Chalmers University of Technology
Division of Fluid Mechanics

University of Stuttgart
Institute of Fluid Mechanics and Hydraulic Machinery

Numerical Investigations of the Unsteady Flow in the Swirl Generator of Stuttgart with OpenFOAM

A co-project between the Chalmers University of Technology, Sweden and the Institute of Fluid Mechanics and Hydraulic Machinery at the University of Stuttgart, Germany

Martin Gramlich

About Gothenburg and Its University

Göteborg

- Citizens: ≈ 550 000
- Surrounding companies:
  - SKF
  - Volvo
  - Ericsson

Chalmers University of Technology

- Private university
- Students: ≈ 11 000
- Focuses: technology, natural science and architecture
- High Performance Cluster:
  - 268 nodes with each 8 cores
  - Nehalem CPUs with 2.27 GHz

About the Project

Motivation

- Graduation at the University of Stuttgart, Germany
- Major at the Institute of Fluid Mechanics and Hydraulic Machinery
- Contact of Dr. H. Nilsson

Involved People

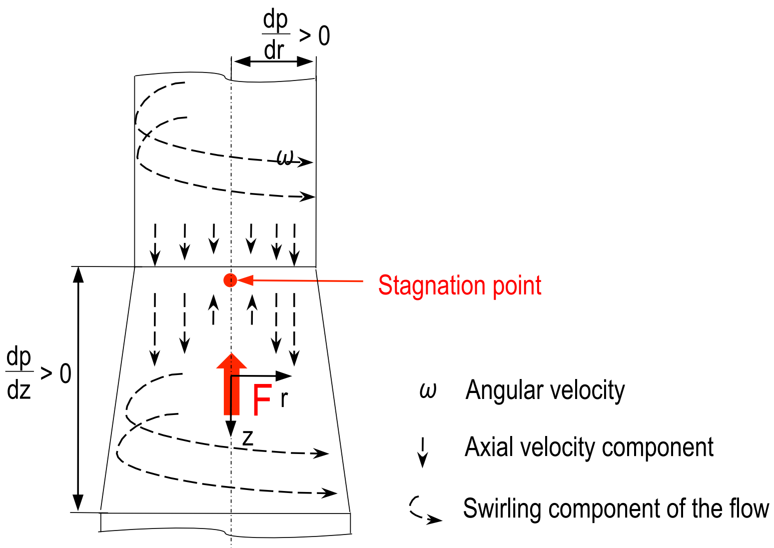
- Dr. H. Nilsson
- Prof. Dr.-Ing. S. Riedelbauch, Dr. A. Ruprecht
- Ms. I. Buntic-Ogor, Mr. T. Krappel
- Mr. E. Ohlberg, Mr. O. Kirschner

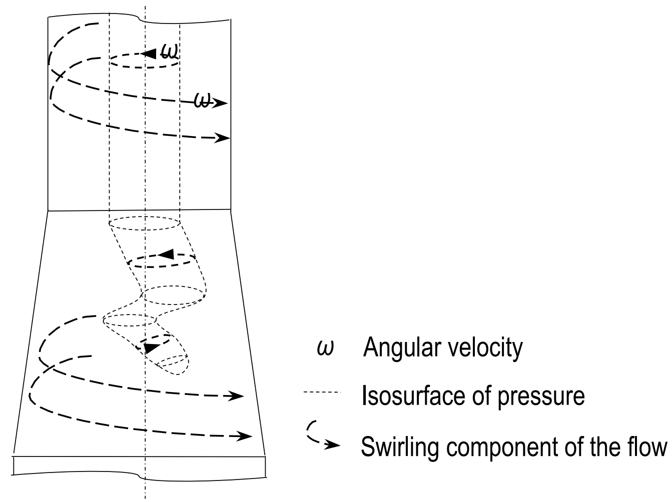
Outline

1. Theoretical Background
2. Cases
3. Results
4. Conclusion and Prospect

Background

- Helical vortex common in hydraulic power plants, which are operated at part load conditions





