# Ditching Simulation of Large Complex Aircraft Models


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ESI Forum, Weimar, November 7th, 2017


DLR

get it right

# Background

- Aircraft emergency condition with controlled impact on water
- Analysis and proof of compliance required as part of aircraft type certification


- High forward velocity
- Hydrodynamic Phenomena
- Nonlinear structural response
- Complex fluid-structure interaction

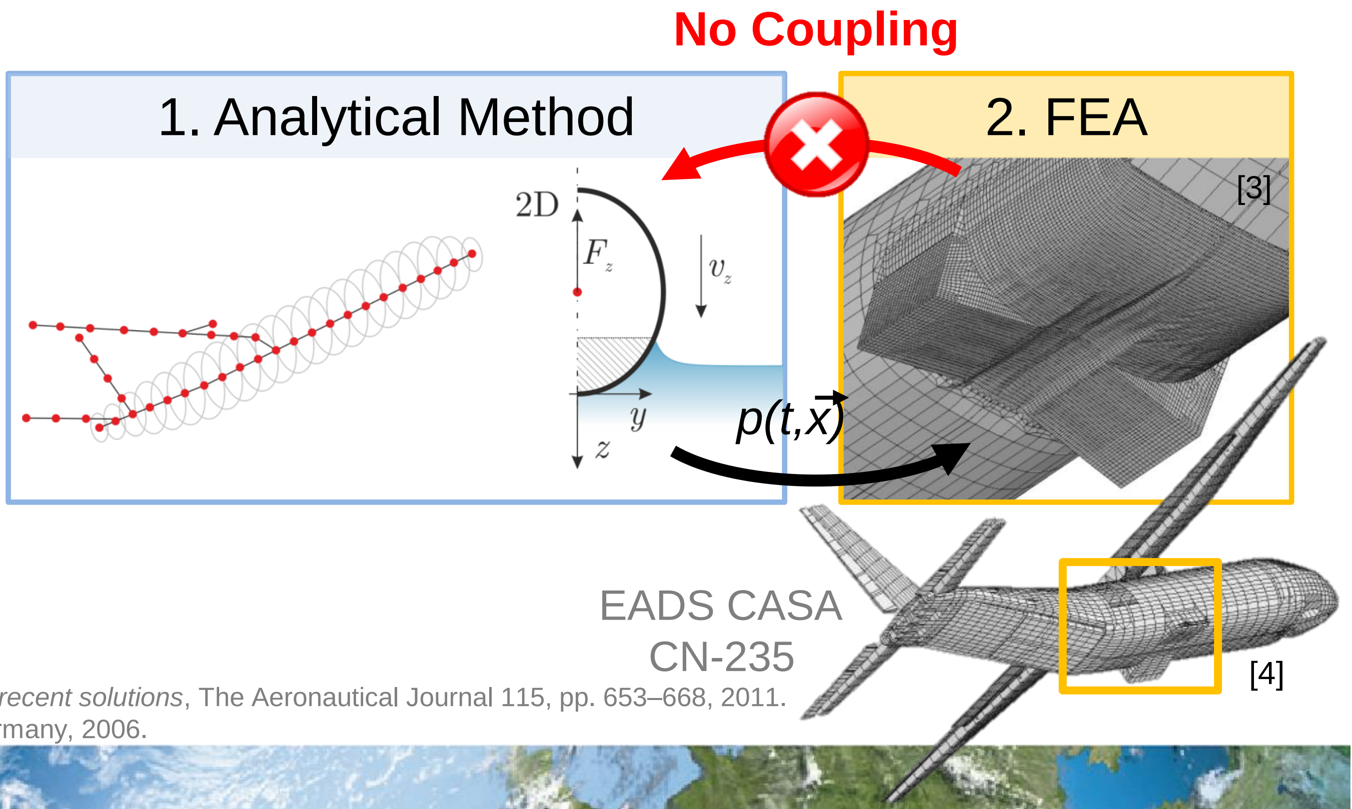
# State of the Art: Design & Certification Procedures

1. **Comparison with aircraft of similar design that were proven to satisfy ditching regulations**

2. **Experiments using sub-scale models**


Experiment with EADS CASA CN-235 (1:8)

3. **Uncoupled numerical analyzes**

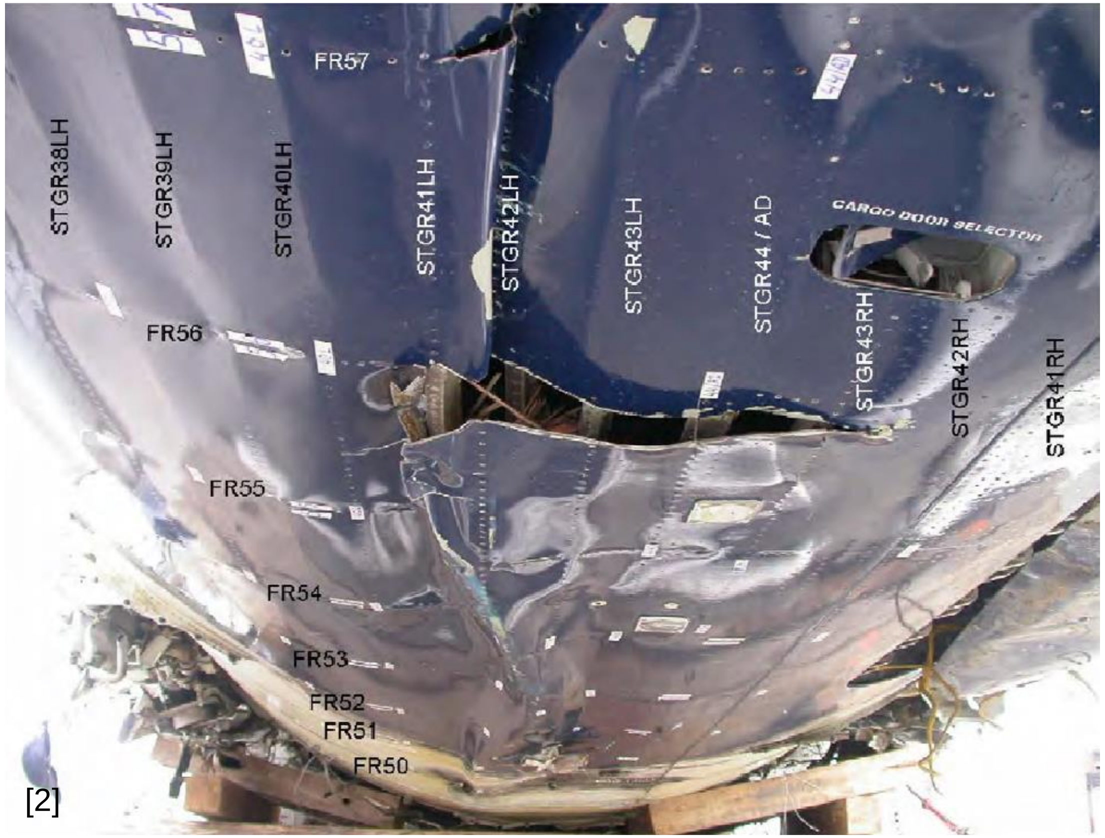



[3] Pérez et al., *Survey of aircraft structural dynamics non-linear problems and some recent solutions*, The Aeronautical Journal 115, pp. 653–668, 2011.
[4] Climent et al., *Aircraft Ditching Numerical Simulation*, in: 25th ICAS, Hamburg, Germany, 2006.

# Motivation


[1]


[2]




[2]

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

[1] http://img.planespotters.net/media/photos/original/076000/PlanespottersNet_076460.jpg, Zugriff 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.

# Motivation


LionAir B737-800NG, April 2013, Denpasar, Bali, Indonesia

Image source: Police photo (Photo: AFP/Indonesian Police), http://avherald.com/h?article=460aeabb&opt=1

# Claim and Research Questions

How and to which extent?

Which mechanisms characterize and affect the structural response?

**Structural deformations significantly affect the hydrodynamic loads** acting during a ditching as they **modify the boundary conditions** the fluid is facing.

Therefore, they should be taken into account for an **accurate assessment of the structural behavior** through **coupled simulations**.

Can the SPH-FE approach predict the structural response?

Which modelling techniques permit efficiency, robustness, and accuracy?

# Objective

→ Experimental and numerical analysis of the structural response under hydrodynamic loads representative of fixed-wing aircraft ditching

## Research Path

- Evaluation of experimental data
- Development, validation, and assessment of numerical model (capab., limit.)
- Investigation of structural response
- Application to larger structural models

## Research Projects

- **SMAES**[1] (EU-FP7, 2011-2014)
- **ADAWI**[2] (ONERA-DLR, 2015-2017)

[1] SMAES = SMart Aircraft in Emergency Situations
[2] ADAWI = Assessment of Ditching and Water Impact

# Guided Ditching Experiment

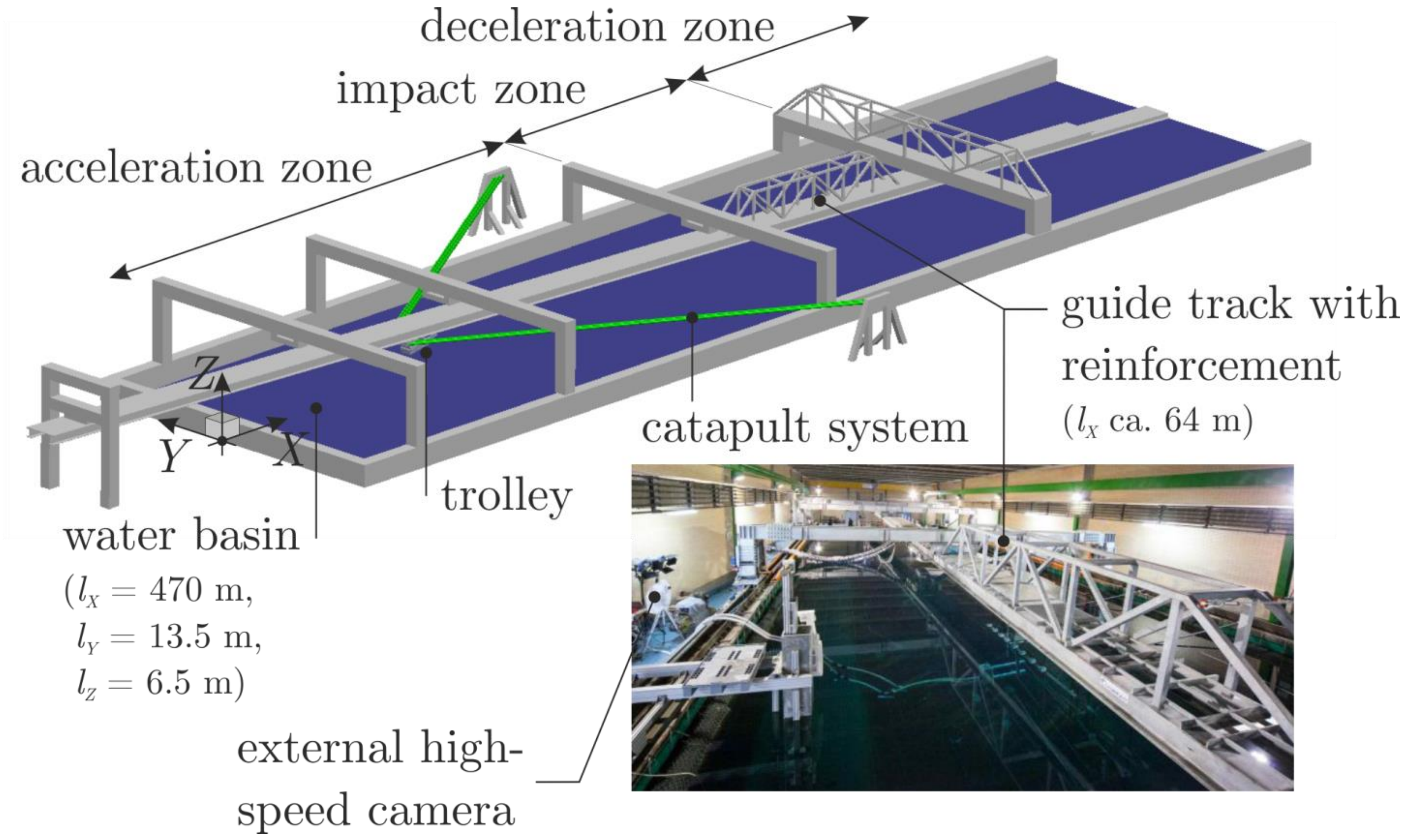
## Simulation Approach and Models

## Full Aircraft Ditching

## Conclusion and Outlook

Knowledge for Tomorrow

# Guided Ditching Experiment – Overview





Real-time camera


High-speed camera

Guided Ditching Experiment

## Simulation Approach and Models

Full Aircraft Ditching

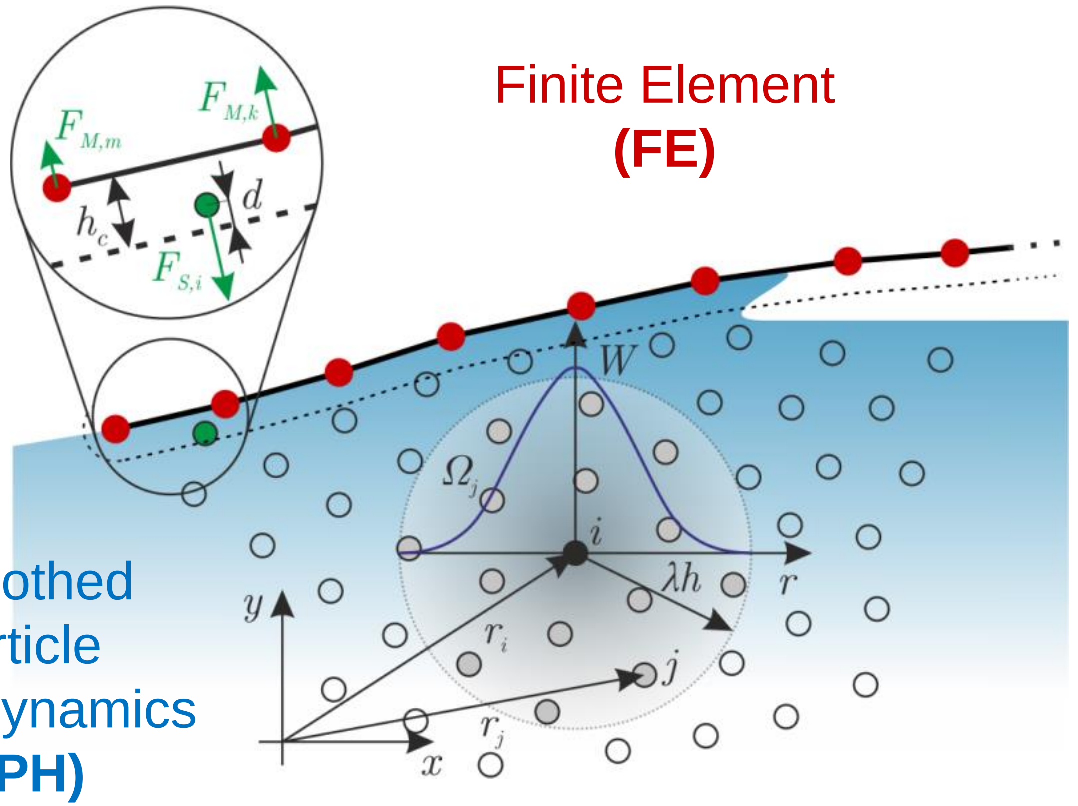
Conclusion and Outlook

# Objectives

- Simple and robust
- Efficient
- Accurate (structural response)

