DLR/ONERA Project ADAWI (Assessment of Aircraft Ditching and Water Impact)
Recent progress to model full aircraft ditching

Bertrand Langrand[1], *Martin H. Siemann*[2, 3], *Dieter Kohlgrüber*[2]

[1] ONERA-DMAS, F-59014 Lille Cedex, France
[2] DLR, Institute of Structures and Design, Stuttgart, Germany
[3] now at Assystem Germany GmbH, Bremen, Germany

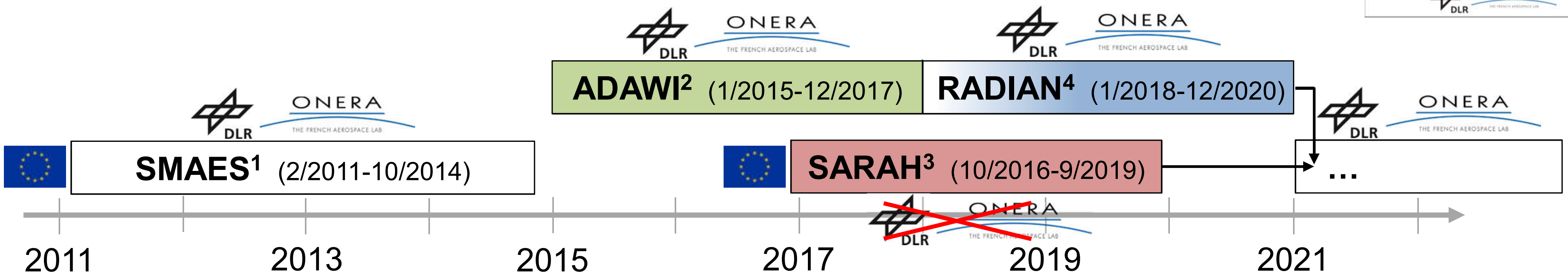
HSDF- Inaugural Event – Rome

October 04, 2018

Content

- Project history of ditching research at DLR/ ONERA
- Approach to achieve realistic full aircraft diching simulation
- Comparison of numerical methods (ALE-FE; SPH-FE)
  - Methods summary
  - Comparison of simulations results
    - SMAES Guided Ditching Tests (GDT)
    - Apollo Command Module (ACM)
    - Generic Transport Aircraft (D150)
- Analysis of flexible structures under ditching loads (SPH Method)
  - Generic flexible lower fuselage panel
  - Current work on generic flexible full aircraft model

Project history of ditching research at DLR/ ONERA



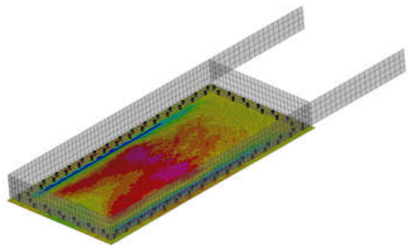
- DLR/ ONERA were partners in SMAES project (2/2011 – 10/2014)
  - Involvement in GDT test definition / evaluation and simulation
  - Contribution to Dassault testcase (testing, analyses)
- DLR/ONERA got internal support to continue work in ADAWI project (2015 - 2017)
- DLR/ONERA management did not permit to participate in H2020 call for SARAH (1/2016)
- DLR and ONERA intend to continue their close collaboration in the new project RADIAN (**R**obust **A**ircraft **Di**tching **An**alysis, initially planed to start in 2018) (2018-2020)

[1]SMAES – EU-FP7 with 15 partners [2/4] ADAWI/ RADIAN – only DLR/ONERA [3]SARAH – 12 partners; without DLR/ONERA

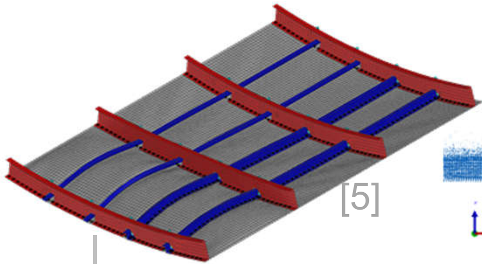
ADAWI
Assessment of Ditching and Water Impact

Approach to achieve realistic full aircraft diching simulation

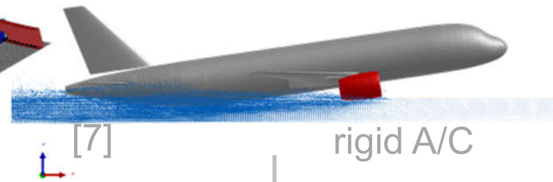
Test cases



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



[5]



[7] rigid A/C

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

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

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

FSI models

SMAES[1] (2/2011-10/2014)	**ADAWI**[2] (1/2015-12/2017)	**RADIAN**[4] (1/2018-12/2020)

- Coupled Eulerian-Lagrangian Method (CEL, Altair Radioss)
- Smoothed Particle Hydrodynamics (SPH-FE, ESI VPS)

[1]SMAES – EU-FP7 with 15 partners [2/4] ADAWI/ RADIAN – only DLR/ONERA

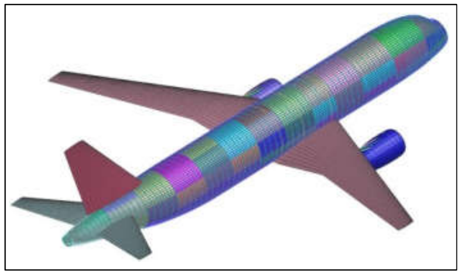
Comparison of numerical methods (CEL; SPH-FE)

- Two different numerical methods to simulation Fluid structure interaction are compared
  - Coupled Eulerian-Lagrangian Method (CEL, Altair Radioss)
  - Smoothed Particle Hydrodynamics (SPH-FE, ESI VPS)

- Applications / test cases
  - SMAES Guided Ditching Tests (GDT)
  - Apollo Command Module (ACM, NASA-TN-D-3980)
  - Generic Transport Aircraft (D150, AC-DITCH, DLR)

SMAES GDT

ACM

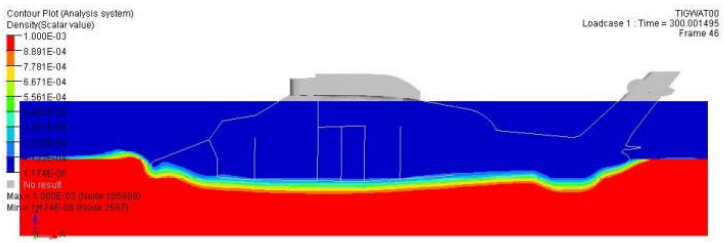


D150

Numerical simulation of ditching (CEL Method)

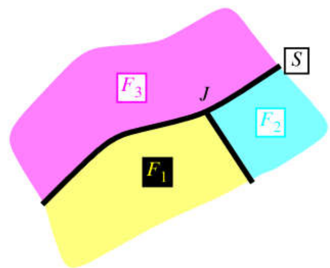
ALE formulation: the mesh moves arbitrarily

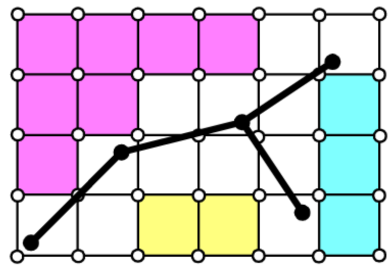
- \+ Simple treatment of F/S interaction
- \+ Combines advantages of Lag./Eul. without respective drawbacks
- ± Additional domain modelled (air)
- \- Fine fluid mesh needed



Coupled approach: embedded F/S interface

- Structure is discretized independently from fluid. Mesh is embedded in the fluid mesh.
- Fluid can be Eulerian, with regular mesh (no mesh entanglement for large structure rotations).
- Treatment of structural failure is greatly facilitated.

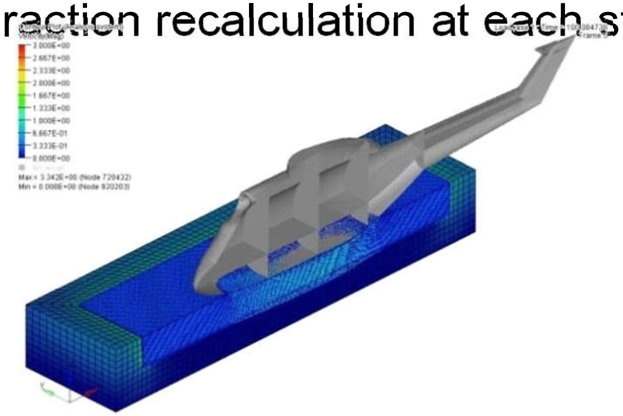




Numerical simulation of ditching (SPH-FE Method)

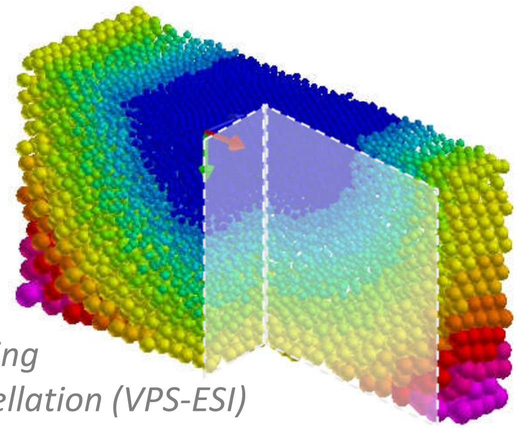
SPH formulation: the mesh is made of particles (no standard connectivity)

+ Same advantages as the Lagrangian formulation: easy B.C.s and only the real domain is modelled
+ Without associated drawbacks: no mesh that can suffer from large deformations
- Particle interaction recalculation at each step costly



Coupled approach: contact interface (non-conforming F/S meshes)

- Structure is discretized independently from fluid
- Usually regular particle spacing for the fluid
- Treatment of structural failure is greatly facilitated

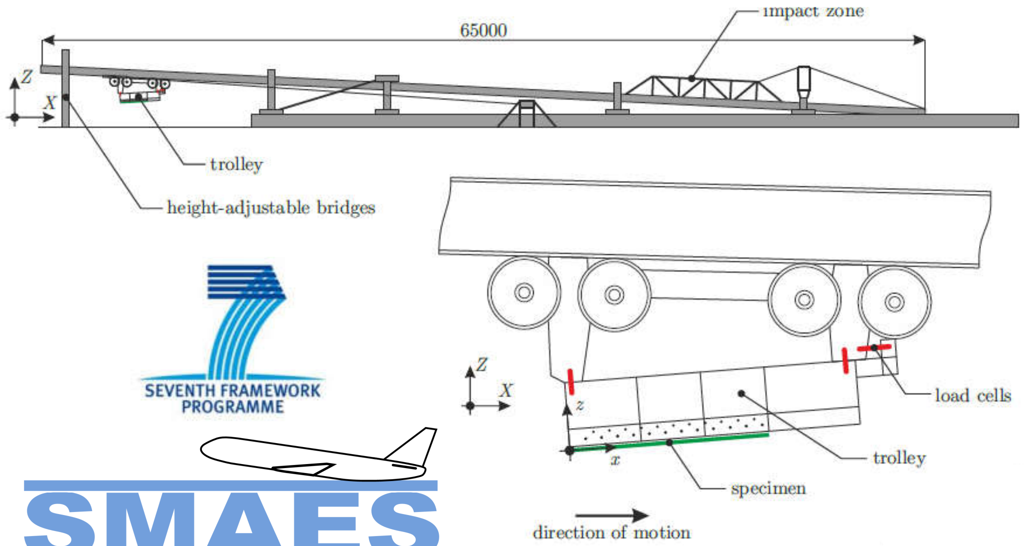


Promising approach using Weighted Voronoi Tessellation (VPS-ESI)

