Coupled CFD and Vortex Methods for Modelling Hydro- and Aerodynamics of Tidal Current Turbines and On- and Offshore Wind Turbines

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Dipl.-Ing. Friedemann Beyer
SIMPACK Projects at SWE

**FLOATGEN**

**Partners:**
- GAMESA, IDEOL, University of Stuttgart, Ecole Centrale de Nantes

**Content:**
- Demonstrate the technical and economic feasibility of fitting a 2 MW turbine model on a floating platform

**Voith Tidal Hydroelasticity**

**Partners:**
- Voith Hydro Ocean Current Technologies, University of Stuttgart

**Content:**
- Development and application of a FSI environment with coupled MBS-CFD for modeling of Tidal Turbines

**LARS**

**Partners:**
- SkyWind GmbH, DLR Braunschweig, University of Stuttgart

**Content:**
- Development of an active load reduction device LARS at the hub for a 2-bladed wind turbine
Motivation

Fluid-Structure-Interaction:
- flow physics often **nonlinear** and highly complex (e.g. flow separation, breaking waves)
- simple methods not capable of including all effects
- need for detailed loads distribution for design purposes
- focus is on **fidelity** rather than quantity

Tacoma-Narrows-Bridge (1940)

[Prelinger Archives]
Content

I. Methodology Coupling

II. Validation

III. Application to
   I. Tidal Current Turbine
   II. Floating Offshore Wind Turbine
   III. Onshore Wind Farm

IV. Summary and Conclusions
I. Methodology Coupling

II. Validation

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IV. Summary and Conclusions
### Comparison of FSI against FMBI

<table>
<thead>
<tr>
<th>Property</th>
<th>FSI (CFD + FEM)</th>
<th>FMBI (CFD + MBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fluid</td>
<td>recalculated each time step</td>
<td></td>
</tr>
<tr>
<td>structure</td>
<td>recalculated each time step</td>
<td>actualization of mode shapes</td>
</tr>
<tr>
<td>repeated objects</td>
<td>independent</td>
<td>common database</td>
</tr>
<tr>
<td>higher order kinematics</td>
<td>complex</td>
<td>included</td>
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<tr>
<td>required data</td>
<td>detailed geometry</td>
<td>property distributions</td>
</tr>
<tr>
<td>load mapping</td>
<td>pressure mapping</td>
<td>discrete number of forces</td>
</tr>
<tr>
<td>usage</td>
<td>post design process</td>
<td>integrated to design process</td>
</tr>
</tbody>
</table>
Tasks within the FMBI Coupling Code

- **translator**: coordinate transformations & interpolation
- **sender**: collecting local data & transfer to common storage
- **receiver**: distributing coupling data & synchronization of time
- **moderator**: communication procedure & convergence control
FMBI Solver Scheme

- fully **implicit** method
- coupling data is exchanged for each coefficient loop of CFX
- SIMPACK solver repeated after each coupling time step integration
- convergence and number of coefficient loops controlled by moderator
CFD Translator: Flexible Body Deformation (1/2)

- \( \Delta x_0 \) and \( \alpha_0 \) only known at discrete \( p_0 \)

- \( p_0 \): reference coordinate system
- \( \Delta x_0 \) and \( \alpha_0 \): rotational and translational deformation of \( p_0 \)
- \( p_{loc} \): location of undeformed point with respect to \( p_0 \)
- \( \Delta x_{loc} \): deformation of \( p_{loc} \)
- $\Delta x_0$ and $\alpha_0$ only known at discrete $p_0$
- Discrete $p_0$ are assembled to “beams”
- Interpolation of $p_0$, $\Delta x_0$ and $\alpha_0$ based on 9 splines $f_0$, $f_{\Delta x_0}$ and $f_{\alpha_0}$
Characteristics

- CFD-Surface is split into finite number of sections (e.g. 8 for a rotor blade)
- each section is coupled to a marker in SIMPACK
- integration of loads on each section and transfer to corresponding marker in SIMPACK
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Validation: Spring Pendulum, Rigid Body (1/2)

Description:
- spring pendulum in water basin
- free-decay motion
- loads due to **added-mass** and **drag**

