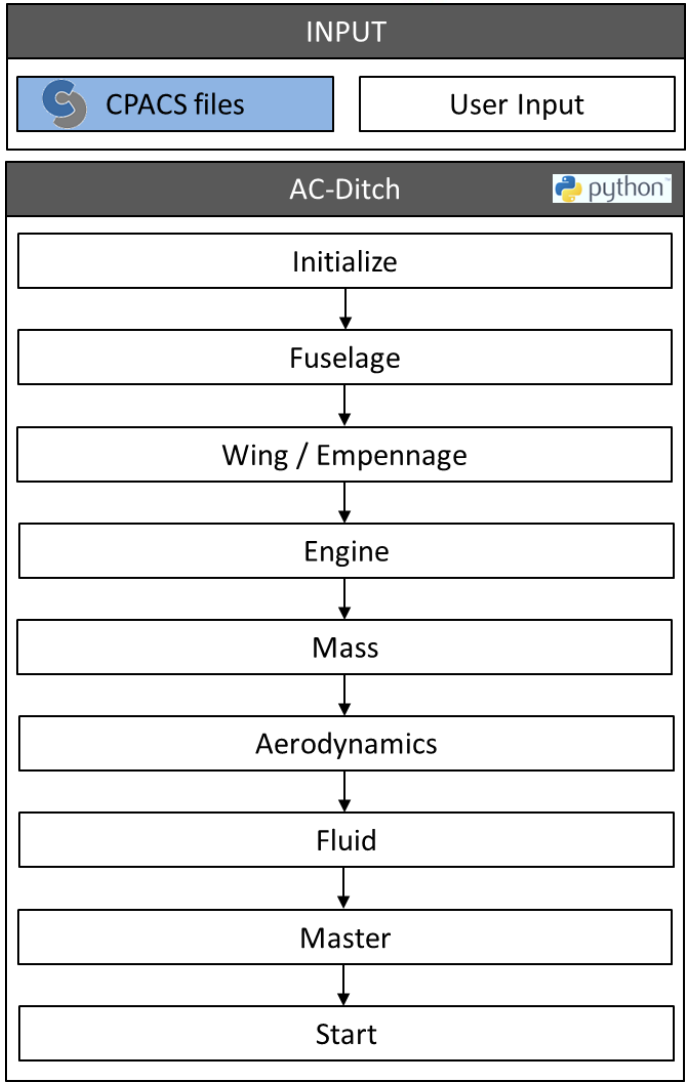
Input: CPACS data set

Common Parametric Aircraft Configuration Schema (CPACS)

- Data set for definition of air transport systems
- Multidisciplinary design
- Easy exchange: .xml format





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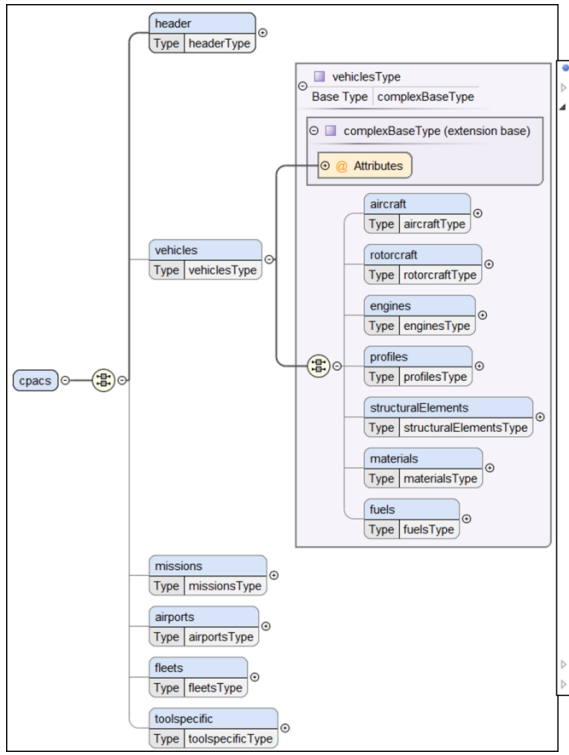
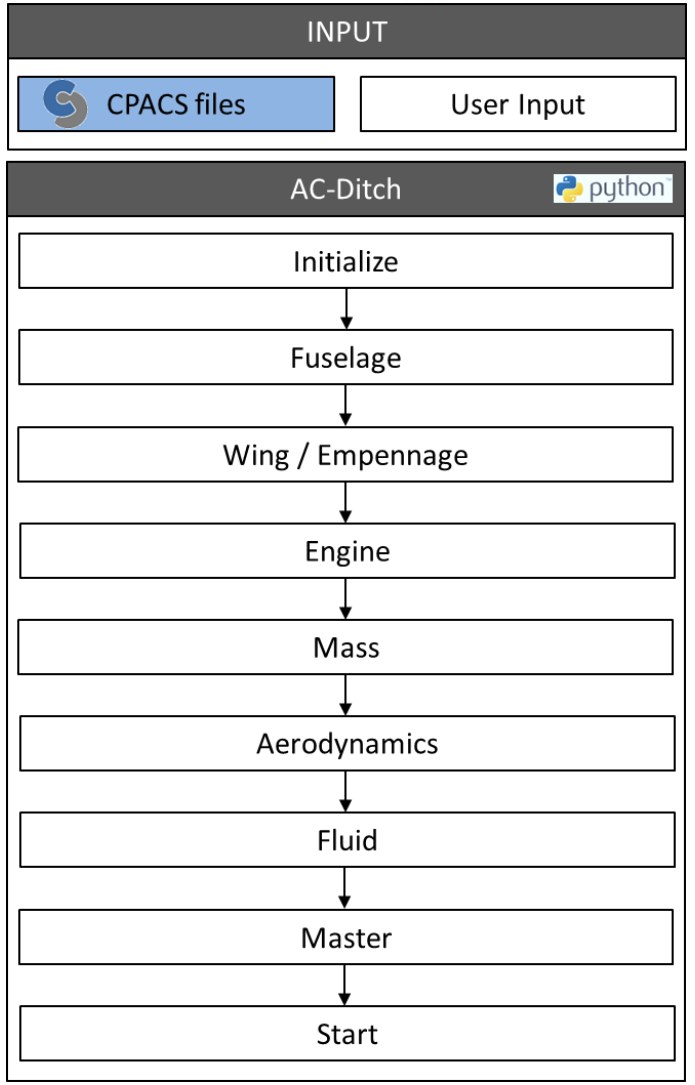


