Fluid-Structure Interaction of Thin Structures in Turbulent Flows

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HELMUT SCHMIDT UNIVERSITÄT

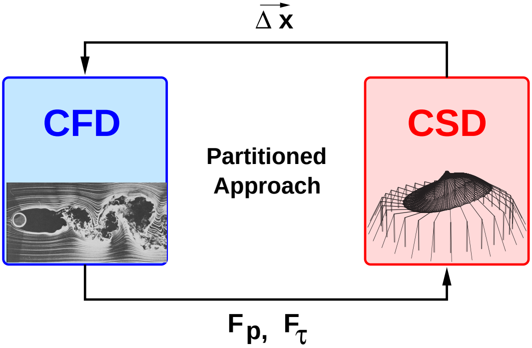
SuperMUC Review Workshop
Garching, July 2014

PfS

1. Motivation / Objectives
2. Computational Methodology
3. Validation
   - Definition of the Test Cases
   - Simulations and Comparison with Experiments (FSI-PfS-2a)
4. Conclusions

Tents / Sun Shades / Mobile Umbrellas

FSI in Turbulent Flows

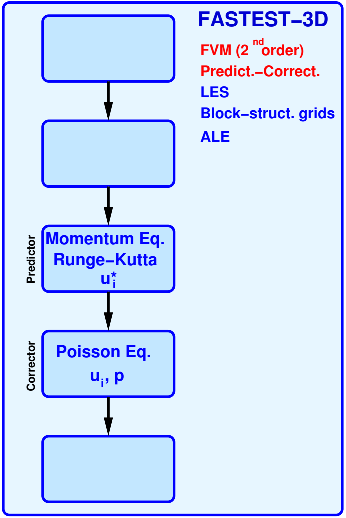


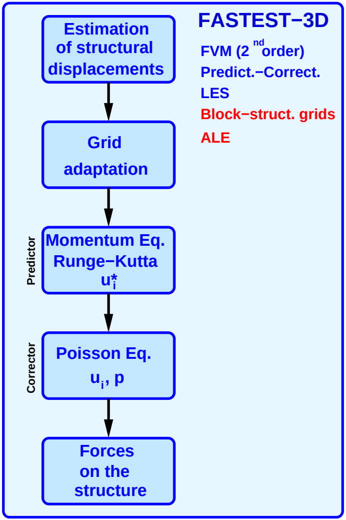
Publication

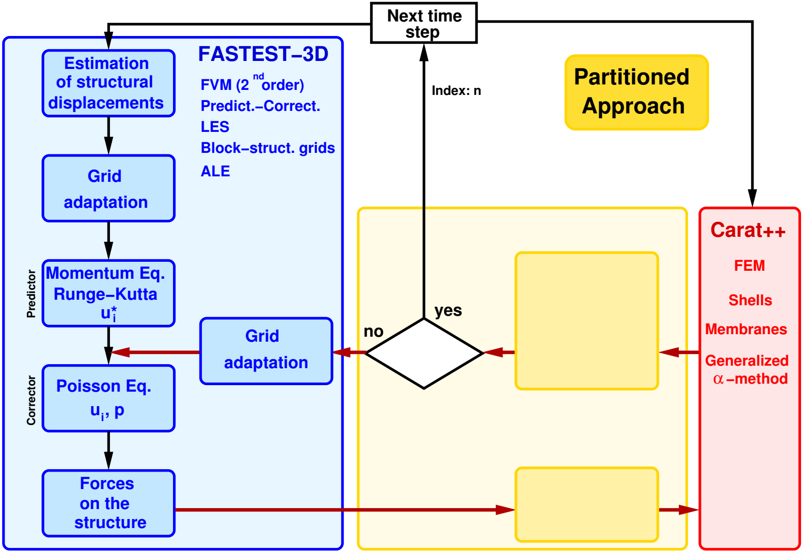
Breuer, M., De Nayer, G., Münsch, M., Gallinger, T., Wüchner, R.:

Fluid-Structure Interaction Using a Partitioned Semi-Implicit Predictor-Corrector Coupling Scheme for the Application of Large-Eddy Simulation.

