Numerical and Experimental Investigation of the Structural Behavior during Aircraft Emergency Landing on Water

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Institute of Structures and Design

Note that all work presented herein has been performed at the German Aerospace Center (DLR).

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Hamburg, 20 Feb 2024

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

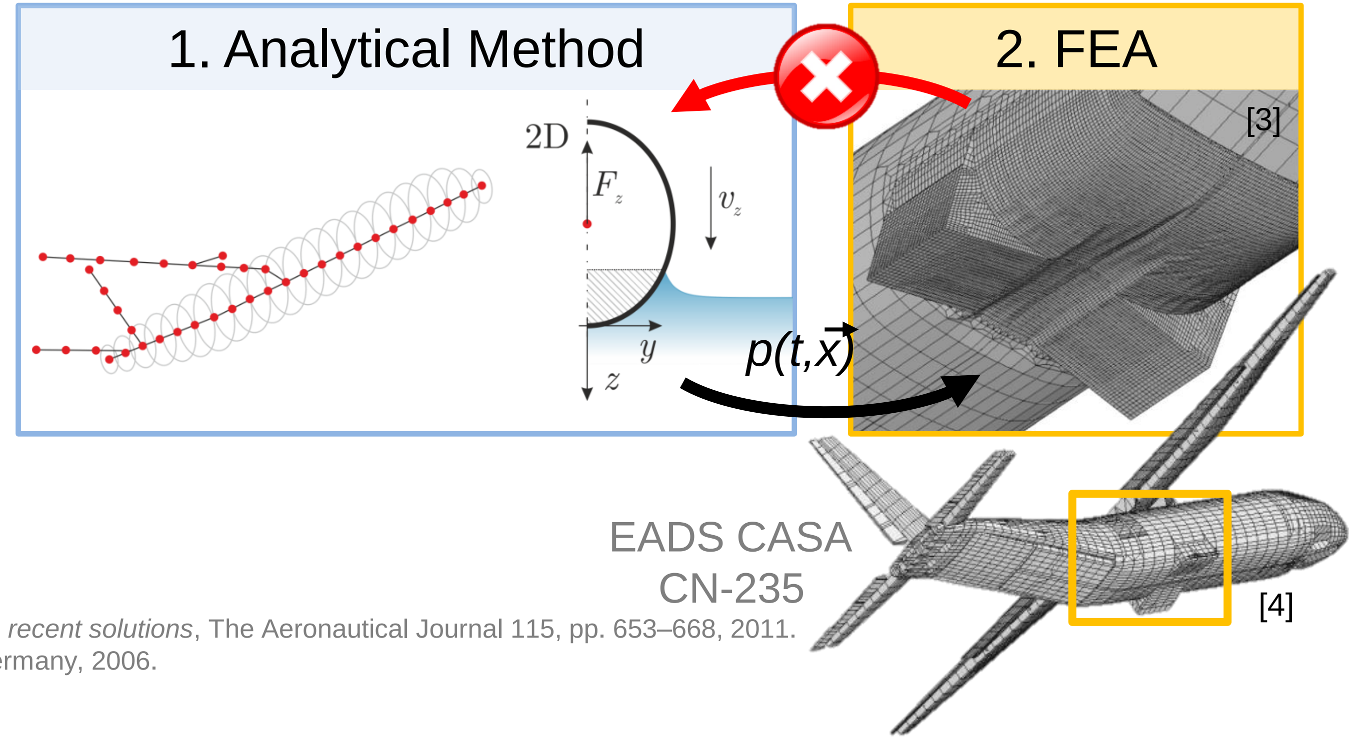
1. **Comparison with A/C of similar design that were proven to satisfy ditching regulations**

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

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

3. **Uncoupled numerical analyzes**

No Coupling

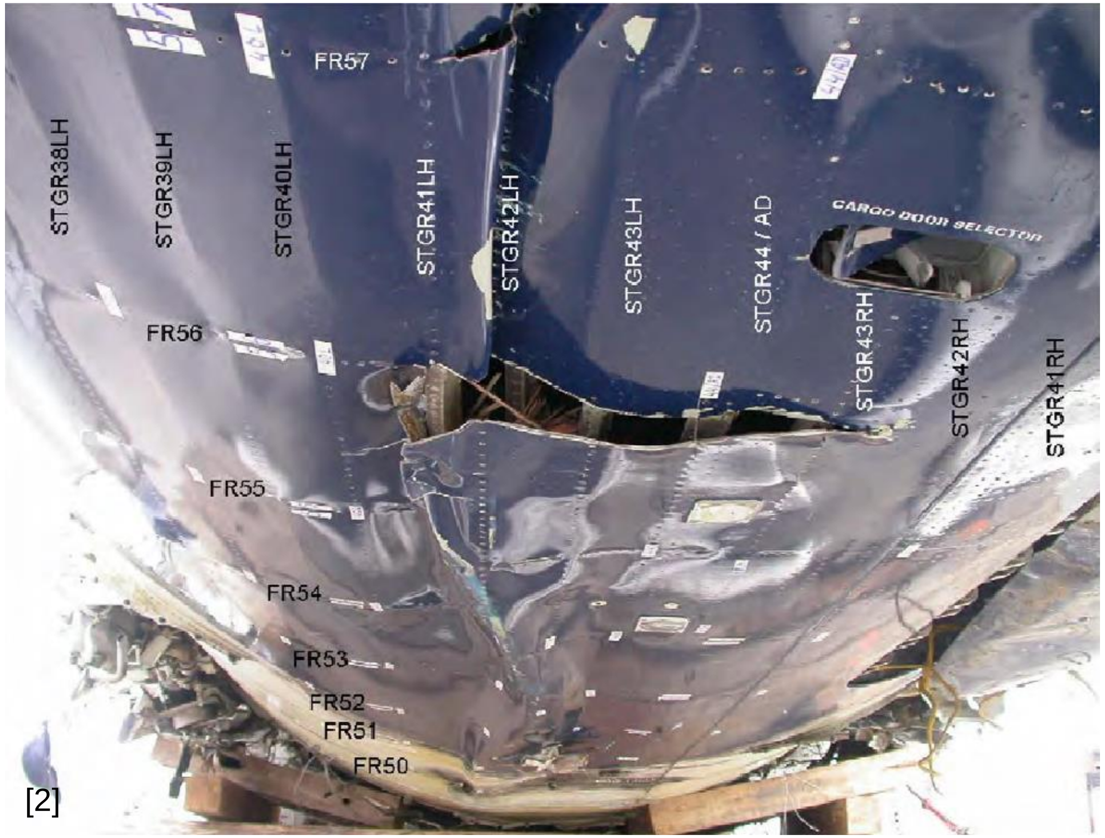


[3] Pérez et al., *Survey of aircraft structural dynamics non-linear problems and some recent solutions*, The Aeronautical Journal 115, pp. 653–668, 2011.
[4] Climent et al., *Aircraft Ditching Numerical Simulation*, in: 25th ICAS, Hamburg, Germany, 2006.

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.

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.

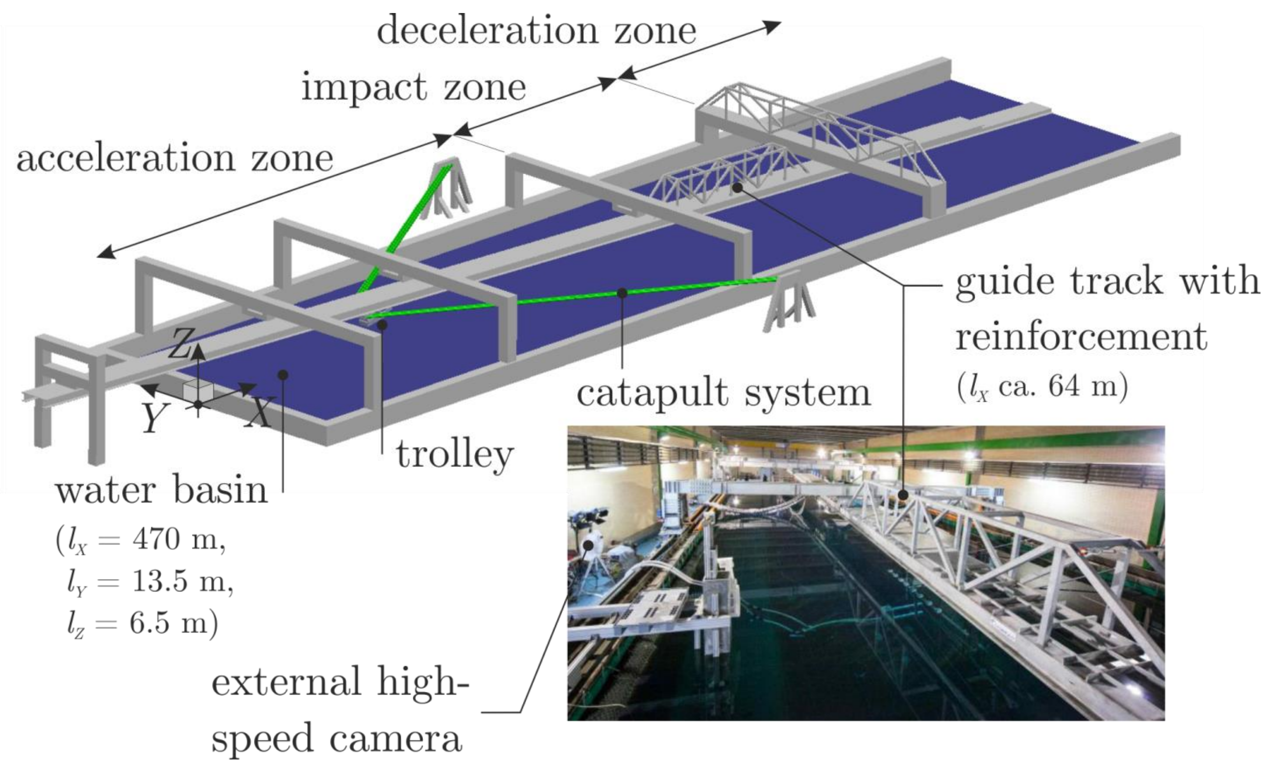
Therefore, they should be taken into account for an **accurate assessment of the structural behavior** through **coupled simulations**.

Can the SPH-FE approach predict the structural response?

Investigated Cases

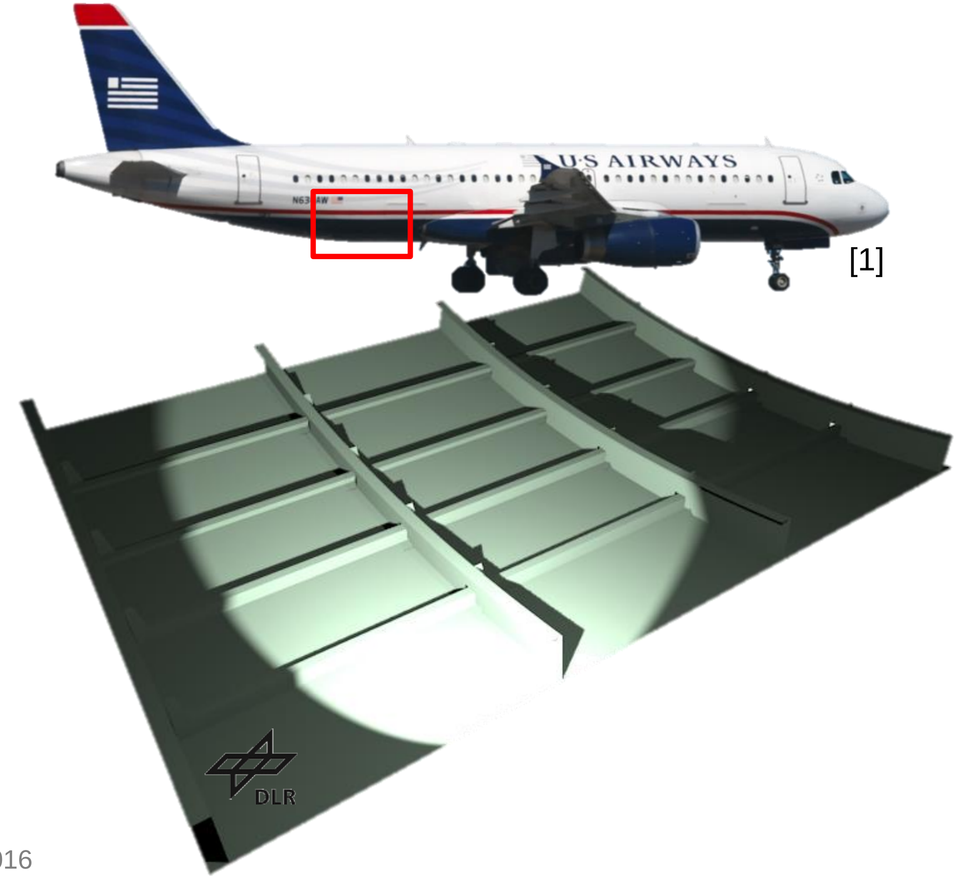
(1) Guided Ditching Experiment (SMAES[1])