Hierarchical scheme: Tree structure

Attributes

Branches



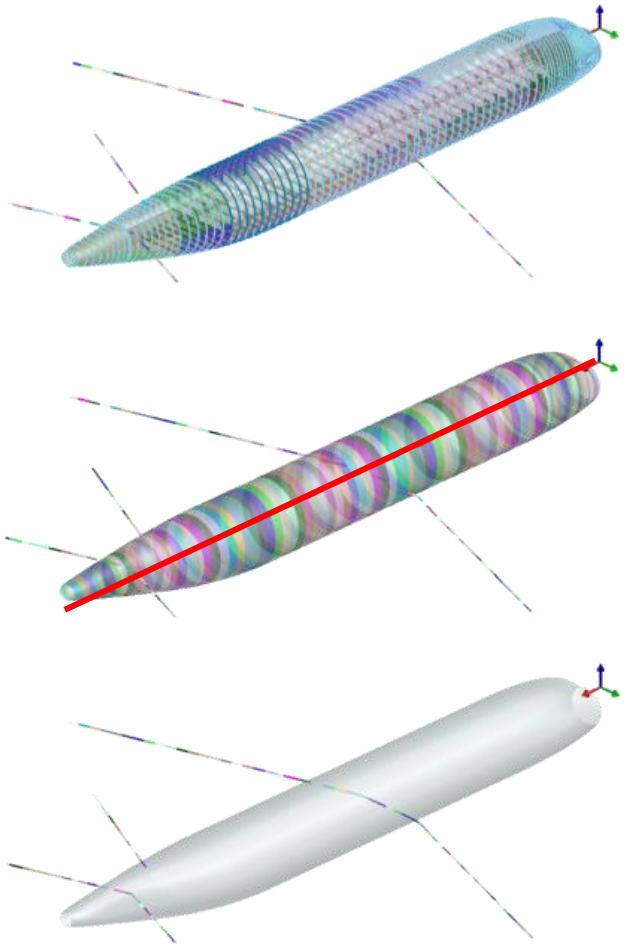
Fuselage Model

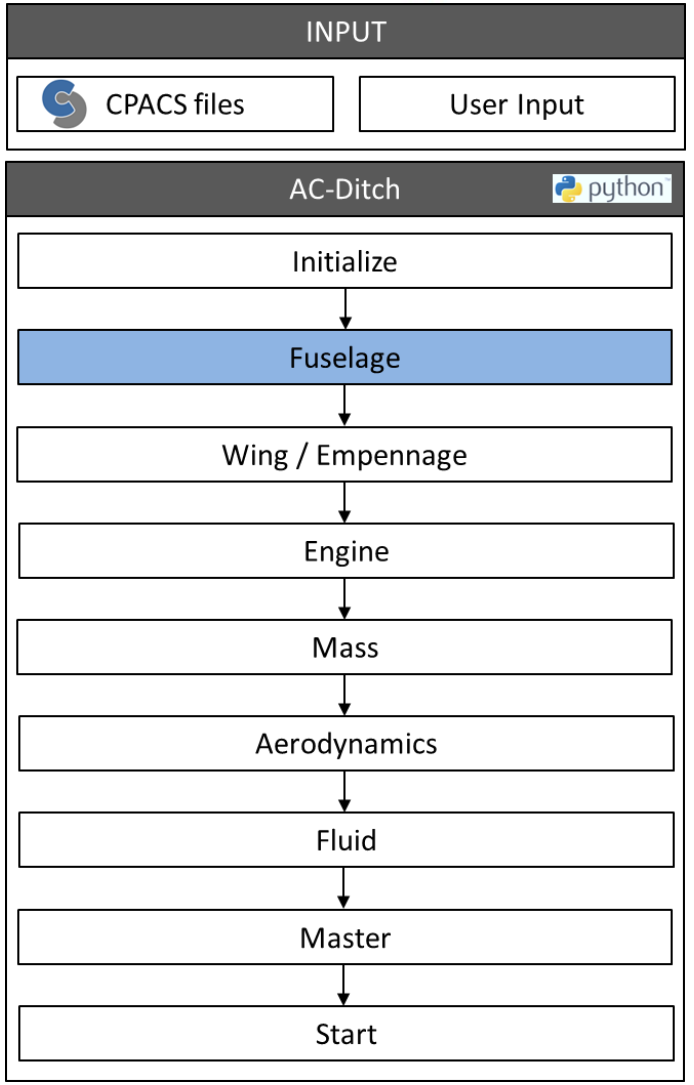
Global/Detailed FE Model

Global Beam Model

Rigid Body Model

Complexity / Level of detail





Fuselage Model

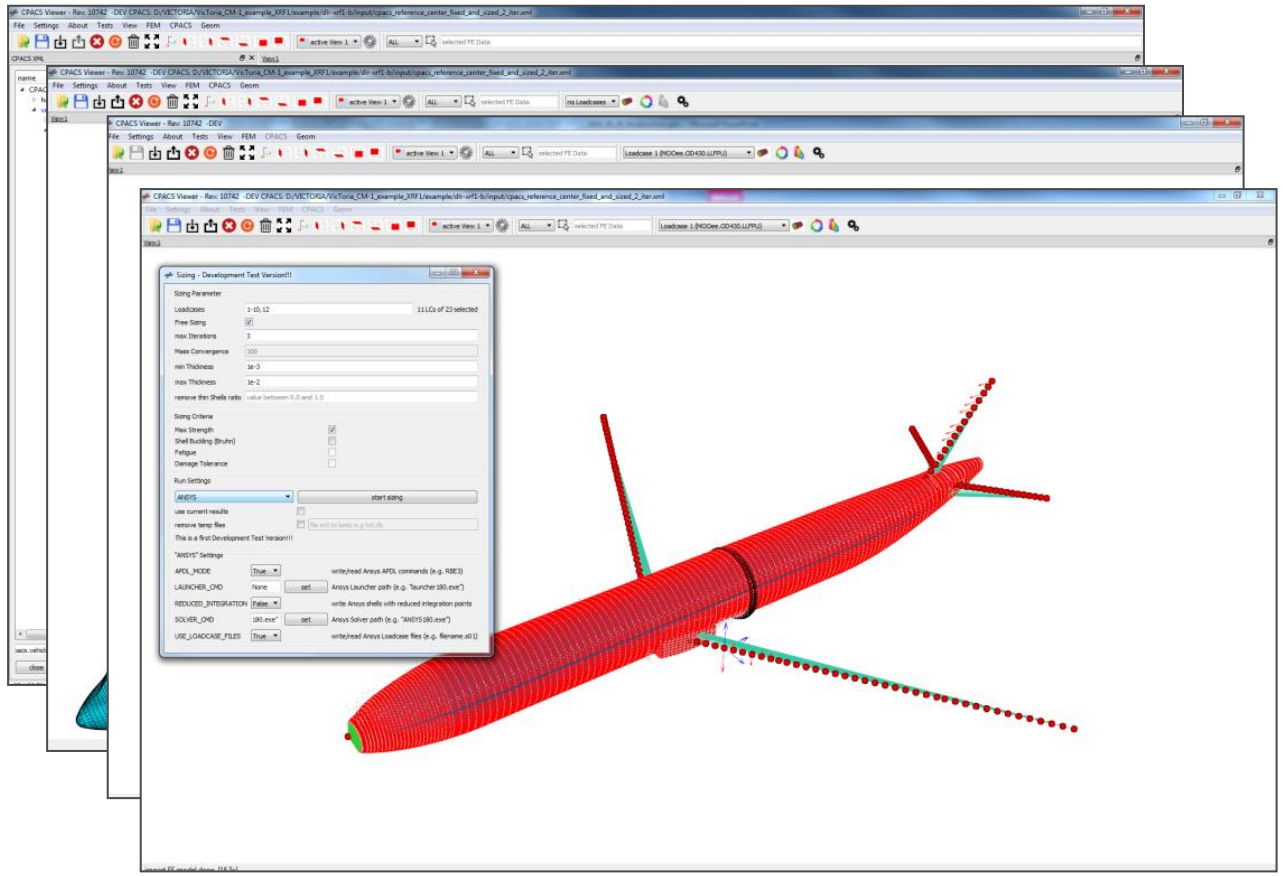
PANDORA (Parametric Numerical Design and Optimization Routines for Aircraft)

- PYTHON based modelling and sizing tool
- Modular architecture
- Integrated GUI cpacs_viewer

Functionalities:

- CPACS visualisation / manipulation
- CPACS based model generation
  - Surface models (e.g. ditching w. rigid aircraft)
  - GFEM fuselage model
- Data conversion to different solver formats
  - static: ANSYS, NASTRAN, B2000++,…
  - dynamic: **VPS**, LS-DYNA, …
- Starting of FE analyses (static analyses)

[6]



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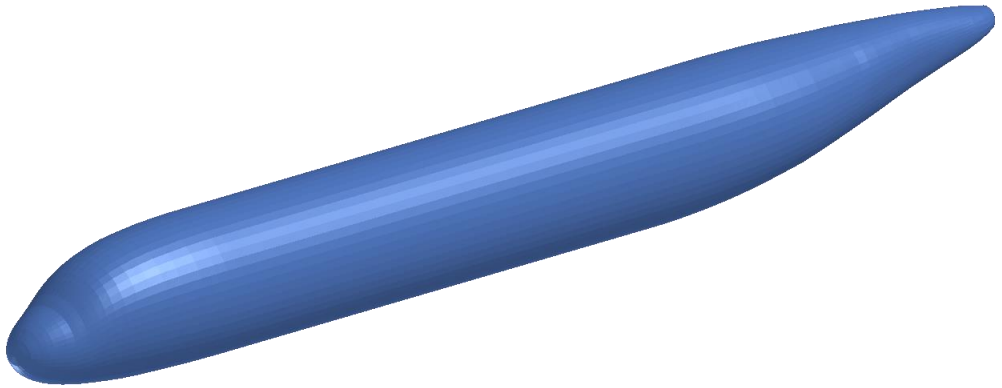
[6] M. Petsch, J. Walther, D. Kohlgrüber: Development of a Fully Automated Transport Aircraft Fuselage Modelling and Sizing Tool using Python, DLRK 2017, 5.-7.09.2017, München

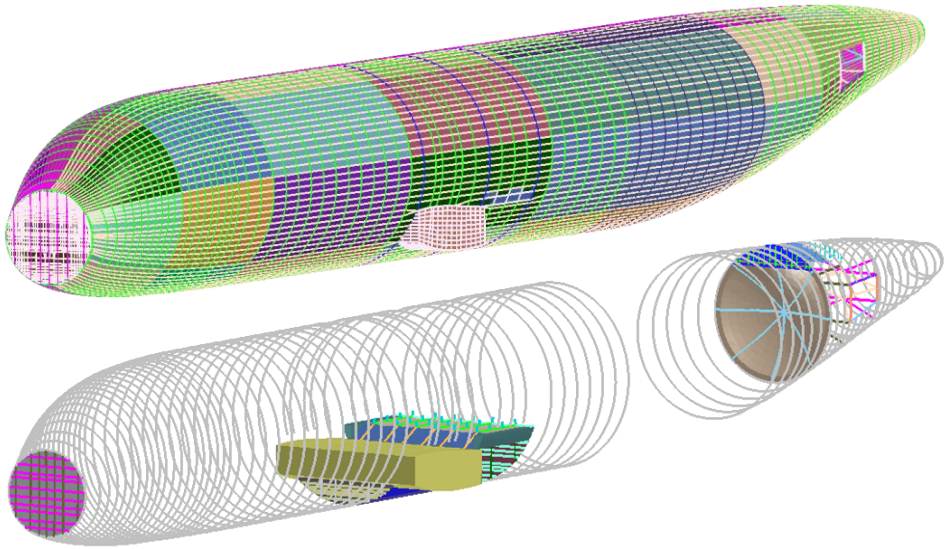
Fuselage Model

Rigid fuselage



- Generation of all required cards (VPS)
- Generic model
- Surface Model
- Rigid coupling with wings

Flexible fuselage

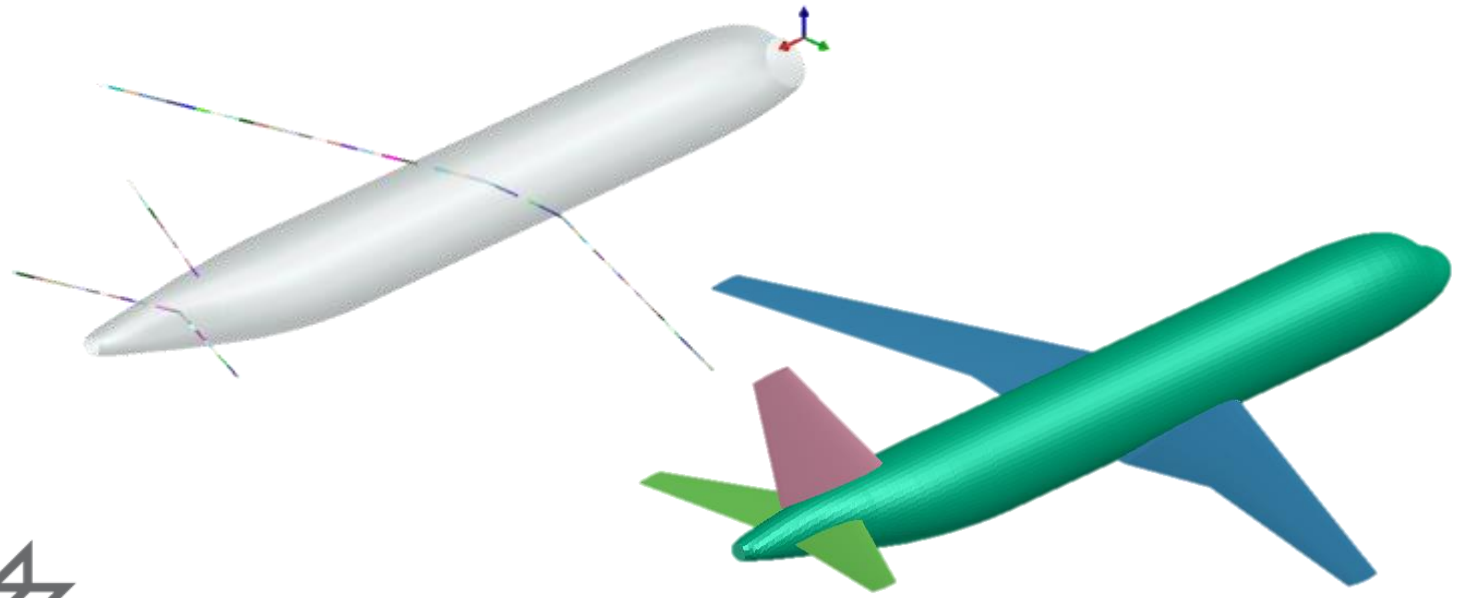


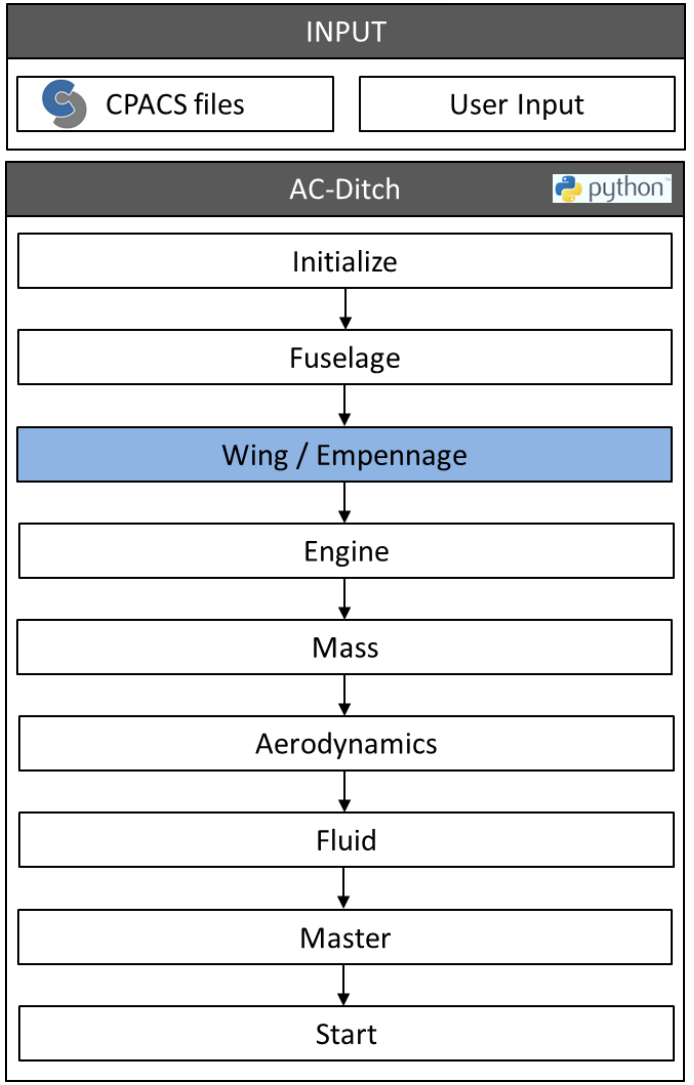
- Generation of all required cards (VPS)
- Deformation visible
- Center Wing Box/ Bulkheads available
- VTP- & HTP bay available
- More realistic load interaction with wings

Wing Model

Modelling approach

- **Beam** (rigid/elastic) or **shell** (rigid) models
- Shell model generated with PANDORA

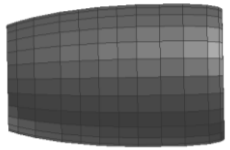




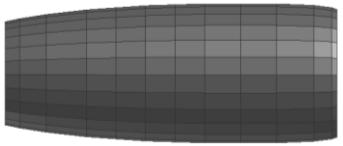
Engine Model

Settings

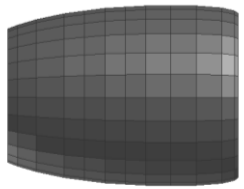
- number, position, and type of engines
- failure load