GDT – Structural model

- Exemplary test case (from SMAES tests)
  - Flat panel (1 x 0.5 m)
  - Pitch angle: 6°
  - Vertical initial velocity: -1.5m/s,
  - Horizontal initial velocity: 40m/s
  - Panel thickness
    - 15mm, 3mm, and 0.8mm
    - Quasi-rigid, elastic and permanent deformation test cases

ADAWI
Assessment of Ditching and Water Impact



SEVENTH FRAMEWORK PROGRAMME

SMAES

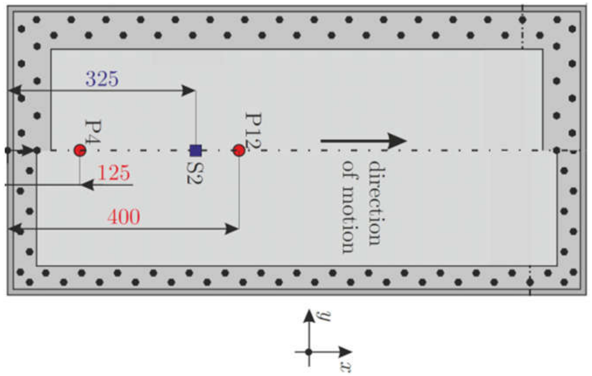
M.H. Siemann, B. Langrand, Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches, *Computers and Structures* **188**(2017):95-108

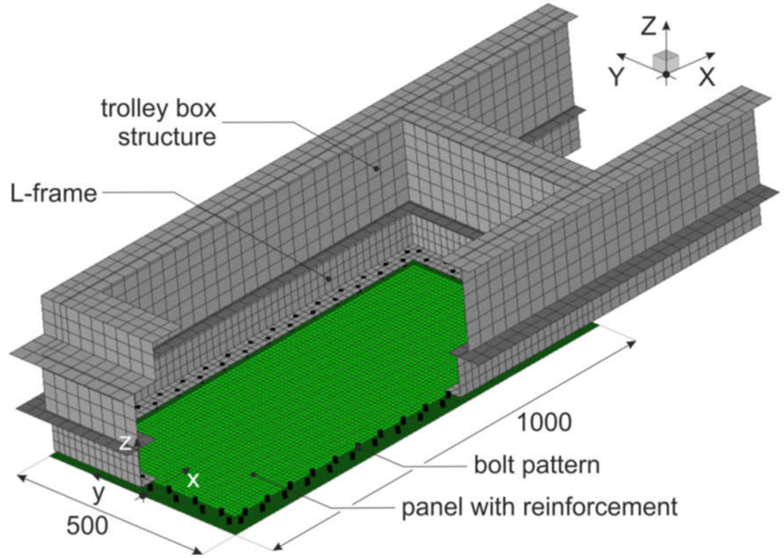
DLR ONERA

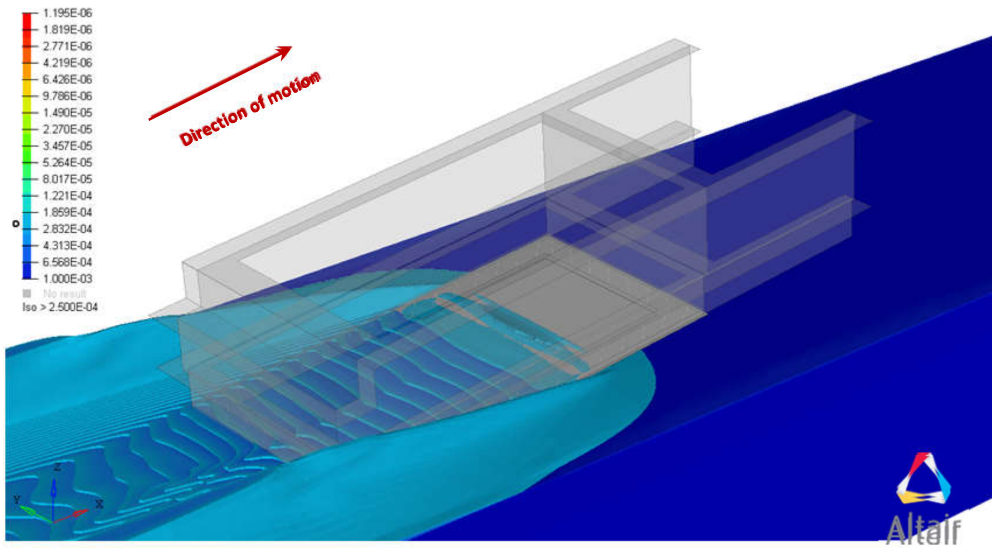
GDT – Structural model

- Common model
    - Panel (Al2024-T351)
        - Mesh size: 10mm
        - Ramberg-Osgood law
    - Quasi-rigid trolley
    - Bolts (connectors)

- Measurements
    - Vertical force
    - Local pressures
    - Local strains

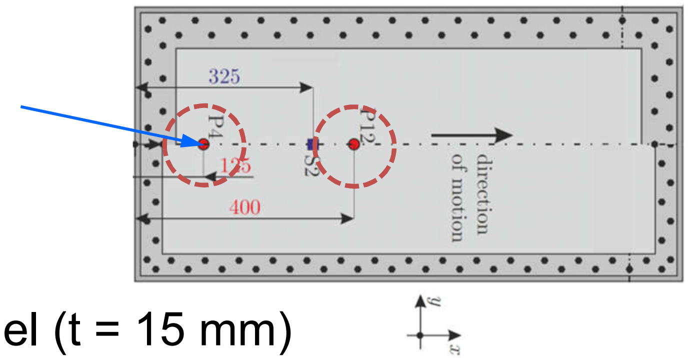






DLR ONERA

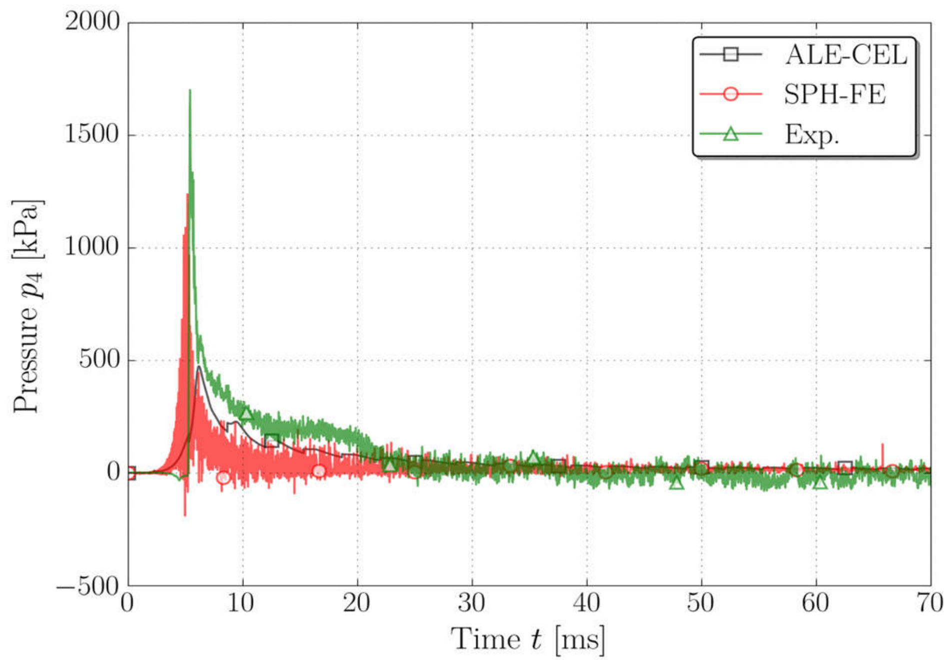
GDT – Results comparison



Local pressures

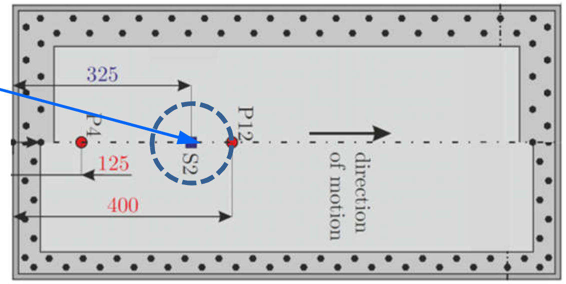
P4 - Thick panel (t = 15 mm)

- Both ALE / SPH simulations compared
  - Timing correct
  - Pressure pulse underestimated
- SPH more noisy
  - Post-treatment method
  - Numerical formulation (particles impact)



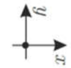
M.H. Siemann, B. Langrand, Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches, *Computers and Structures* **188**(2017):95-108

GDT – Results comparison



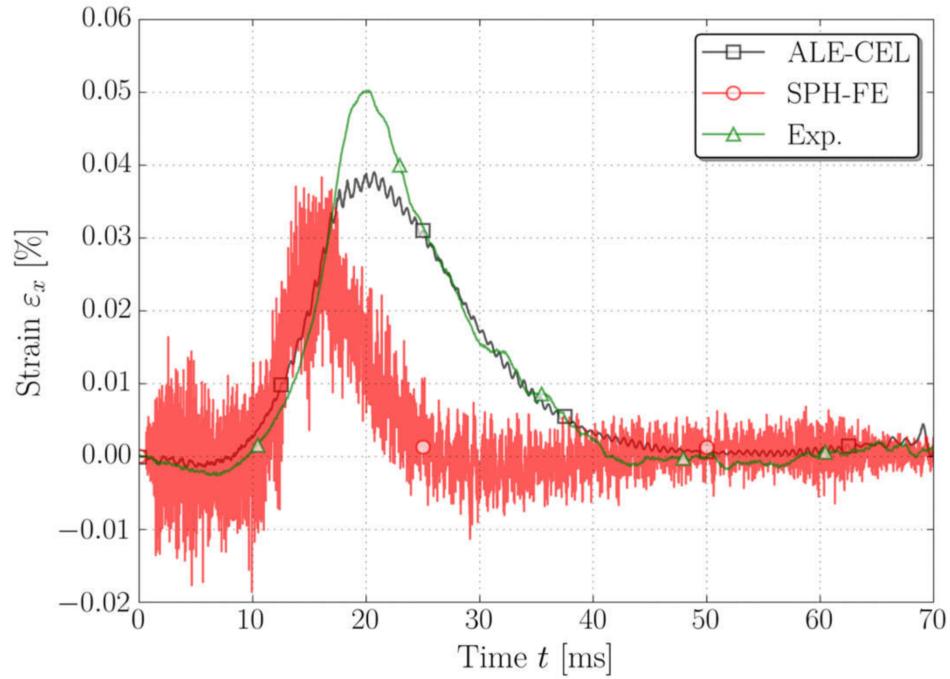
Local strains

$S2_x$ – Thick panel (t = 15 mm)