# Challenges

- Multiscale problem in time and space
- Nonlinear structural response
- Large fluid displacements
- Complex free surface shapes

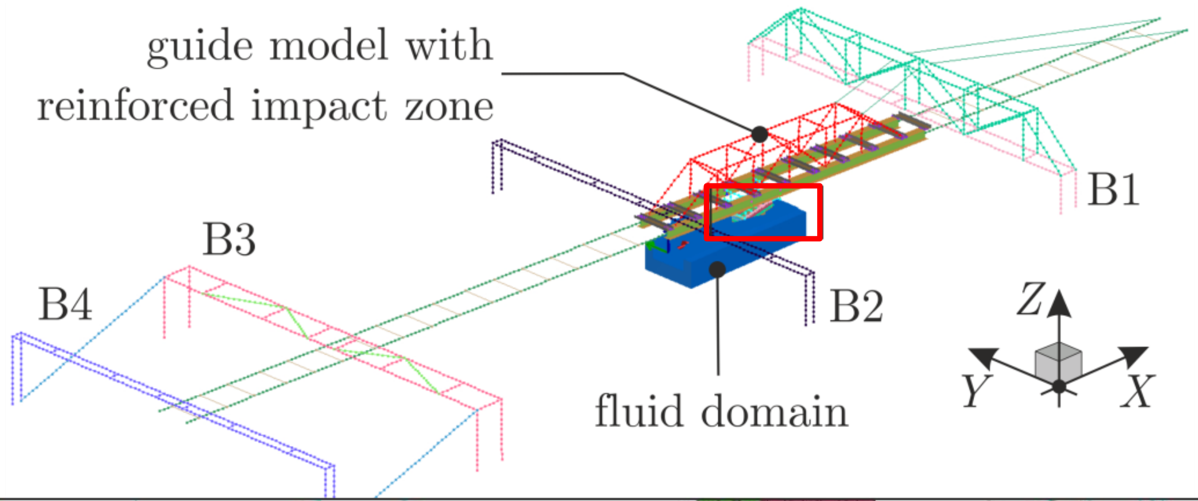



**SPH-FE Approach**

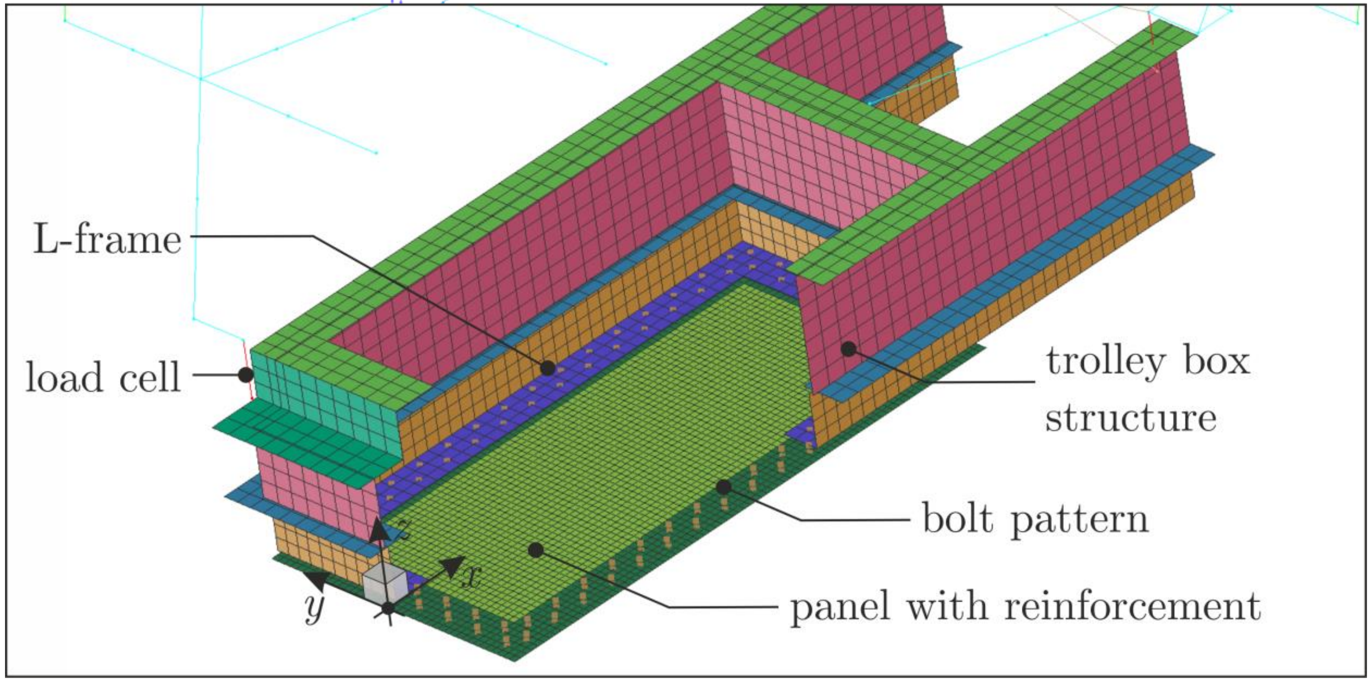
Virtual Performance Solution

# Structural Model

- FE method
- Guide structure for proper boundary conditions




- Modelling strategies from aeronautical crash FEA domain
- Shell elements with $l_{char} \geq 10$ mm **(time step relevant)**



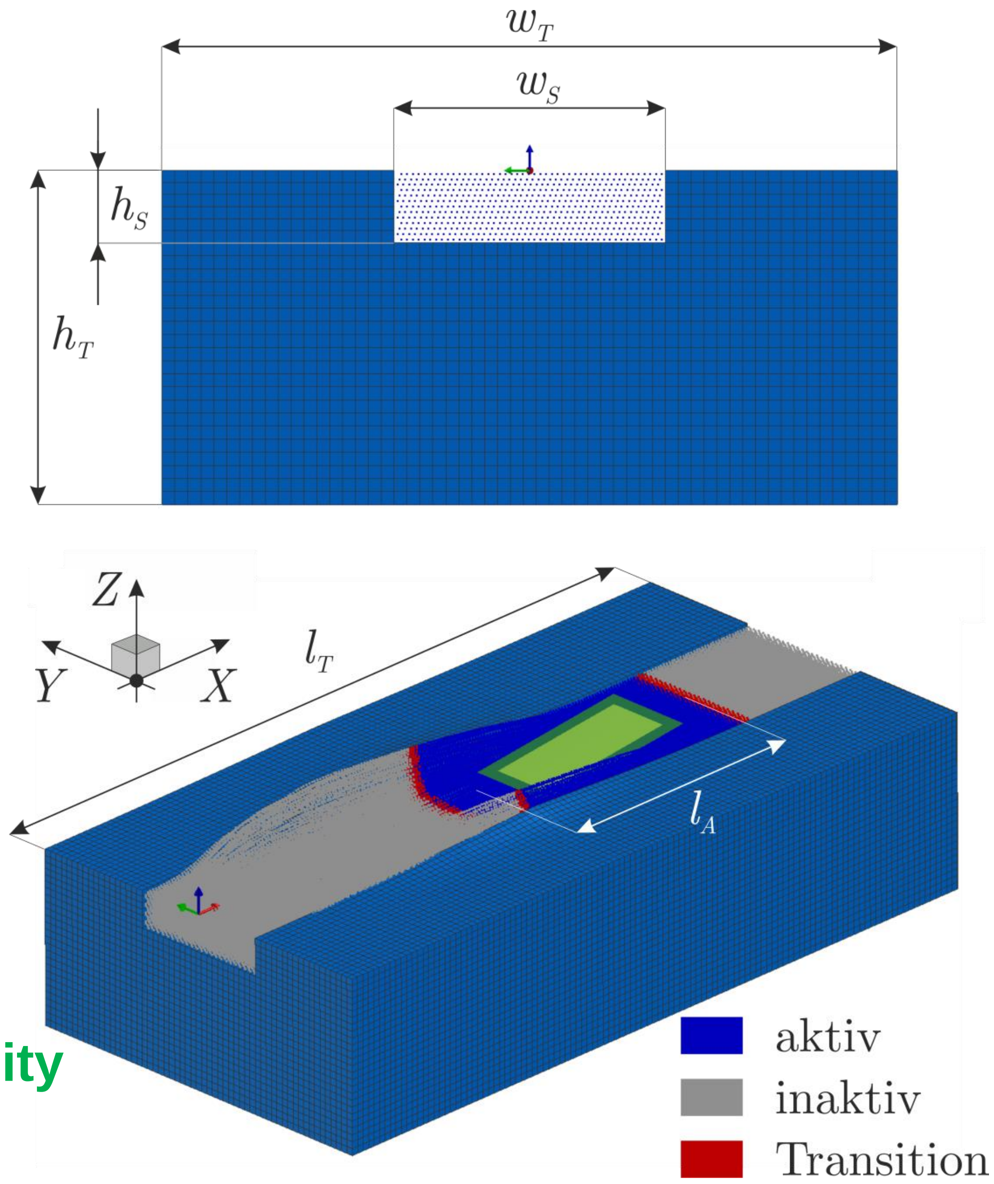
# Fluid Model

- Hybrid SPH-FE model
- Only water / no air modelled

- 1.0 – 1.2 Mio. particles with *ds* = 10 mm
  **(computational effort)**

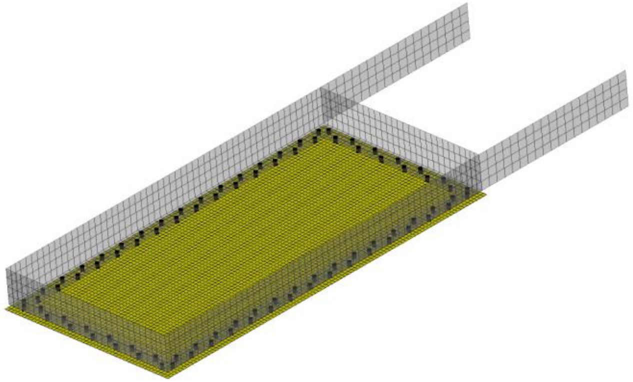
- „Translating Active Domain“ *
  **→ efficiency increased x 2 - 4**

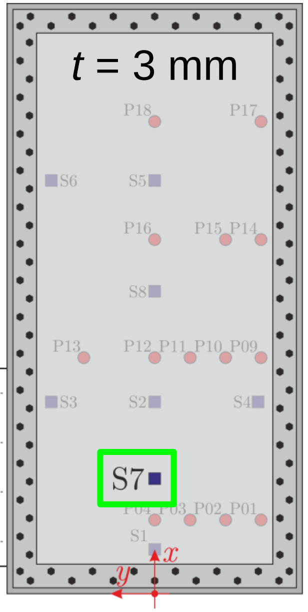
- Correction methods of SPH algorithm *
  (pressure, particle distribution)
  **→ reduced pressure oscillations & increased stability**