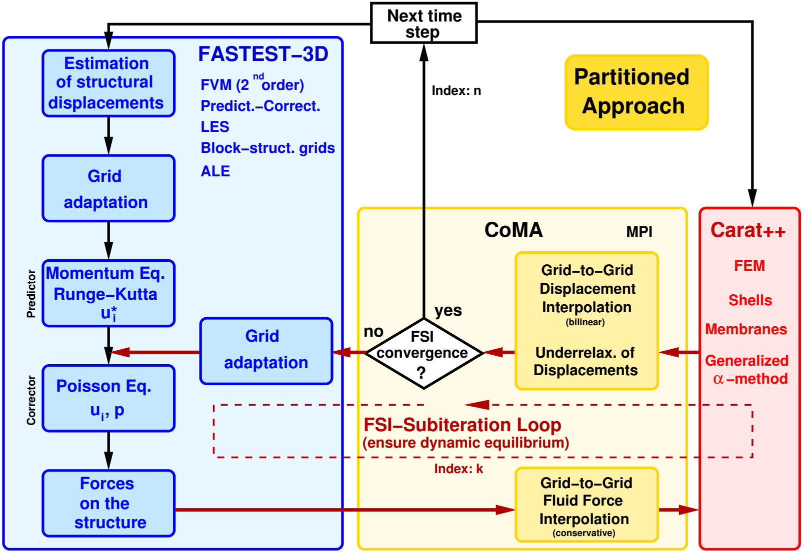
Journal of Fluids and Structures 29, 107-130, 2012.


FASTEST–3D
FVM (2 nd order)
Predict.–Correct.
LES
Block–struct. grids
ALE
Predictor
Momentum Eq.
Runge–Kutta
u_i^*
Corrector
Poisson Eq.
u_i, p


FASTEST−3D
FVM (2 nd order)
Predict.−Correct.
LES
Block−struct. grids
ALE
Estimation of structural displacements
Grid adaptation
Predictor
Momentum Eq. Runge−Kutta u_i^*
Corrector
Poisson Eq. u_i, p
Forces on the structure



Computational Methodology: FSI with LES and Thin Structures



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Computational Methodology: FSI with LES and Thin Structures

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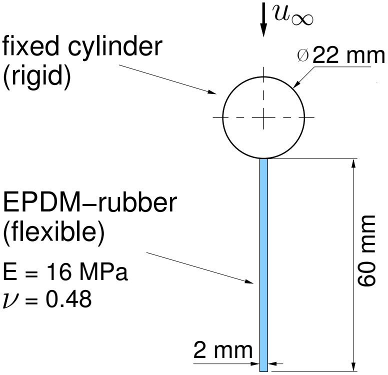
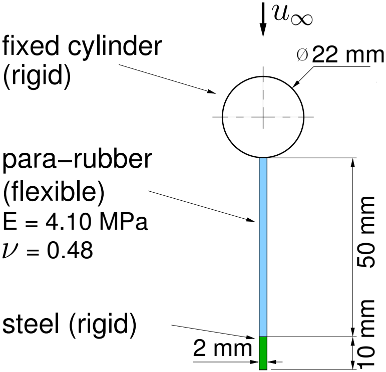
FSI-PfS-1a



- Re $=$ 30,470
- quasi 2D-deformations
- small deformations
- first swiveling mode

FSI-PfS-2a



- Re $=$ 30,470
- 2D-deformations
- large deformations
- second swiveling mode

Publications for FSI-PfS-1a

- De Nayer, G., Kalmbach, A. Breuer, M., Sicklinger, S. and Wüchner, R.:

  Flow past a cylinder with a flexible splitter plate: a complementary experimental-numerical investigation and a new FSI test case (FSI-PfS-1a).