- Both ALE / SPH simulations compared
  - Timing
  - History/shape
  - Amplitude

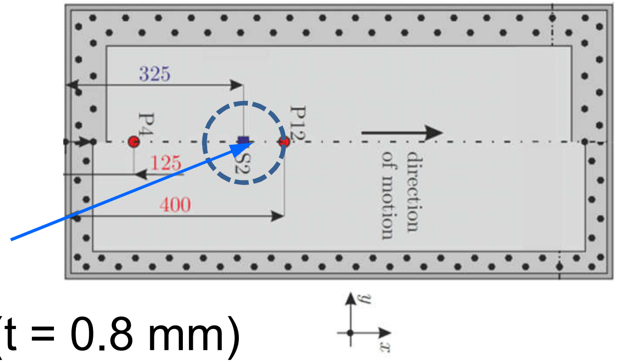
- SPH more noisy because of numerical formulation
  (particles impact)



M.H. Siemann, B. Langrand, Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches, *Computers and Structures* **188**(2017):95-108

ONERA

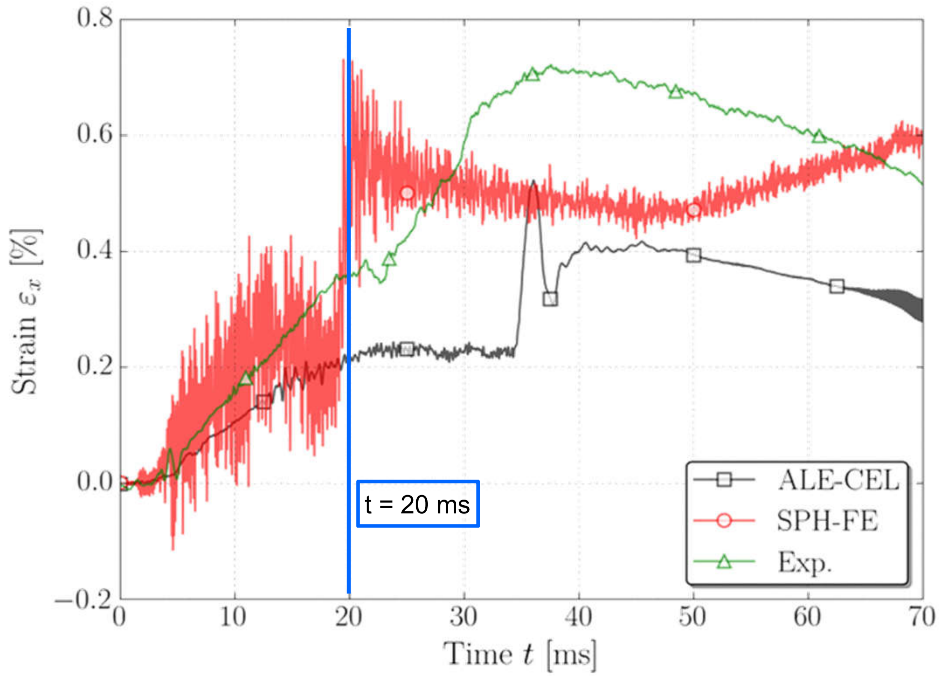
GDT – Results comparison

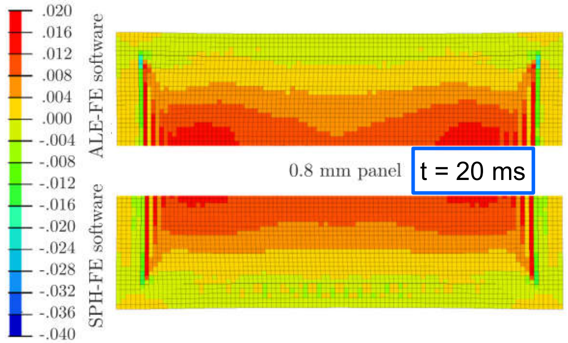


Local strains

- Lower strain rate for ALE simulation
  - Pressure rises too smooth
- Both ALE / SPH simulations compared
  - High strain rate in x-direction when the jet root passes the gauge location
  - Experimental data features a much smoother and more steady rise of the strain

$S2_x$ – Thin panel (t = 0.8 mm)



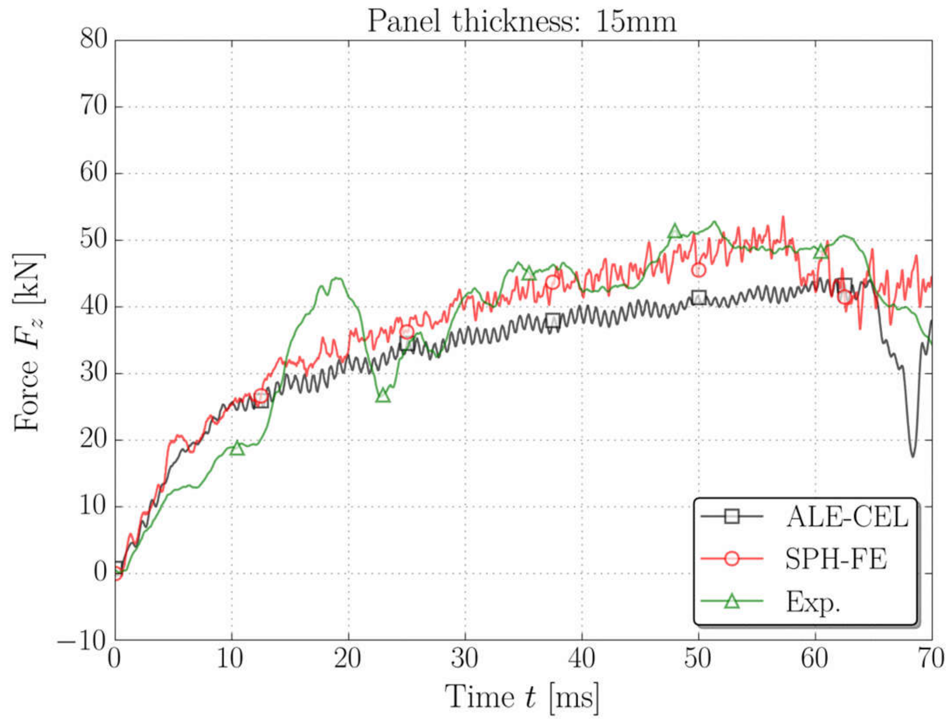


M.H. Siemann, B. Langrand, Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches, *Computers and Structures* **188**(2017):95-108

GDT – Results comparison

Global normal force

- Best with the SPH-FE
- Underestimated with the CEL method
  - Small water 'leakages' detected
  - Pressure pulse underestimated
- Both ALE / SPH simulations
  - Local force peak in the cases with deformable panels predicted correctly (just before leading edge immersion)

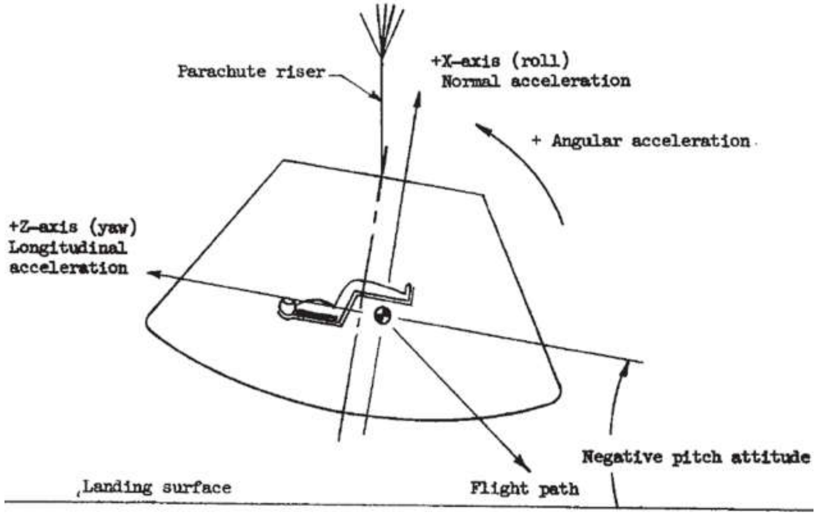


M.H. Siemann, B. Langrand, Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches, *Computers and Structures* **188**(2017):95-108

ACM – Structural model

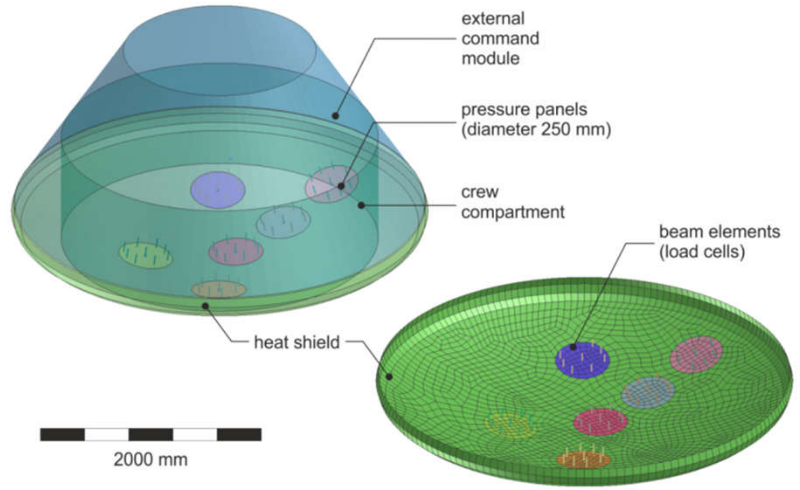
- Test matrix
  - Pitch angles: -15°, -30°
  - Vertical, horizontal initial velocities:
    - Drop tests: -9,5m/s, (0m/s)
    - Ditch tests: -8m/s, 15m/s

- Physical properties in literature
  - C.o.G. position
  - Gross weight
  - Moments of inertia