→ Fundamental knowledge and validation



(2) Generic lower fuselage panel

→ Transfer toward application



[1] http://img.planespotters.net/media/photos/original/076000/PlanespottersNet_076460.jpg, Accessed 15.06.2016

[1] SMAES = SMart Aircraft in Emergency Situations

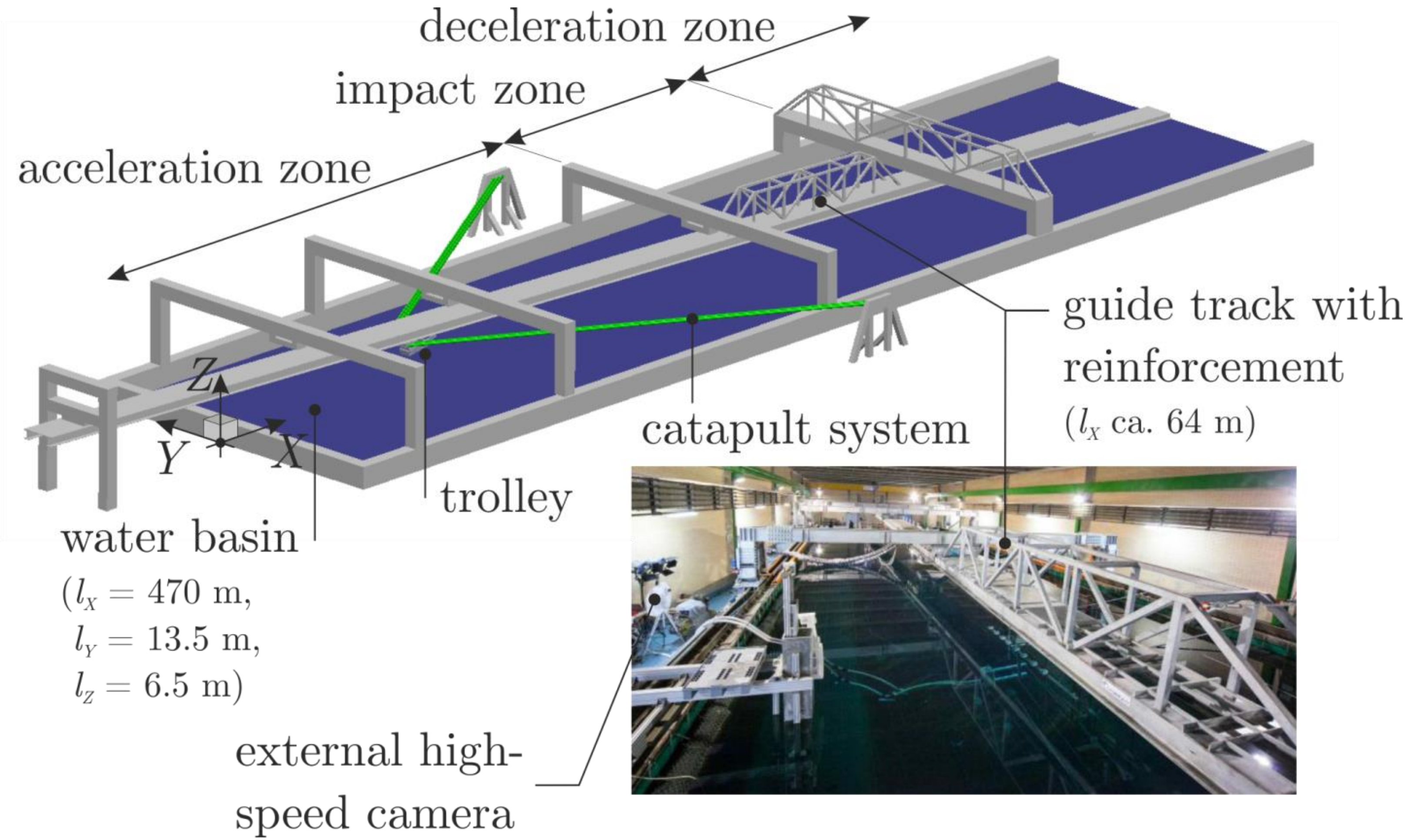
Key Experimental Findings

Simulation Approach and Models

Simulation Results & Analyses

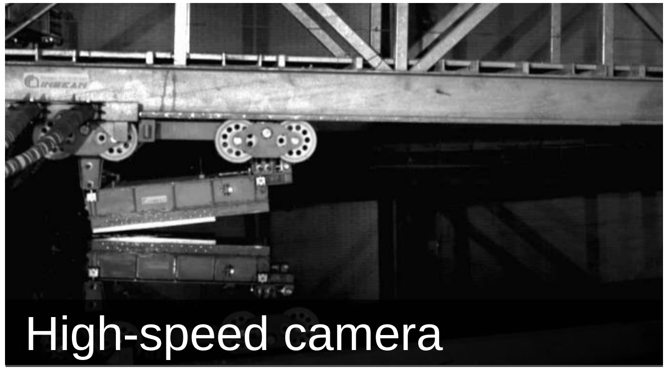
Conclusion and Outlook

Guided Ditching Experiment – Overview

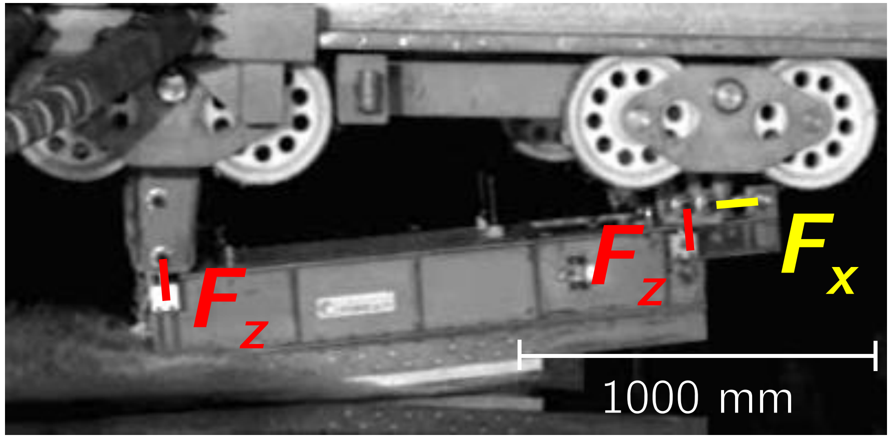


ISTITUTO DI INGEGNERIA DEL MARE
INSTITUTE OF MARINE ENGINEERING

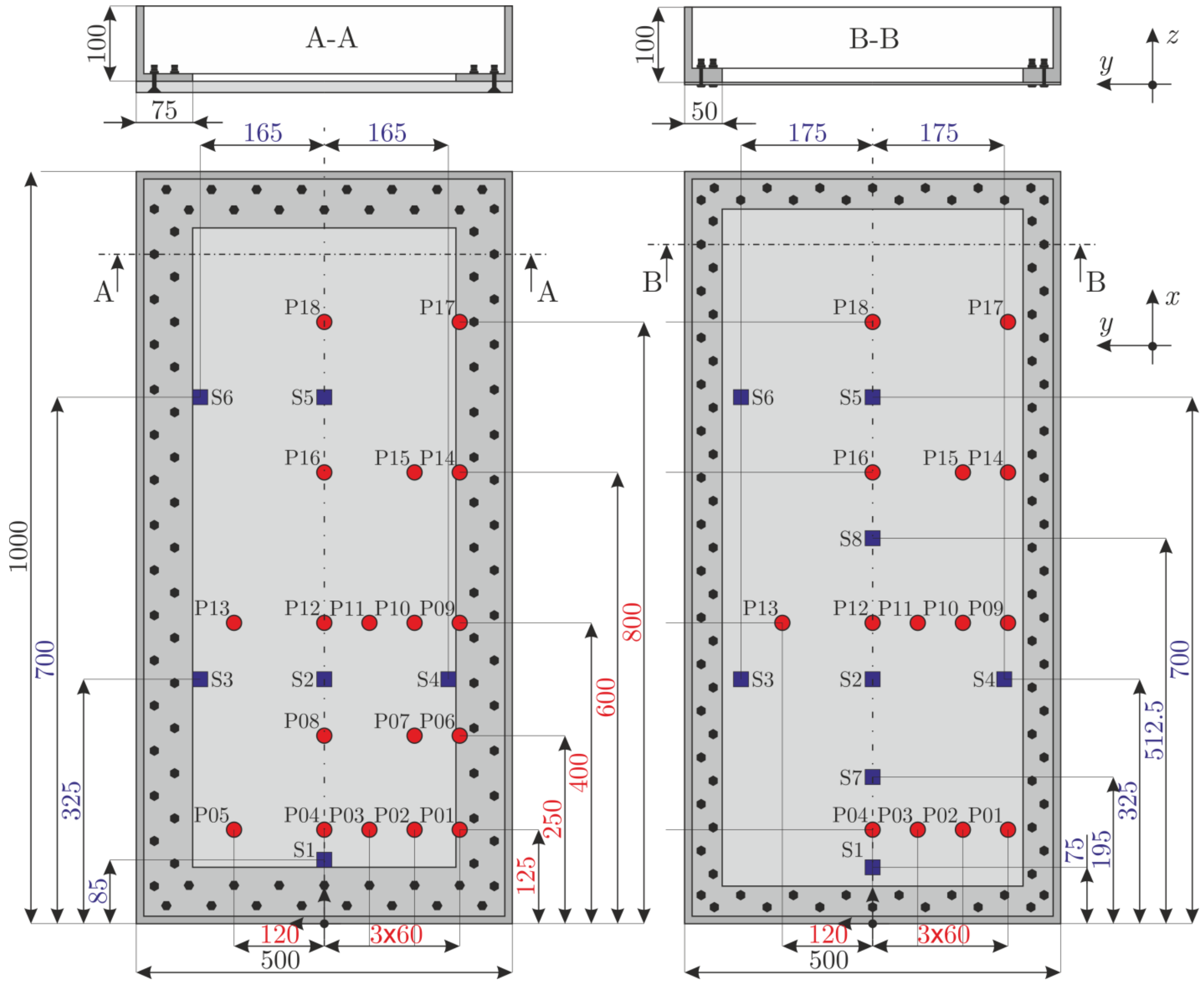

Real-time camera


High-speed camera

Instrumentation

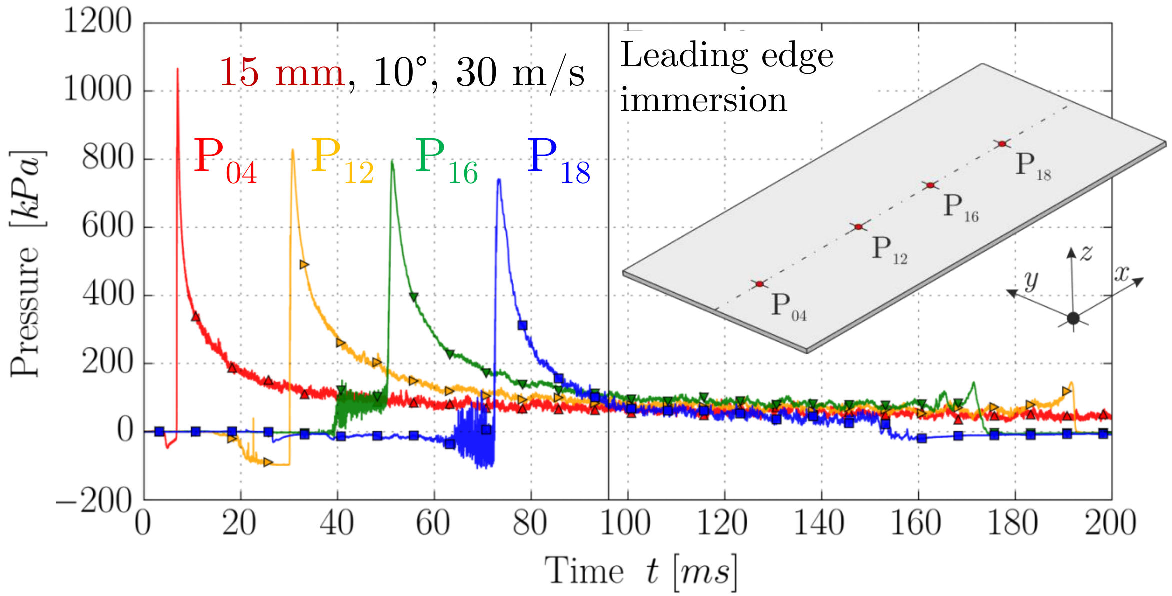


- Accelerations
- Velocity
- Forces
- Pressures
- Strains



Key Findings (Guided Ditching Experiments)