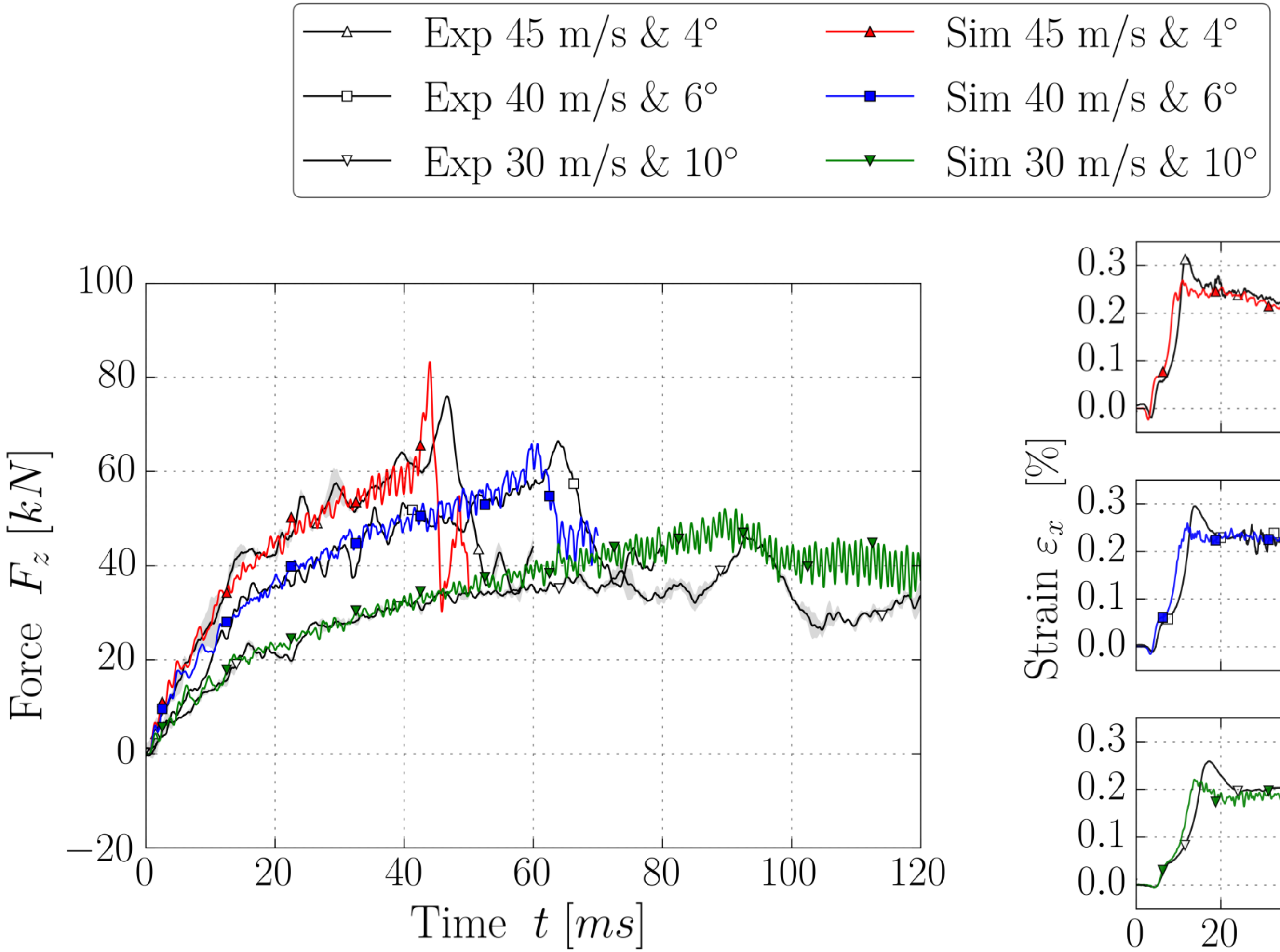


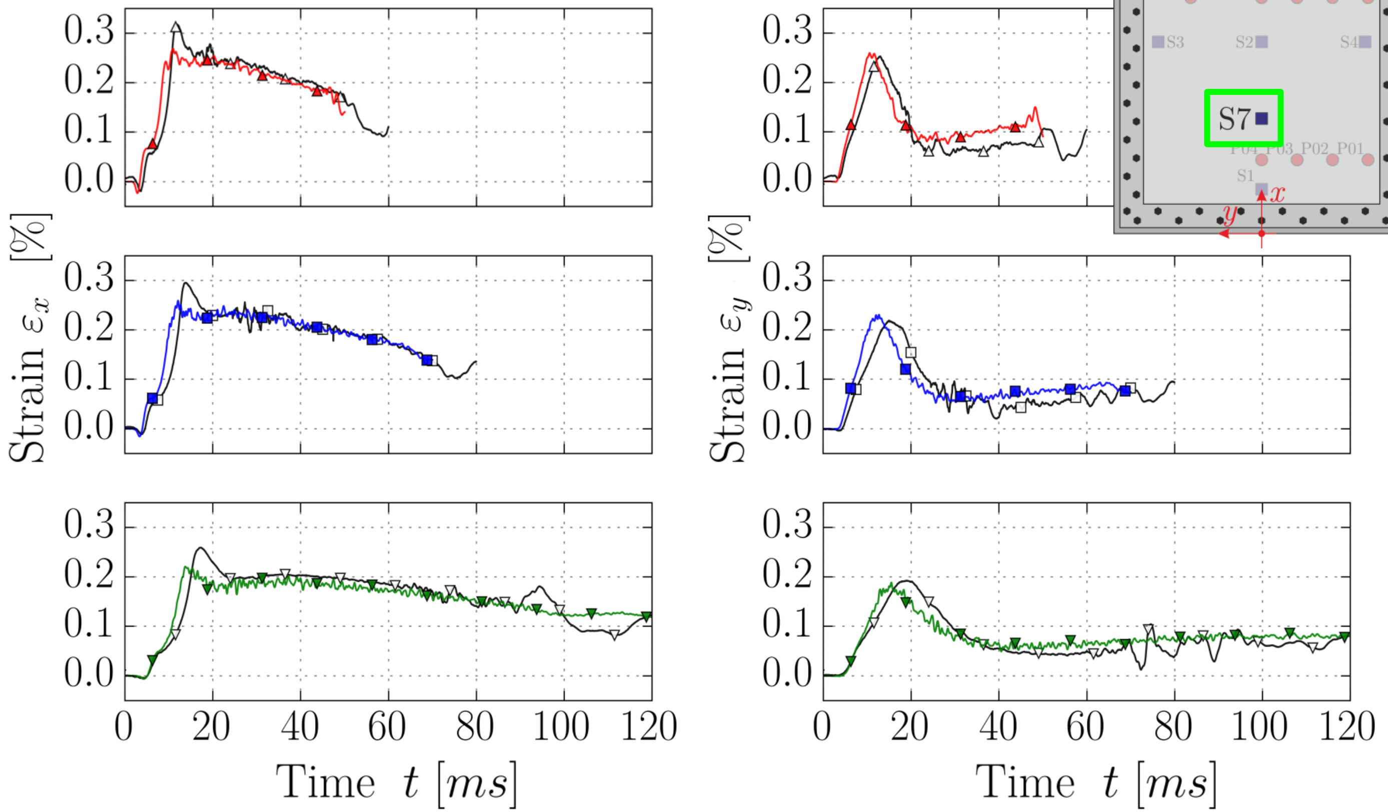

*available in VPS development version

# Validation (Guided Ditching Simulation)





Guided Ditching Experiment

Simulation Approach and Models

**Full Aircraft Ditching**

Conclusion and Outlook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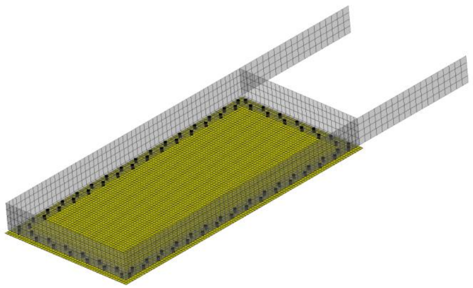
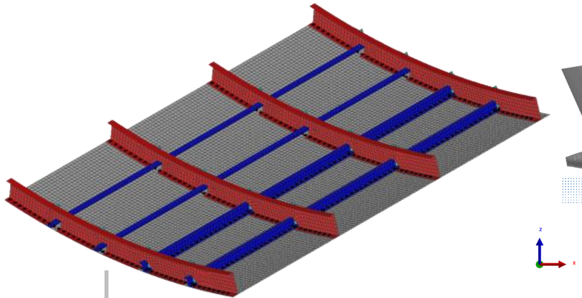
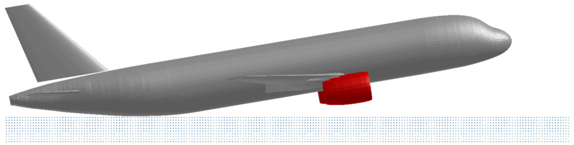
# Overview

strategic



- Simple flex. structure
  (generic panels)
- Prescribed motion

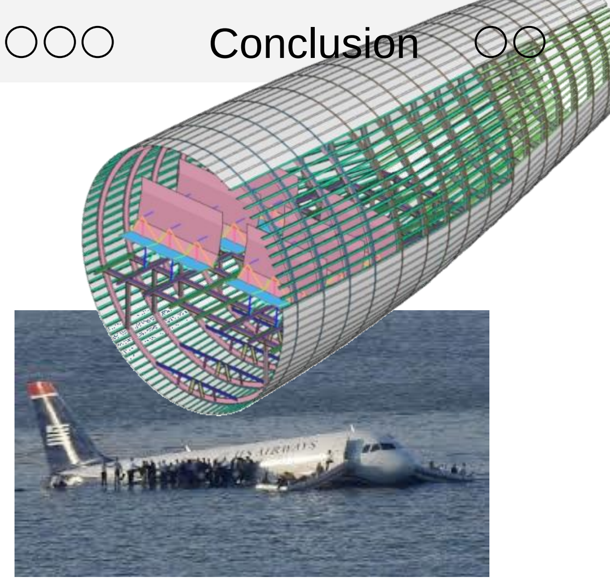




rigid A/C

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

- Rigid structure
  (generic aircraft, Apollo capsule)
- Free motion



- **Highly complex, flexible structure** (generic full aircraft)
- **Free motion**
- **Sea state**

| **SMAES** (2/2011-10/2014) | **ADAWI** (1/2015-12/2017) | ***RADIAN*** *(1/2018-…)* |
|---|---|---|

scientific

**Structural deformations significantly affect the hydrodynamic loads acting during water impact! [1]**

**Do structural deformations affect the <u>global aircraft kinematics</u> during ditching?**
(How? To which extent? …)

[1] Siemann, M. H. (2016) **Numerical and Experimental Investigation of the Structural Behavior During Aircraft Emergency Landing on Water.** Dissertation, University of Stuttgart.

+ 5 journal / 13 conference papers (incl. presentations) and 4 BSc/MSc thesis during 2011-2017

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# *AC-Ditch*

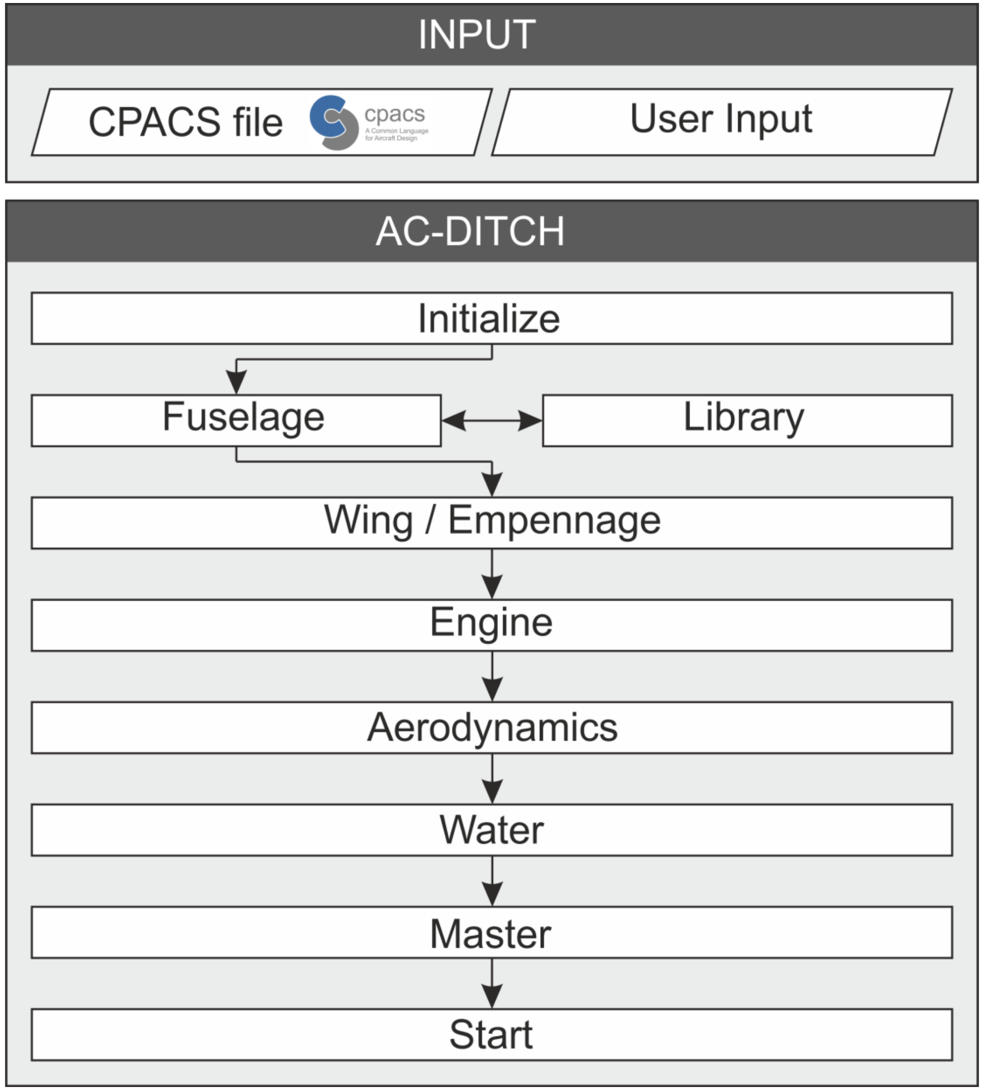
## Why?

- Complex and very large/extensive models
- Frequent changes during design process

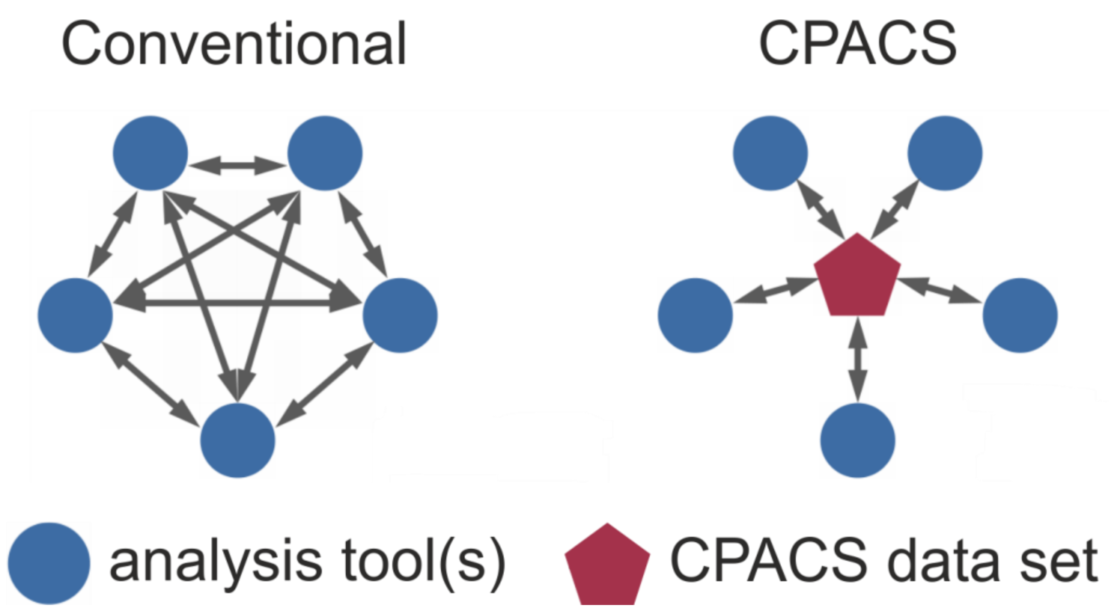
## How?