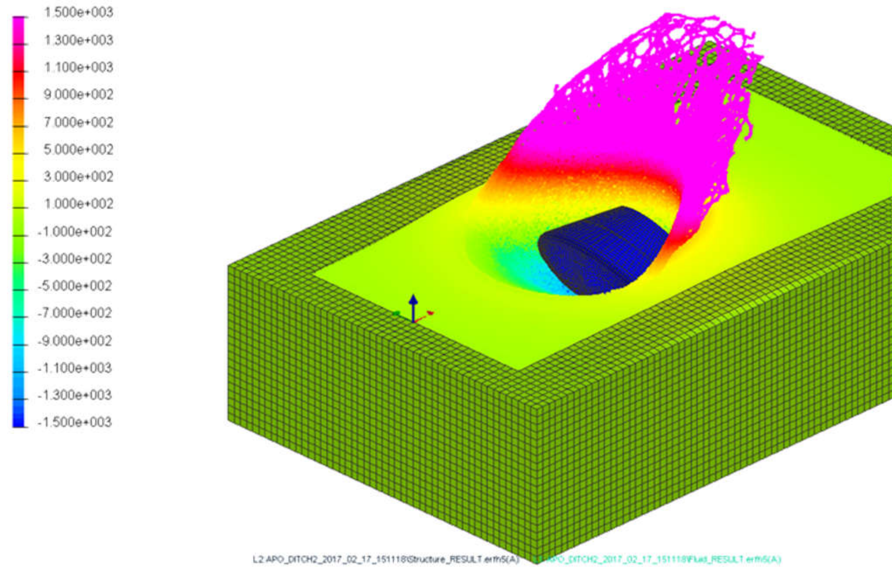
Sandy M. Stubbs, Dynamic model investigation of water pressures and accelerations encountered during landings of the Apollo spacecraft, NASA-TN-D-3980, September 1967

ACM – Structural model



- Common model (full scale)
  - Rigid body
  - Panels (∅ 250 mm) used as load cell for mean pressure

- Measurements
  - Max. mean pressure (panels)
  - Max. accelerations (a_x, a_z, w_y)

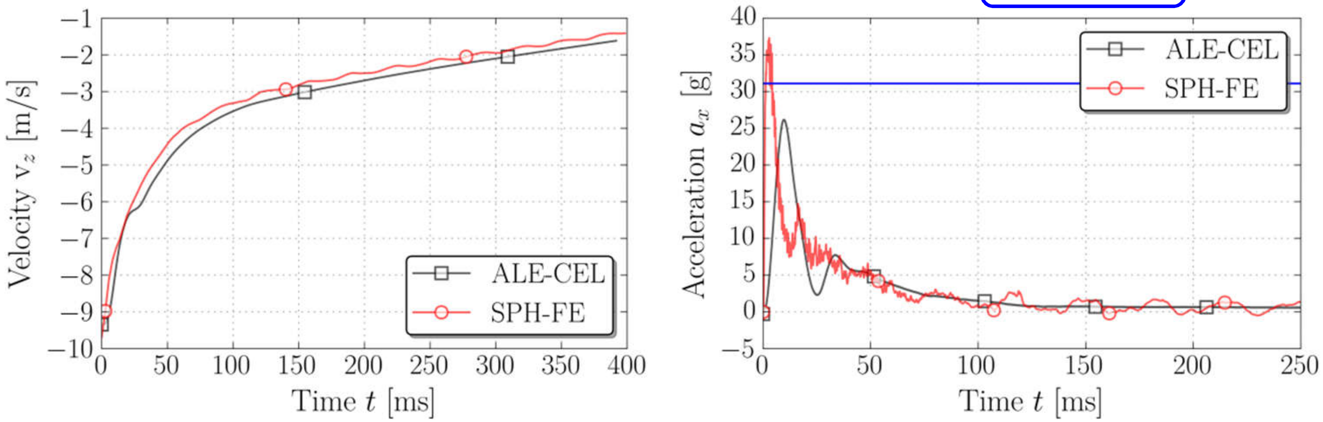


Ditching test case	
V_x	15m/s
V_z	-8m/s
α_y	-30°

ACM – Results comparison

Drop test α_y = -15° ; V_z = -9.5 m/s, V_x = 0 m/s

Max. Exp.



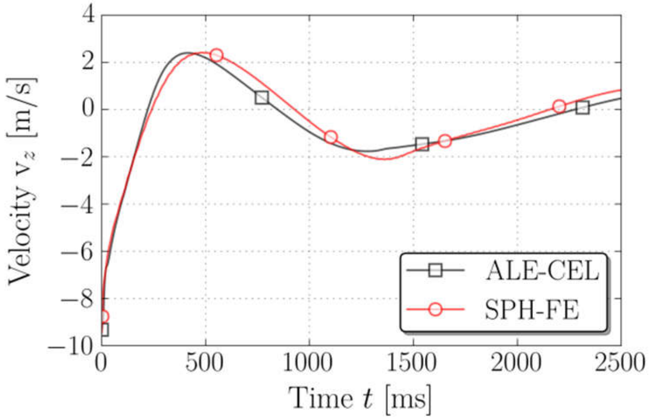
- Both methods predicted almost the same velocity time histories
- Maximum accelerations (a_x, a_z, w_y) correctly estimated by both simulation methods
- Mean pressures under/over-estimated by the ALE/SPH methods
- ALE: time rise (pressure, acceleration) was overestimated

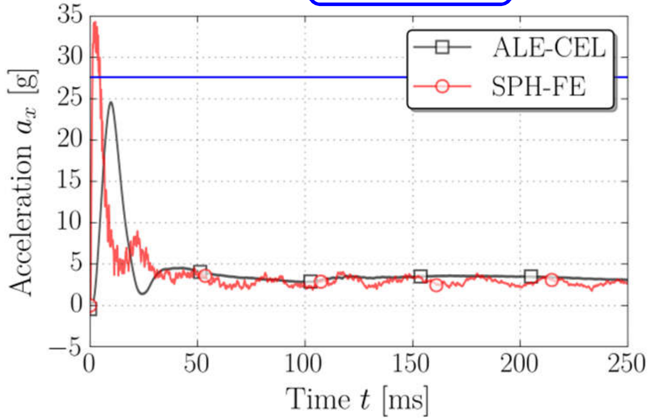
B. Langrand, M.H. Siemann, Full-scale aircraft ditching simulation: a comparative analysis of advanced coupled fluid-structure computational methods, ICILSM Conference, May 7-11, 2018, Xi' an, China

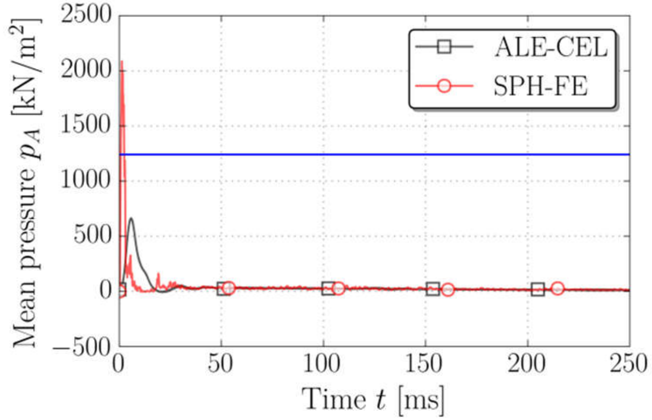
ACM – Results comparison

Ditch test α_y = -15° ; V_z = -8 m/s ; V_x = 15m/s

Max. Exp.







- Both methods predicted almost the same velocity time histories
- Maximum accelerations (a_x, a_z, w_y) correctly estimated by both simulation methods
- Mean pressures under/over-estimated by the ALE/SPH methods
- ALE: time rise (pressure, acceleration) seemed overestimated

B. Langrand, M.H. Siemann, Full-scale aircraft ditching simulation: a comparative analysis of advanced coupled fluid-structure computational methods, ICILSM Conference, May 7-11, 2018, Xi' an, China

Generic Transport Aircraft model

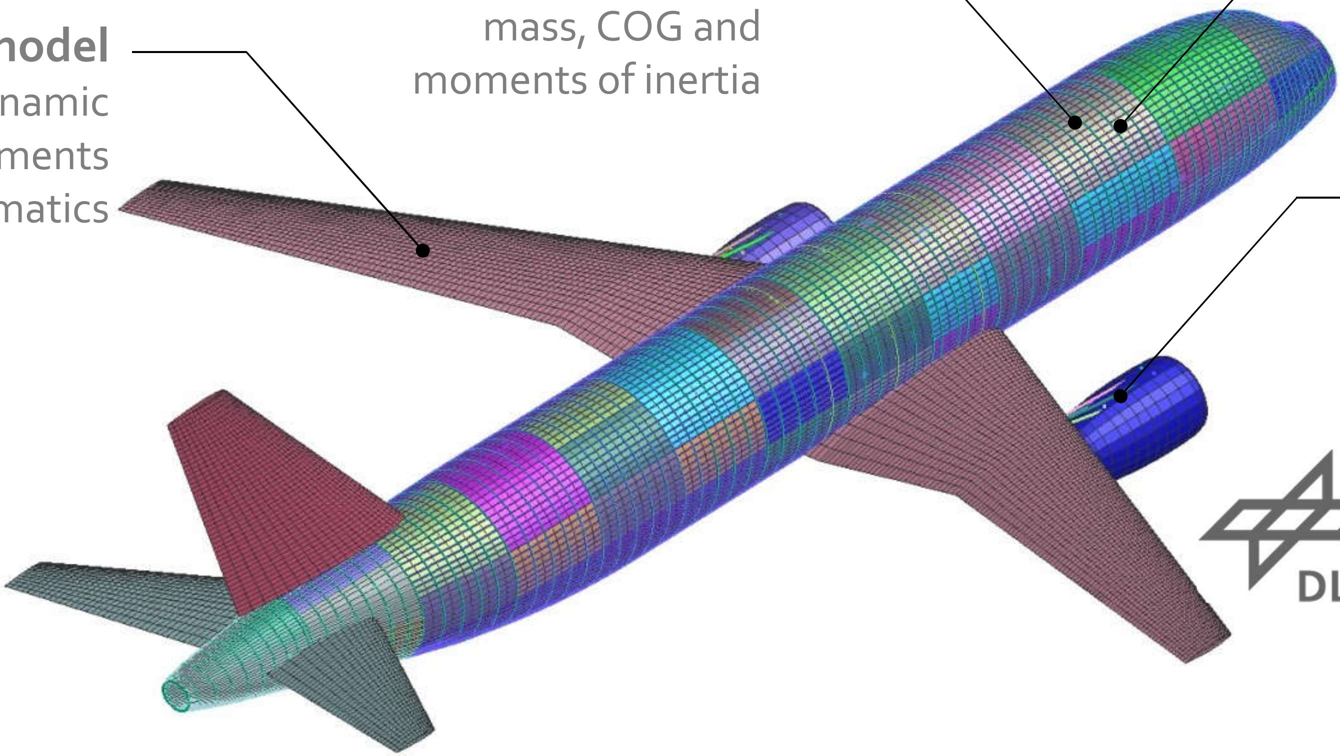
Models are in this study **rigid**.
Flexible fuselages are under development.