→ Structural deformations significantly affect pressure time histories



– **Lower peak pressures** that are still of short duration, thus, insignificant for structural loading

– More voluminous *p-t* curves → integral p(t) dt larger → **momentum increases**

→ Structural deformations significantly increase hydrodynamic loads

– **Higher normal forces** over complete impact duration

– Distinct normal force peaks prior to leading edge immersion

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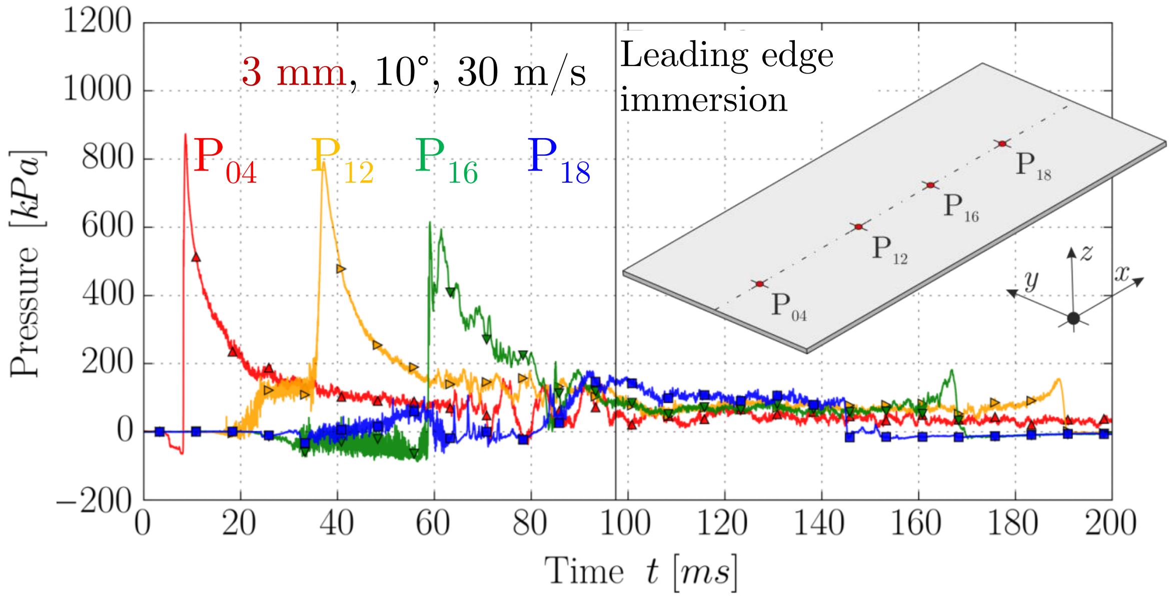

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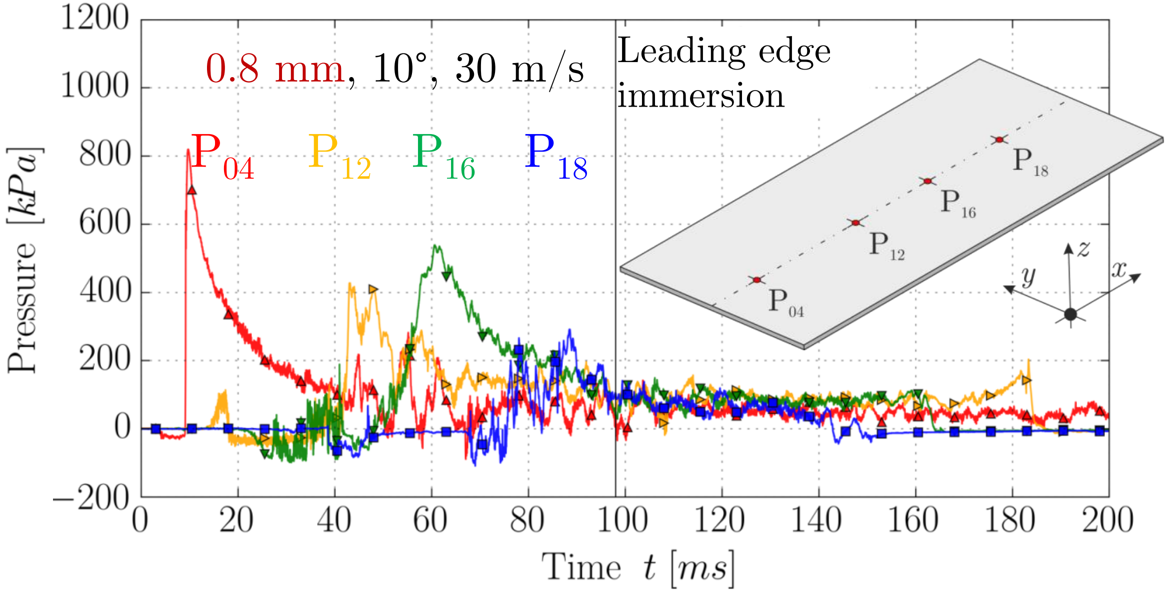

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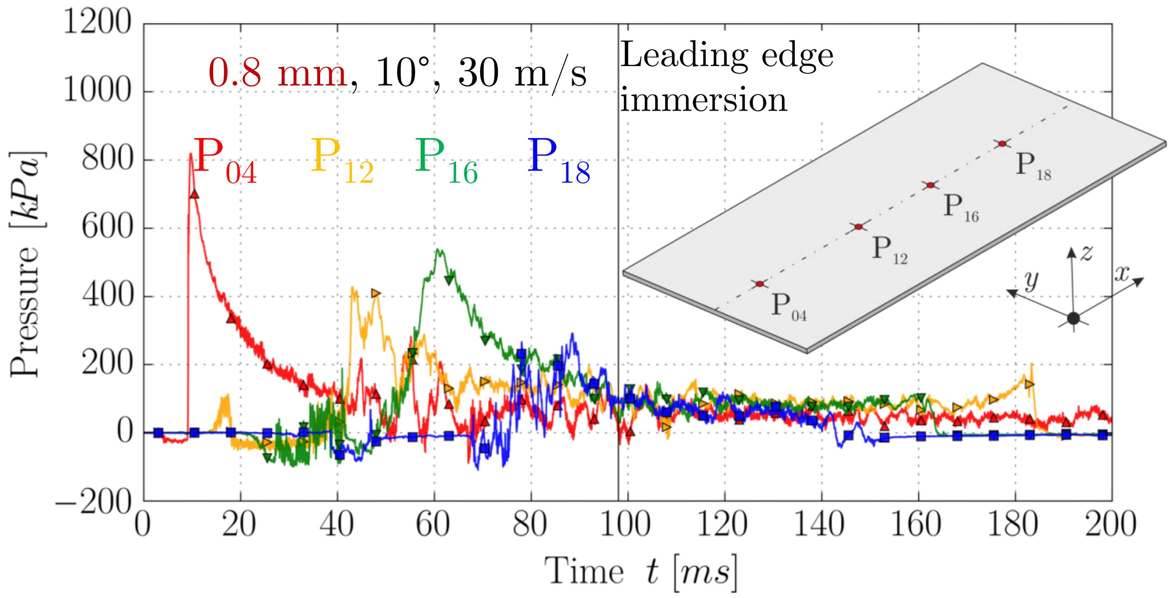

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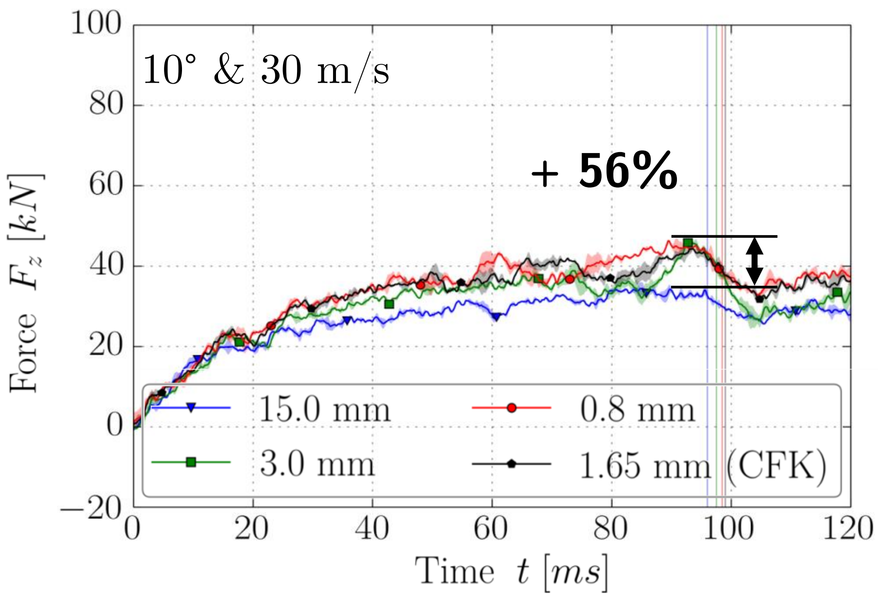

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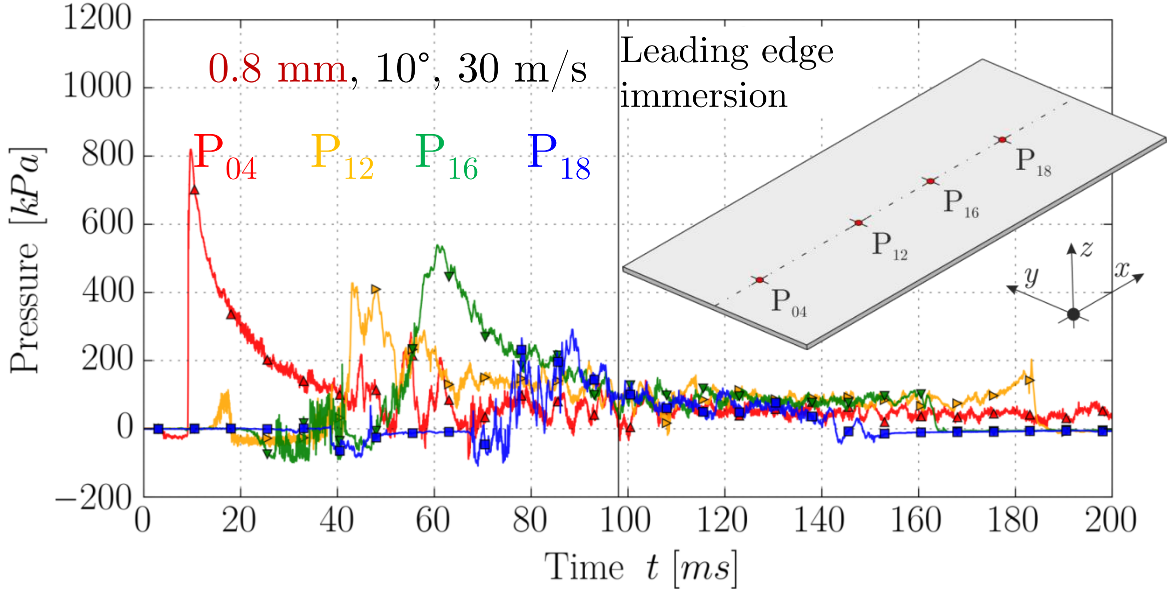

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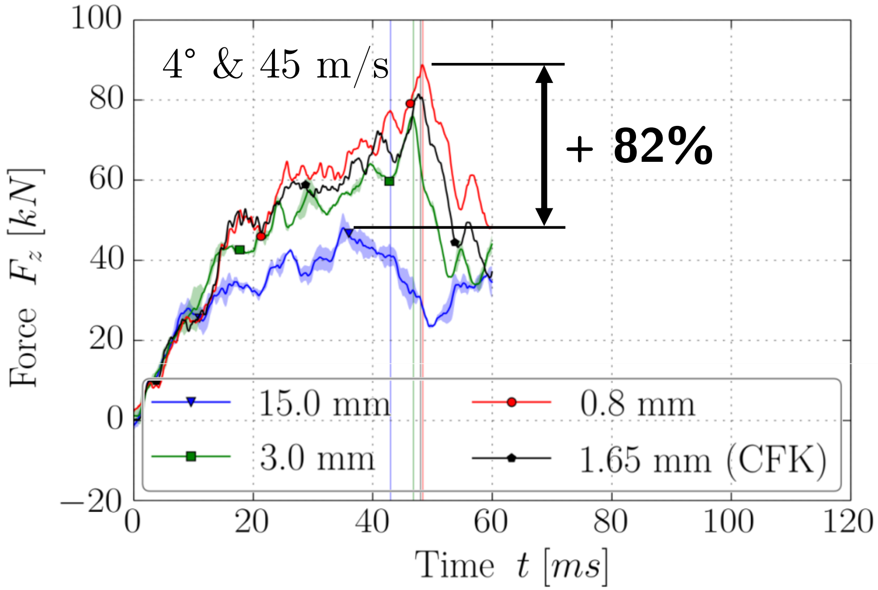