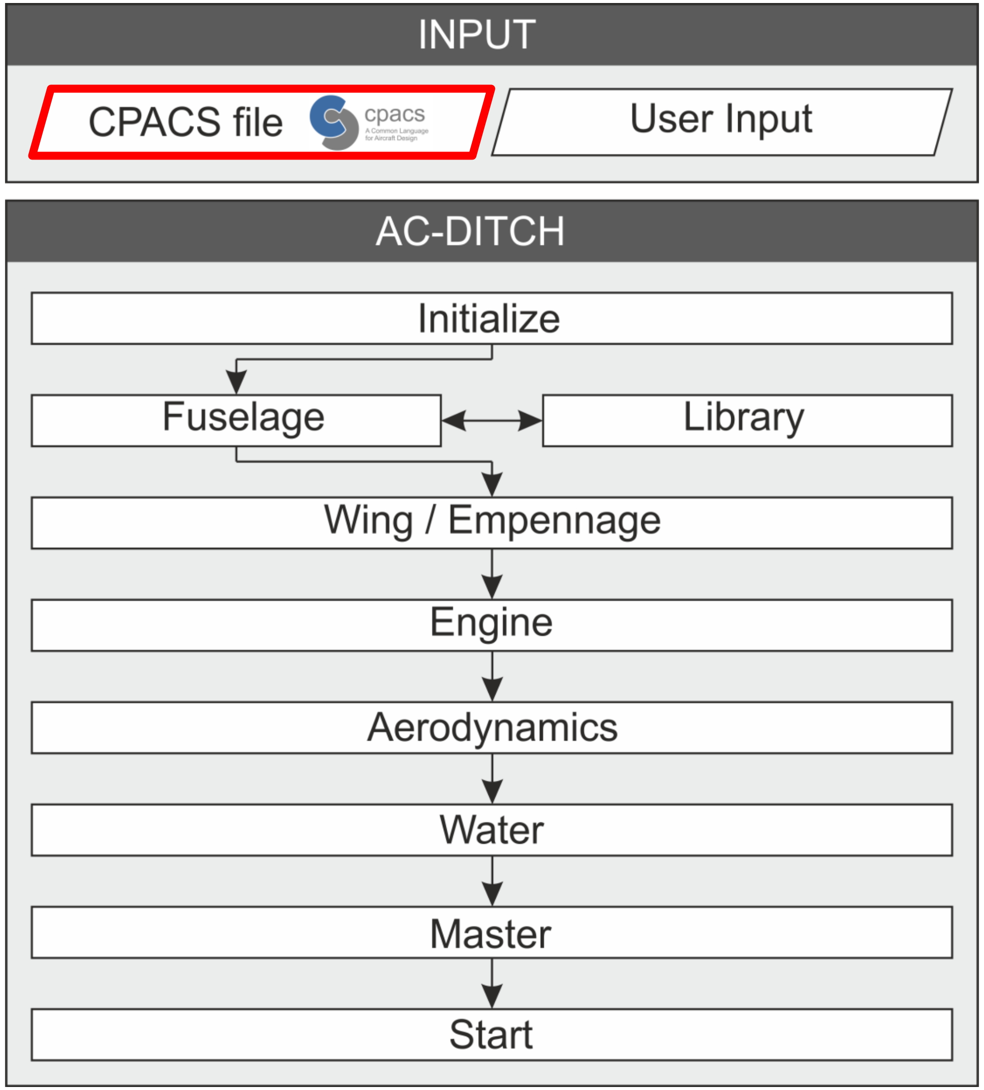
- Highly automated process
- Modular tool
- Solid Foundation

**→ pre-processing of VPS models**



# AC-Ditch

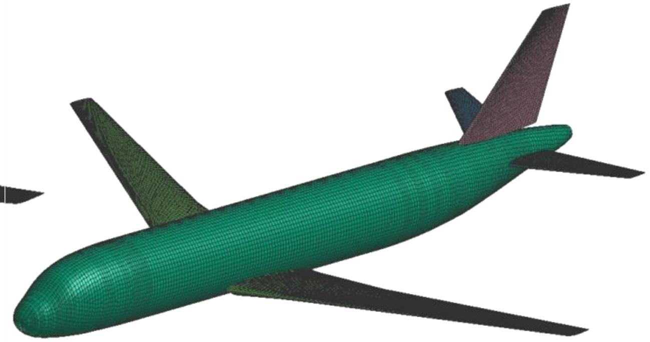


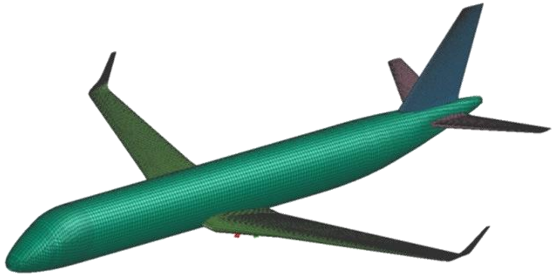

CPACS = Common Parametric Aircraft Configuration Schema
https://software.dlr.de/p/cpacs/home/

# *AC-Ditch*

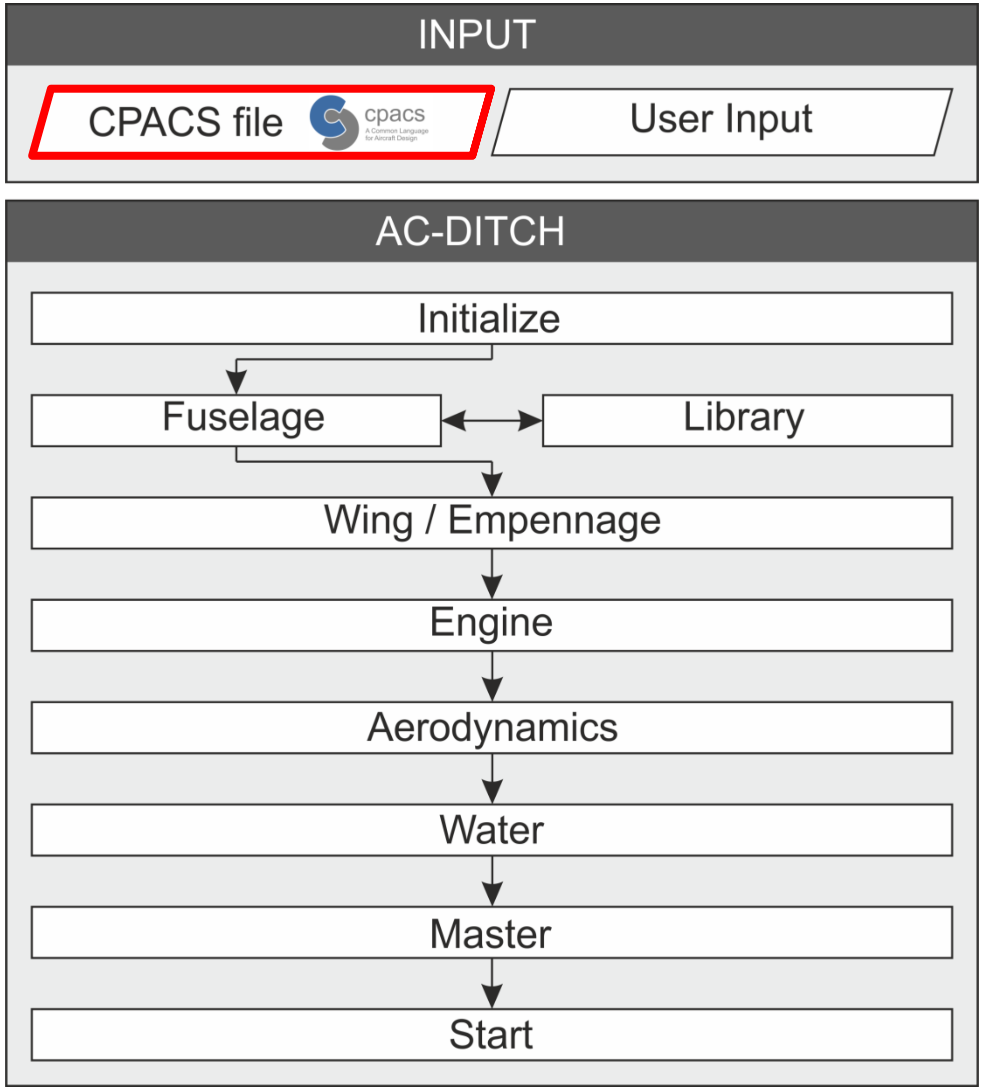
**Generic “XRF1”**
- size similar to A330
- ca. 250-400 PAX



**Generic “D150”**
- size similar to A320
- ca. 150 PAX



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

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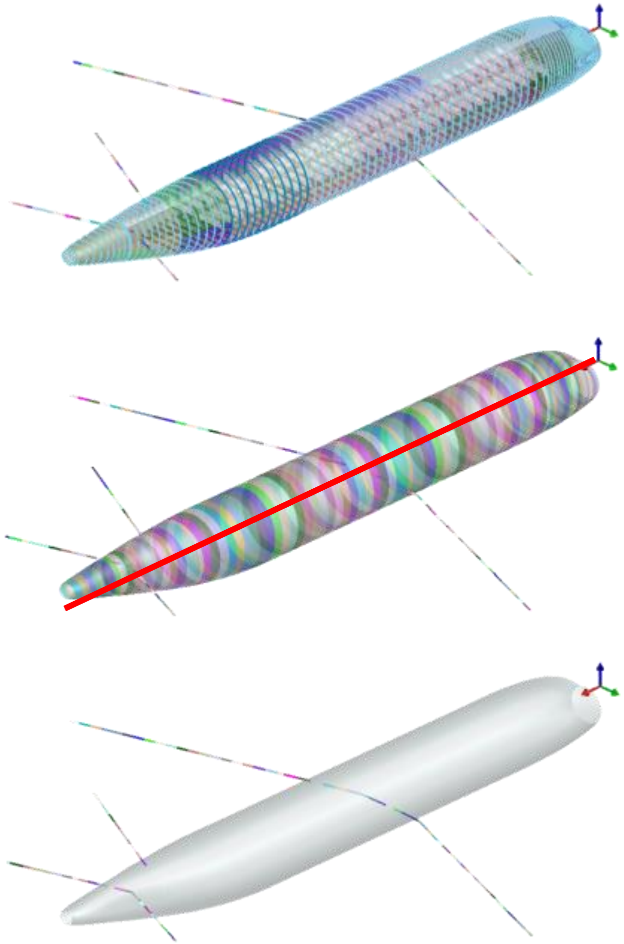
# Fuselage Modeling