ADAWI
Assessment of Ditching and Water Impact

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

Generic transport aircraft mesh
(parametric model,
autom. generated)

Aerodynamic model
coupling aerodynamic
forces / moments
to aircraft kinematics



Engine model
with potential
failure of attachment /
pylons upon overload

AC-Ditch,
an automated pre-processor for
ditching simulations
(developed by DLR
since 2014)

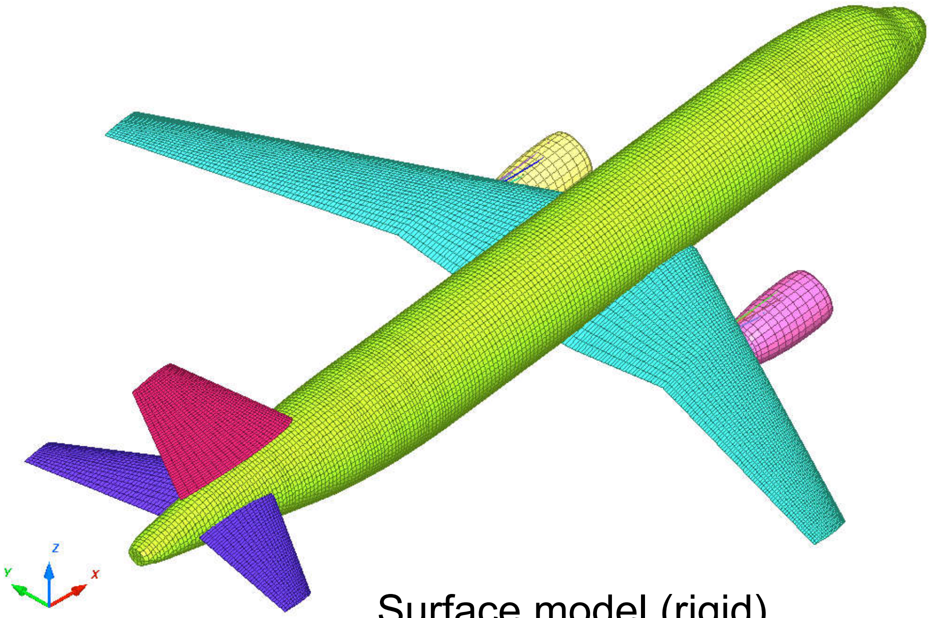
Generic Transport Aircraft model

Models are in this study **rigid**.
Flexible fuselages are under development.

ADAWI
Assessment of Ditching and Water Impact

- Short- to medium-range commercial passenger
  - PAX capacity: ~150
  - Fuselage length: ~37.5m
  - Fuselage diameter: ~4.1m
  - Wingspan: ~34m

- Simple mass model:
  - Definition of COG position
  - Definition of suitable mass inertia data wrt. to predefined COG



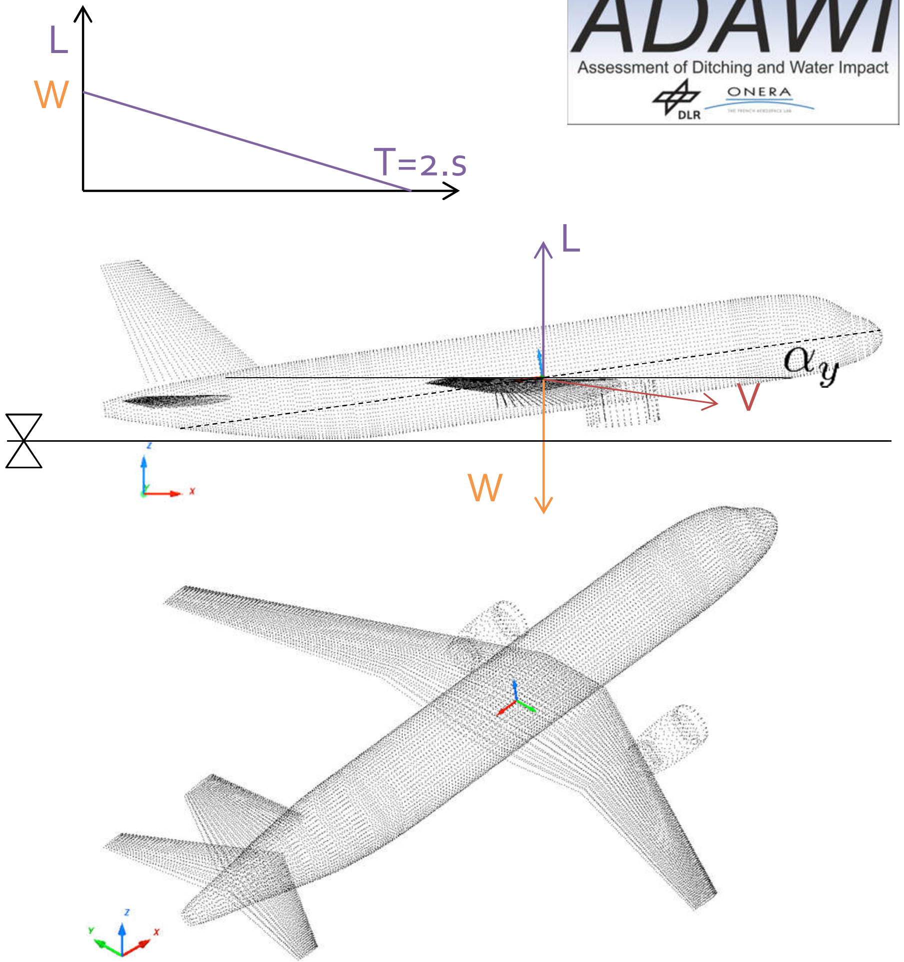
Surface model (rigid)

B. Langrand, M.H. Siemann, Full-scale aircraft ditching simulation: a comparative analysis of advanced coupled fluid-structure computational methods, ICILSM Conference, May 7-11, 2018, Xi' an, China

D150 – Structural model

Ditching **reference** configuration
- Rigid body
- Gross mass: 72.5 x 10^3 kg
- Lift model: ON
- Approach conditions
  - V_x, V_z: 70m/s, -1.5m/s
  - Roll, Pitch*, Yaw: 0°, 8°, 0°

Results analysis (C.o.G)
- Velocities , displacements (global ref. frame)
- Accelerations (<u>local</u> ref. frame)
- Pitch angle (global ref. frame)



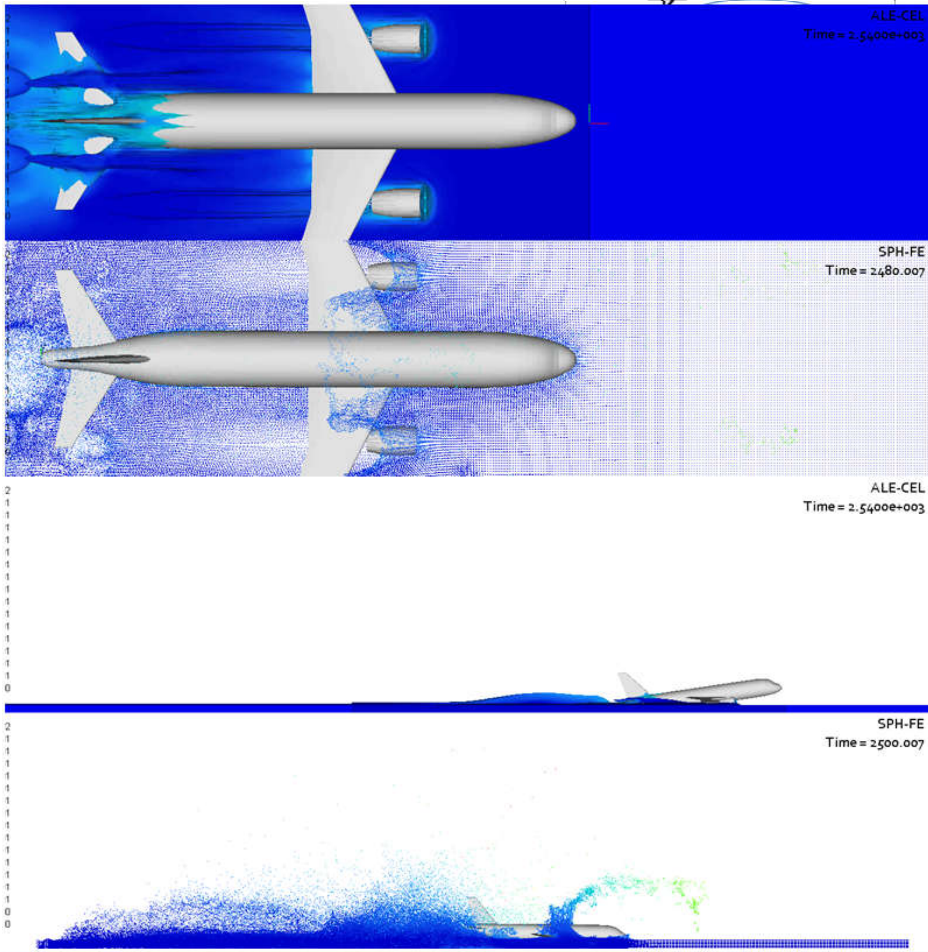
ADAWI
Assessment of Ditching and Water Impact

*According to the used coordinate frame, this angle is mathematically negative.

B. Langrand, M.H. Siemann, Full-scale aircraft ditching simulation: a comparative analysis of advanced coupled fluid-structure computational methods, ICILSM Conference, May 7-11, 2018, Xi' an, China

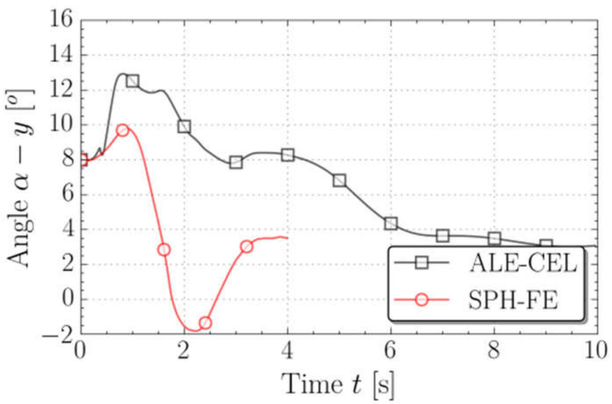
D150 – Results comparison

Test case			
M (10^3 kg)	V_x (m/s)	V_z (m/s)	α_y (°)
72.5	**70.0**	-1.5	**-8.0**



Ditching **reference** configuration

- Tendency to skip in the ALE-CEL simulation
- Increase in attitude higher in the ALE-CEL simulation
- Length of run larger in the ALE-CEL simulation (5 vs. 3 in SPH-FE)
- Engines hit water at
    - 1.3 ms SPH-FE
    - 2.1 ms ALE-CEL



DLR ONERA

D150 – Results comparison

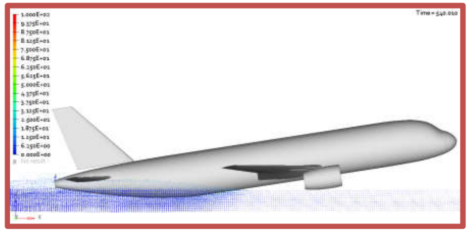
Test case			
M (10^3 kg)	V_x (m/s)	V_z (m/s)	α_y (°)
72.5	**70.0**	-1.5	**-8.0**