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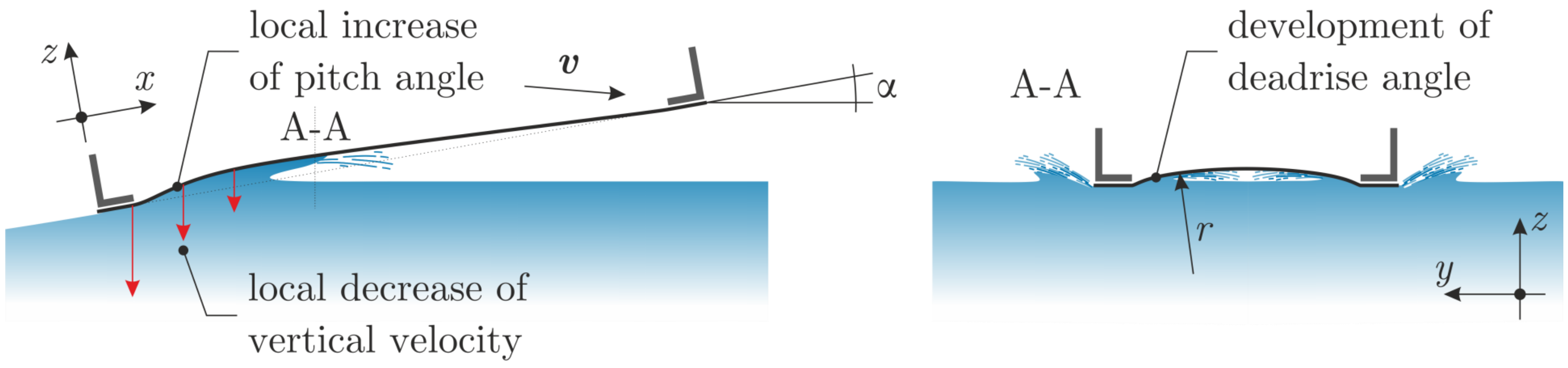
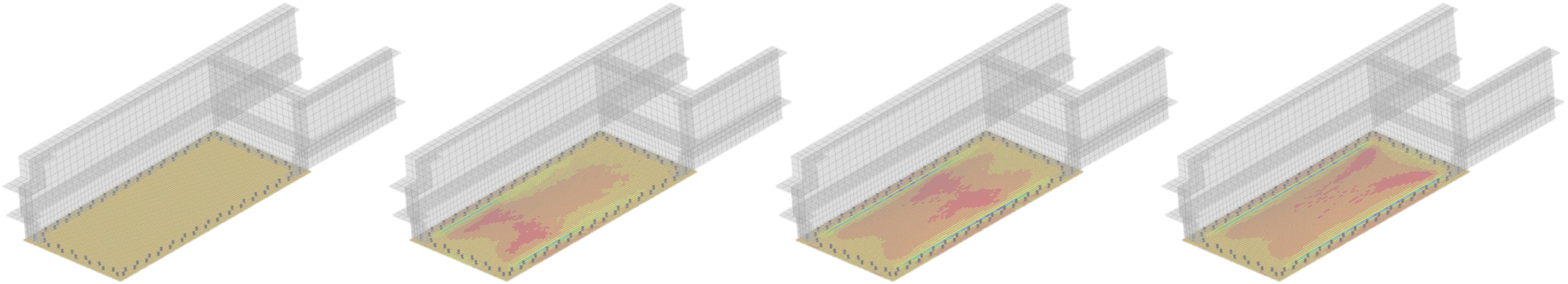
Key Findings (Guided Ditching Experiments)

- Results are qualitatively associated to three **key mechanisms of structural response**



Which mechanisms are the key contributors?



Key Experimental Findings

Simulation Approach and Models

Simulation Results & Analyses

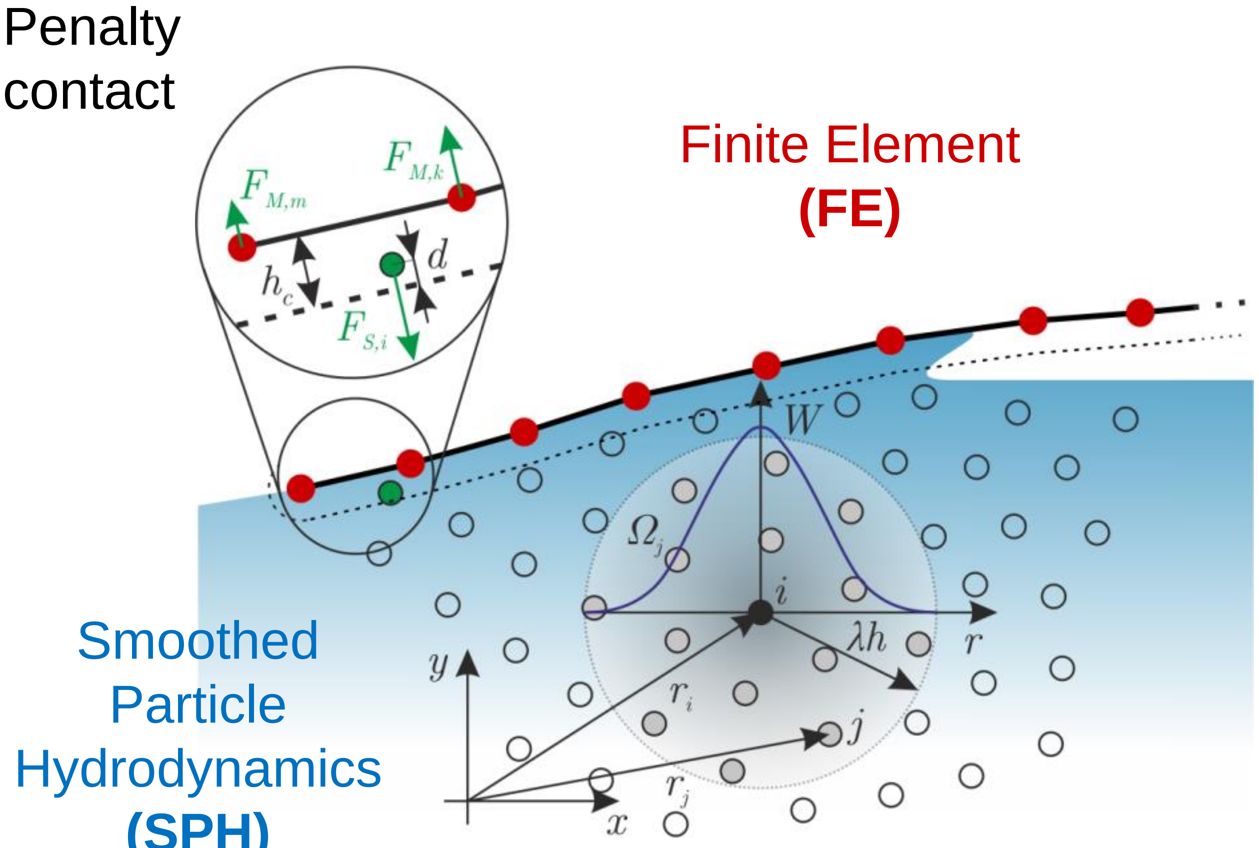
Conclusion and Outlook

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

Investigated Cases

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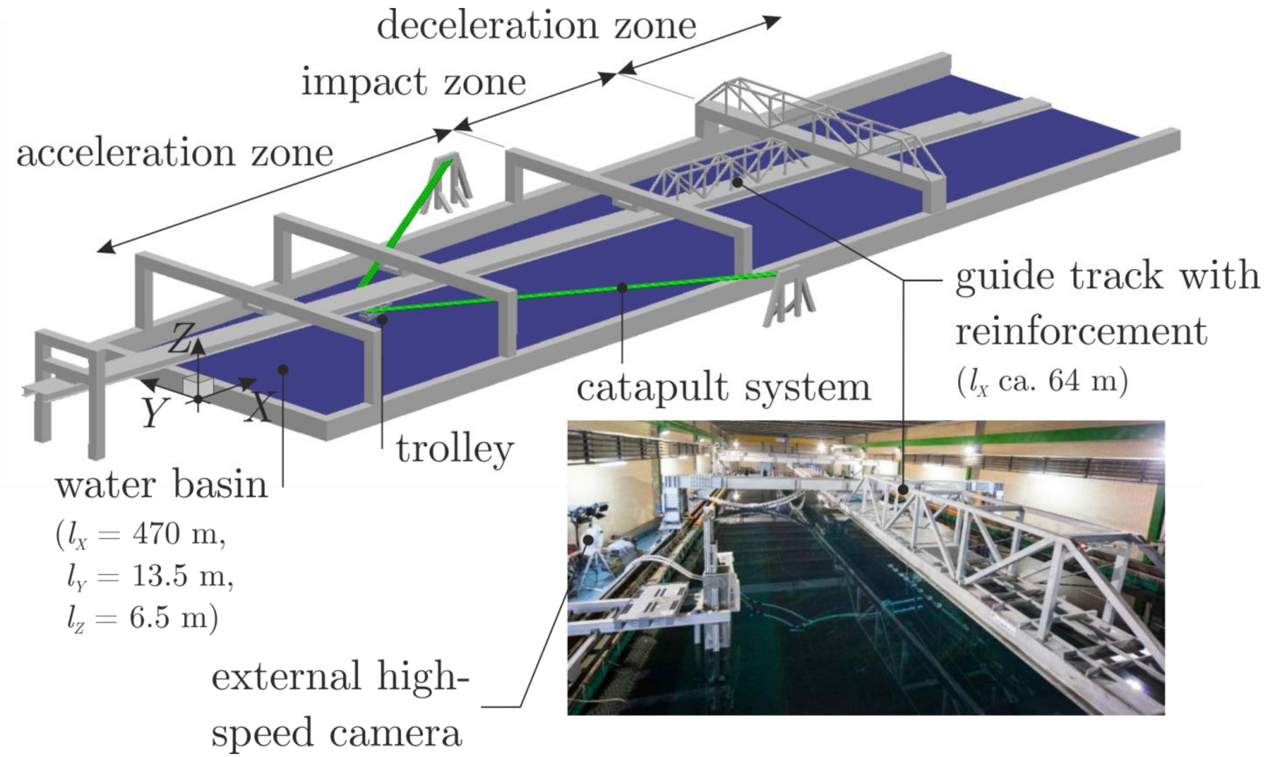
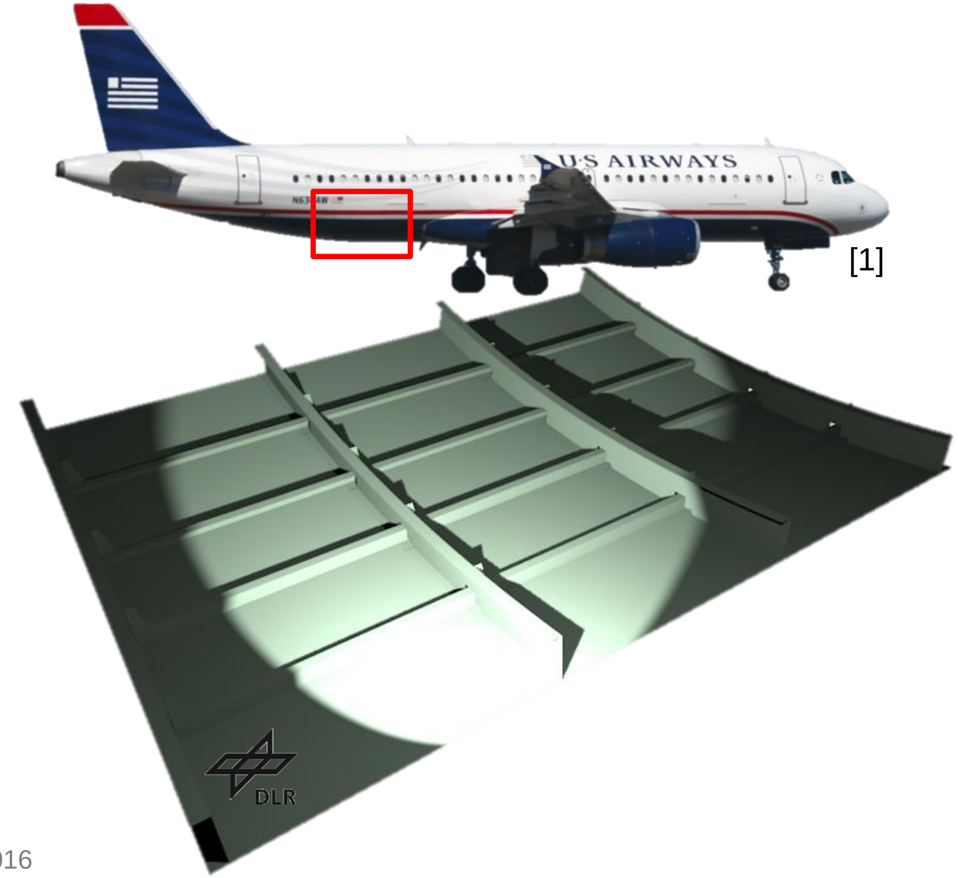