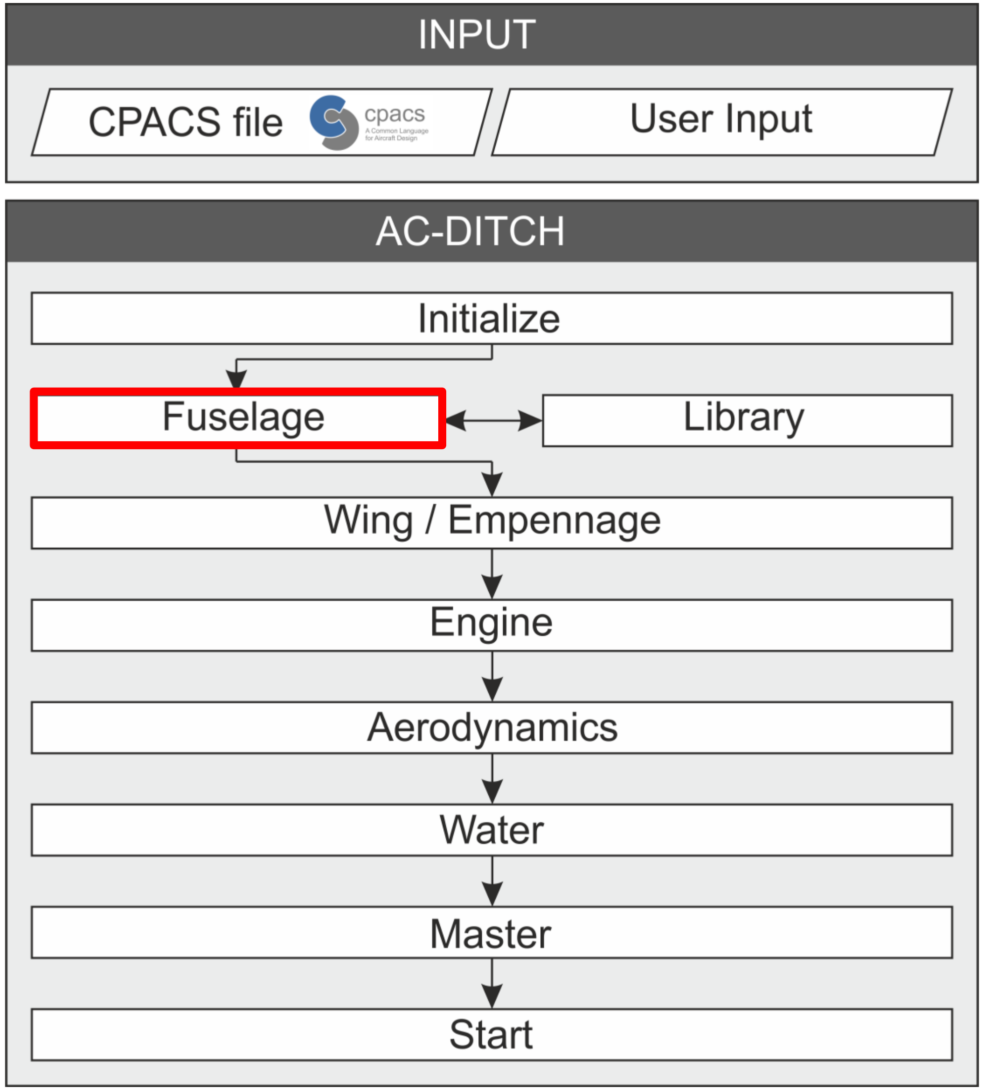
*Global/Detailed FE Model*

*Global Beam Model*

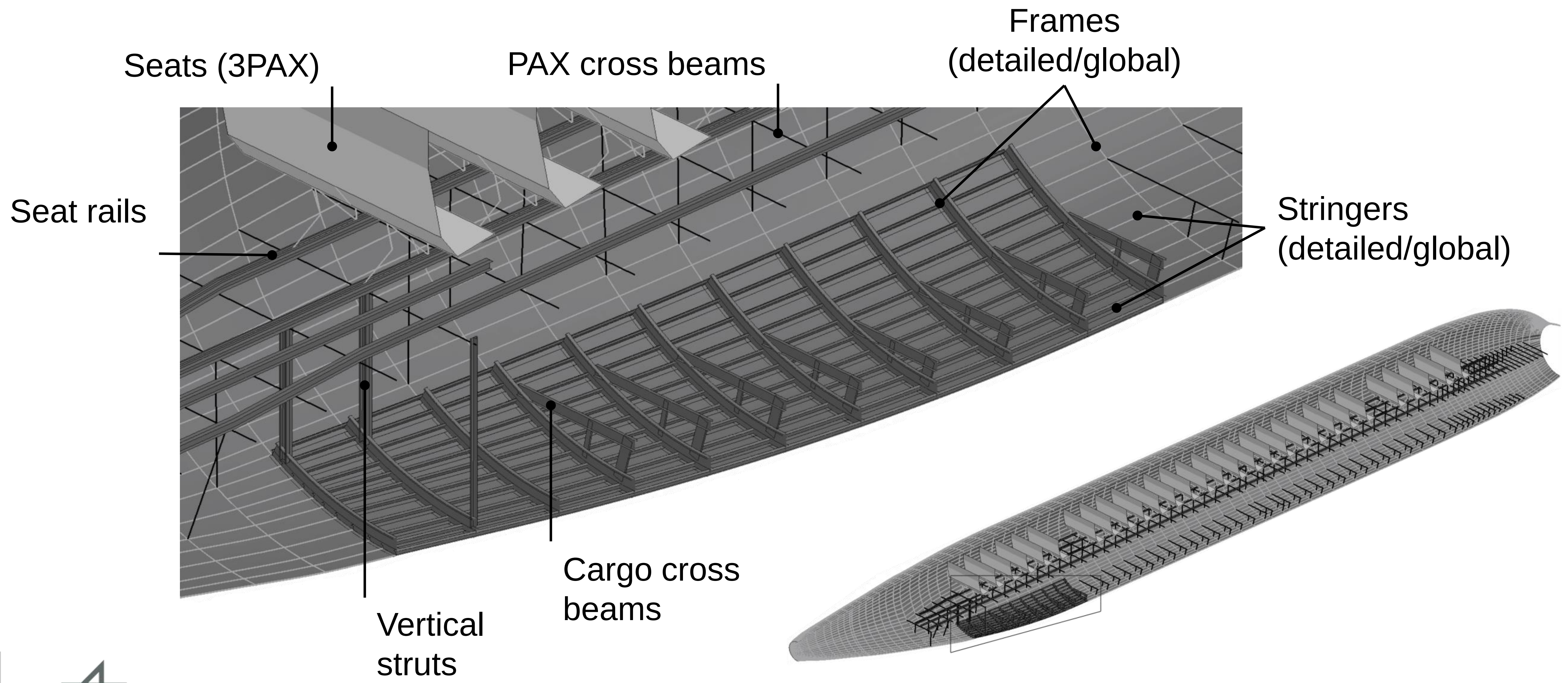
*Rigid Body Model*

*Complexity / Level of detail*



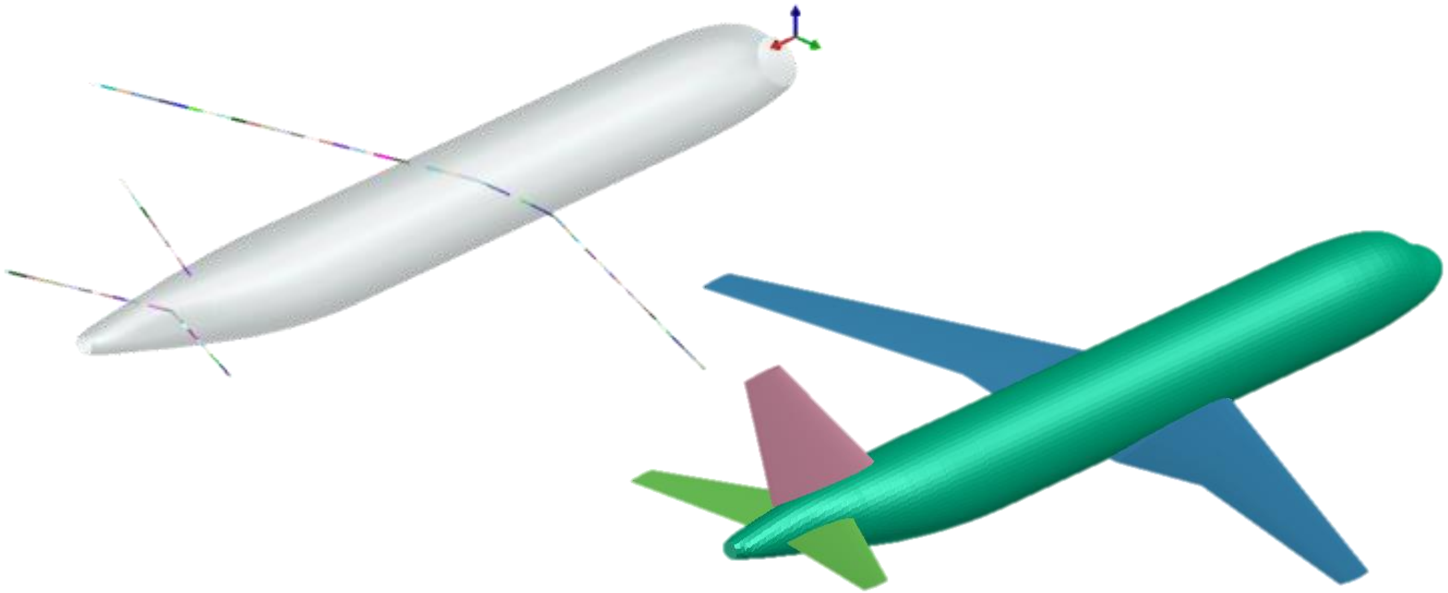


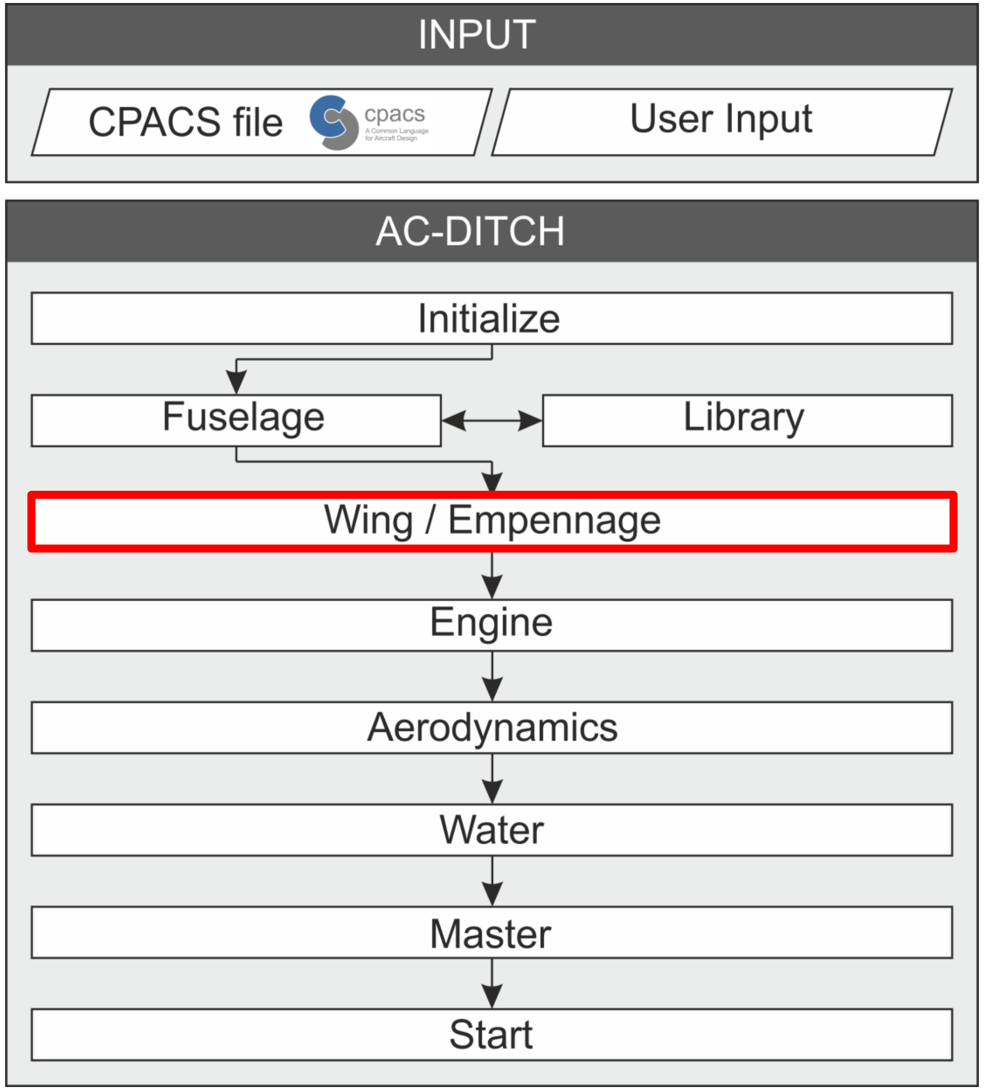
# Fuselage Modeling – DFEM level of detail



# Wing/Empennage Modeling

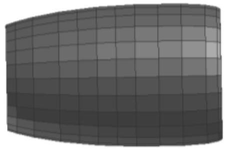
- **Beam** (rigid/elastic) or **shell** (rigid) models



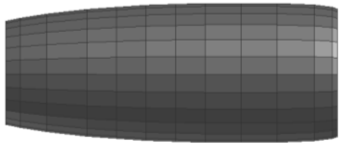


# Engine Modeling

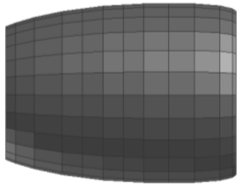
- Settings: number, position, and type of engines, failure load