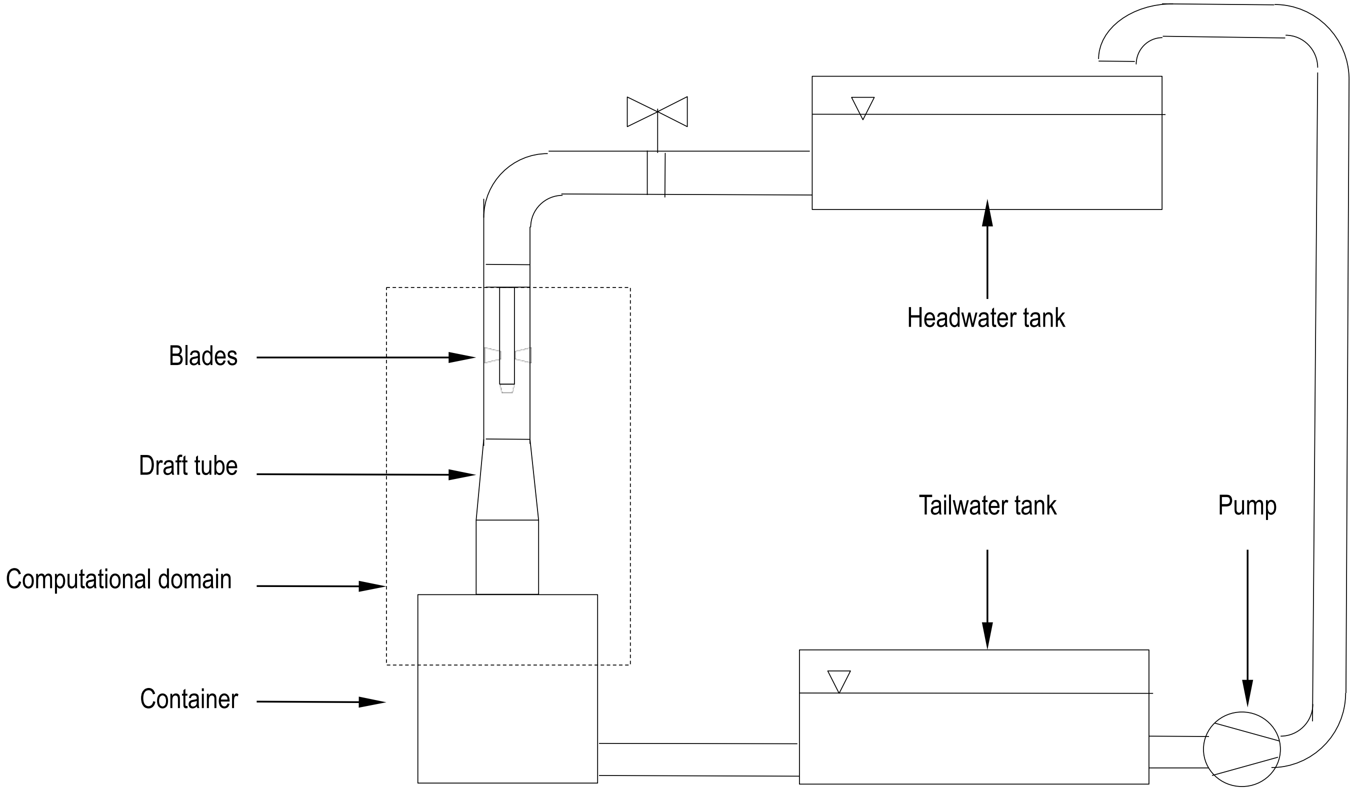
Motivation

- Physical phenomenon far from being completely understood
- Possible effects on the power plant:
  - ➢ Increases the risk of **fatigue failure**
  - ➢ Could lead to **resonance vibration**
  - ➢ **Lowers the efficiency** of the power plant

Necessary to simulate the helical vortex precisely!