(2) Generic lower fuselage panel

→ Transfer toward application



[1] http://img.planespotters.net/media/photos/original/076000/PlanespottersNet_076460.jpg, Accessed 15.06.2016

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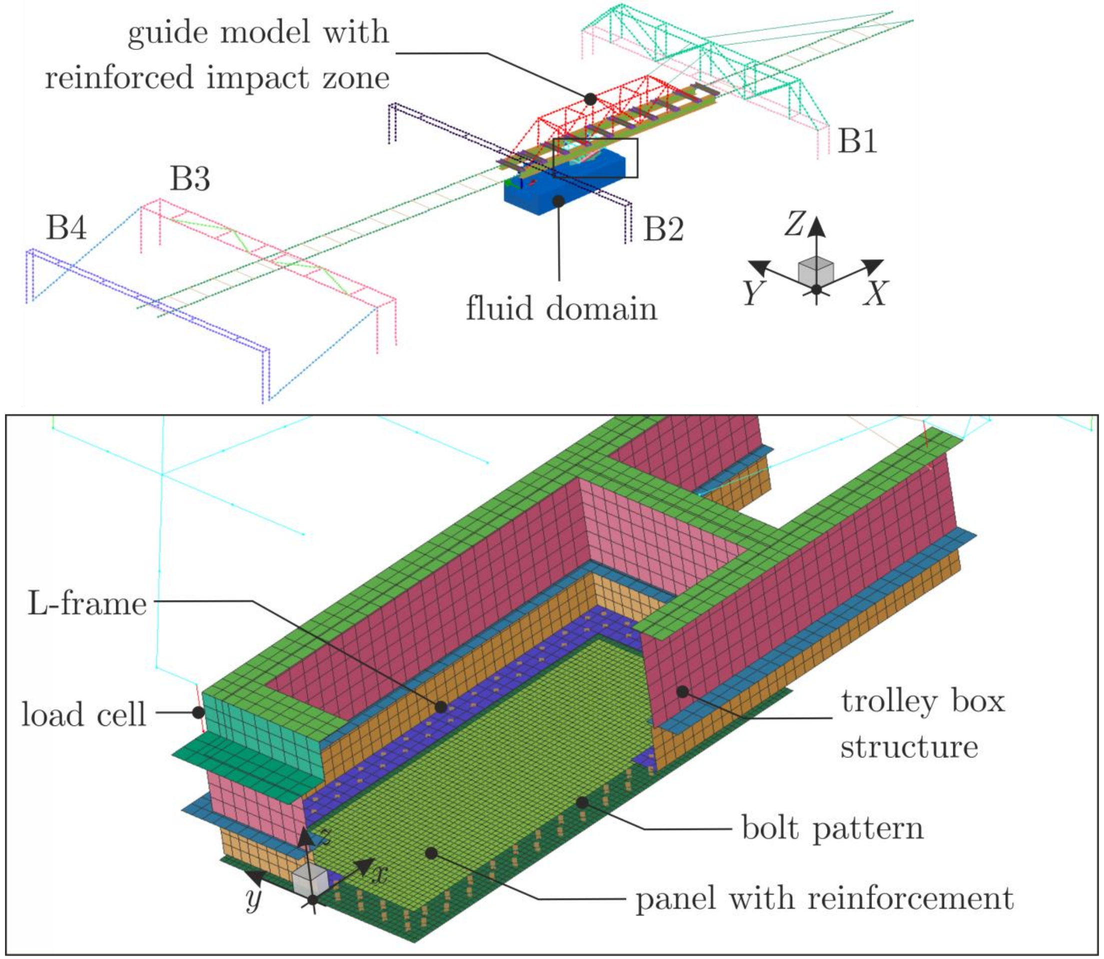
Structural Models

(1) Guided Ditching Experiment (SMAES[1])



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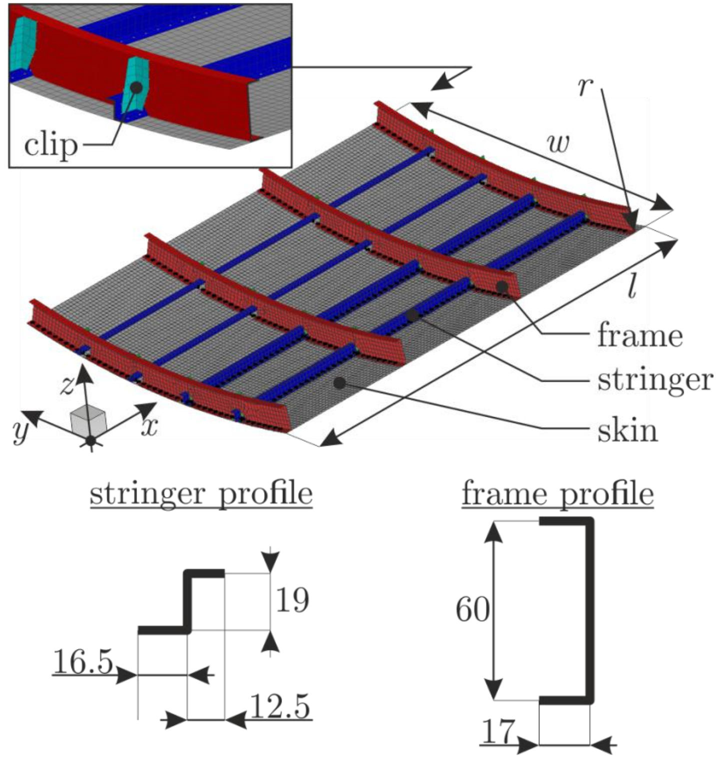

Key Experimental Findings

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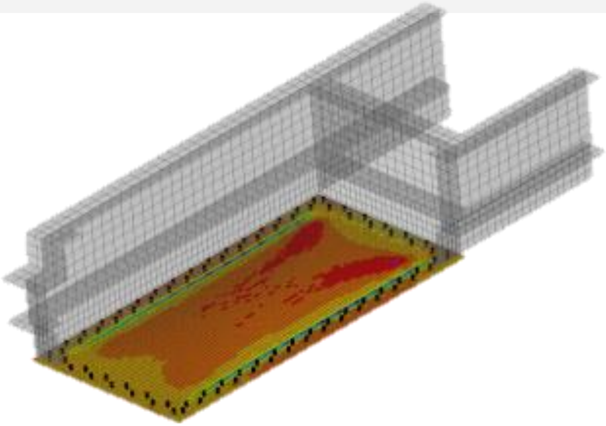
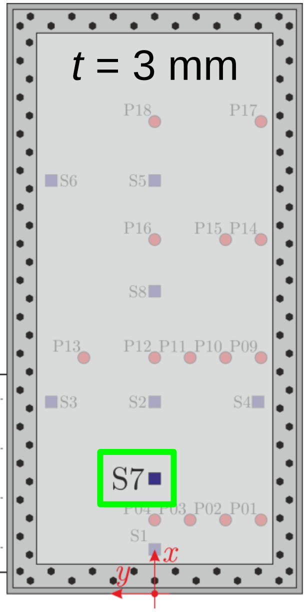
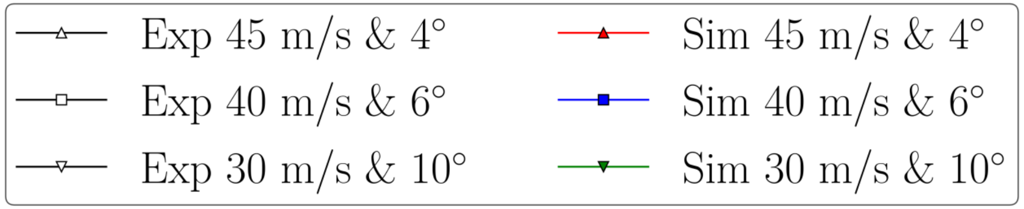
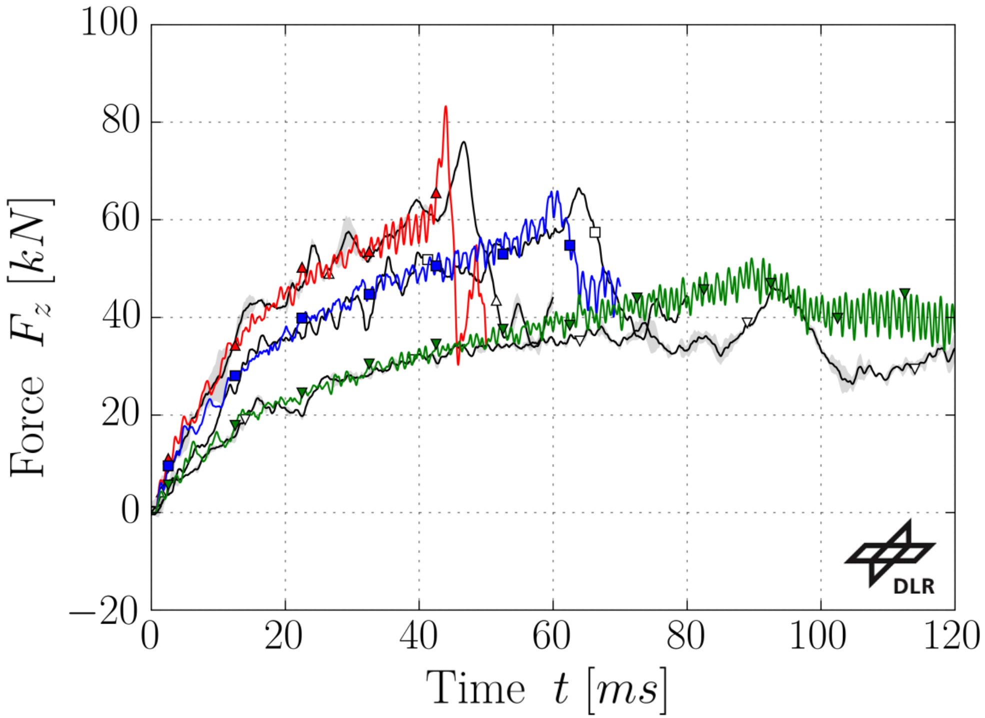
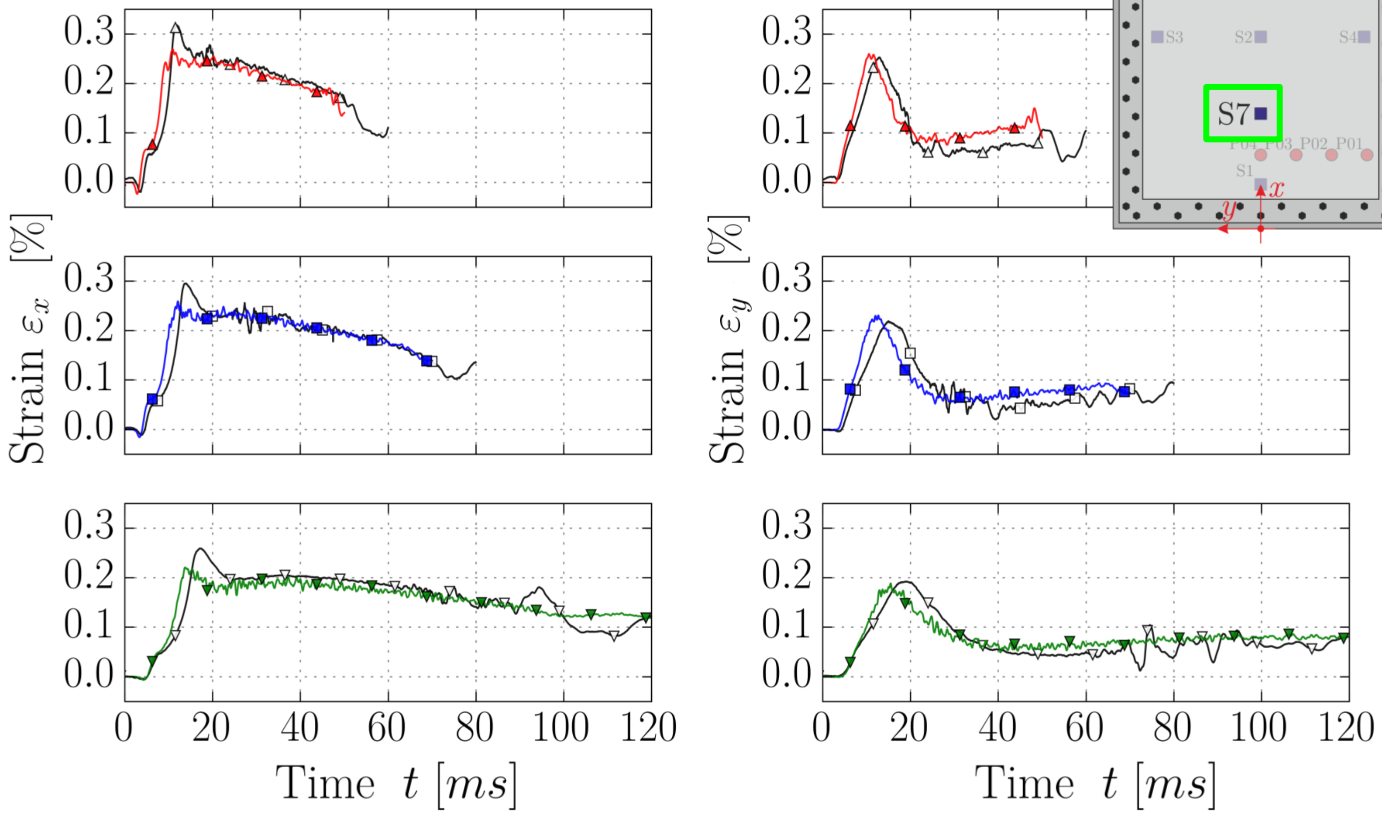
Validation (Guided Ditching Simulation)