  Int. Journal of Computers and Fluids 99, 18-43, 2014.

- `http://qnet-ercoftac.cfms.org.uk/w/index.php/UFR_2-13`

Publications for FSI-PfS-2a

- Kalmbach, A. and Breuer, M.:

  Experimental PIV/V3V Measurements of Vortex-Induced Fluid-Structure Interaction in Turbulent Flow New Benchmark FSI-PfS-2a.

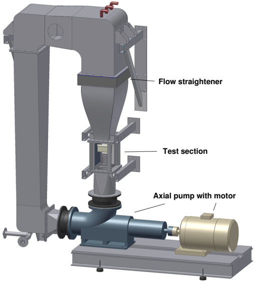
  Journal of Fluids and Structures 42, 369-387, 2013.

- De Nayer, G. and Breuer, M.:

  Numerical FSI Investigation based on LES: Flow past a cylinder with a flexible splitter plate involving large deformations (FSI-PfS-2a).

  Submitted.

- `http://qnet-ercoftac.cfms.org.uk/w/index.php/UFR_2-14`



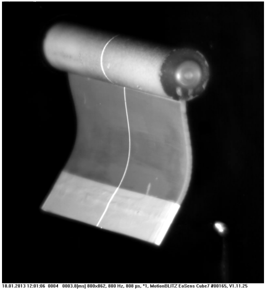
Water Channel

+

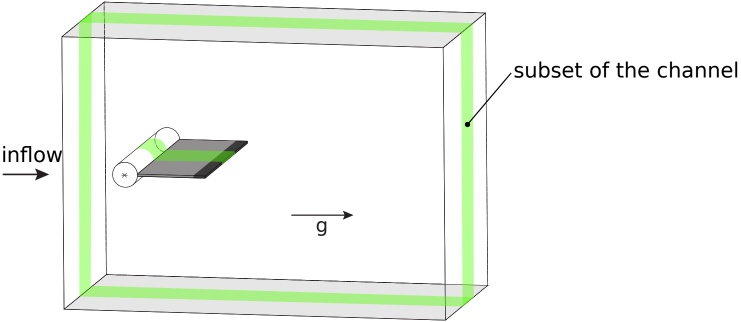
Flow measurement methods (PIV / V3V)
Laser displacement sensor

⇓

Experimental Data



High-speed video
(real frequency 11.25 Hz)



Fluid/CFD:

- wall–resolved LES
- 13.5 million CVs
- 72 CVs in spanwise direction
- periodic boundary conditions

Structure/CSD:

- 7–parameter shell elements
- 30 $\times$ 10 quadrilateral four-node elements
- zero z–deformation vs. periodic b.c.
- (Rayleigh damping)

93 cores needed for each simulation

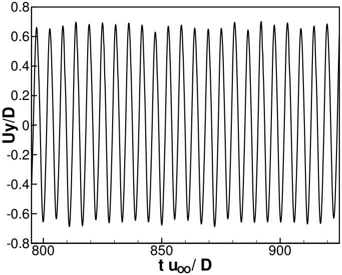
- 13.5 million CVs on 91 blocks → 91 processes for CFD
- 1 process for CSD
- 1 process for coupling program

2 seconds physical time computed for each simulation

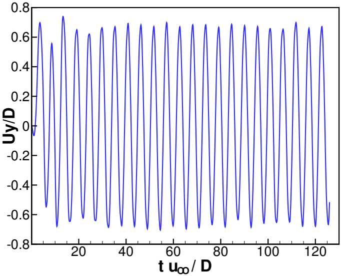
- CPU: 1000 hours wall-clock
- RAM: 242 Mbytes per core → 22 Gbytes for the entire simulation

Sensitivity study on FSI-PfS-2a

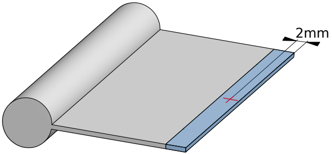
- about 30 simulations with different parameters conducted