**CFD: CFX**

**MBS: SIMPACK**

**Vertical Position and Fluid Loading**

- force output.$F_{CFX2SPCK}.M001: Fy
- body pos.$B_Body1.y

colormap: velocity 0...0.1 m/s
Validation: Spring Pendulum, Rigid Body (2/2)

Experiment:
- simple aquarium filled with water
- various pendulums for validation
- **motion tracking** using camera and Matlab

Comparison to Simulation:
- very good correlation
**Validation: Bending Pendulum, Flexible Body**

**Experiment:**
- sheet of spring steel, additional masses for frequency calibration

**Comparison to Simulation:**
- very good correlation

![Image of experiment setup]

** colormap: velocity 0...0.1 m/s**

![Graph showing comparison between experiment and simulation]
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Characteristics

- „wind turbine under water“
- **harvesting currents** caused by lunar tides
  - complex flow conditions
  - turbulent environment
  - rotor-stator interaction
- added mass
- impact of **structural flexibility** on loads and rotor blade flow still unknown

Voith HyTide 1000-16®
P = 1 MW
D = 16 m
Tidal Test Site: European Marine Energy Centre

Voith HyTide 1000-13®
P = 1 MW
D = 13 m
MBS and CFD Modell Setup (2/2)

**Voith HyTide 1000-13®**

- $P = 1 \text{ MW}$
- $D = 13 \text{ m}$

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**Force Element Properties: $F_{CFX2SPCK}$**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>$F_{CFX2SPCK}$</td>
<td></td>
</tr>
<tr>
<td>From Marker</td>
<td>$M_{lays}$</td>
<td></td>
</tr>
<tr>
<td>To Marker</td>
<td>$M_{lays}$</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>$3D$: CPX/SPOC/CoUpl</td>
<td></td>
</tr>
</tbody>
</table>

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**Model Tree**

- Voith_HyTide_1000_13
- ...
Tidal Turbine in Ultimate Load State (1/2)

Time = 19.1513 [ s ]
Deformation Scaling: 50

Total Mesh Displacement [m]
Tidal Turbine in Ultimate Load State (2/2)

Blade Root My

Tower Base My
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Simulation Parameters

- NREL offshore 5-MW baseline wind turbine, rigid OC3-Hywind spar-buoy

Load Case Definition
- Free-decay in platform surge (initial condition $x = 21$ m)
- Enabled DOF: surge, sway, roll, pitch, yaw (no heave)
- No wind, still water
Platform Surge

- MBS+CFD
- FAST (integrated WT model)
- MBS+HydroDyn+AddDamping
- MBS+HydroDyn (reduced PtfmCD)
Platform Pitch

Simulation Time, $t [s]$ vs. platform pitch $[\degree]$
Vorticity and Tangential Velocity (2/2)

- $z = -82.5$ m (overall CM)
Vortex Core Region
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Motivation for Vortex Methods

- limitation of **computational resources**
- industrial application of CFD for extremely large domains difficult
- **alternative** semi-empirical approaches like BEM and **vortex methods**
- CFX2SPCK coupling extended to WInDS
Free Vortex Method

Lifting Line Theory:
- Kutta-Joukowski
- bound vortex at finite wing
- Helmholtz’s vortex theorem, Kelvin’s circulation theorem

Vortex Lattice Method:
- vortex filaments convect and deform freely
- shed filaments: flow unsteadiness
- trailing filaments: spanwise variation in lift

[Katz, Plotkin]
Wind Farm Simulation using WInDS/SIMPACK

- **Matlab** based Wake Induced Dynamic Simulator (WInDS)
- **GPU** accelerated
- free vortex method for aerodynamics
- implicit and explicit **coupling** to SIMPACK
- current studies:
  - code-2-code comparison (ECN Aeromodule AWSM)
  - wind farm simulation
  - wind farm **control** and layout optimization
Skywind 3.4 MW Wind Farm

- D = 107 m
- rated conditions
- 2D distance
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Summary and Conclusions

- FMBI coupling between SIMPACK and ANSYS CFX based on exchange of force and motion information of markers:
  - successfully developed and validated
- application to tidal current turbine and floating offshore wind turbine
  - strong influence of fluid on flexible structure and vice versa
- demonstration of new approach for GPU accelerated wind farm simulation using SIMPACK and WInDS

Outlook:
- simulation of extreme wave events on floating platforms
- wind farm control and layout optimization
Acknowledgements

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Thank you for your attention!

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