Features of the Swirl Generator

- 8 non-rotating blades:
  - Angle adjustable
  - Not curved



Goal of My Thesis

Set up of Cases for the Swirl Generator of Stuttgart with OpenFOAM

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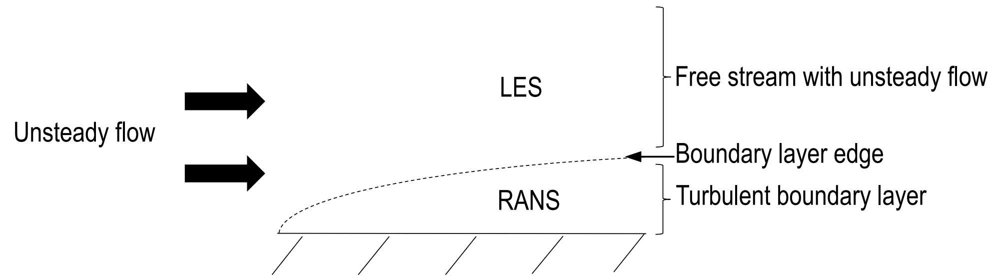
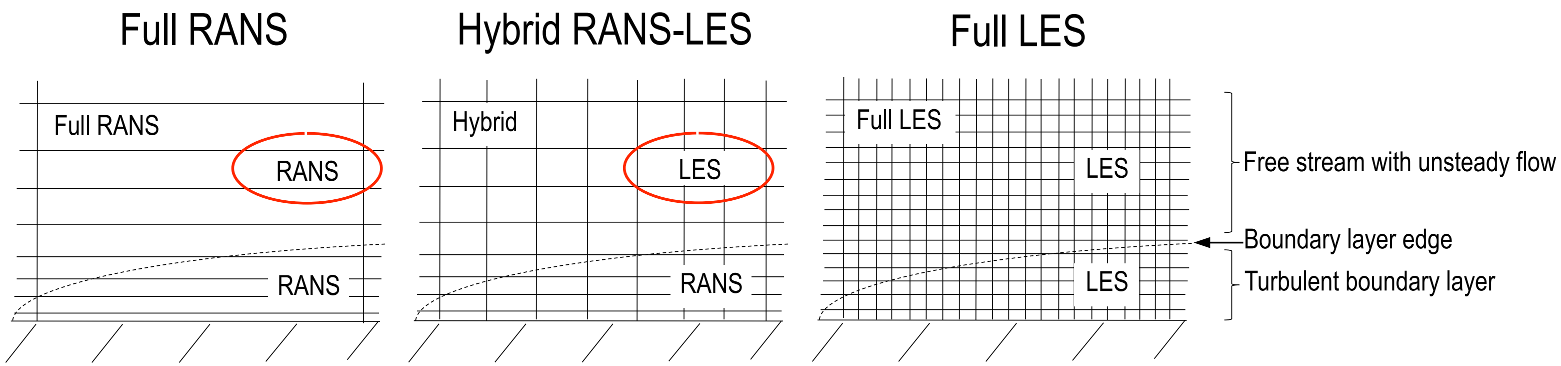
Focus: hybrid RANS-LES turbulence models

Idea of hybrid strategies



Advantages of hybrid strategies

- Lower mesh resolution than for full LES
- Resolution of large scale turbulent structures



Cases

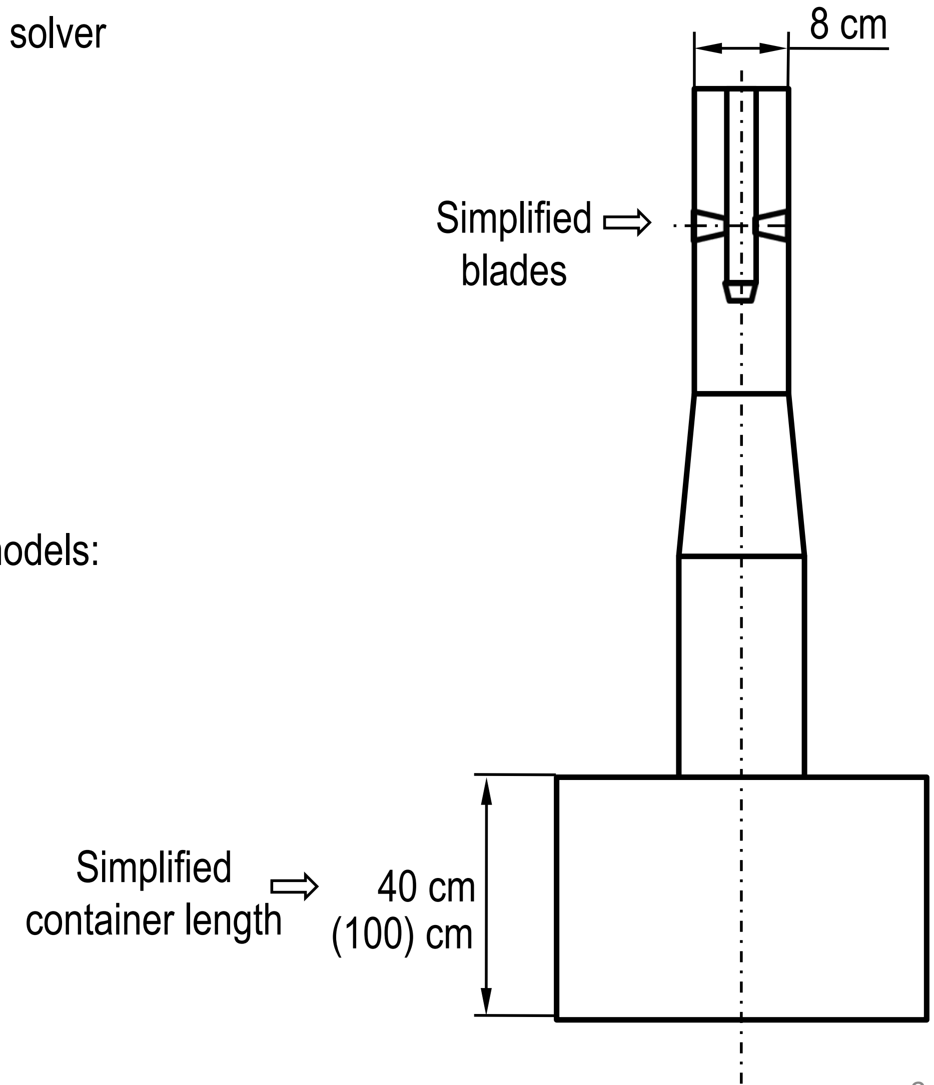
- OpenFOAM 1.6-ext. with the pimpleFoam solver
- Blade angle of 30°
- Discharge of 25 m^3/h and 40 m^3/h