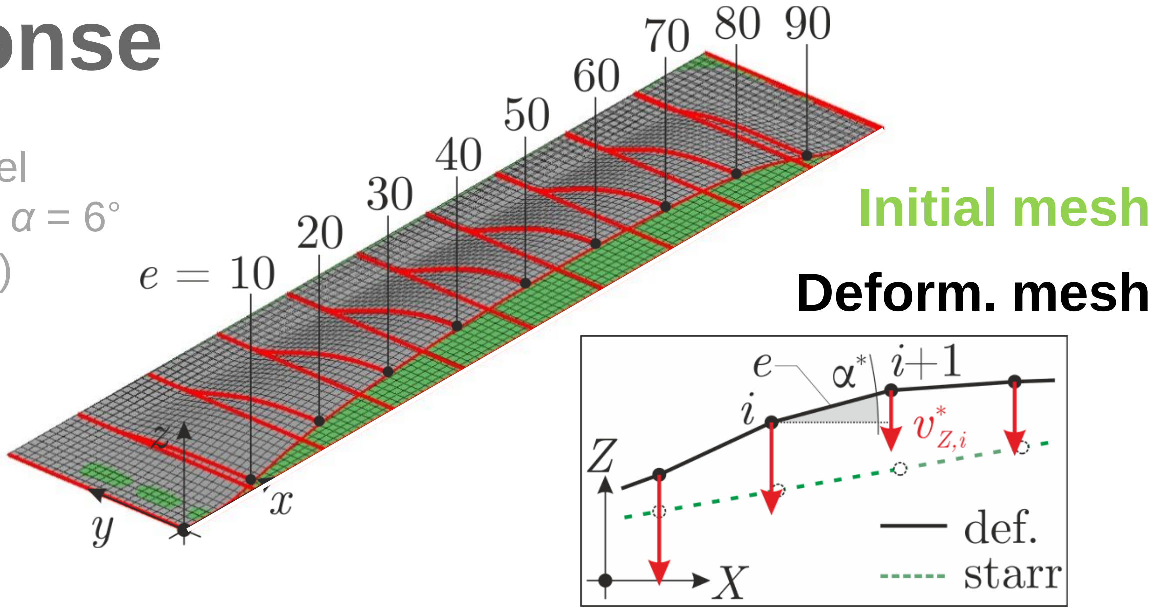


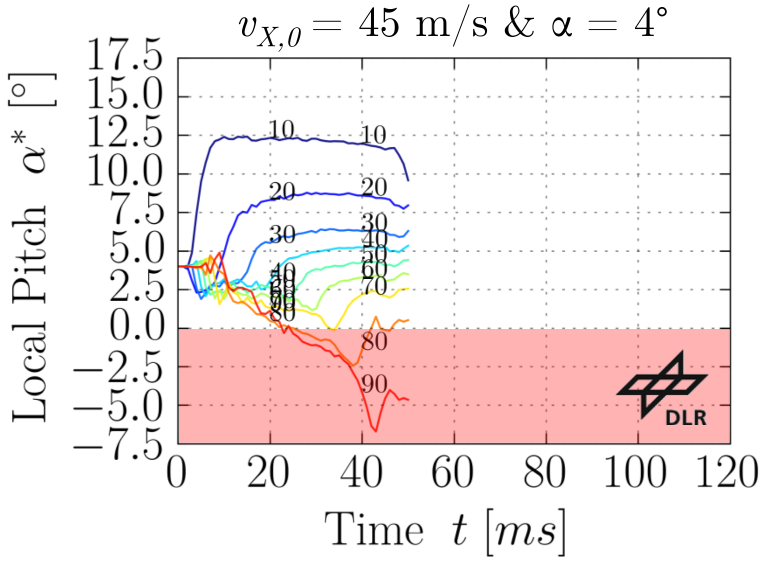


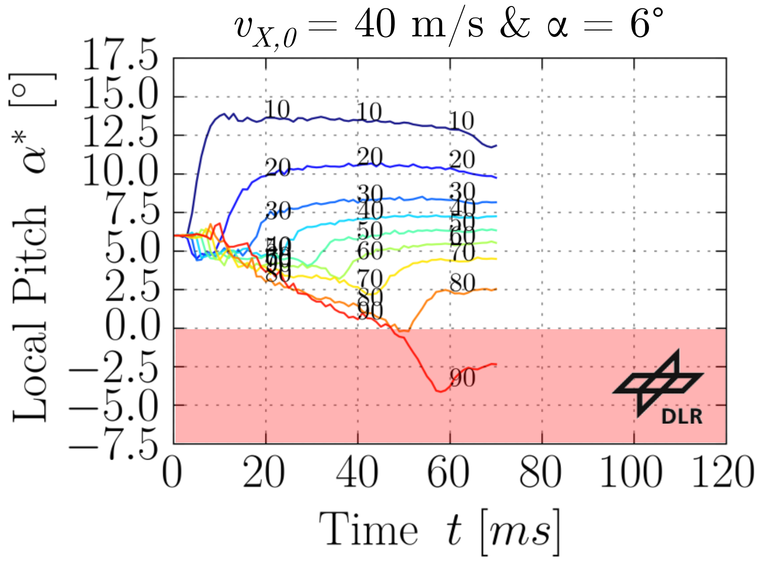
Analysis of Structural Response

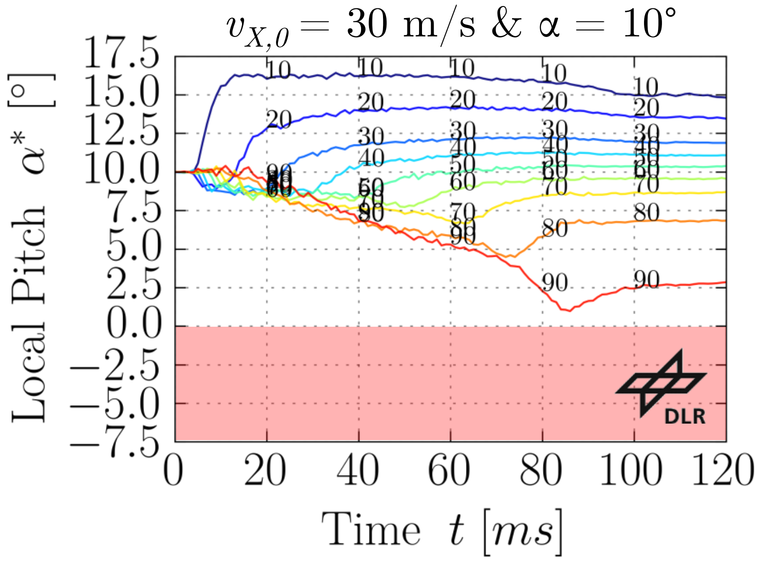
- Concave curvature
- Local reduction of vertical velocity (temporary)
- Change of local pitch angle

3 mm AL panel
$v_{X,0}$ = 40 m/s, α = 6°
(2 x amplified)