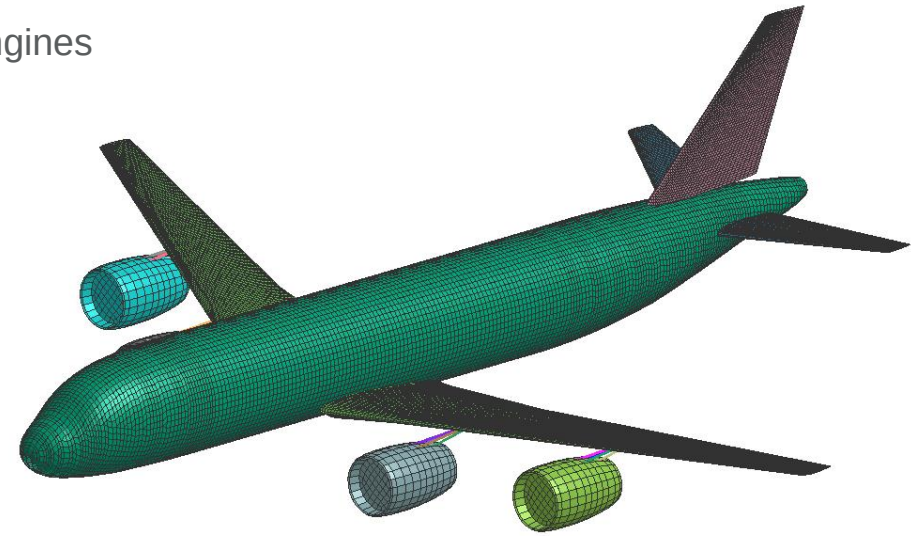
Shape: CFM56

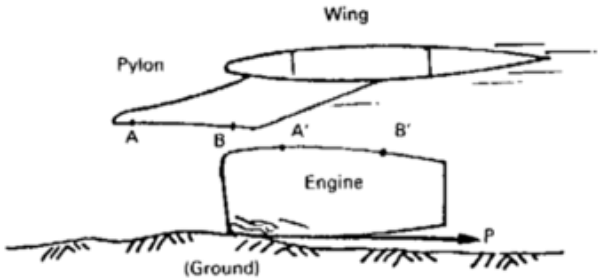


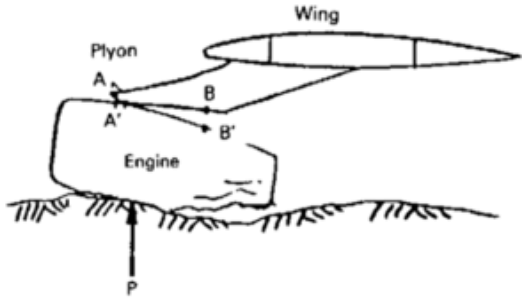
Shape: V2500

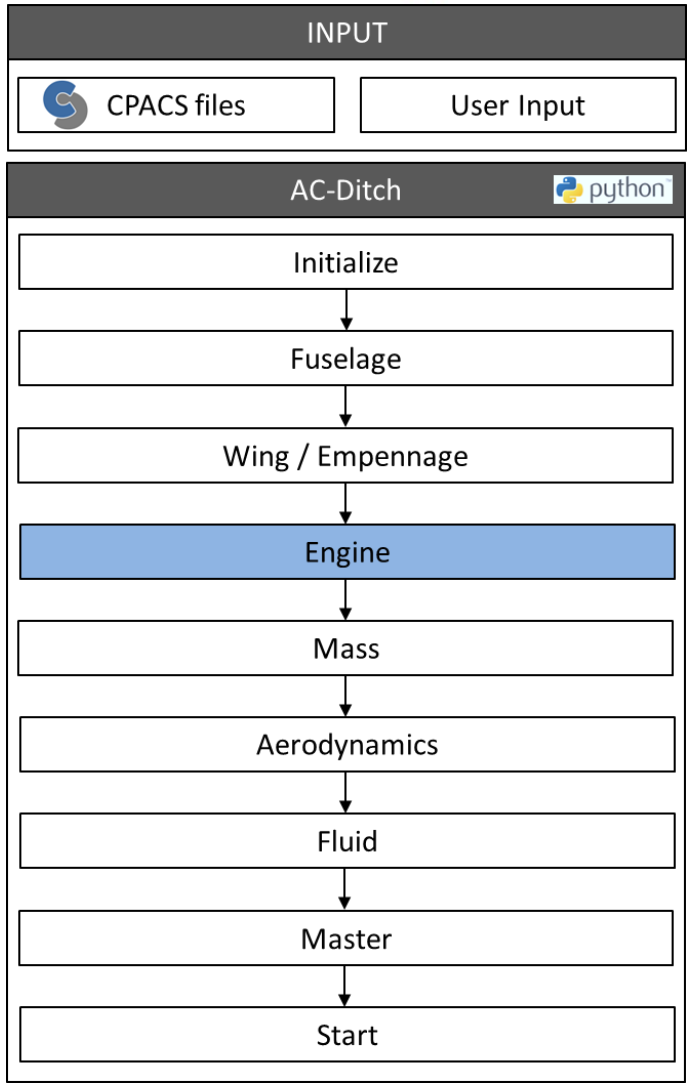


Shape: PW1100G [7]





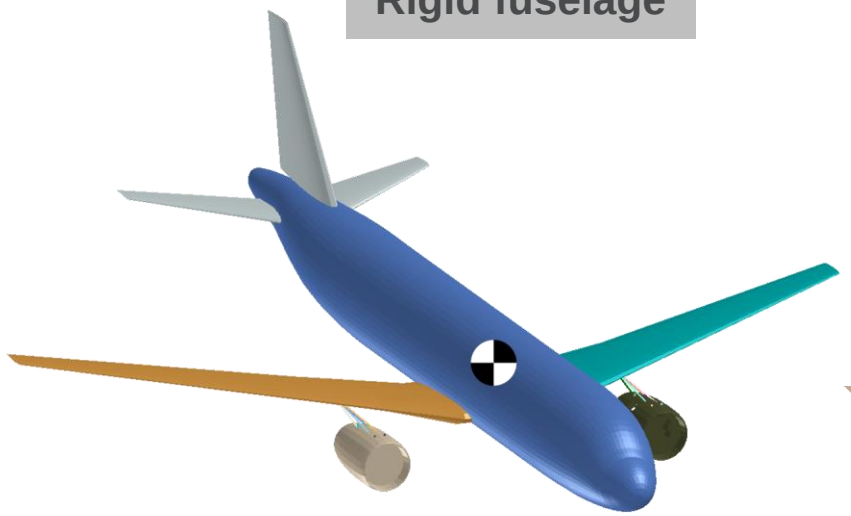




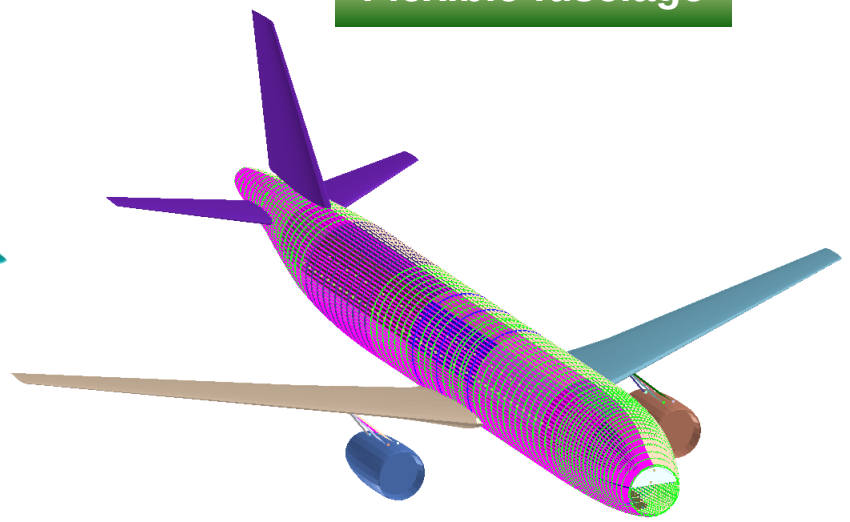
[7] M. C.-Y. Niu. Airframe Structural Design: Practical Design Information and Data on Aircraft Structures, 1988.