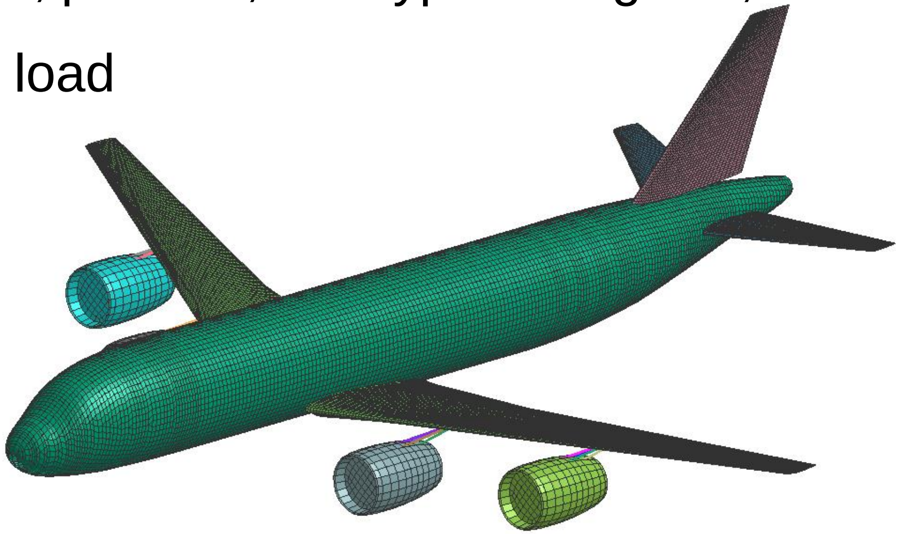
CFM56

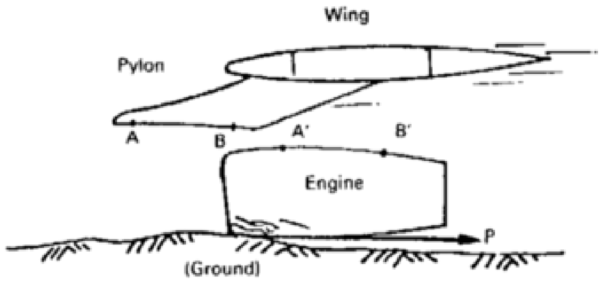


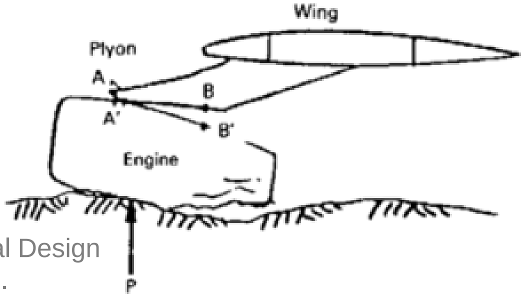
V2500



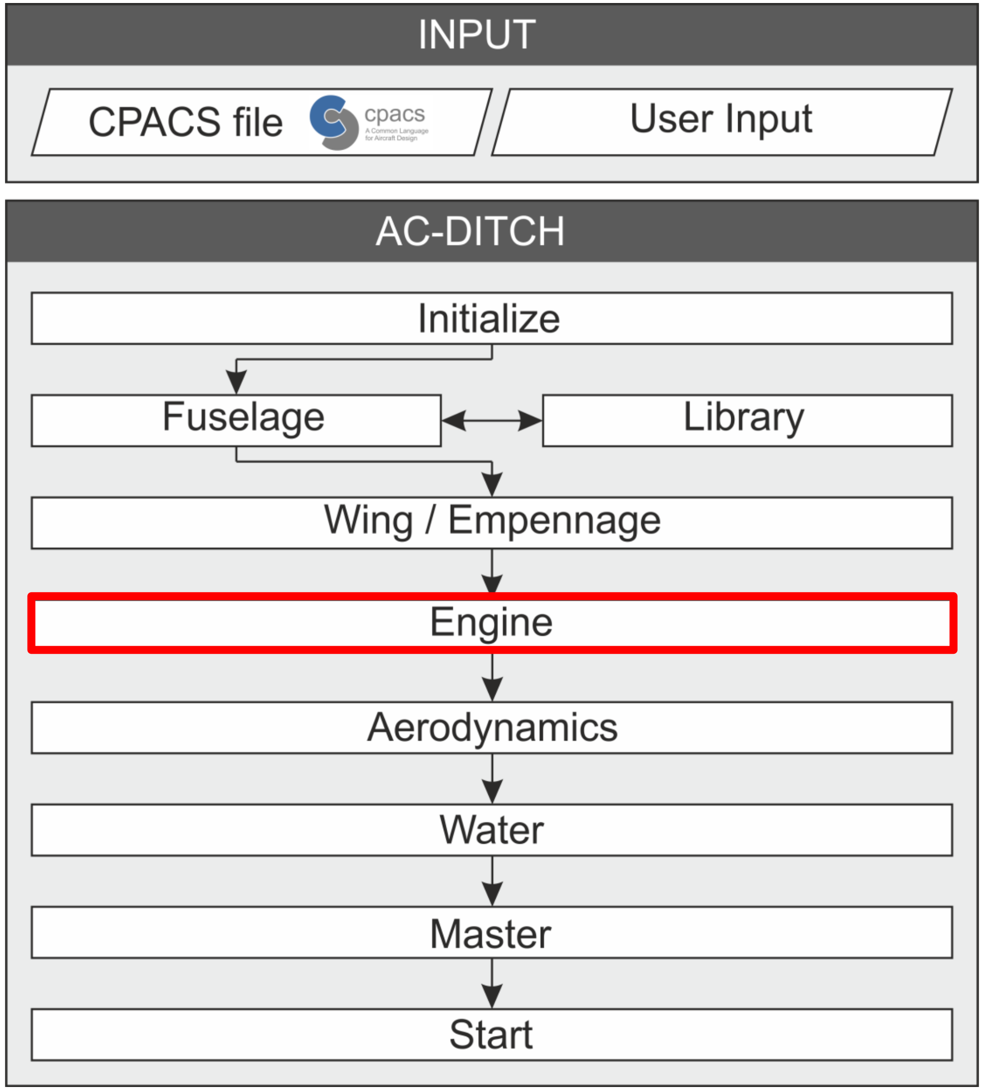
PW1100G





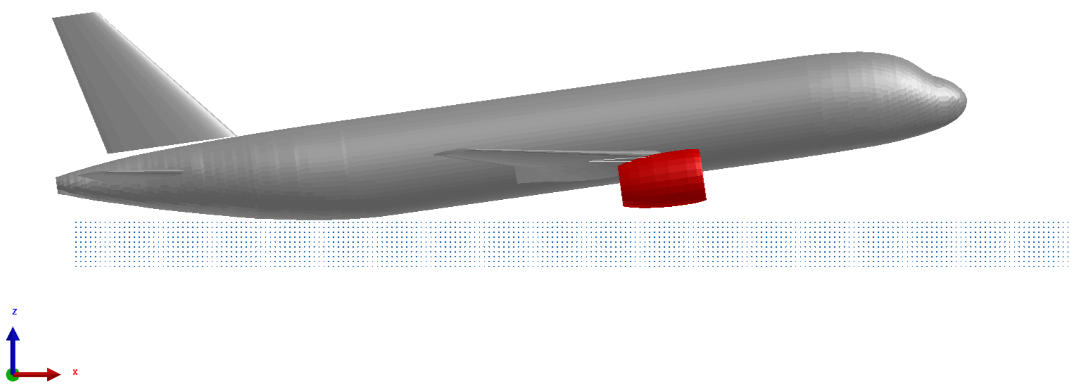



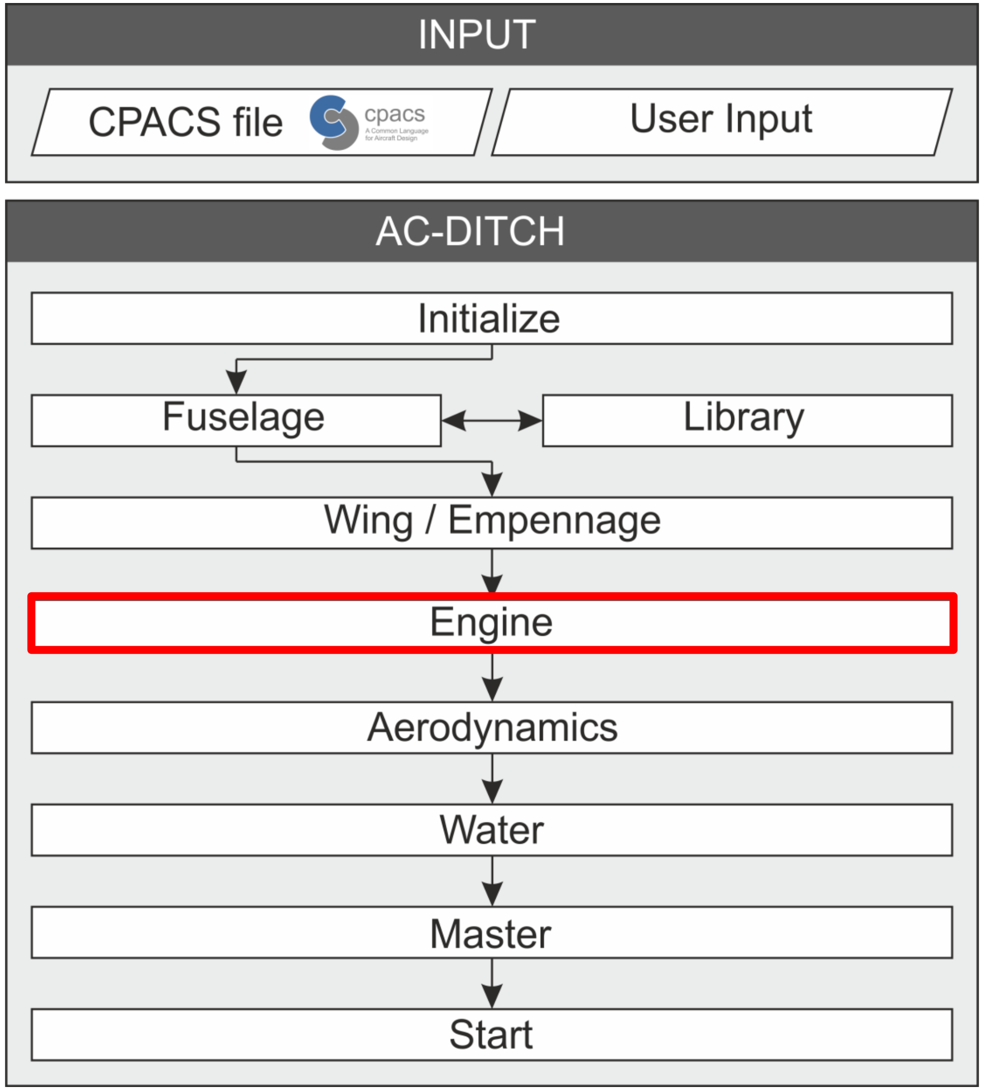

M. C.-Y. Niu. Airframe Structural Design: Practical Design Information and Data on Aircraft Structures, 1988.



# Engine Modeling

- Engine attachment failure due to overload (reference case)



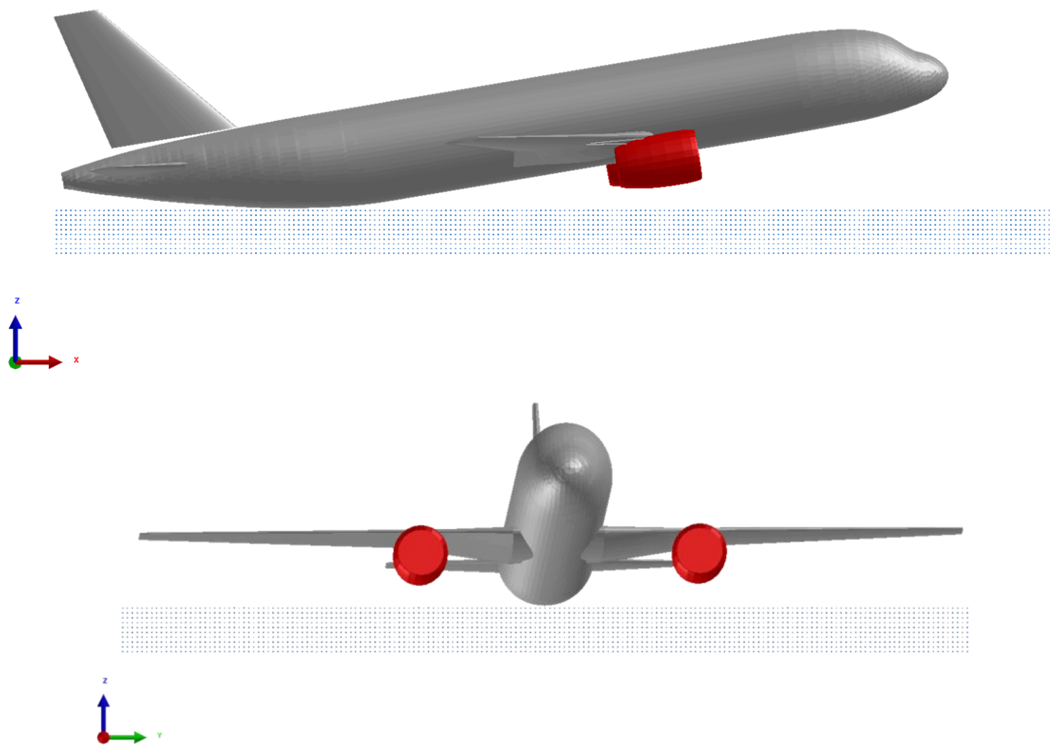


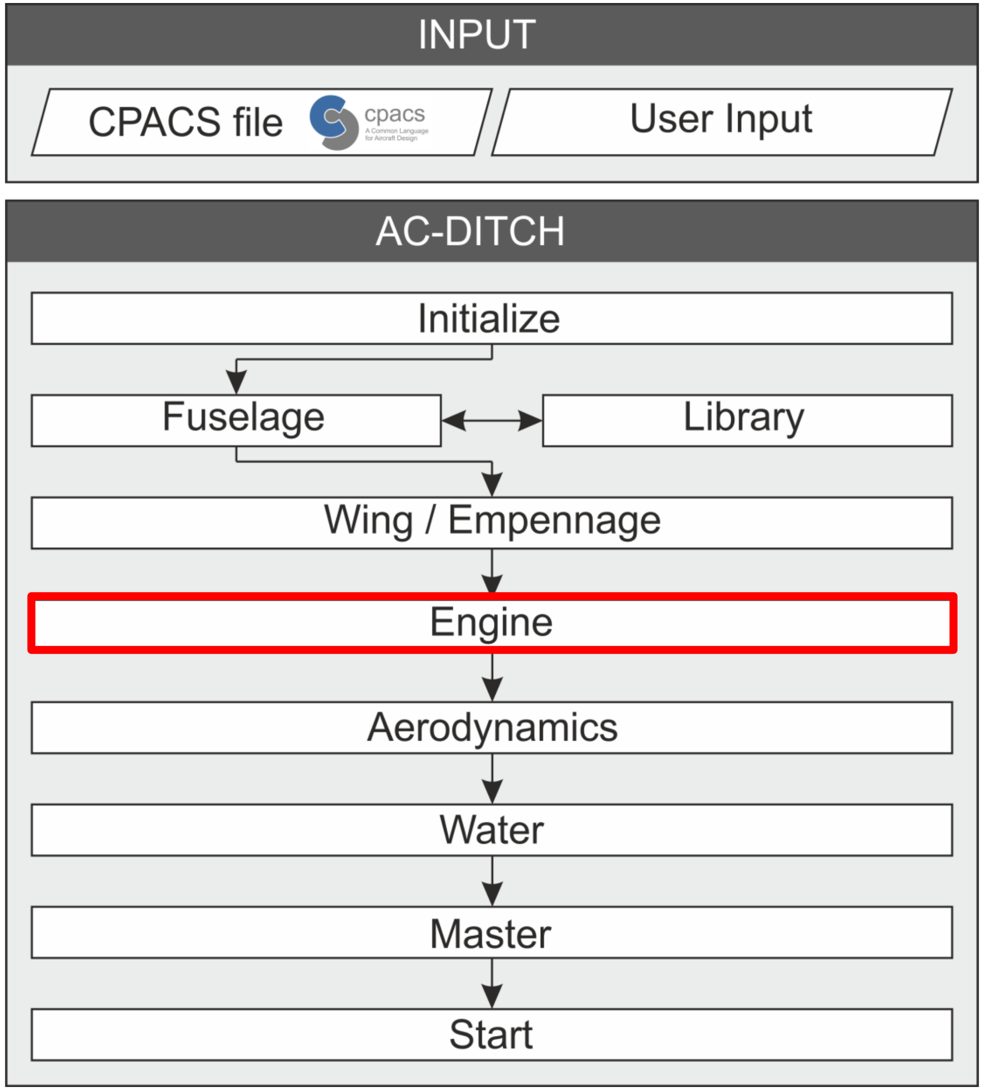


Fluid Volume Elements hidden for clarity

# Engine Modeling

- Unsymmetrical load case (Hudson impact conditions)