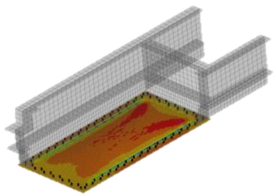




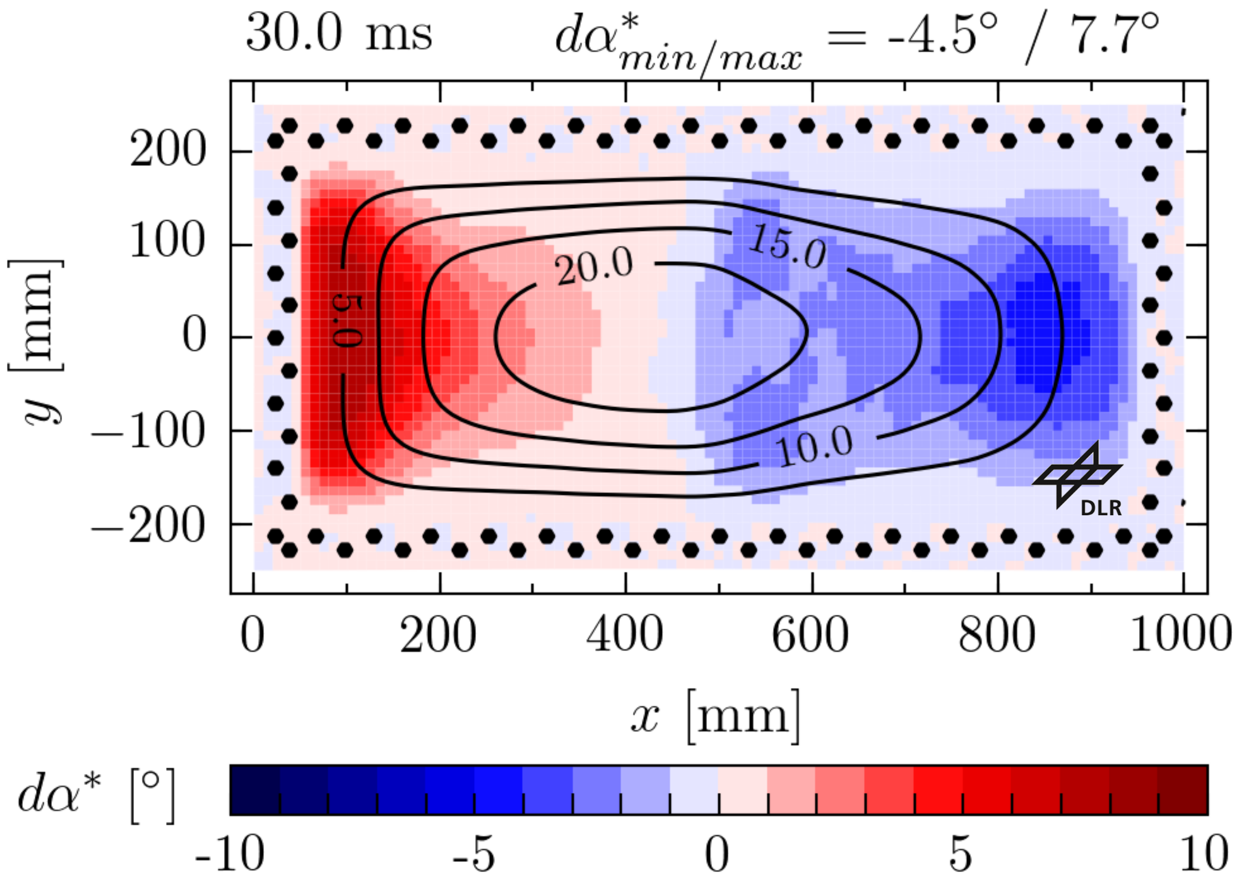




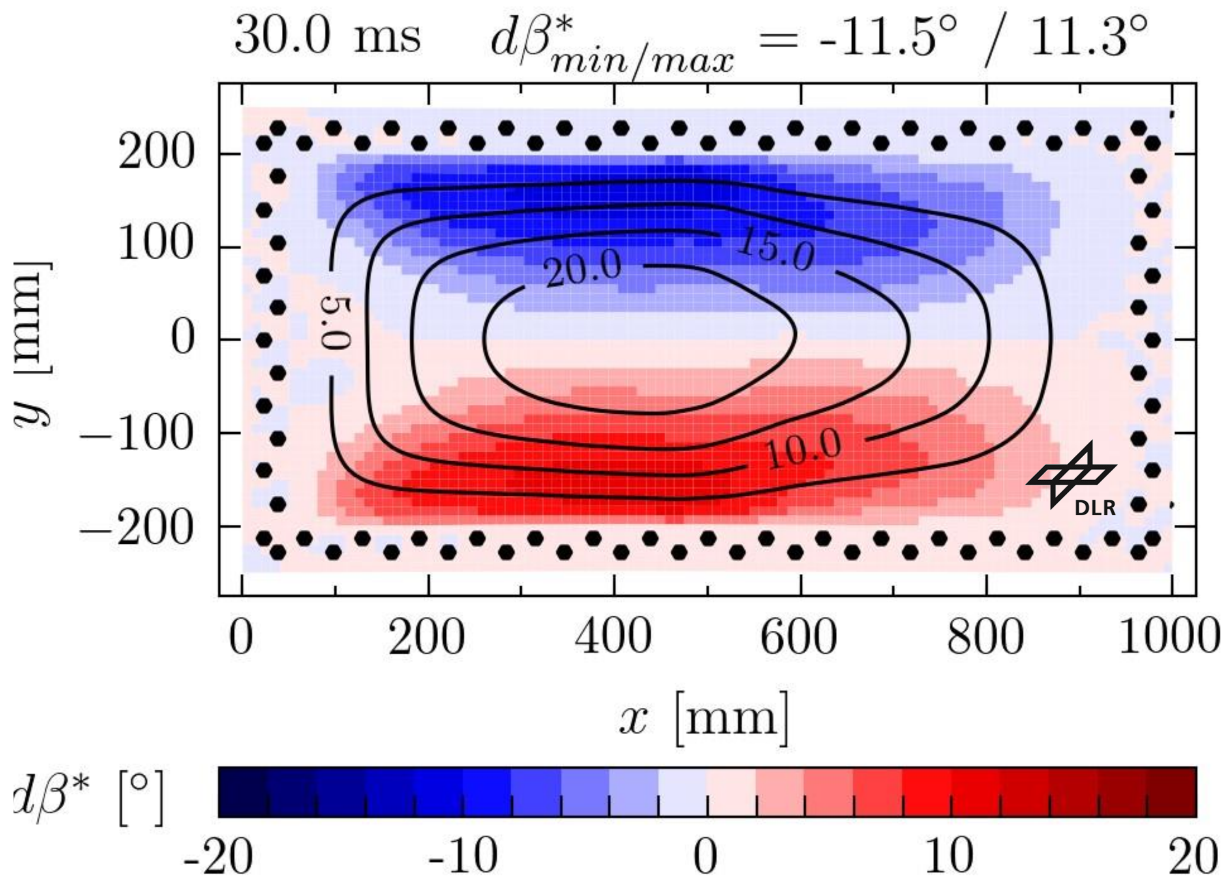
Analysis of Structural Response



Local pitch angle, $\alpha^* = grad(x)$

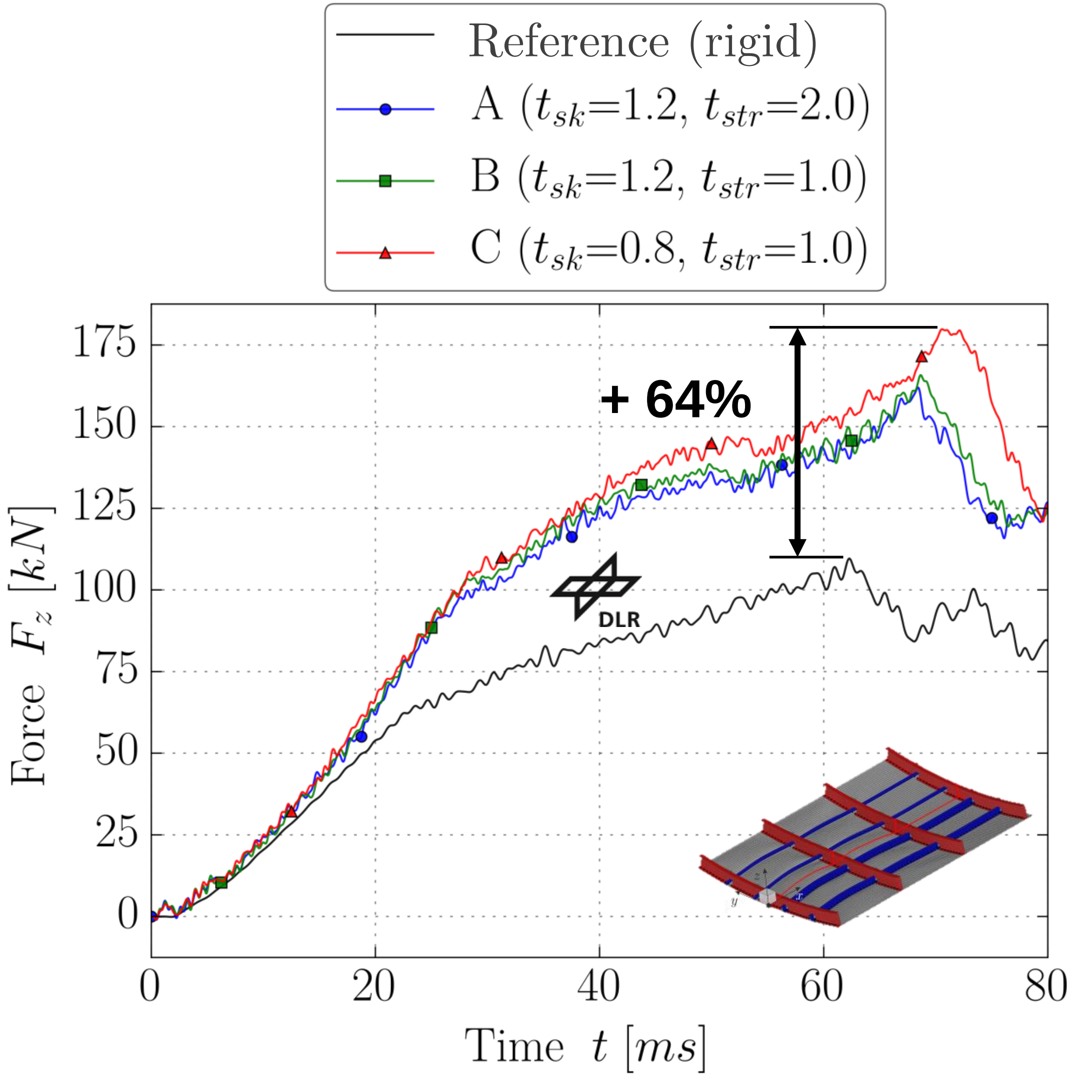


Local deadrise angle, $\beta^* = grad(y)$



$v_{x,0}$ = 40 m/s & α = 6°

Results (Generic Lower Fuselage Panel)

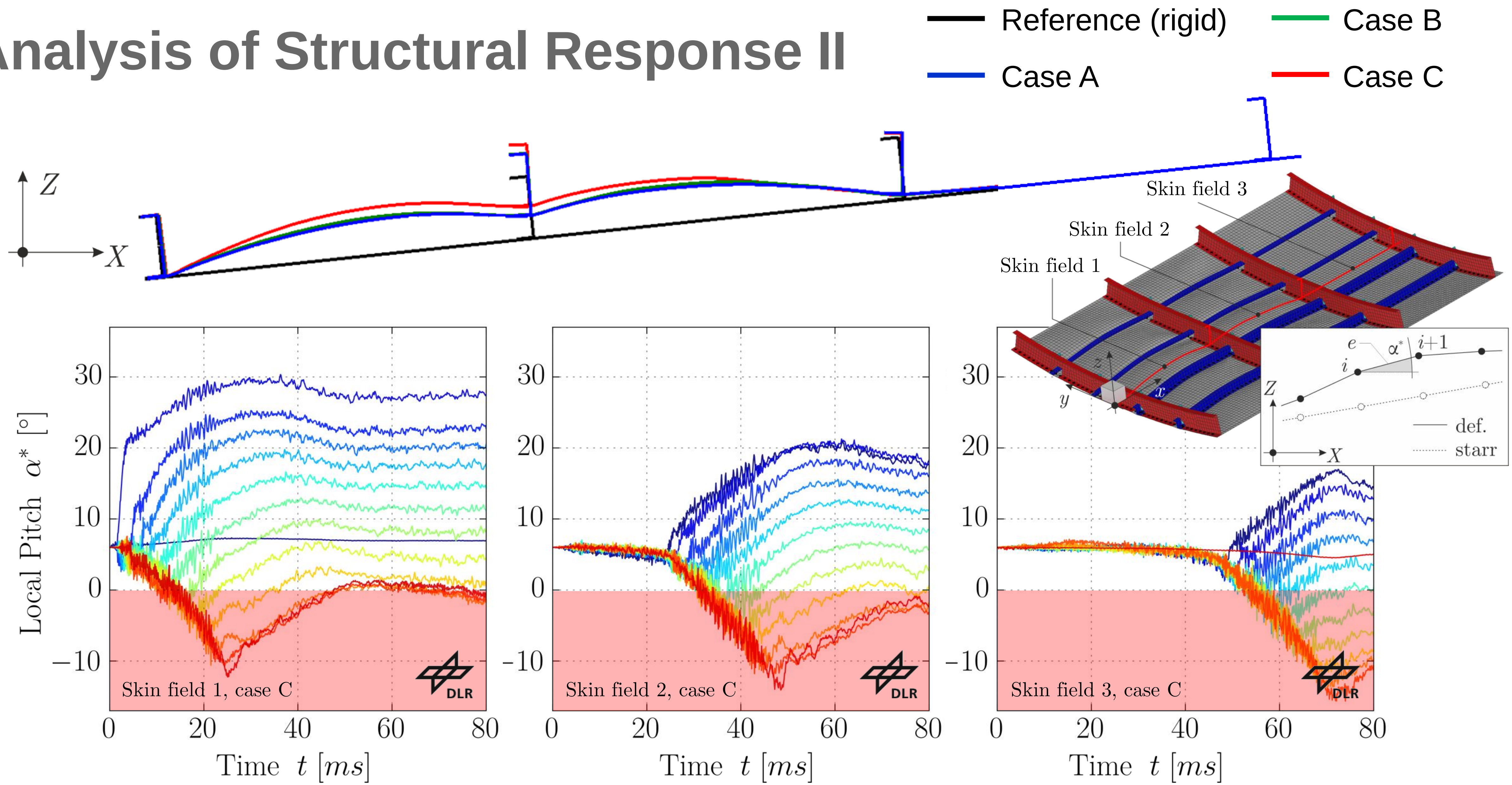


v_X = 40 m/s & α = 6°

- Qualitatively similar normal force time histories compared to GDS with unstiffened panels
- Progressive increase due to convex curvature

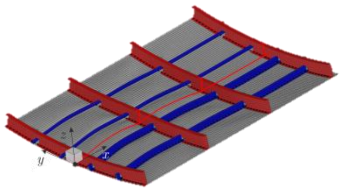
→ **Structural deformations significantly increase hydrodynamic loads**