Mass Model

Rigid fuselage



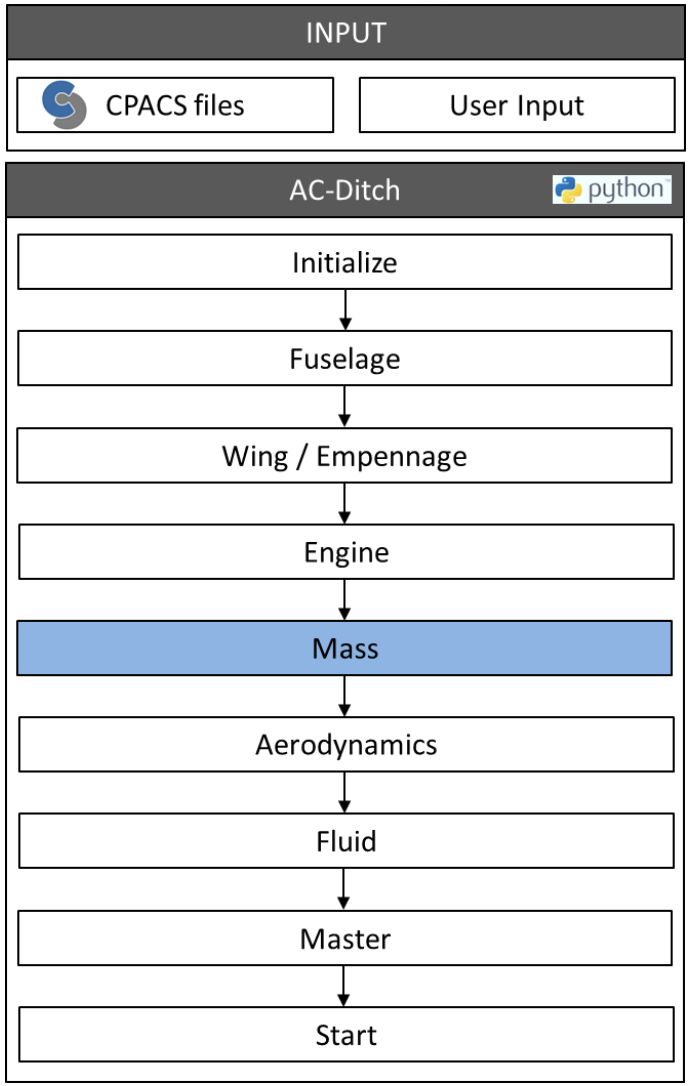
Flexible fuselage



Ditching with RBM ➔ Predefined global properties of rigid aircraft

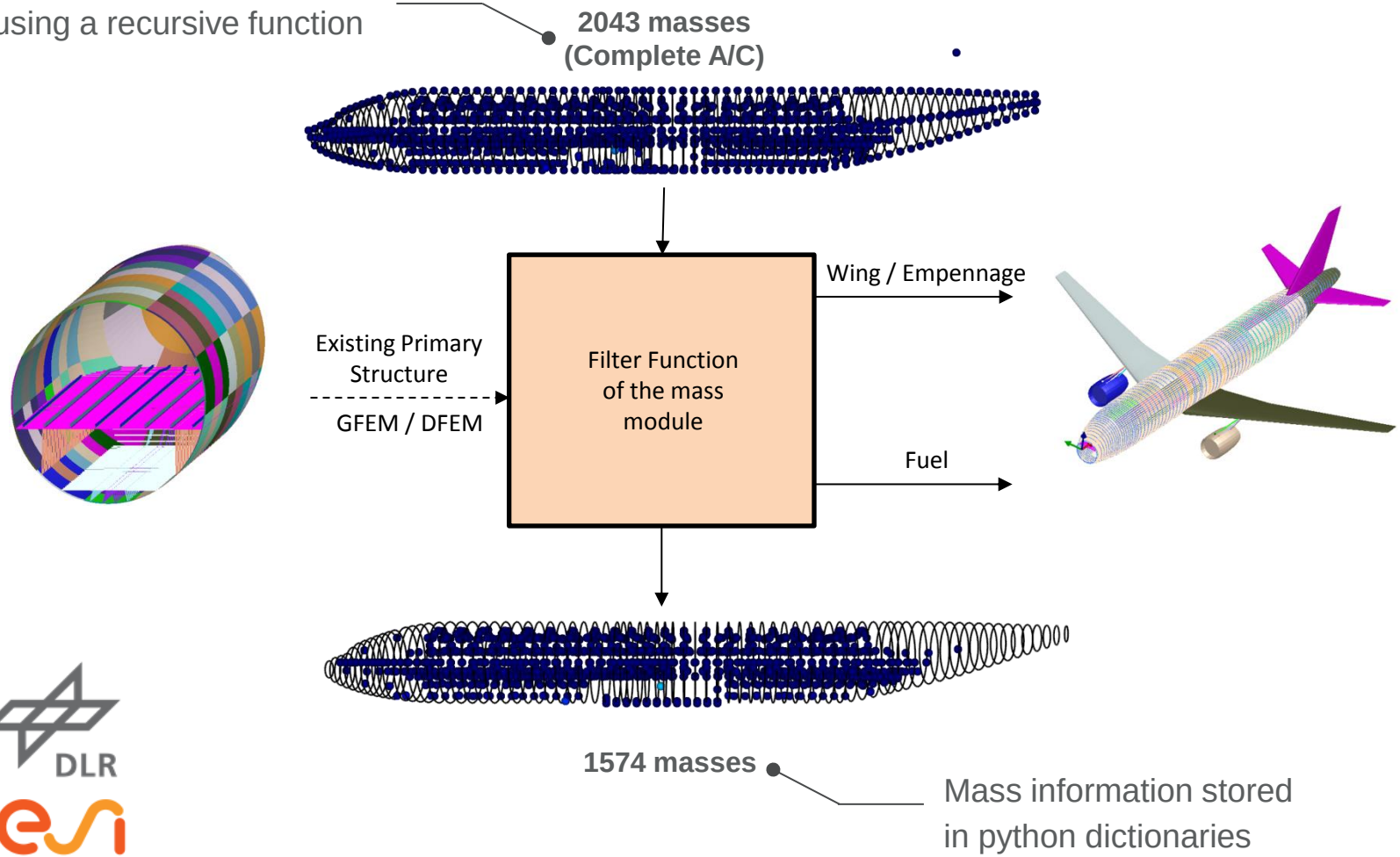
Ditching with GFEM ➔ More detailed models integrate mass properties from the physical properties of the finite elements & secondary masses

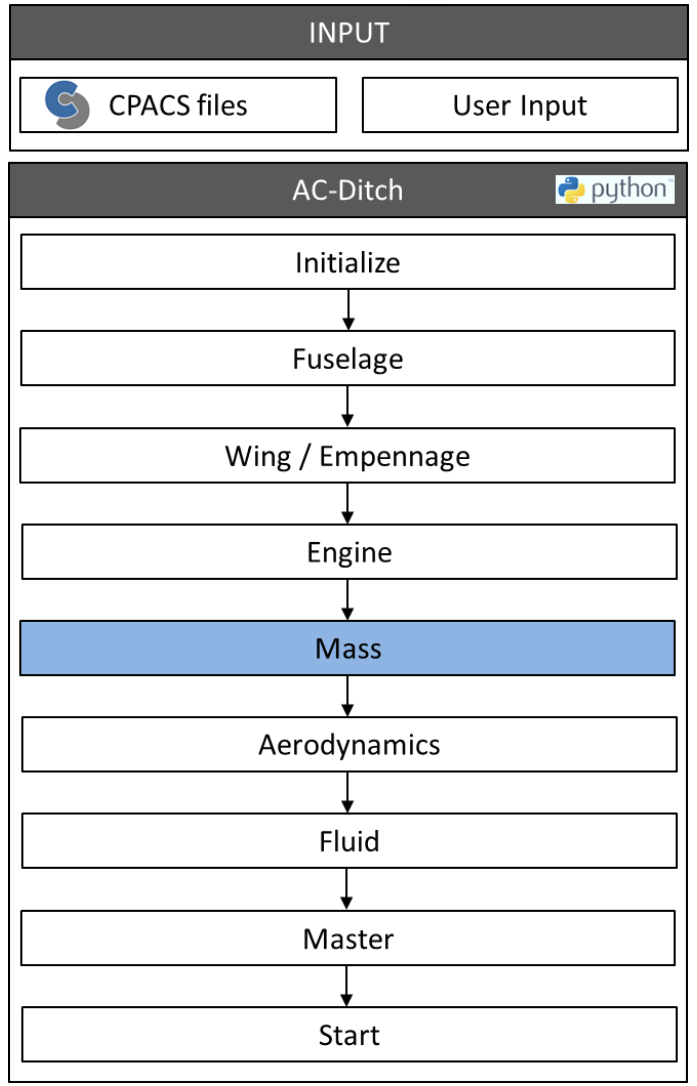
→ Mass model required



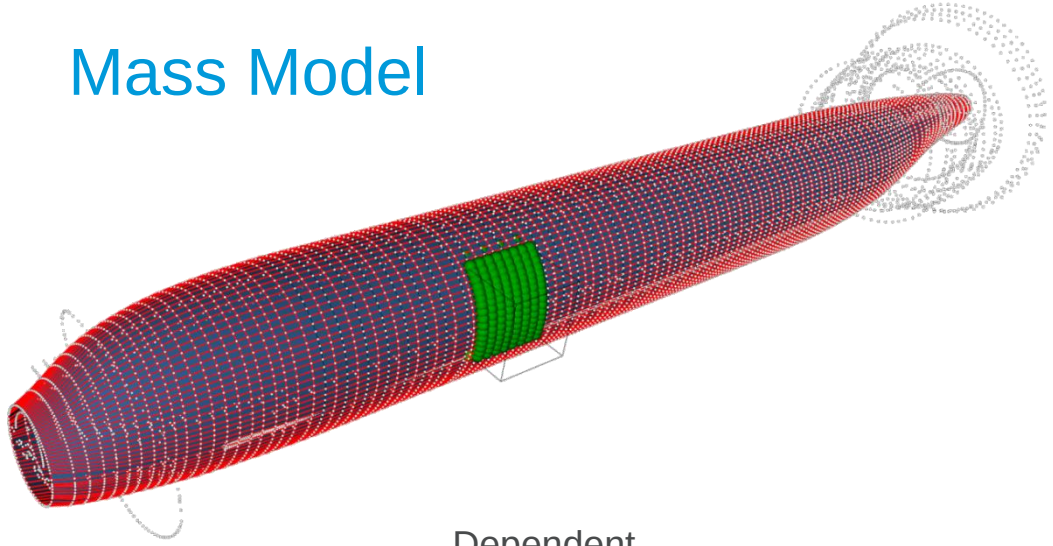
Mass Model

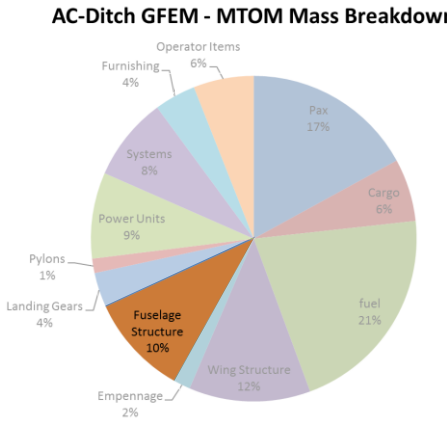
Import of mass information using a recursive function