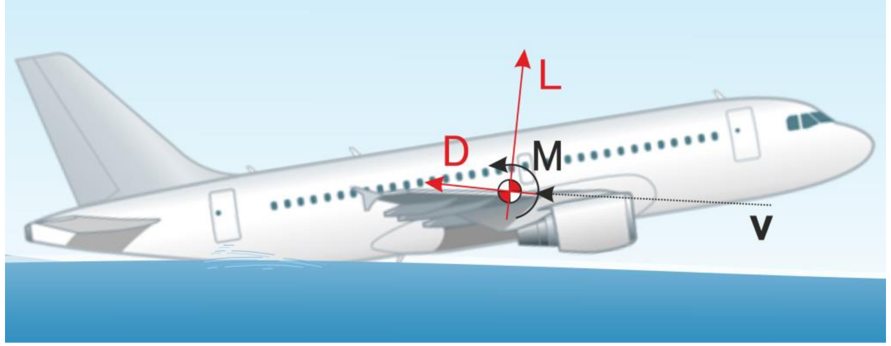




Fluid Volume Elements hidden for clarity

# Aerodynamic Modeling

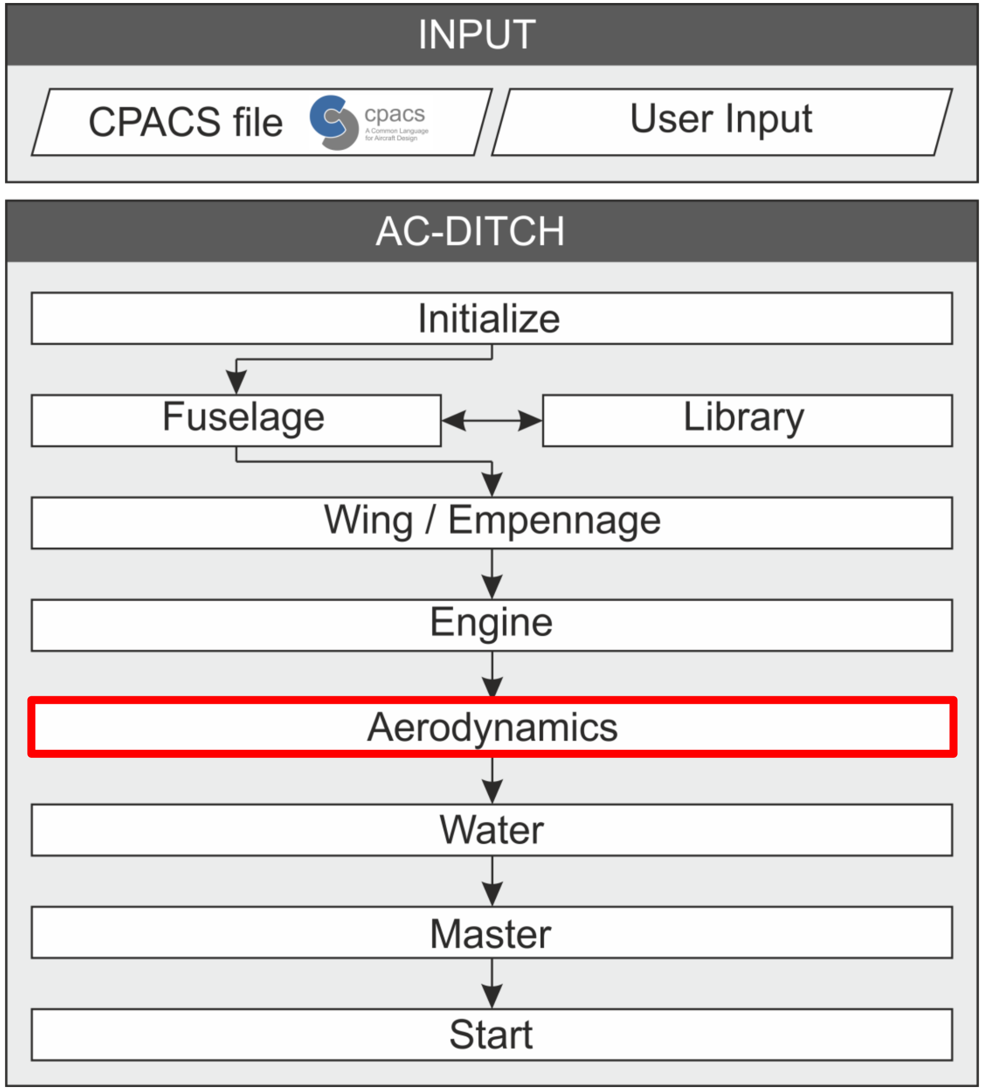
- Simple aerodynamics model




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

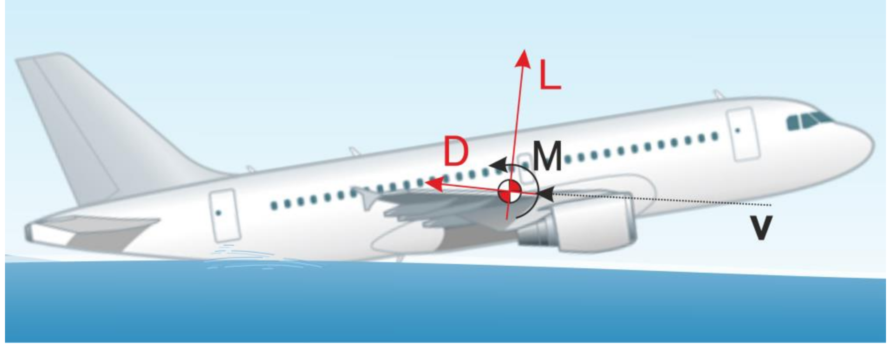
$$D = \frac{\rho}{2} S C_D v^2$$

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



# Aerodynamic Modeling

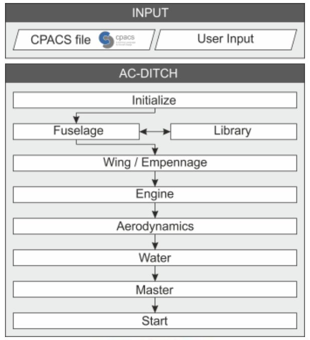
- Simple aerodynamics model




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

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

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

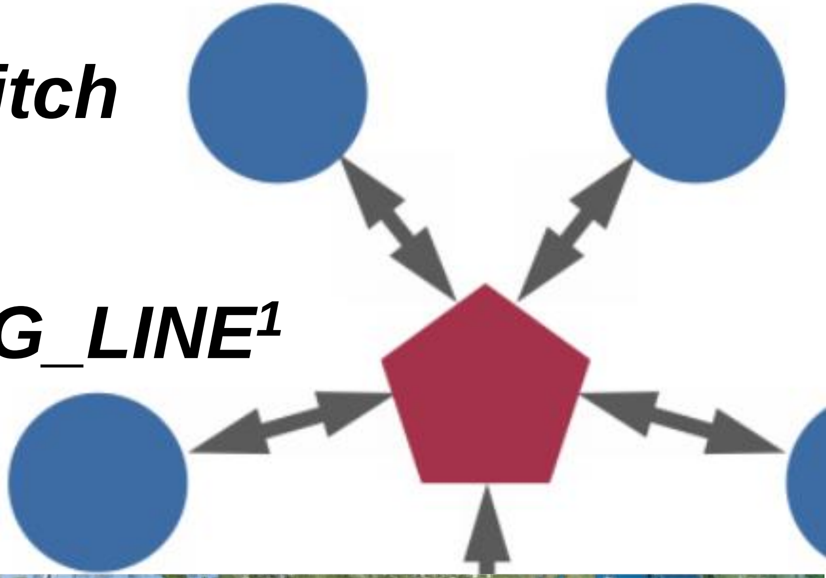



- Fully coupled with CPACS data set

- Aerodynamic coefficients provided by aerodynamics specialists (aerodynamics pre-design tools)