Analysis of Structural Response II



$v_X = 40$ m/s, $\alpha = 6°$

Analysis of Structural Response II



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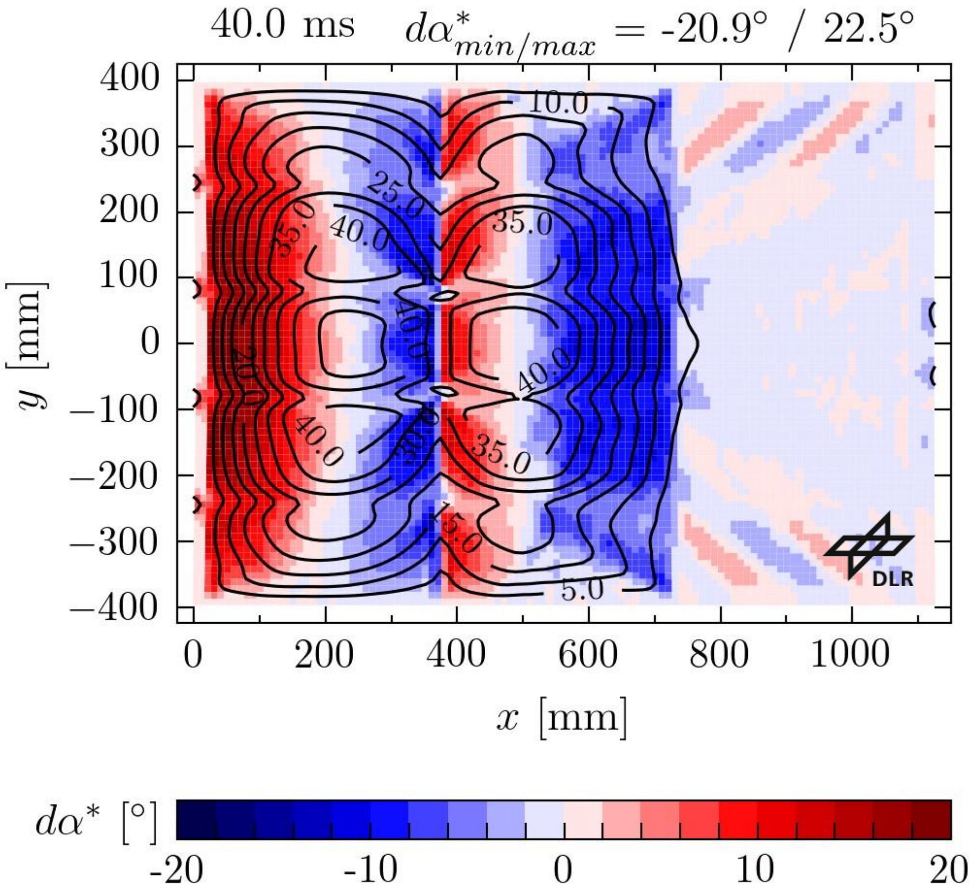
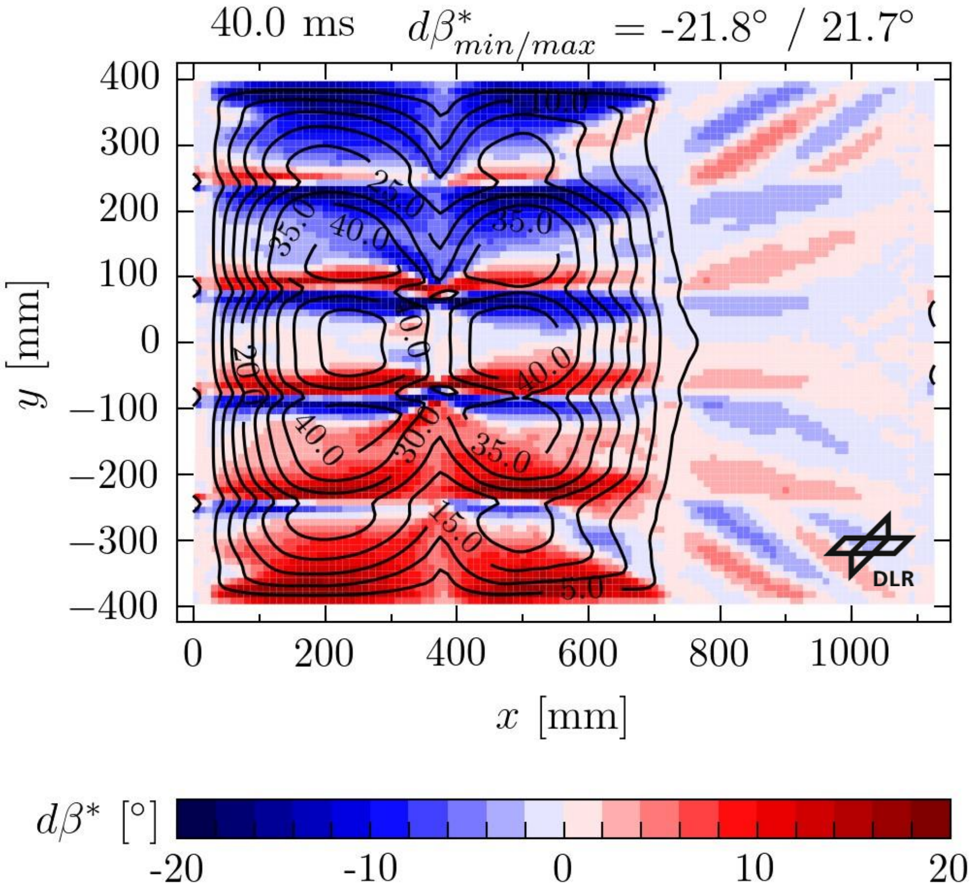


Local deadrise angle, $\beta^* = grad(y)$



v_X = 40 m/s, α = 6°, t_{sk} = 0.8 mm, t_{str} = 1.0 mm

Key Experimental Findings

Simulation Approach and Models

Simulation Results & Analyses

Conclusion and Outlook

Conclusions

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

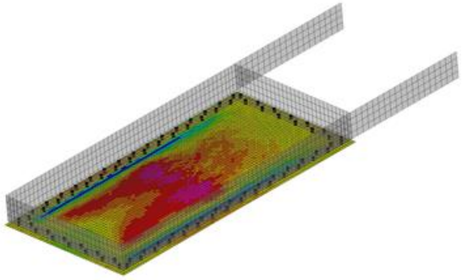
2. **Coupled simulation approach** for **analysis of structural response** developed, validated, and assessed based on simple structures and applied to generic lower fuselage panels

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

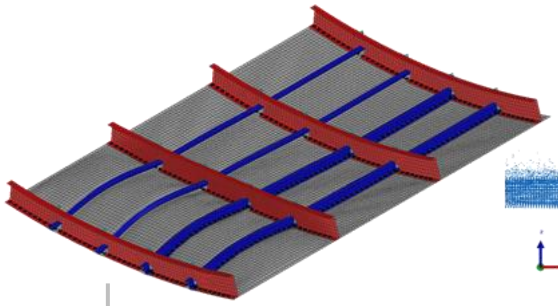
- The application of **coupled numerical approaches** is recommended for an **accurate analysis of the structural behavior**.

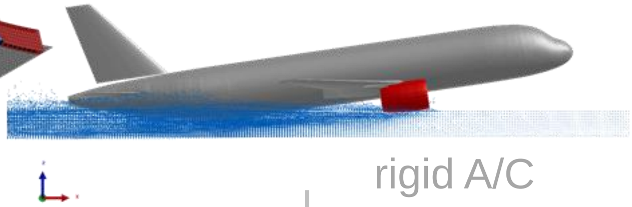
Outlook

strategic



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

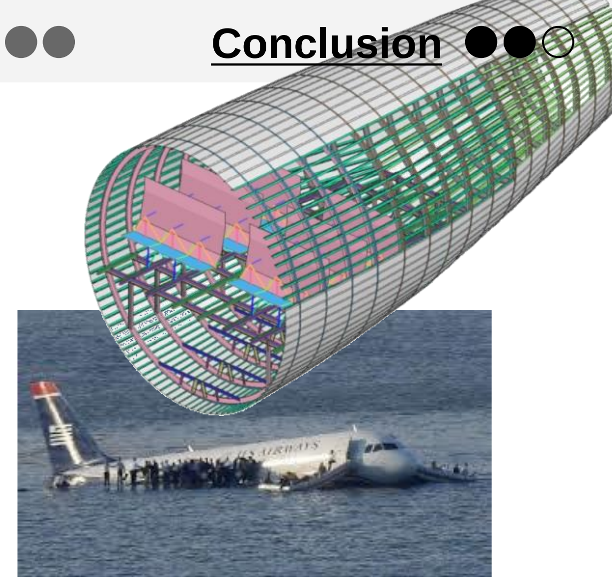




rigid A/C

- 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*** *(1/2019-2023),* ***INSIDE*** *(ongoing)*

scientific

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

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

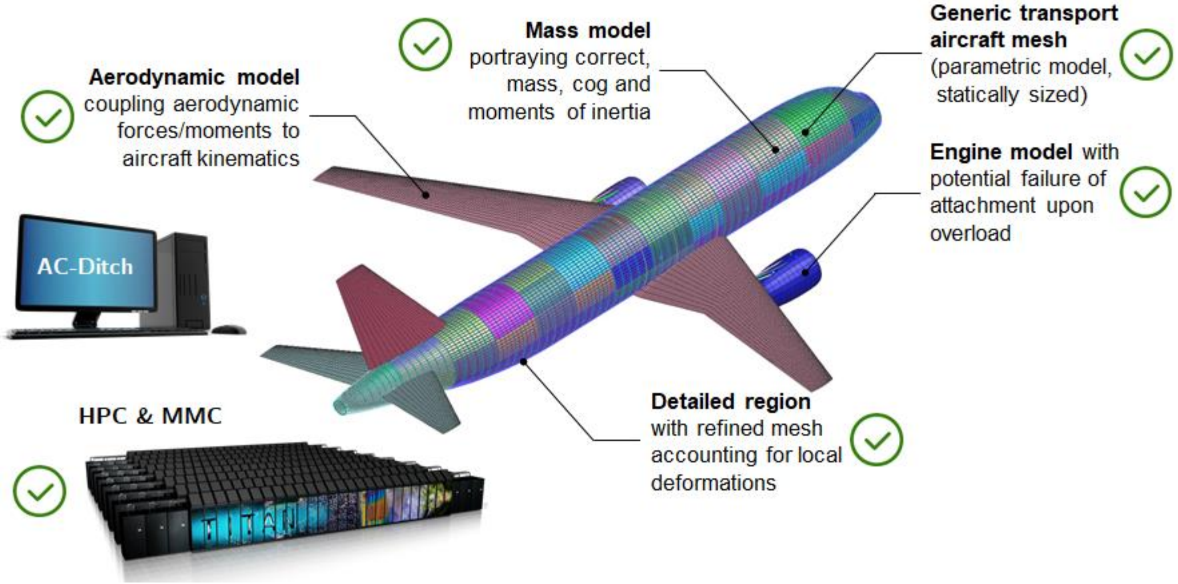
+ 5 journal / 13 conference papers (incl. presentations) and 4 BSc/MSc thesis during 2011-2017

→

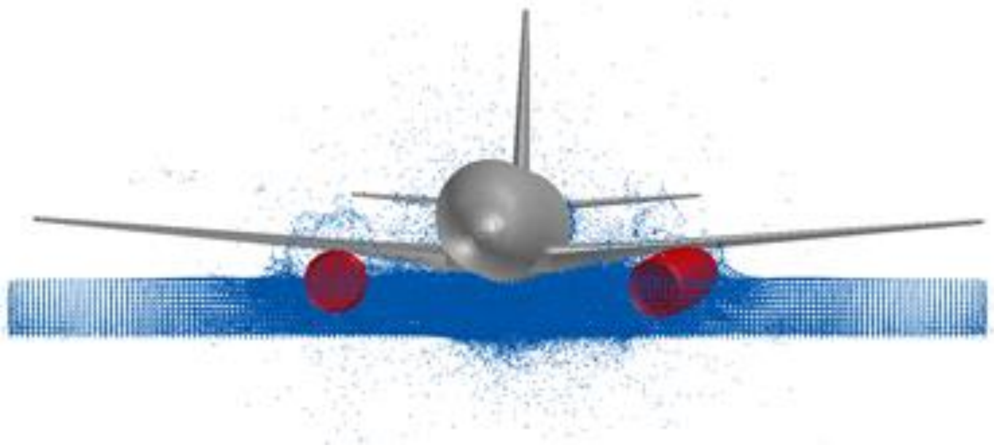
Do structural deformations affect the <u>global aircraft kinematics</u> during ditching?
(How? To which extent? …)

Outlook

- **Transfer to larger structures incl. structural failure**



- **Full aircraft ditching simulation** → effects of local deformations on global aircraft kinematics



Rigid body aircraft model with engine failure model

→ Continuous research at DLR-BT-SIN (Stuttgart) to extend ditching numerical simulation capabilities

Thank you for your attention!

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