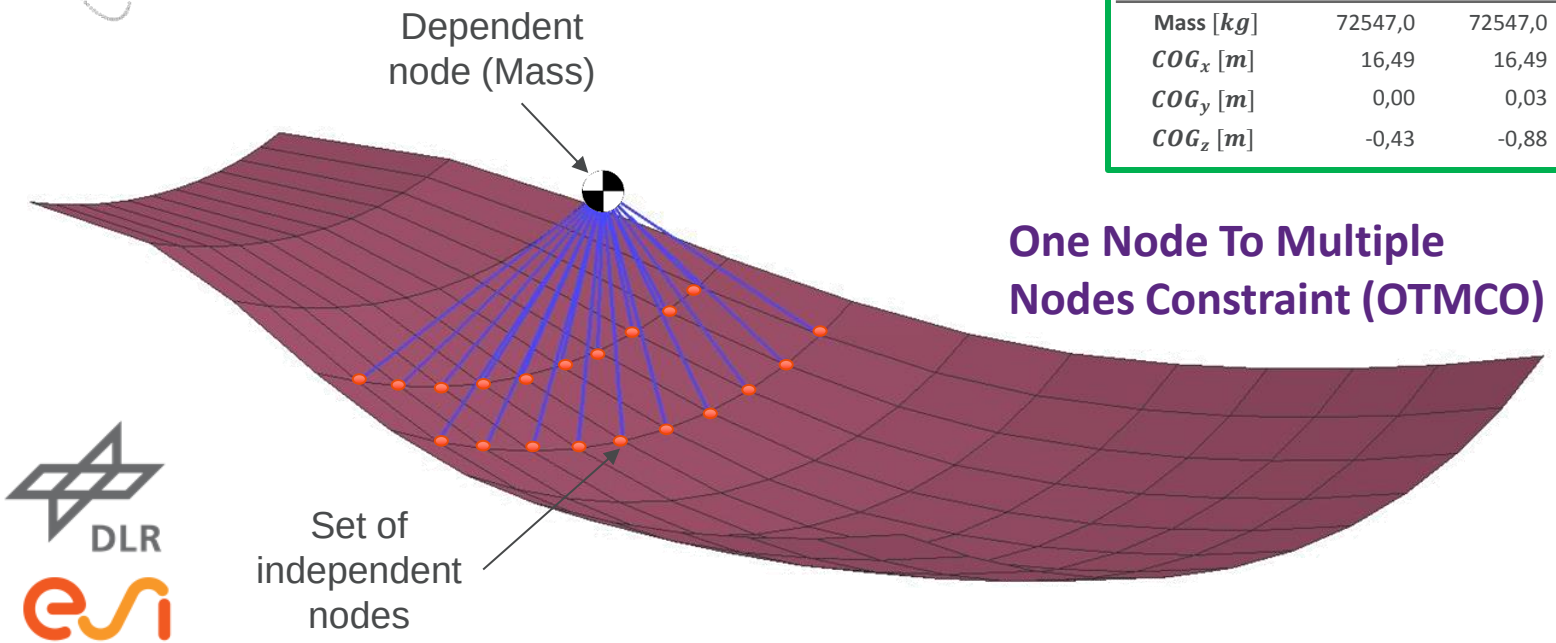


Mass Model

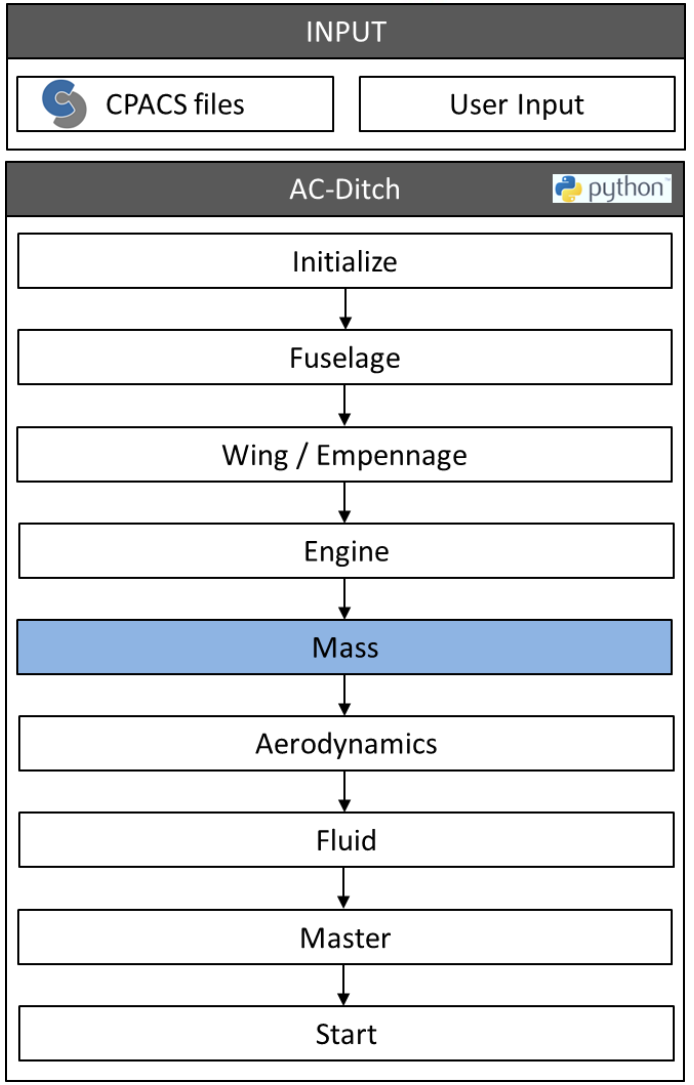




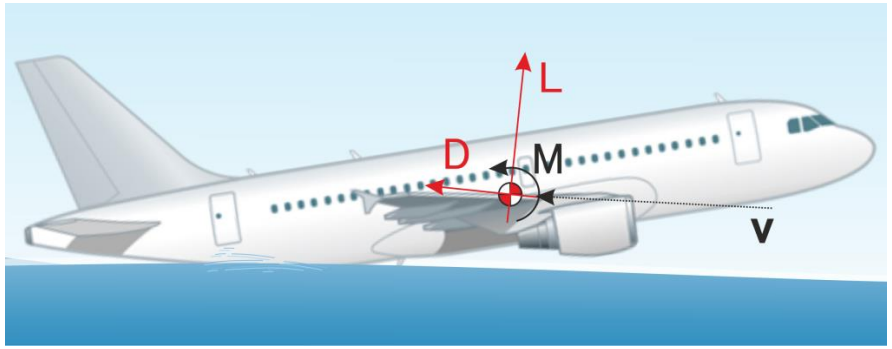
Properties	RBM	GFEM
Mass $[kg]$	72547,0	72547,0
COG_x $[m]$	16,49	16,49
COG_y $[m]$	0,00	0,03
COG_z $[m]$	-0,43	-0,88



One Node To Multiple Nodes Constraint (OTMCO)



Aerodynamics

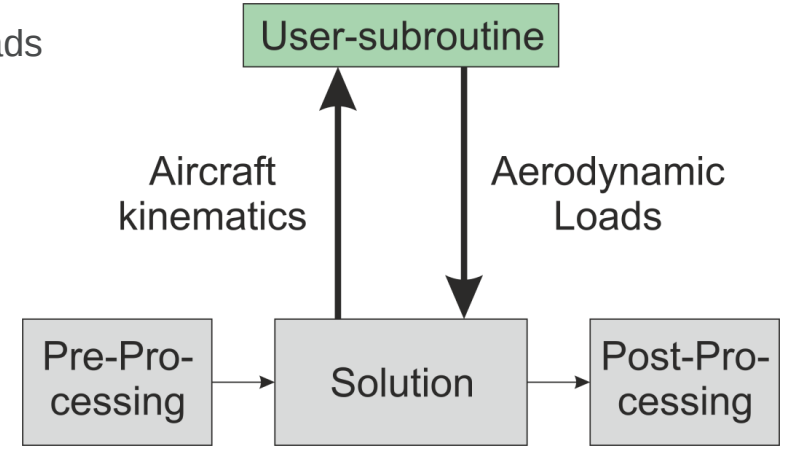


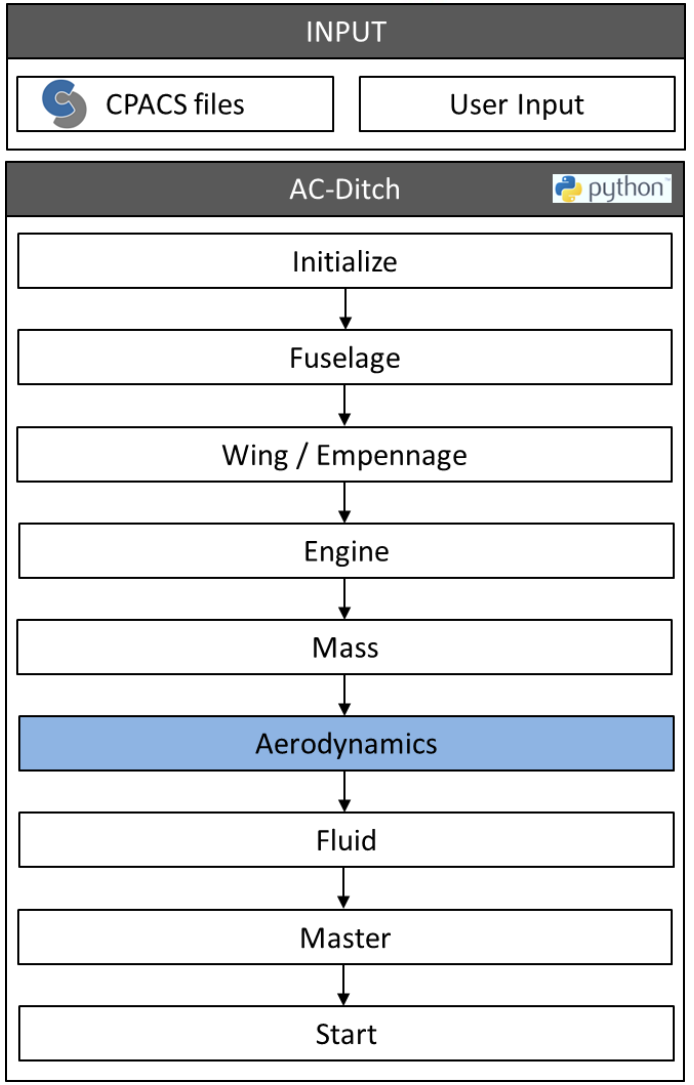
$$L = \frac{\rho}{2} S C_L v^2$$

$$D = \frac{\rho}{2} S C_D v^2$$

$$M = \frac{\rho}{2} S l C_M v^2$$

- Fully coupled with CPACS data set
- Aerodynamic coefficients provided by aerodynamics specialists (aerodynamics pre-design tools)
- Coupling of aircraft motion and aerodynamic loads
  - ➢ User-Subroutine
  - ➢ Realistic flight mechanics





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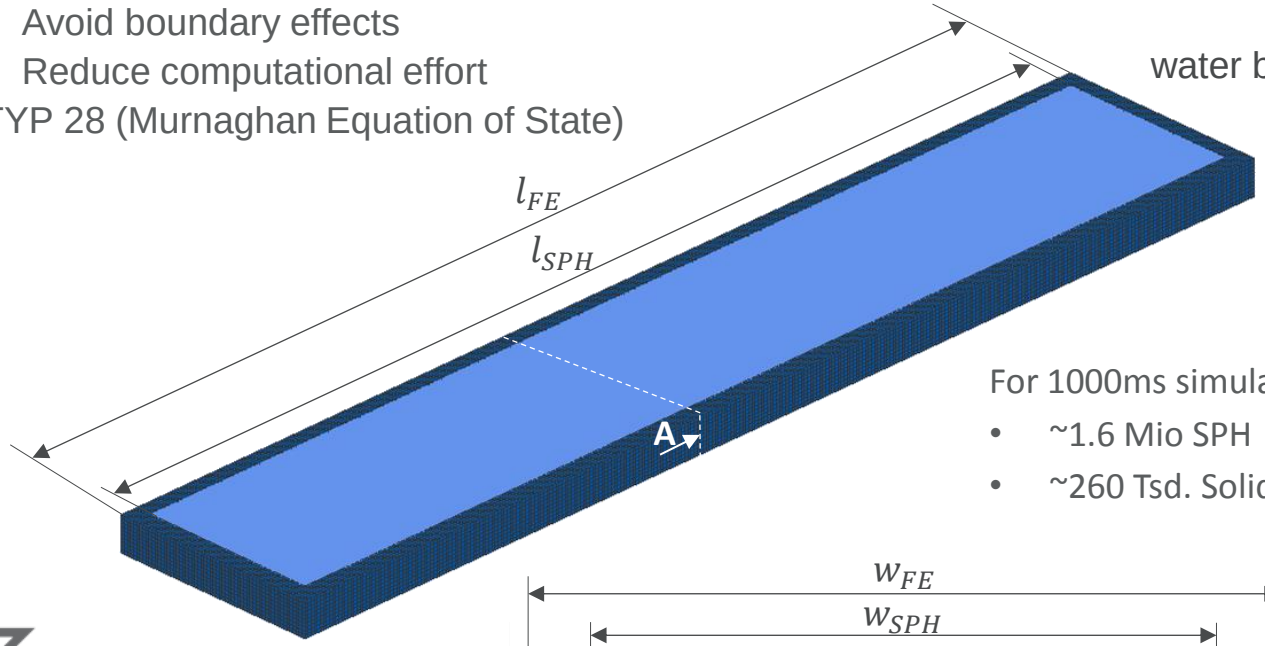
Fluid Model

Hybrid water domain

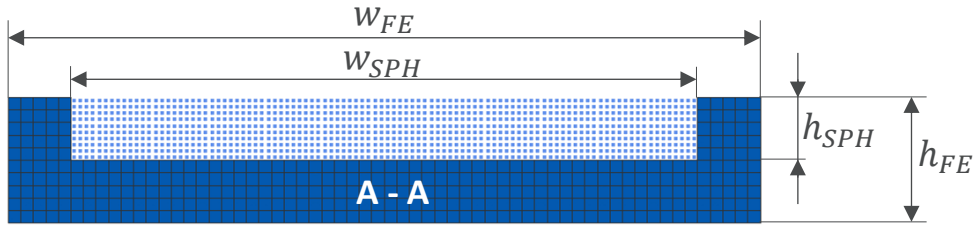
- **Smoothed Particle Hydrodynamics (SPH)**
- **Finite Elements (FE)** → Surroundings
  - Avoid boundary effects
  - Reduce computational effort
- MATYP 28 (Murnaghan Equation of State)

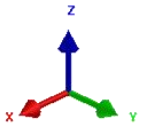


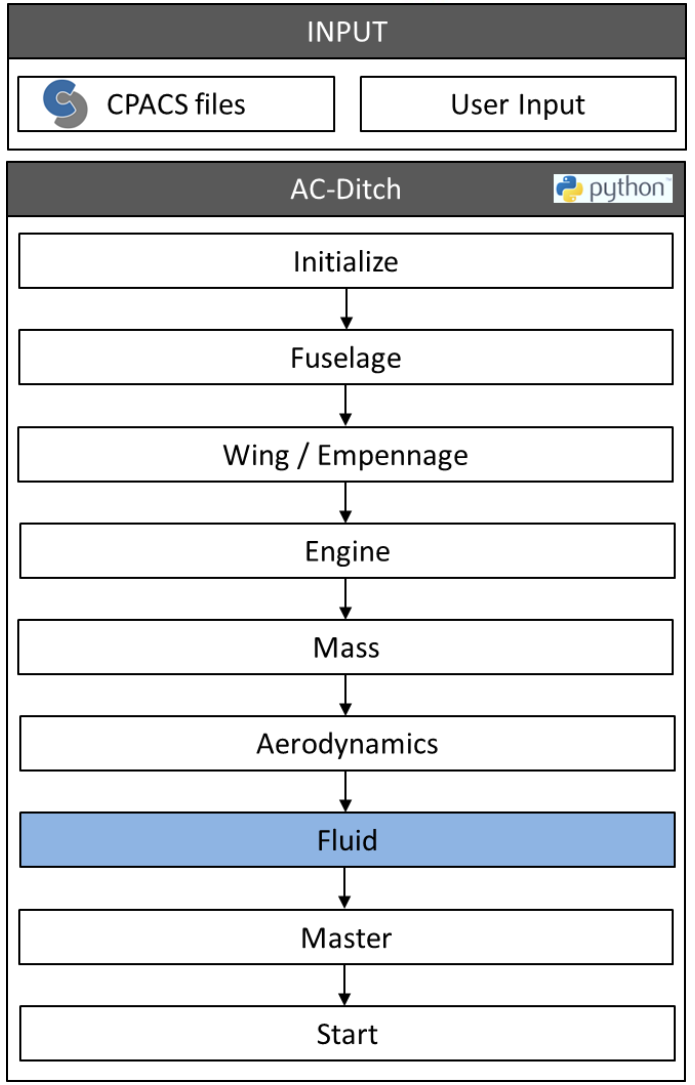
water basin model

For 1000ms simulation time:

- ~1.6 Mio SPH
- ~260 Tsd. Solids

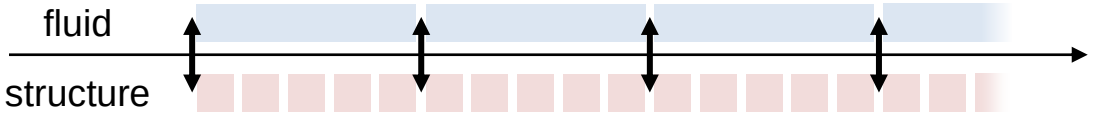




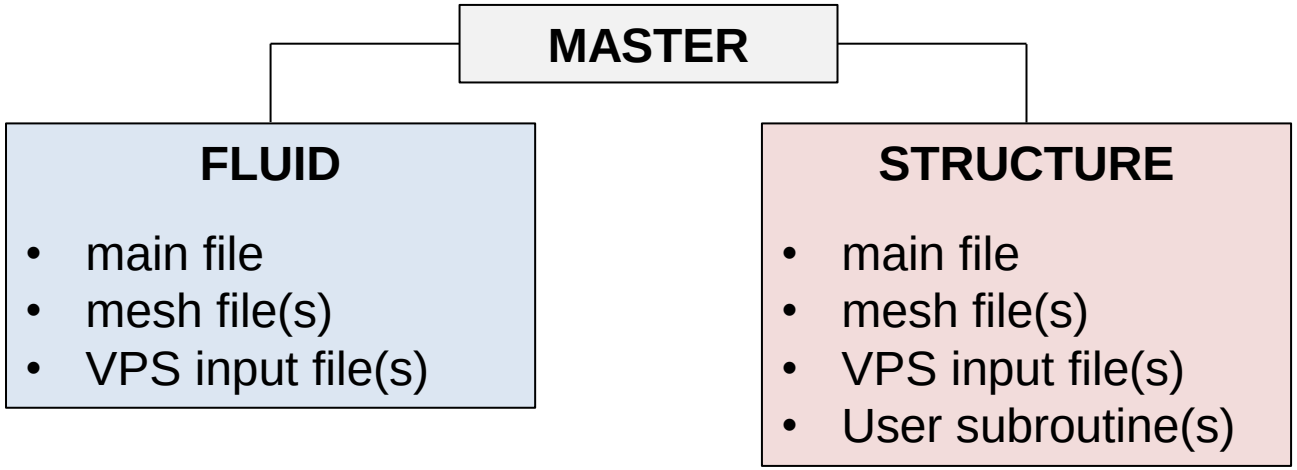


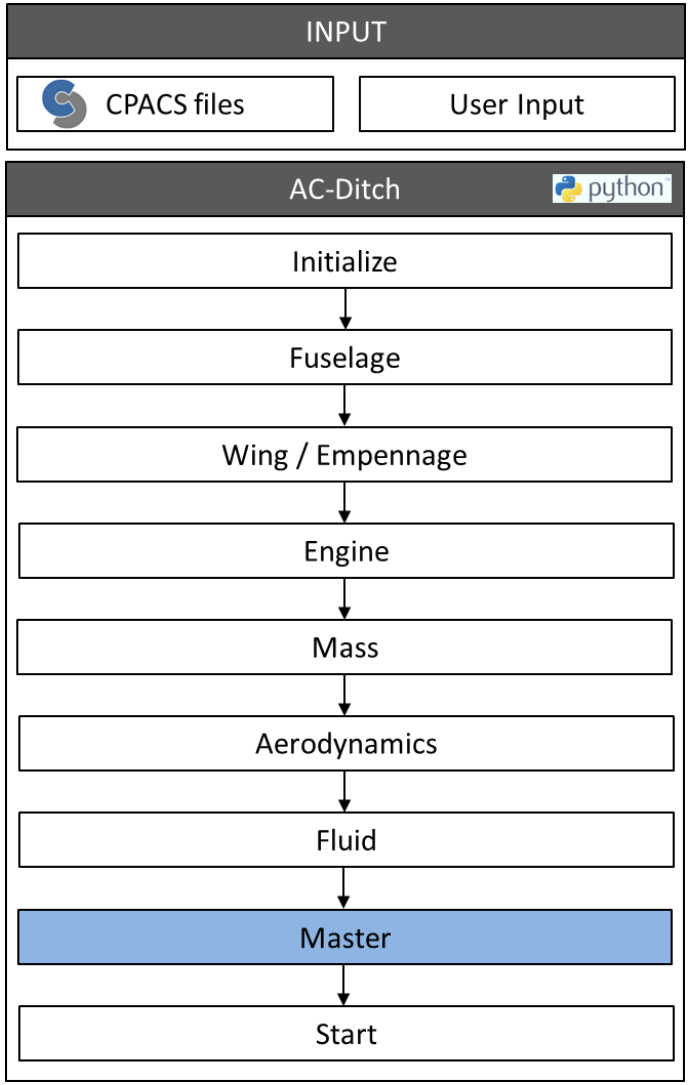
Master: Multi-Model Coupling

- Co-simulation with different time steps



- VPS model setup

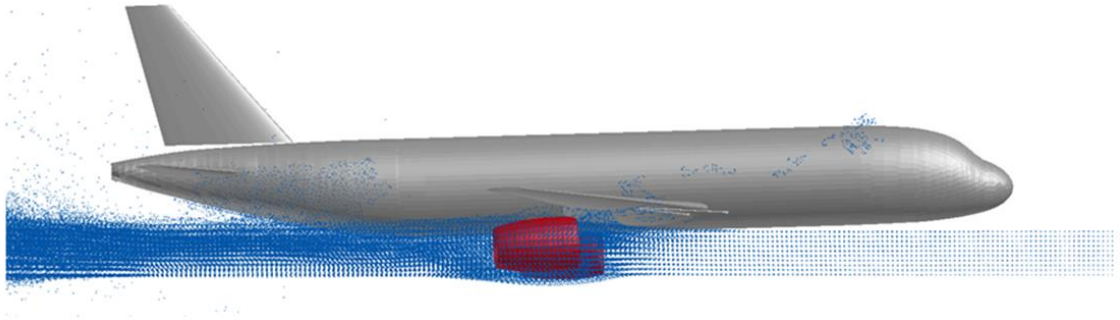




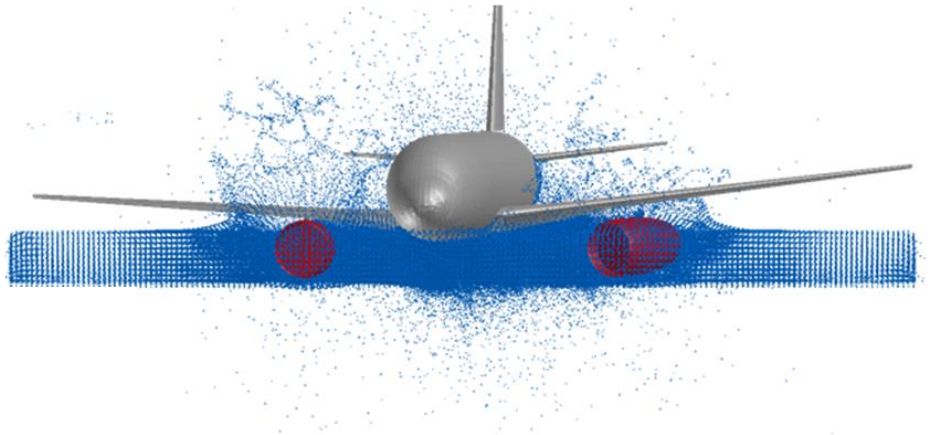
Results: ditching simulation (RBM)

Rigid fuselage

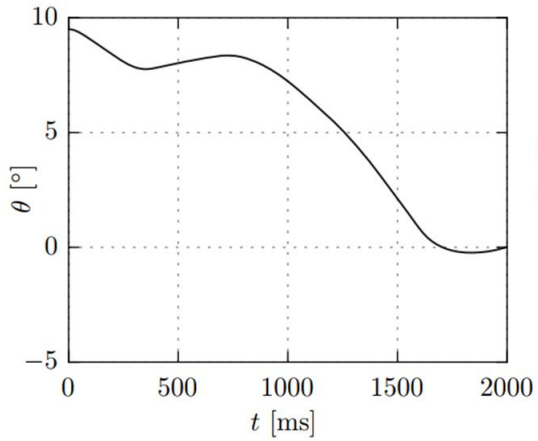
- **Reference case**

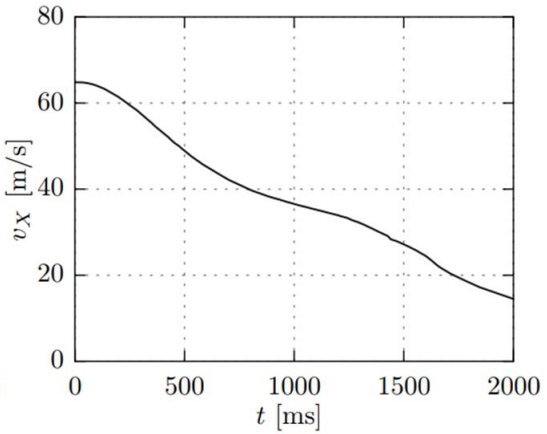


- **<u>Unsymmetrical</u> load case (Hudson impact conditions)**



→ Rigid ditching simulation with different initial conditions
→ Identical mass and inertia characteristics
→ Aircraft kinematics:
  - Displacement
  - Velocity
  - Rotation (e.g. pitch angle)

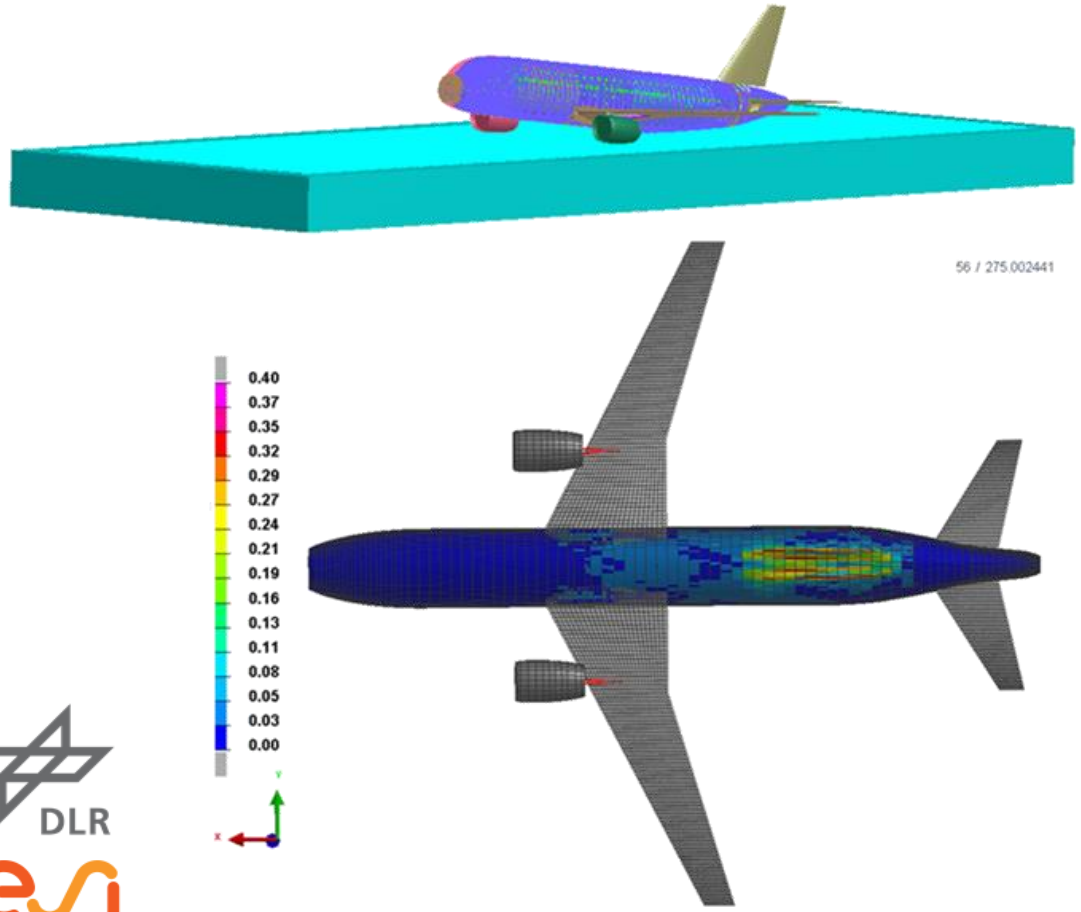




Results: ditching simulation (GFEM)

Flexible fuselage

- **Reference case**



→ Flexible ditching simulation with different initial conditions
→ Comparable mass and inertia characteristics
→ Large deformation due to hydrodynamic loads visible

Structural deformation in the rear bottom section of the A320 ditched on the Hudson River [2]

Next Steps:

→ Integration of the tool in pre-design process chains
→ Enhancement of aircraft modelling process chain (RBM/ GFEM)
→ Alternative GFEM models (conventional/ arbitrary…)

[2] NTSB, Structures Group Chairman's Factual Report, Attachment 2, Photos, SA-532 7-F, Technical Report Addendum 1, NTSB, Washington DC, USA, 2009.