***AC-Ditch***

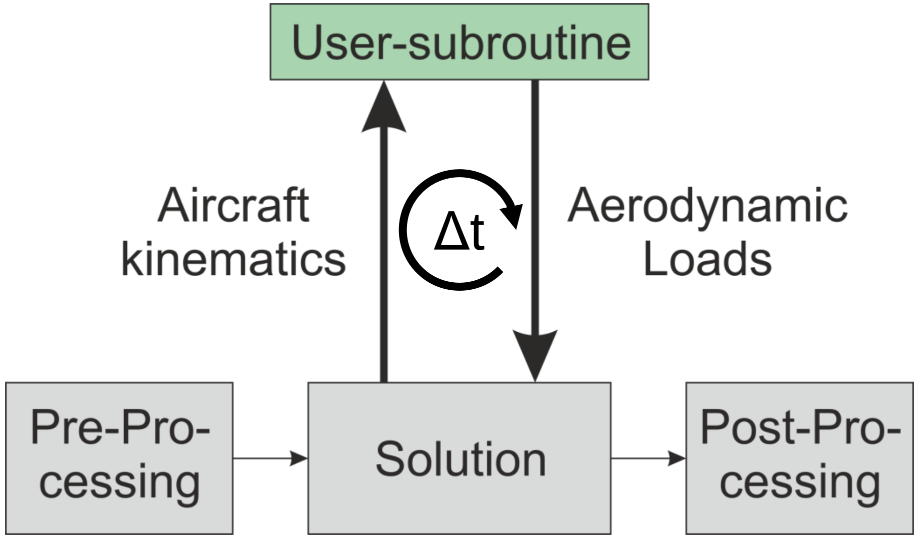
***LIFTING_LINE[1]***

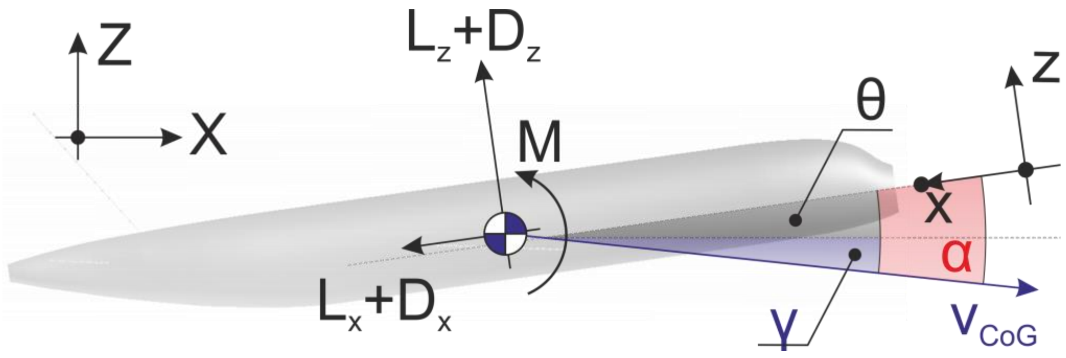


[1] LIFTING_LINE uses multi lifting line method

# Aerodynamic Modeling

- Coupling of aircraft motion and aerodynamic loads
  → user-subroutine

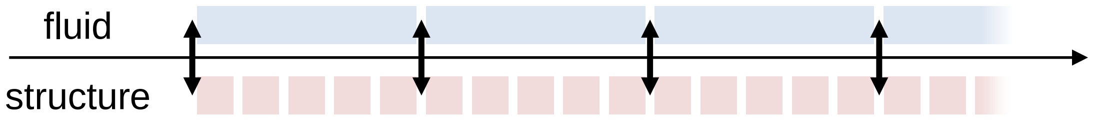


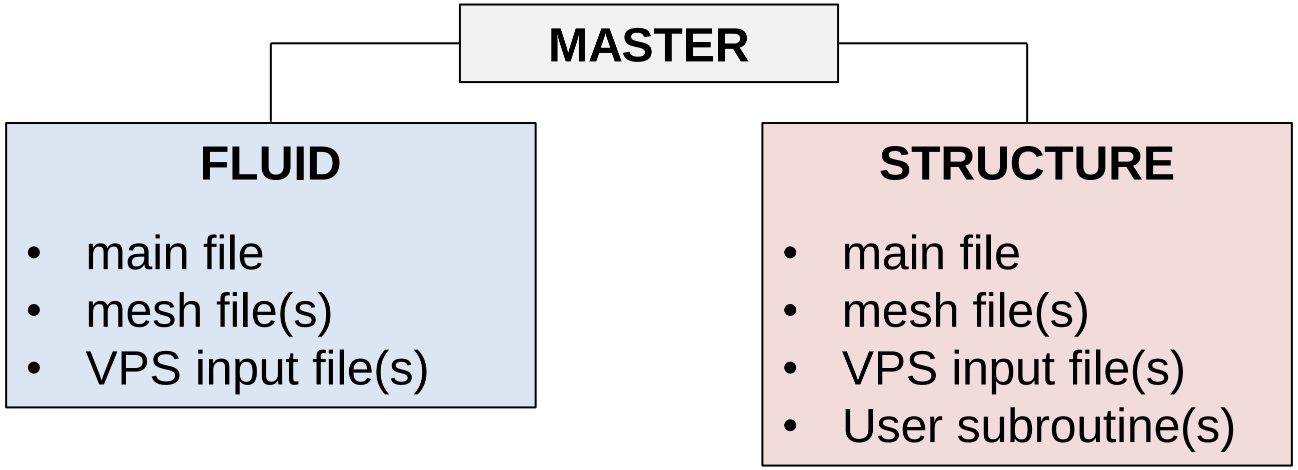

**→ Improved predictability (more realistic flight mechanics)**

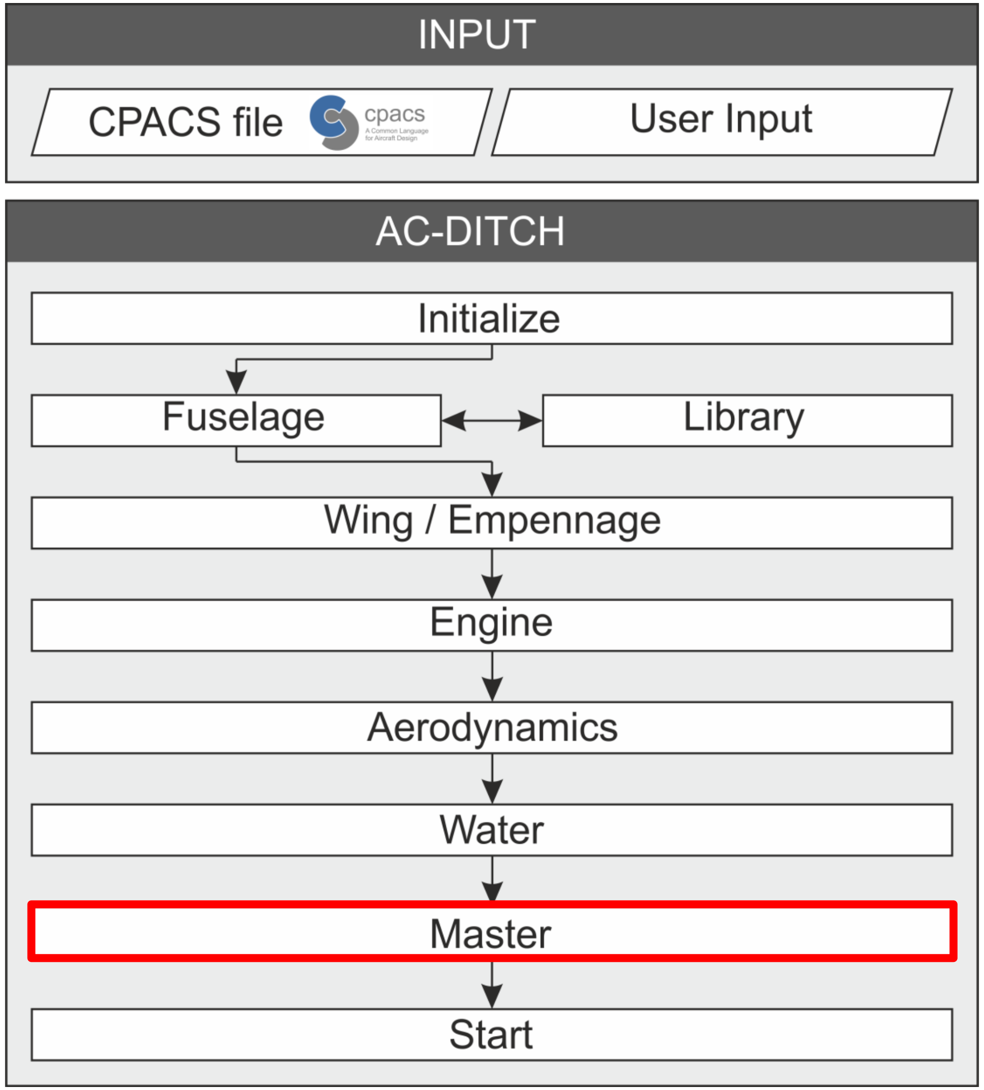
# Multi-Model Coupling

- Co-simulation with different time steps



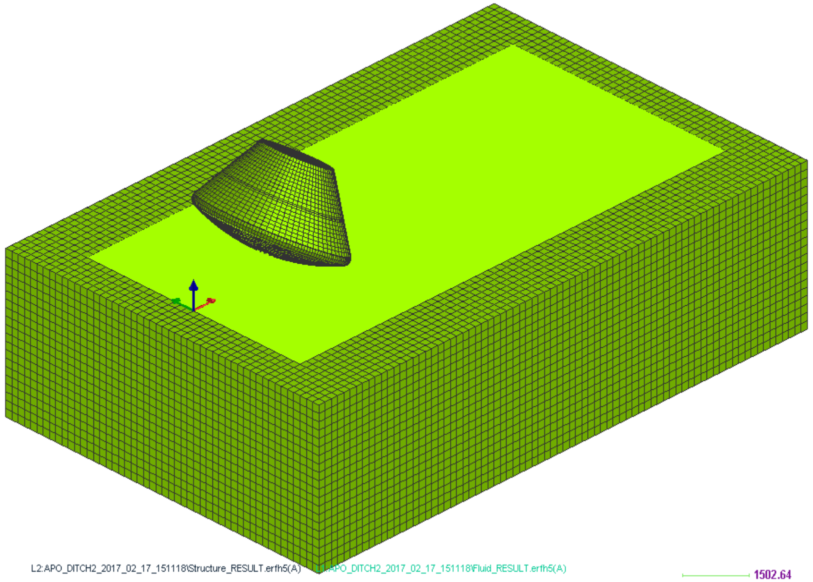

- VPS model setup

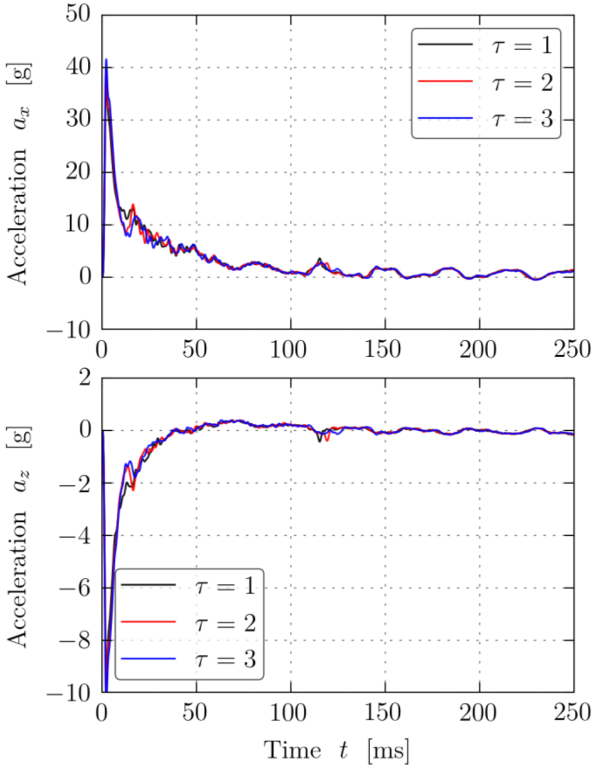


# Multi-Model Coupling – Validation

- Apollo command module water impact experiments (NACA, 1959-1968) used for validation
- Quasi-identical results for standard and MMC simulations with time step ratios up to 3 (depending on the fluid domain resolution)

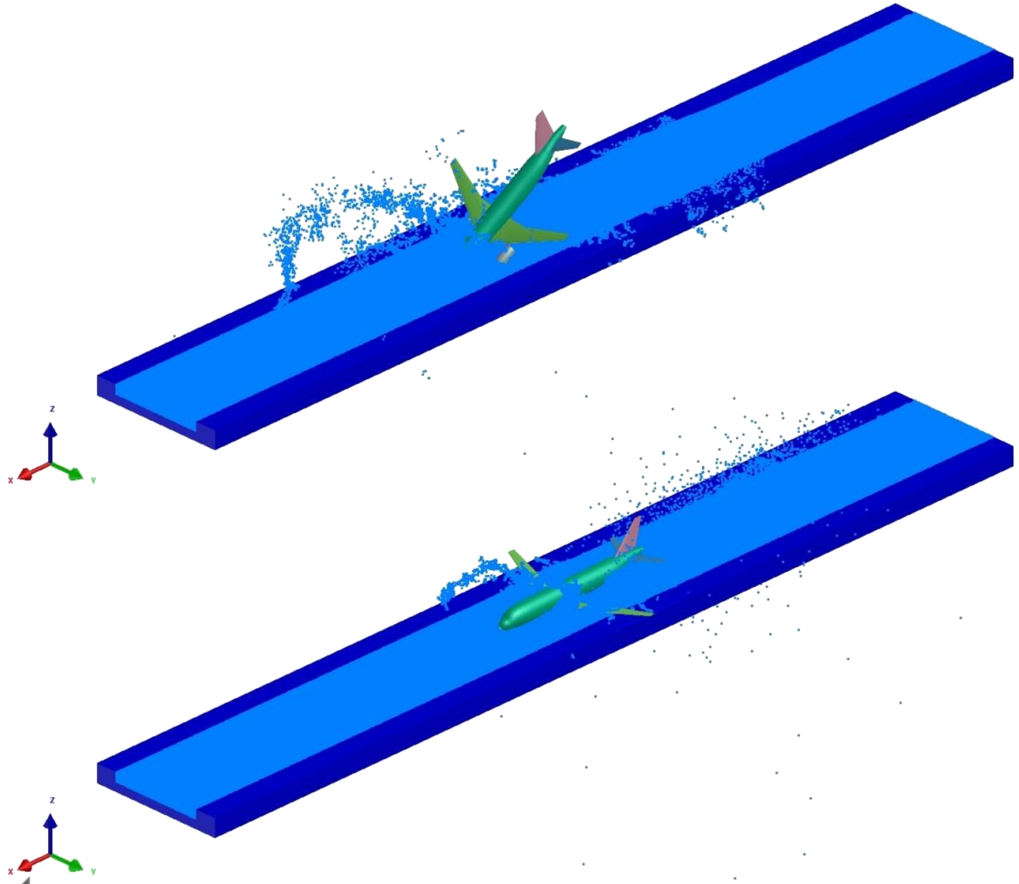


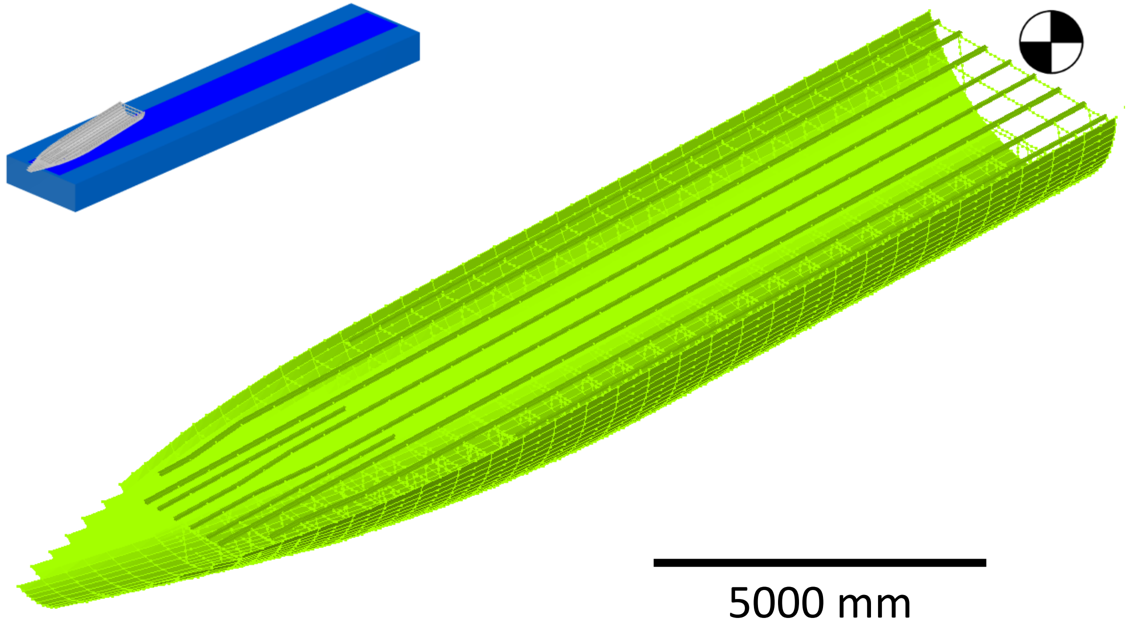

- Validation for deformable structures (GDS) ongoing

# Simulation Results

- Rigid body model (RBM)



- Deformable global FE sub-model (GFEM)



Guided Ditching Experiment

Simulation Approach and Models

Full Aircraft Ditching

# Conclusion and Outlook

# Conclusion

1. **Fundamental knowledge about structural response** under characteristic ditching loads established (experimental & numerical)

   → **Structural deformations significantly increase hydrodynamic loads** during water impact at ditching conditions

2. **Coupled simulation approach** for **analysis of structural response** developed, validated, and assessed based on simple structures and applied to generic lower fuselage panels

   → **Detailed investigation and assessment of structural response became possible**

3. **Full flexible aircraft ditching simulation capabilities largely developed**

   → **Virtual analysis and design of full flexible aircraft ditching is around the corner**

- The application of **coupled numerical approaches** is recommended for an **accurate analysis of the structural behavior** under ditching loads

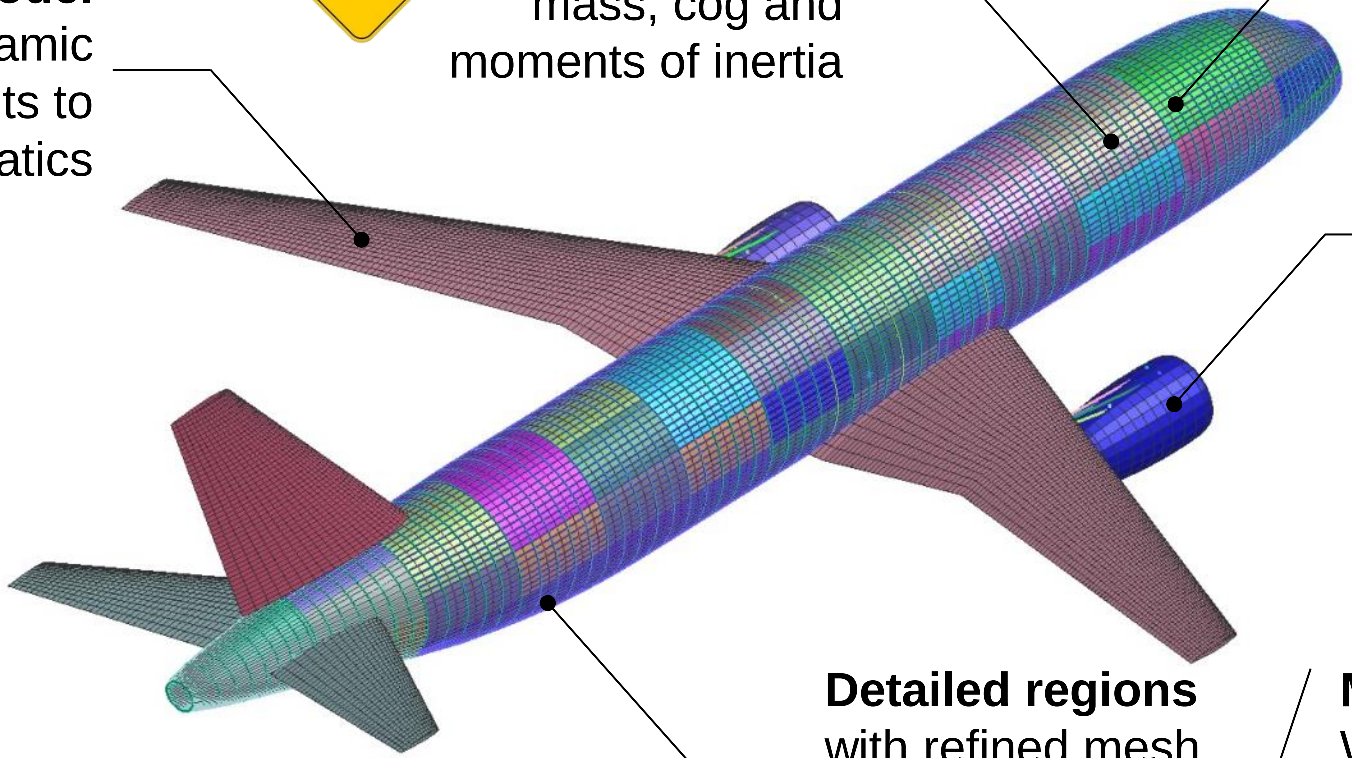
# Conclusion

**Aerodynamic model** coupling aerodynamic forces/moments to aircraft kinematics

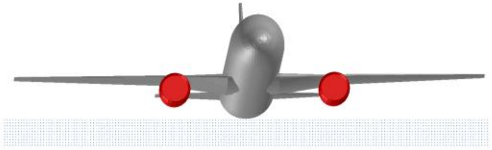
WORK IN PROGRESS

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

**Generic transport aircraft mesh** (parametric model, statically sized)



**Engine model** with potential failure of attachment upon overload




**HPC & MMC**

WORK IN PROGRESS


**Detailed regions** with refined mesh accounting for local deformations

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

WORK IN PROGRESS

# Thank you for your attention!

## Ditching Simulation of Large Complex Aircraft Models

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