Ditching Simulation of Large Complex Aircraft Models

M.H. Siemann\textsuperscript{1}, D. Kohlgrüber\textsuperscript{1}, D.B. Schwinn\textsuperscript{1}, M. Petsch\textsuperscript{1}, P. Groenenboom\textsuperscript{2}, and O. Amoignon\textsuperscript{3}

\textsuperscript{1} German Aerospace Center (DLR e. V.)
Institute of Structures and Design
Stuttgart, Germany

\textsuperscript{2} ESI Group Netherlands
Leidschendam, The Netherlands

\textsuperscript{3} ESI Group Scandinavia
Sollentuna, Sweden

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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

3. Uncoupled numerical analyzes


Motivation

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

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
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.

Claim and Research Questions

- How and to which extent?
- Which mechanisms characterize and affect the structural response?
- 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
Guided Ditching Experiment – Overview

- Deceleration zone
- Impact zone
- Acceleration zone
- Guide track with reinforcement ($l_x$ ca. 64 m)
- Catapult system
- Water basin ($l_x = 470$ m, $l_y = 13.5$ m, $l_z = 6.5$ m)
- Trolley
- External high-speed camera

Images:
- 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

Finite Element (FE) vs. Smoothed Particle Hydrodynamics (SPH)
Structural Model

- FE method
- Guide structure for proper boundary conditions

- Modelling strategies from aeronautical crash FEA domain
- Shell elements with $l_{\text{char}} \geq 10$ 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)

<table>
<thead>
<tr>
<th>Force $F_z [kN]$</th>
<th>Strain $\varepsilon_x [%]$</th>
<th>Strain $\varepsilon_y [%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time $t [ms]$</td>
<td>Time $t [ms]$</td>
<td>Time $t [ms]$</td>
</tr>
</tbody>
</table>

- Exp 45 m/s & 4°  
- Exp 40 m/s & 6°  
- Exp 30 m/s & 10°  
- Sim 45 m/s & 4°  
- Sim 40 m/s & 6°  
- Sim 30 m/s & 10°  

$t = 3 \text{ mm}$
Guided Ditching Experiment
Simulation Approach and Models

Full Aircraft Ditching

Conclusion and Outlook
Overview

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

- 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

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


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

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

Conventional  CPACS

○ analysis tool(s)  ▶ CPACS data set

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

Full A/C Ditching
Fuselage Modeling

Global/Detailed FE Model

Global Beam Model

Rigid Body Model

Complexity / Level of detail

Full A/C Ditching

Introduction

Experiment

Simulation

Conclusion

INPUT

CPACS file
User Input

AC-DITCH

Initialize

Fuselage

Library

Wing / Empennage

Engine

Aerodynamics

Water

Master

Start
Fuselage Modeling – DFEM level of detail

- Seats (3PAX)
- PAX cross beams
- Frames (detailed/global)
- Stringers (detailed/global)
- Seat rails
- Vertical struts
- Cargo cross beams

Intro | Experiment | Simulation | Full A/C Ditching | Conclusion

Full A/C Ditching

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

Engine Modeling

- Engine attachment failure due to overload
  (reference case)
Engine Modeling

• **Unsymmetrical** load case (Hudson impact conditions)
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

\[ L = \frac{\rho}{2} S C_L v^2 \]
\[ D = \frac{\rho}{2} S C_D v^2 \]
\[ M = \frac{\rho}{2} S I C_M v^2 \]

• 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

**FLUID**
- main file
- mesh file(s)
- VPS input file(s)

**STRUCTURE**
- main file
- mesh file(s)
- VPS input file(s)
- User subroutine(s)

**INPUT**
- CPACS file
- User Input

**AC-DITCH**
- Initialize
- Fuselage → Library
- Wing / Empennage
- Engine
- Aerodynamics
- Water
- Master
- Start
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
  - 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

Detailed regions
- with refined mesh accounting for local deformations

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

HPC & MMC

AC-Ditch
Thank you for your attention!

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