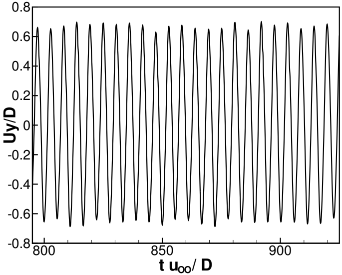
EXP: Raw Signal

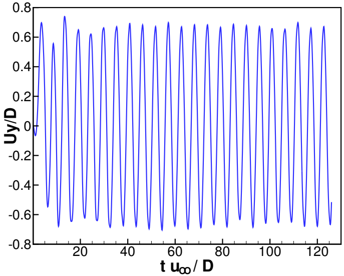


CFD: Raw Signal



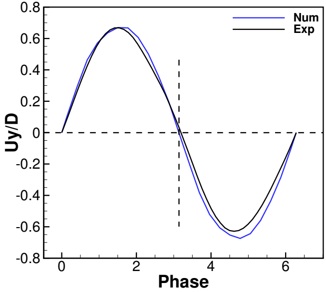
Monitoring Point (mid plane)





EXP: Raw Signal

CFD: Raw Signal



Averaged Phase

Frequency

	St	f_{FSI}	Error
		(Hz)	(%)
EXP	0.177	11.25	-
CFD	0.183	11.53	2.49

Frequency

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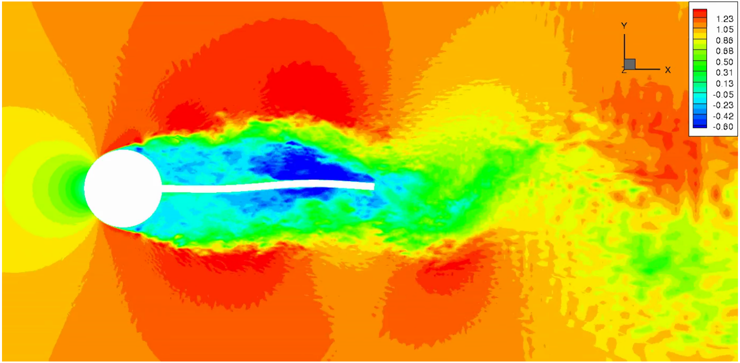
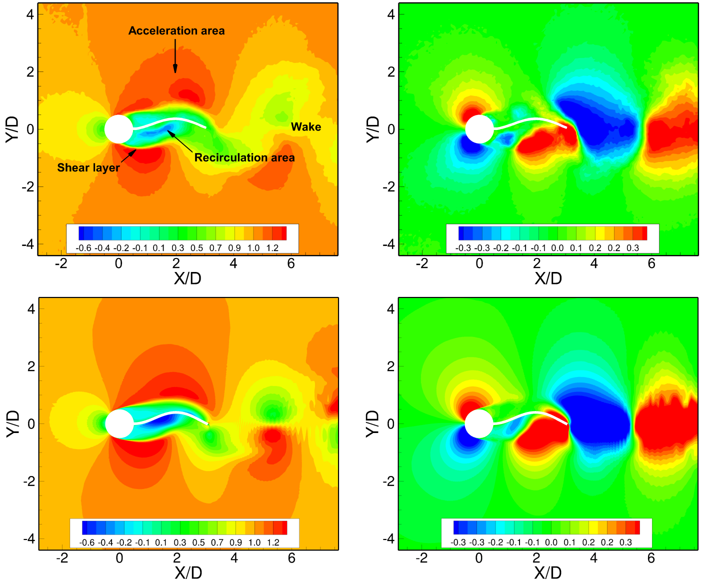
Displacements

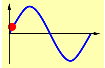
	$U_y/D\|_{max}$	Error	$U_y/D\|_{min}$	Error
		(%)		(%)
EXP	0.667	-	-0.629	-
CFD	0.670	0.5	-0.674	7.2