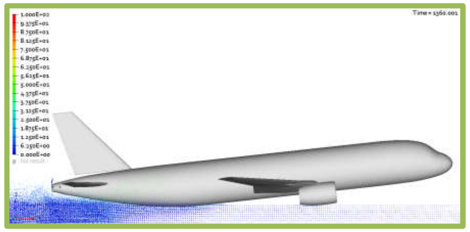
ADAWI
Assessment of Ditching and Water Impact

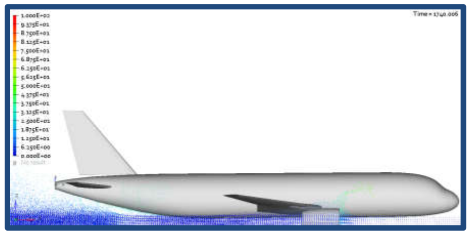
Longitudinal accelerations

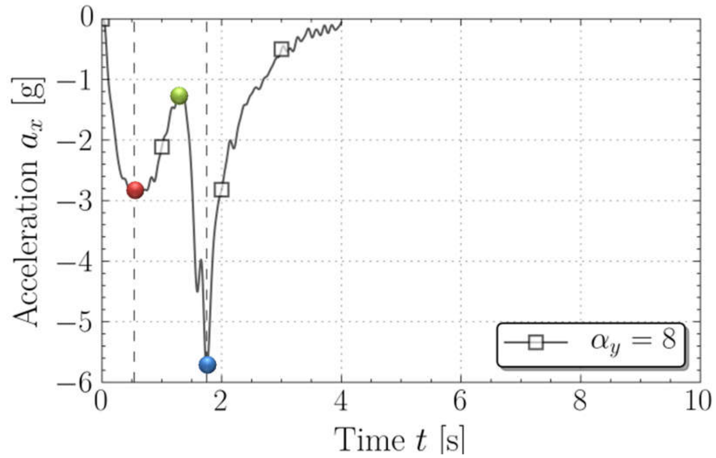
- Acc. in peaks (SPH-FE)
  - Impact phase
    - During pitch up (~0.5 s)
  - Landing phase
    - Engines hit water
    - Engines entered deeply into water (~1.75 s)

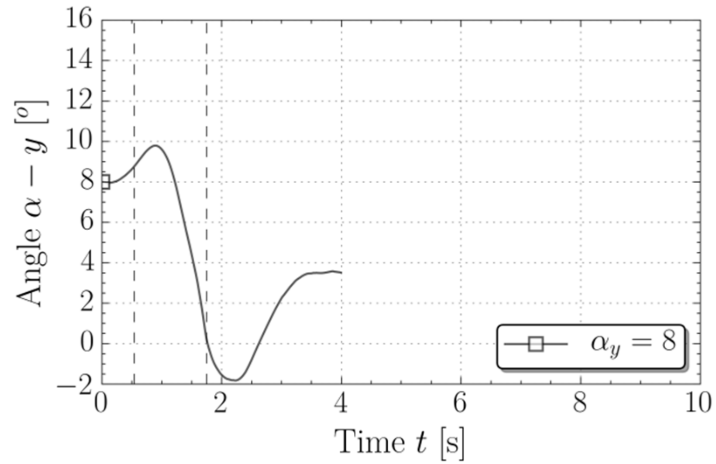
2nd peak very high because pitch attitude almost zero











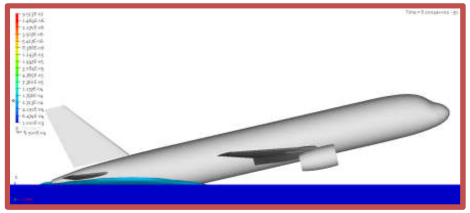
D150 – Results comparison

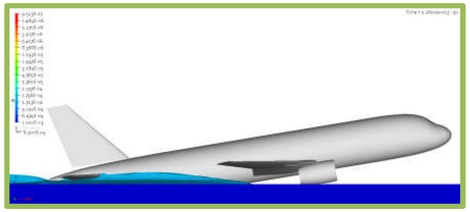
Test case			
M (10^3 kg)	V_x (m/s)	V_z (m/s)	α_y (°)
72.5	**70.0**	-1.5	**-8.0**

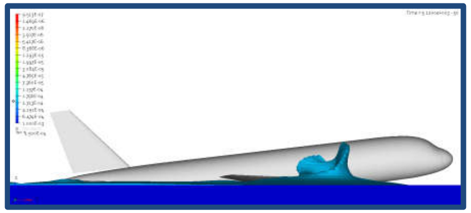
ADAWI
Assessment of Ditching and Water Impact

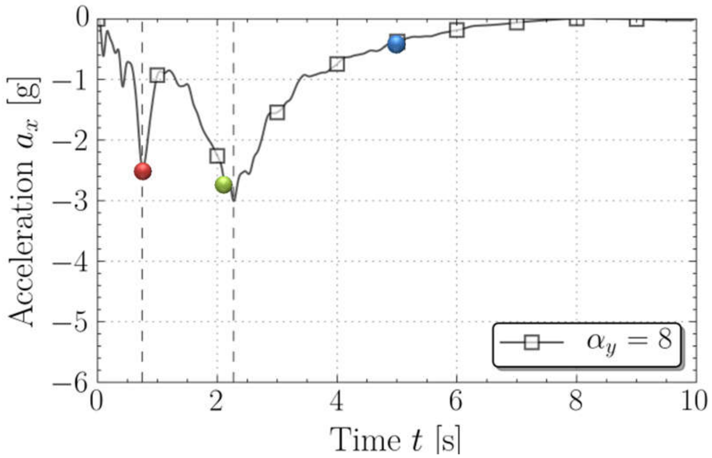
Longitudinal accelerations

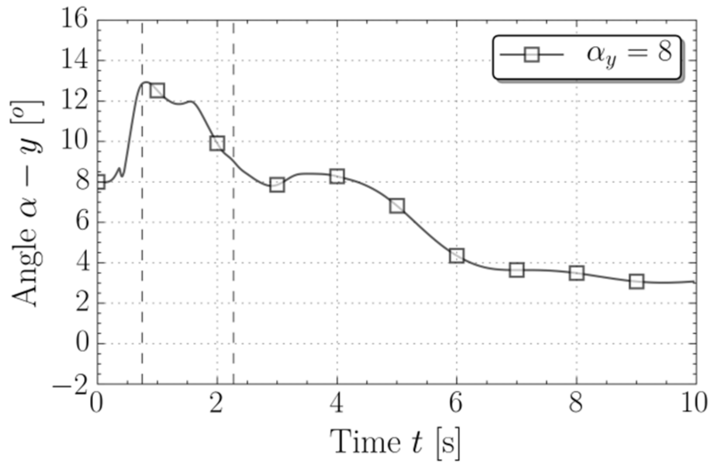
- Acc. in peaks (ALE-CEL)
  - Impact phase
    - During pitch up (0.75 s)
  - Landing phase
    - Engines hit water and started entering into water (~2.1 s)











2nd peak lower because pitch attitude higher during landing phase

DLR

ONERA

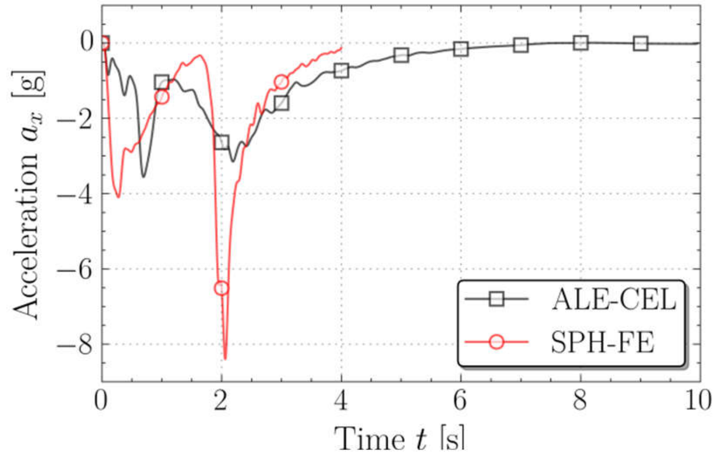
D150 – Results comparison

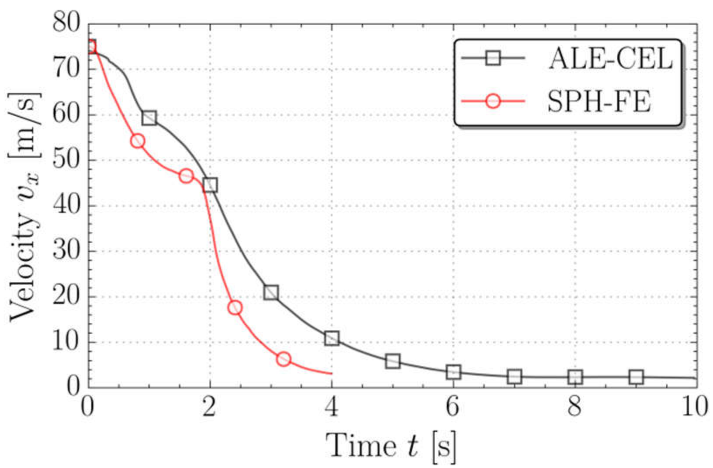
Test case			
M (10^3 kg)	V_x (m/s)	V_z (m/s)	α_y (°)
72.5	**75.0**	-1.5	**-5.2**

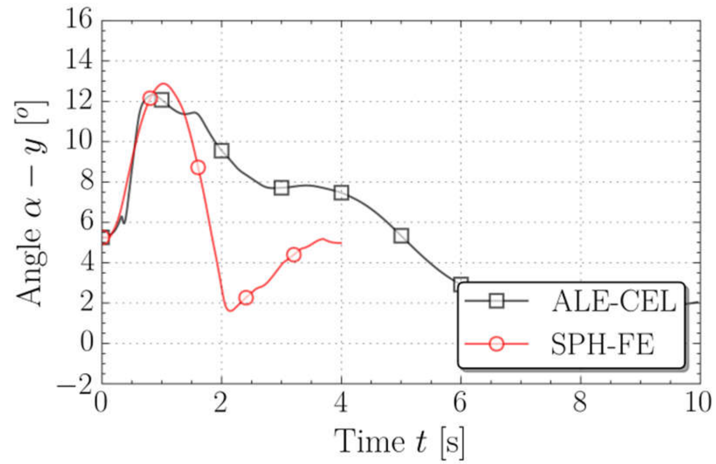
ADAWI
Assessment of Ditching and Water Impact

Ditching configuration with **lowest pitch** attitude (higher speed)

- Impact phase
  - Almost the same maximum pitch up
  - Acc. in peaks very similar
- Landing phase
  - Aircraft decelerate more rapidly in the SPH-FE simulation
  - Pitch attitude decreased rapidly in the SPH-FE simulation







DLR ONERA

Conclusions of method comparison (GDT, ACM, D150)