Agenda

Motivation

Aircraft Ditching Simulation

Multidisciplinary Aircraft Design

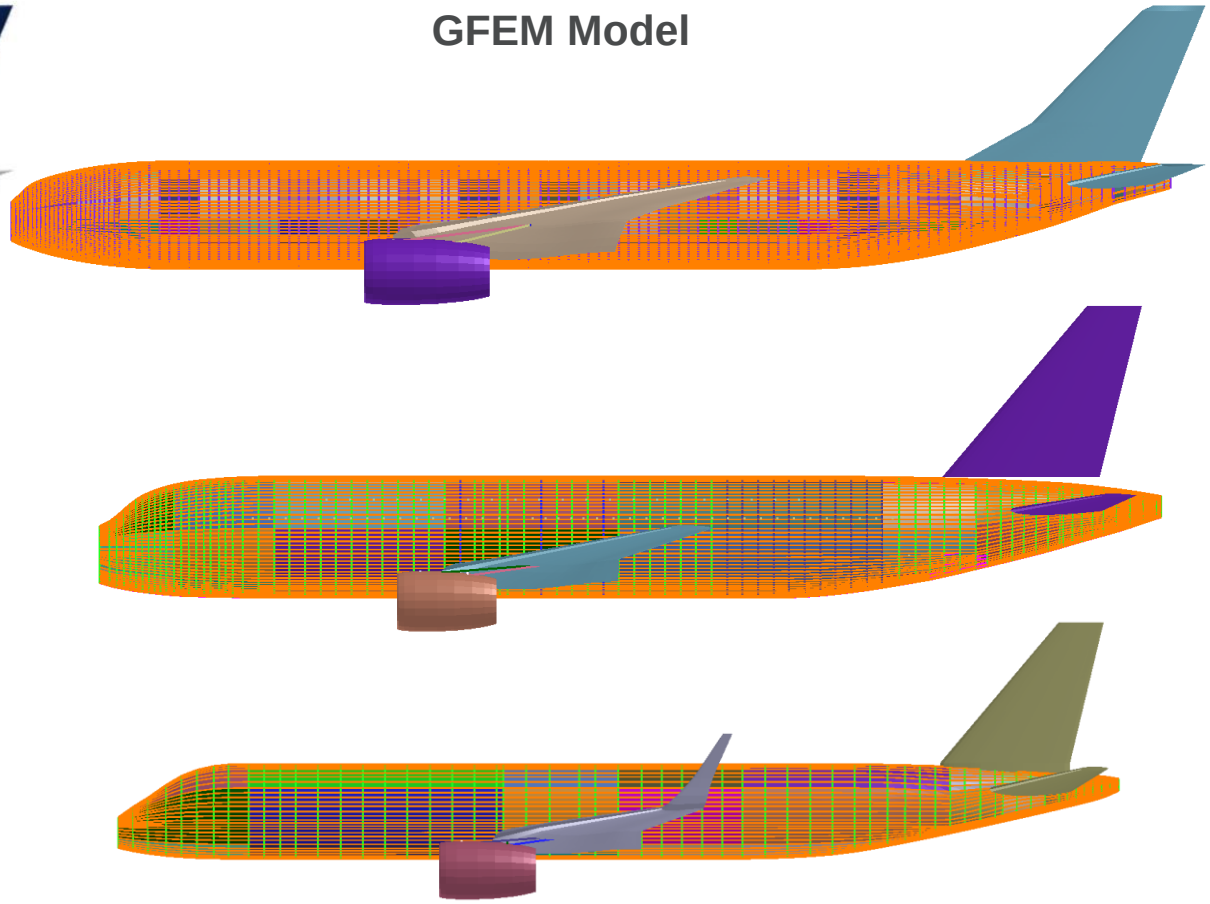
Summary and Outlook

Multidisciplinary Aircraft Design Process Chain

Classical configuration

Background: A330, A320 and E190 [8]

GFEM Model

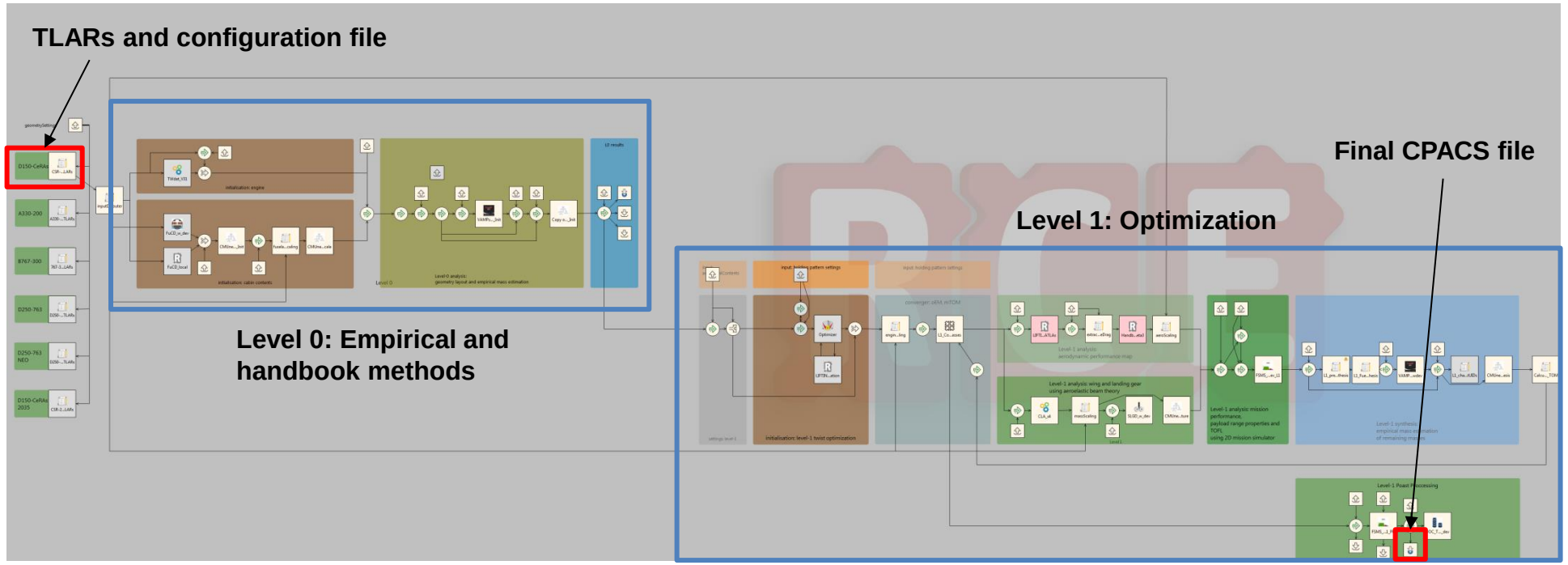


Generic long, medium and short range aircraft models

[8] https://magazin.lufthansa.com/xx/de/flotte, accessed 01.10.2019

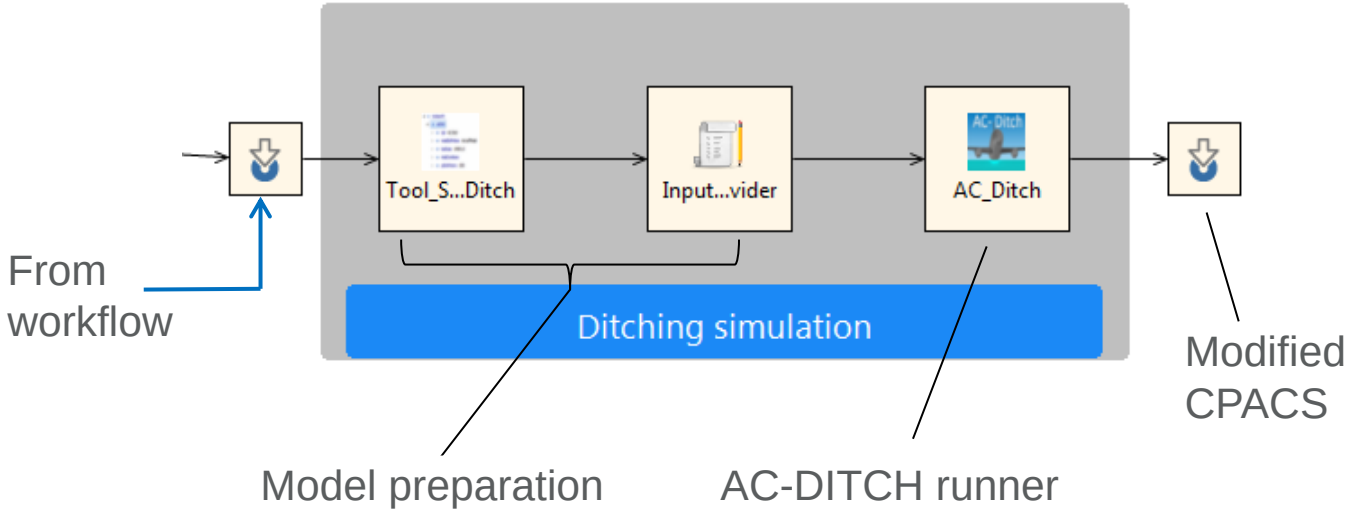
Multidisciplinary Aircraft Design Process Chain

Advanced Technology Long-Range Aircraft Concepts (ATLAs) Project



Multidisciplinary Aircraft Design Process Chain

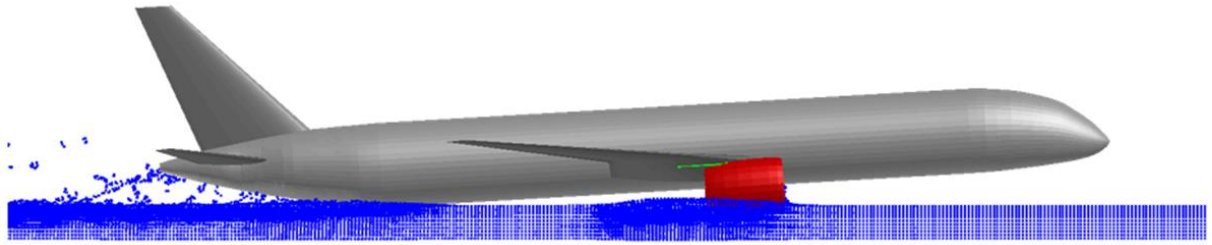
Rigid fuselage



Modelling capabilities

<u>Rigid</u> fuselage:

- Implementation of a *RCE* based process chain (*ATLAs*)
  - Geometry
  - Global mass, COG, inertia
  - Aerodynamic data
  - Engine generation
- Surface mesh generation using *PANDORA* framework
- Full model generation using *AC-DITCH* on *RCE* server
- Running of ditching simulation on local Cluster
- **Solver: *VPS***