Streamwise velocity in the midplane



Streamwise velocity | Transverse velocity



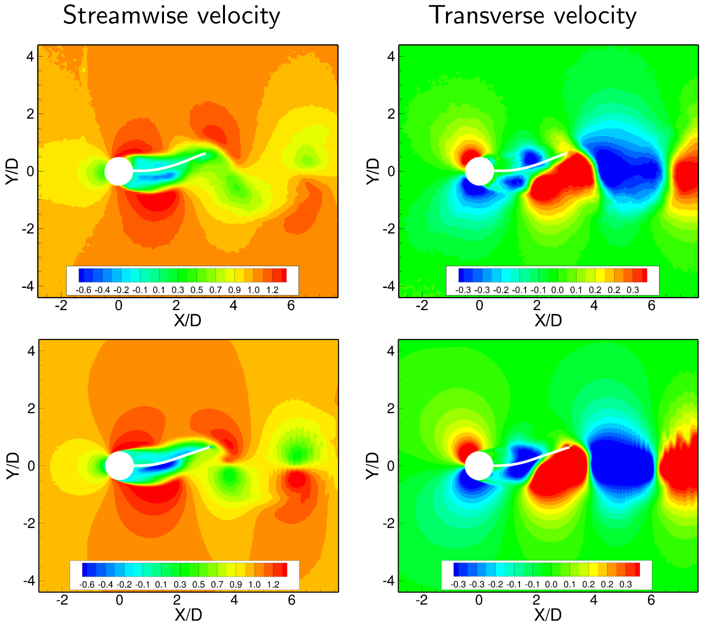


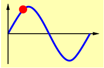
EXP

CFD

FSI-PfS-2a: Comparison of Phase-averaged Data ($t \approx 1/24$ T)

Helmut Schmidt Universität





EXP

CFD

FSI-PfS-2a: Comparison of Phase-averaged Data ($t \approx 5/24$ T)

Computational Methodology for FSI and Thin Structures

- Each program **specialized** in its task
- Each program **parallelized (MPI, OpenMP)**
- **New** FSI coupling scheme developed
  - ☞ based on **explicit** time–marching scheme (predictor–corrector), but nevertheless **stable and strong** FSI algorithm
  - ☞ corrector step and structural computation directly connected in a FSI subiteration loop to achieve dynamic equilibrium

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Validation

- Methodology validated for **laminar flows** (not presented here)
- Methodology validated for **turbulent flows** (FSI-PfS-2a,...)
- Generation of FSI test cases for the community with **experimental and numerical data available online** (ERCOFTAC/QNET wiki)

Outlook

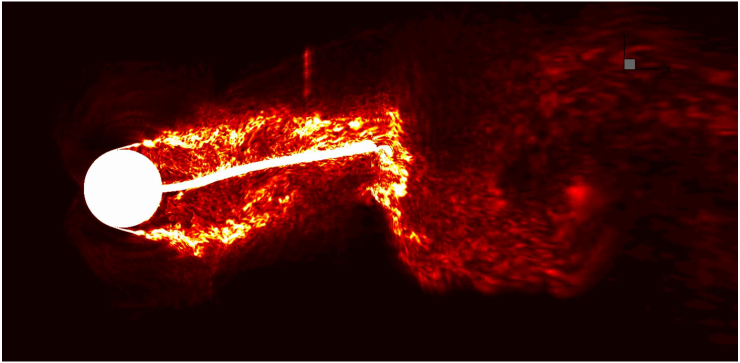
- New coupling program (EMPIRE) → **more flexibility** in the coupling
- **Reduce the CPU costs** with the help of special wall models

Acknowledgments:

- Thanks to **Jens Nikolas Wood** for his support.

- Financially supported by the *Deutsche Forschungsgemeinschaft* (BR 1847/12-1)

- Computations on the Top-Level Computer **SuperMUC** at LRZ Munich.



Thanks for your attention