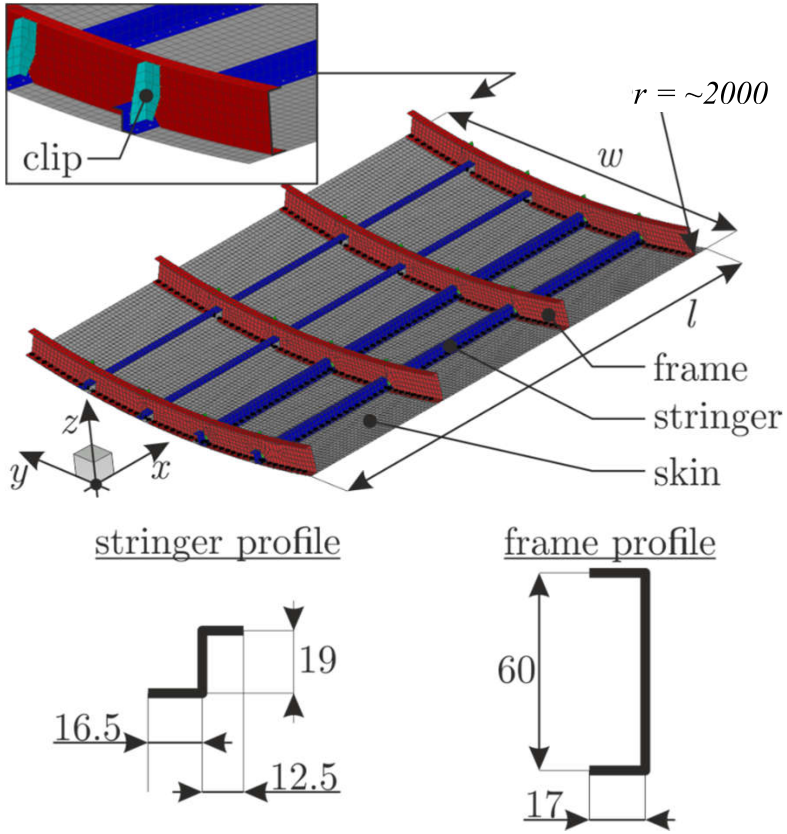
Both approaches capable of simulating ditching with
- Large horizontal velocities
- Large physical time

- SMAES GDT
  - Good agreement in global force
  - Good timing in pressure pulse, peak pressure underestimated
  - Lower correlation on strain results (especially with deformable panels)
- ACM
  - Experiments correctly predicted
  - Run time expensive to obtain correct pressure data
- Generic full aircraft
  - Differences in numerical responses
  - Accelerations in peaks quite similar for the impact phase, more deviation for landing phase

Generic flexible lower fuselage panel

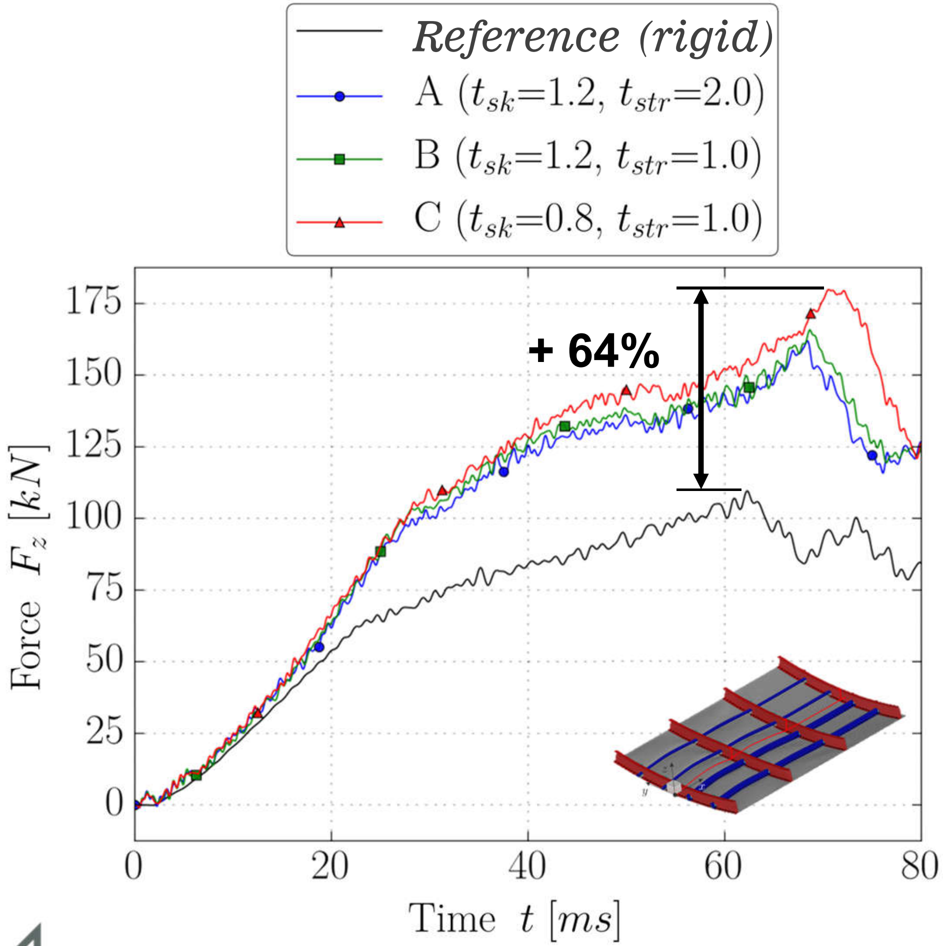
- Extension of study on deformable panel tests from SMAES project
- Numerical simulation with SPH-FE parameters (validated on SMAES GDT results)
- Metallic panel modelled representative for generic lower fuselage panel
- Variation of skin, stringer and frame thickness

Case	Skin t_{skin}	Stringer t_{str}	Frame t_{fr}
Ref	Rigid	Rigid	Rigid
A	1.2	2.0	4.0
B	1.2	1.0	4.0
C	0.8	1.0	4.0



M.H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of Flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, Volume 8, Number 3, pages 505-521 (2017)

Generic flexible lower fuselage panel



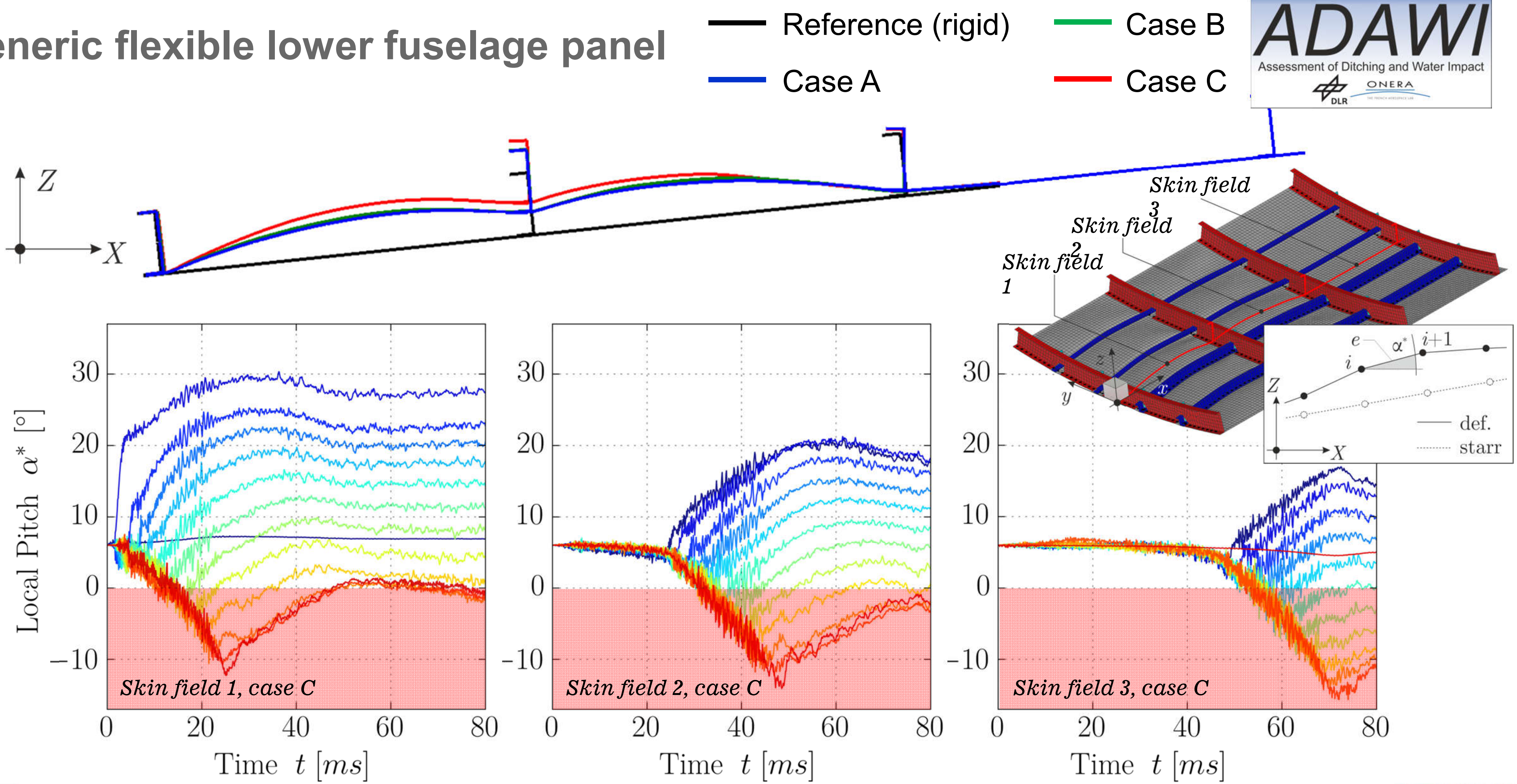
v_X = 40 m/s & α = 6°

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

→ **Structural deformations significantly increase hydrodynamic loads**

M.H. Siemann, D. Kohlgrüber, H. Voggenreiter, Numerical simulation of Flexible aircraft structures under ditching loads, CEAS Aeronautical Journal, Volume 8, Number 3, pages 505-521 (2017)