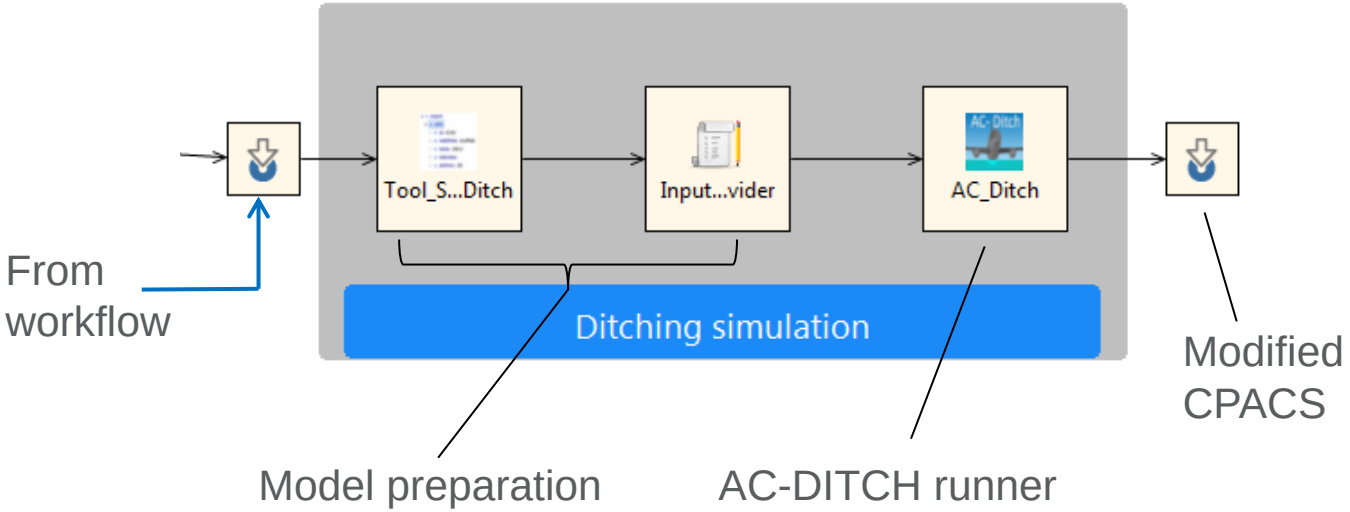


<u>Exemplary</u> ditching simulation (rigid, t=1000ms)

Total mass and inertia at predefined COG

Multidisciplinary Aircraft Design Process Chain

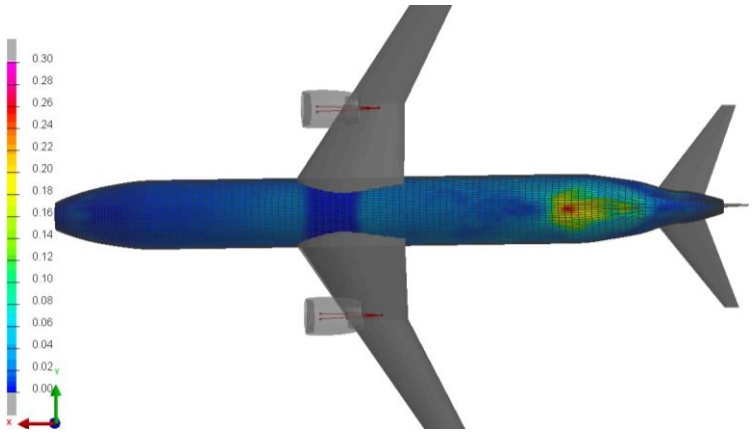
Flexible fuselage



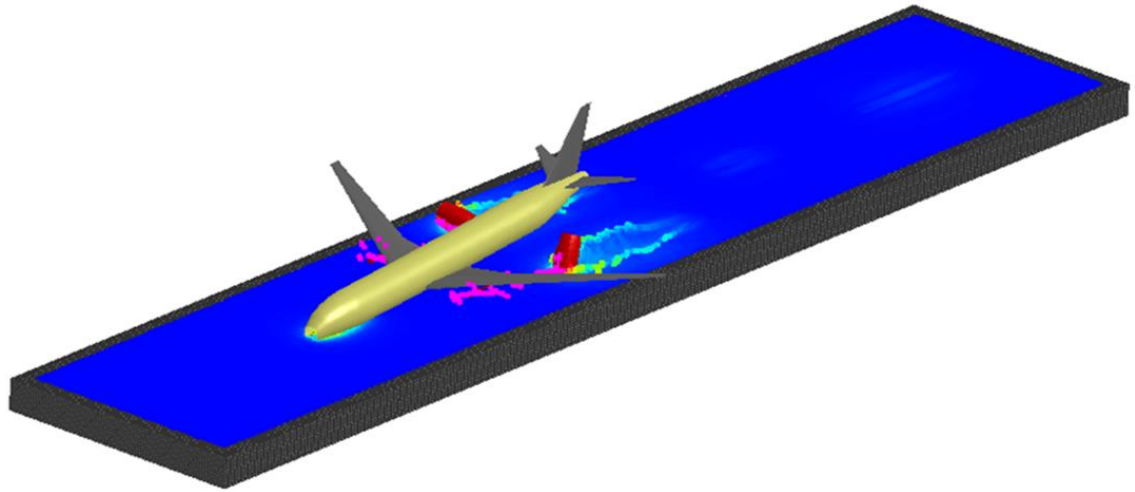
Modelling capabilities

<u>Deformable</u> fuselage:

- Implementation of necessary features to generate GFEM
  - Fuselage topology (external tool)
- GFEM generation (PANDORA) → Mass model
- Ditching simulation generation (AC-Ditch on RCE server)
- **Solver : *VPS***



Structural deformations visible (e.g. stress)



<u>Exemplary</u> ditching simulation (flexible, t=1500ms)

Agenda

Motivation

Aircraft Ditching Simulation

Multidisciplinary Aircraft Design

Summary and Outlook

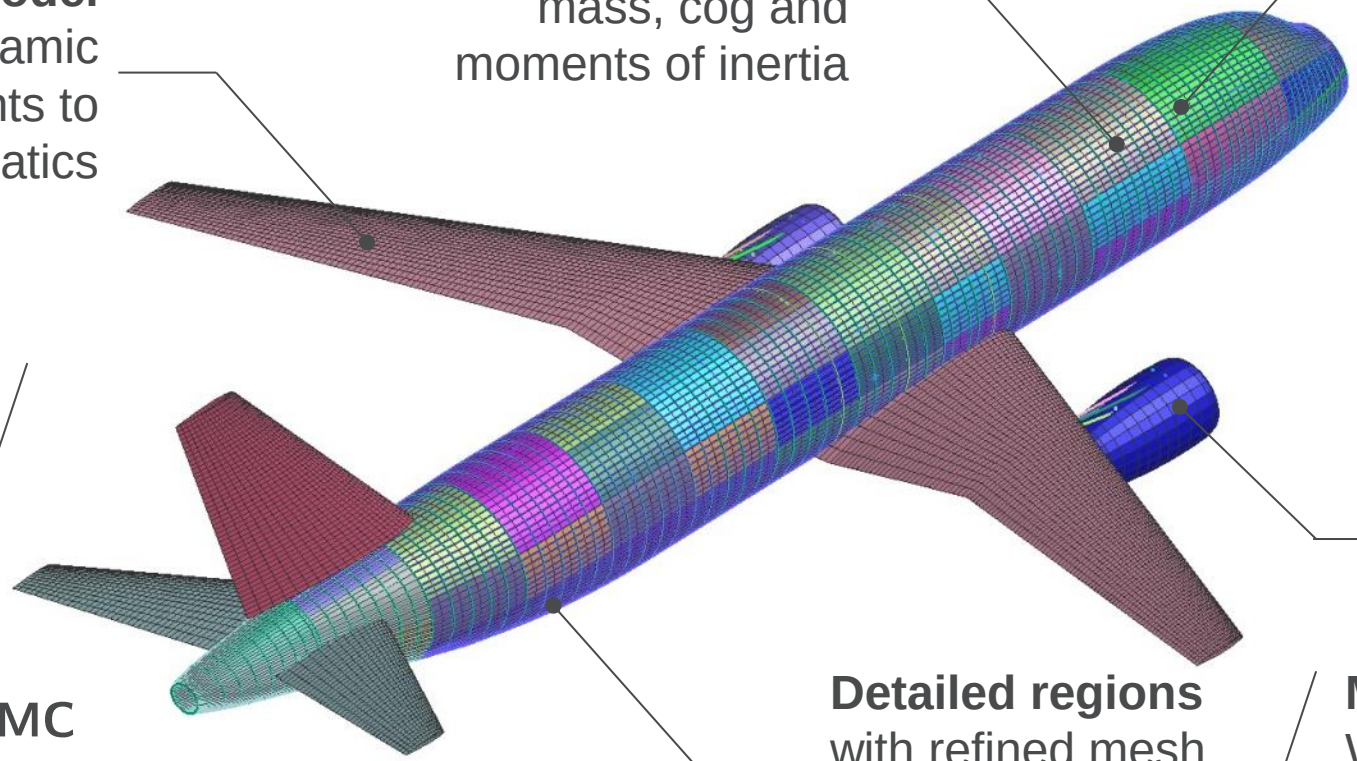
esi FORUM in Germany | NOV 6-7, 2019

Summary

Aerodynamic model coupling aerodynamic forces/moments to aircraft kinematics

Mass model portraying correct, mass, cog and moments of inertia

Generic transport aircraft mesh (parametric model, statically sized)



Design Process Chain
How to define a DFEM?
How to extend models?

WORK IN PROGRESS

Engine model with potential failure of attachment upon overload

HPC & MMC

Detailed regions with refined mesh accounting for local deformations

Mesh quality & Adaptivity
When to use HiFi?
How to refine/unrefine?

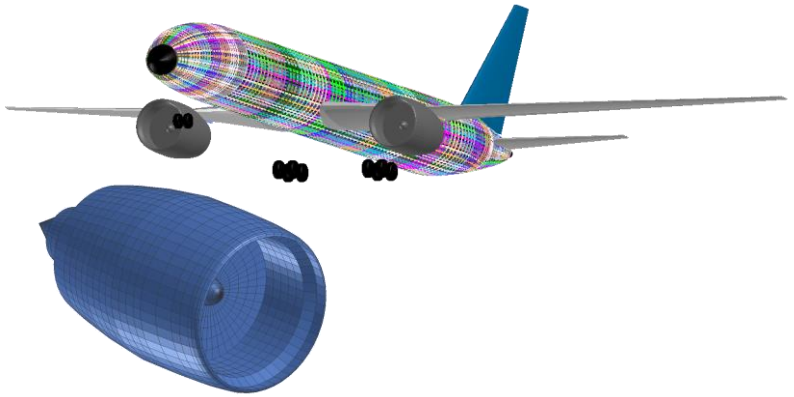
WORK IN PROGRESS

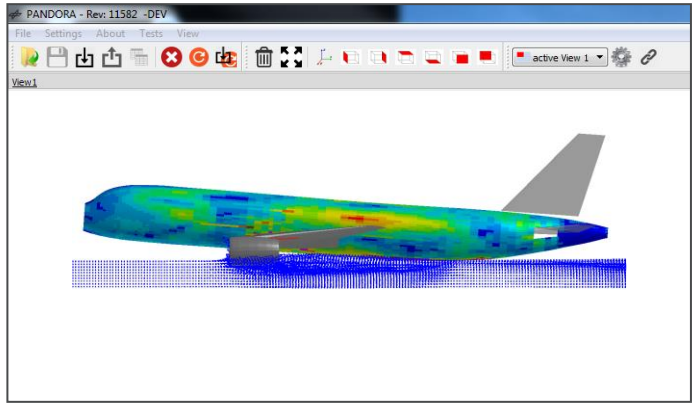
DLR

esi get it right®

Outlook

- Further model capabilities
  - Improved engine models
  - Additional aircraft items
- Full integration of AC-Ditch in PANDORA
  - Enable parametric studies
- Extended ditching analysis
  - Floatation





Initial conditions:
- Low speeds
- Nose-up positions
- Retracted landing gear
- …

Highest hydrodynamic loads:
- Structural integrity
- Local deformations
- Failure of the structure

Hydrodynamic phenomena:
- Suction
- Overpressure
- Cavitation

Evacuation:
- Time
- Structural fractures
- Water ingress

Aircraft Ditching Simulations within a Multi-disciplinary Aircraft Design Process Chain

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Thank you

Questions ?