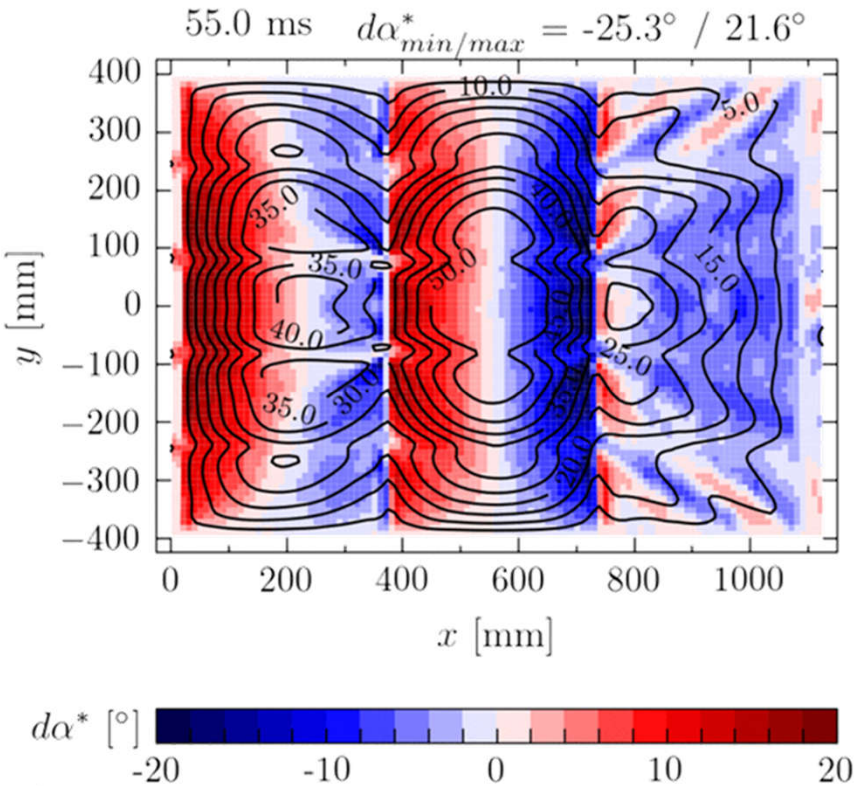
Generic flexible lower fuselage panel



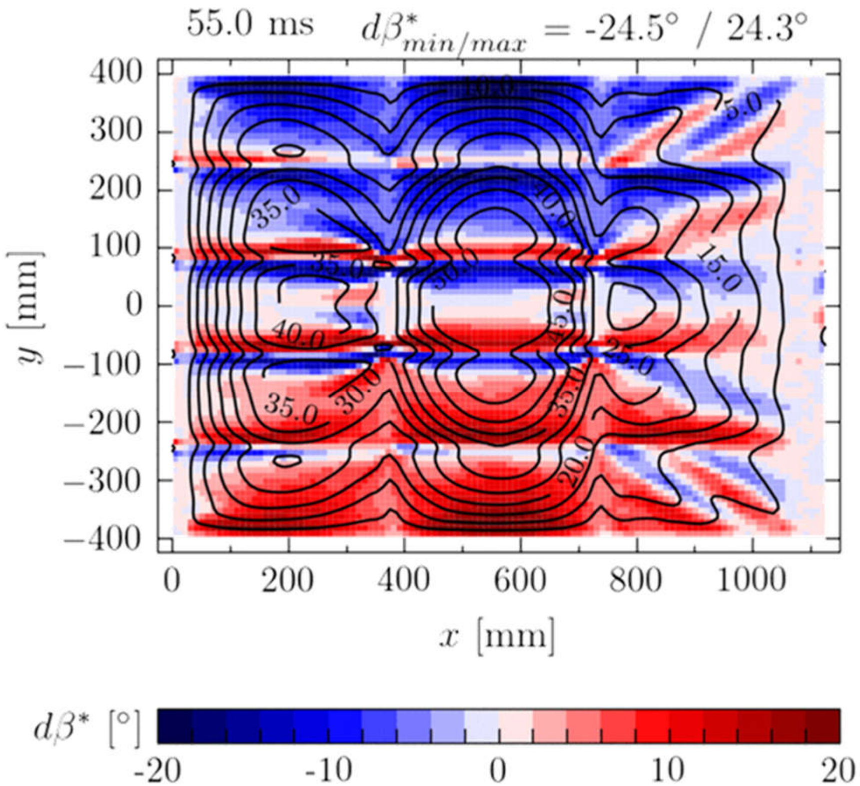
v_X = 40 m/s & α = 6°

Generic flexible lower fuselage panel

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



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



v_X = 40 m/s & α = 6°

t_{sk} = 0.8 mm & t_{str} = 1.0 mm

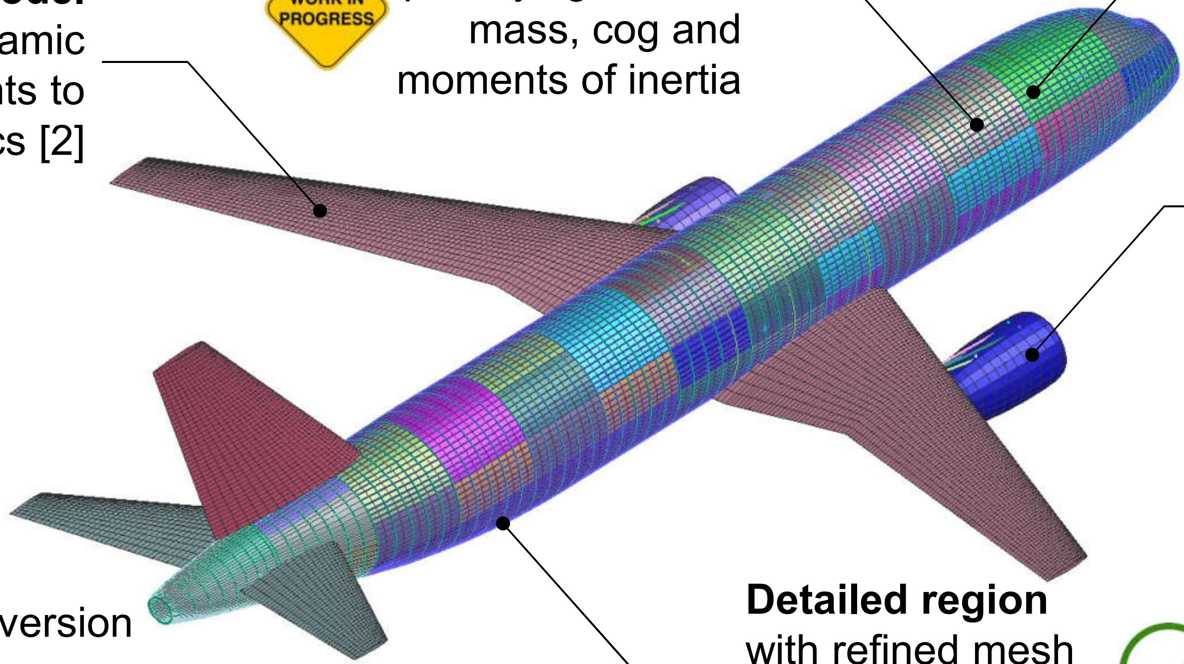
Current work on generic flexible full aircraft model

Aerodynamic model coupling aerodynamic forces/moments to aircraft kinematics [2]

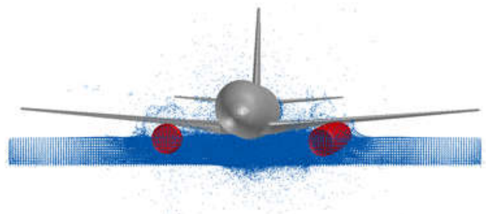
WORK IN PROGRESS

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

Generic transport aircraft mesh (parametric model, autom. generated)



Engine model with potential failure of attachment upon overload [7]



DMP & MMC
customized VPS 2016 version

esi get it right®

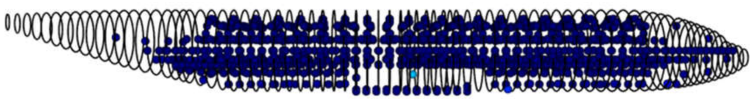
Detailed region with refined mesh accounting for local deformations

DLR ONERA

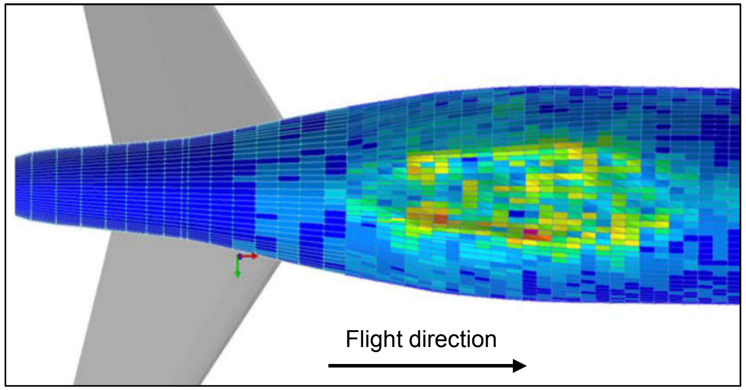
Current work on generic flexible full aircraft model

Currently extension to flexible fuselage model,

- Requires more detailed mass model
  - Lumped masses in addition to primary structure
  - Consistency of mass, CoG position and inertia required
  - Mass model shall be coupled with a general DLR predesign tool chain (incl. data exchange format)
- Additional lumped masses must be coupled to structural model



1574 additional masses considered



Deformations with flexible fuselage model (preliminary result ➔ further checks required)

- Simulation with flexible fuselage model requires parallel version (DMP) with multi-model coupling option (MMC) ➔ available with SPH since summer 2017

Related Publications (2015-2018; mainly ADAWI)

[1] Groenenboom, P. H. L. & Siemann, M. H. (2015). **Fluid-structure interaction by the mixed SPH-FE method with application to aircraft ditching**. *The International Journal of Multiphysics*, *9*(3), 249–265.

[2] Gomes, J. B. (2015). **Numerical Simulation of Aircraft Ditching of a Generic Transport Aircraft: Implementation of an Aerodynamic Model**. *Master thesis*, Instituto Superior Técnico, Lisbon, Portugal.

[3] Siemann, M. H., Schwinn, D. B., Scherer, J. & Kohlgrüber, D. (2015) **Advances in Numerical Ditching Simulation of Flexible Aircraft Models.** In *International Journal of Crashworthiness*, Available online.

[4] Schwinn, D. B., Kohlgrüber, D., Scherer, J. & Siemann, M. H. (2016). **A parametric aircraft fuselage model for preliminary sizing and crashworthiness applications.** In *CEAS Aeronautical Journal*, *7*(3), 357–372.

[5] Siemann, M. H., Kohlgrüber, D. & Voggenreiter, H. (2016) **Numerical Simulation of Flexible Aircraft Structures under Ditching Loads.** In *CEAS Aeronautical Journal,* 8 (3), 505–521.

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

[7] Buchwald, M. (2016) **Numerische Simulation der Notwasserung generischer Luft- und Raumfahrzeug-Strukturen: Entwicklung eines Triebwerkmodells für ein generisches Transportflugzeug** (in German). *Master thesis*, University of Braunschweig, Germany.

[8] Siemann, M. H. & Langrand, B. (2017) **Coupled fluid-structure computational methods for aircraft ditching simulations: comparison of ALE-FE and SPH-FE approaches.** In *Computers & Structures*., 188, 95–108.

[9] Langrand, B. & Siemann, M.H. (2018) **Full-scale aircraft ditching simulation: a comparative analysis of advanced coupled fluid-structure computational methods** International Conference on Impact Loading of Structures and Materials, May 7-11, 2018, Xi' an, China

plus various conferences, e.g. ASIDIC 2015 (Seville) and 2017 (Wichita)

DLR/ONERA Project ADAWI (Assessment of Aircraft Ditching and Water Impact)
Recent progress to model full aircraft ditching

Thanks for your attention