Computational domain

- ≈ 2.9 million cells (RANS models)
- ≈ 6.5 million cells (Hybrid models)

Turbulence models

- Standard high-Reynolds number RANS models:
  - **k-ε**
  - **k-ω SST**
- Hybrid RANS-LES models:
  - **k-ω SST SAS**
  - **Spalart-Allmaras DDES**
  - **Spalart-Allmaras IDDES**



Results of the Simulations with a Discharge of 25 m^3/h

Performance of the Simulations

- Based on the timestep, required time to calculate 1 timestep and maximum Courant number of the latest executed timestep. The values are normalized for simulations decomposed on 32 processors and a maximum Courant number of 1.

	k-ε	k-ω SST	k-ω SST SAS	S-A DDES	S-A IDDES
Timestep in [s]	$9*10^{-5}$	$1*10^{-4}$	$1*10^{-5}$	$2*10^{-5}$	$9*10^{-7}$
Time to calculate 1 timestep in [s]	74	73	227	231	226
Time divided by the average of the RANS models	1	1	3	3	3
Time to simulate 1 s of the flow in [d]	9	9	198	142	2977
Time divided by the average of the RANS models	1	1	22	16	330

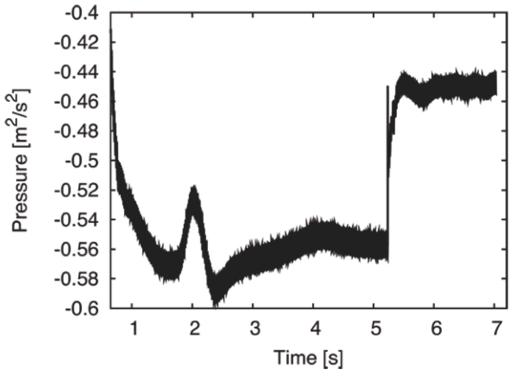
Average Number of Iterations to Calculate the Pressure

- Based on the latest timestep of the simulations and the non-orthogonal corrector step.

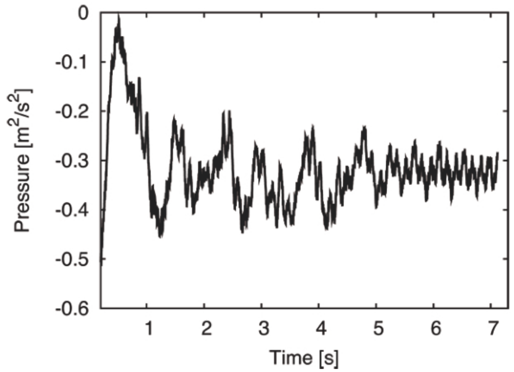
	k-ε	k-ω SST	k-ω SST SAS	S-A DDES	S-A IDDES
Average number of iterations per timestep	437	431	646	680	510
Difference to the average number of iteratioins of the RANS model	-	-	212	246	76

Development of the Simulations

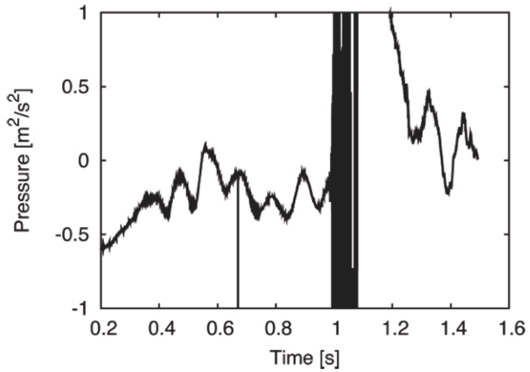
- Based on the development of the pressure signal at position P1



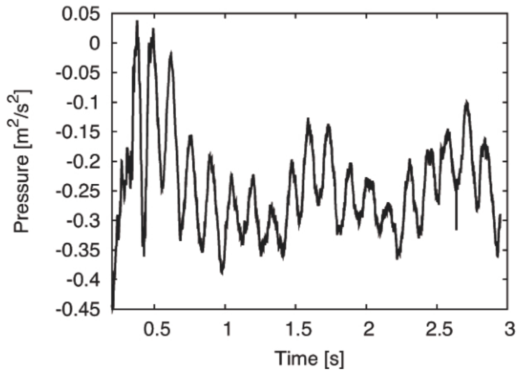
k-ε



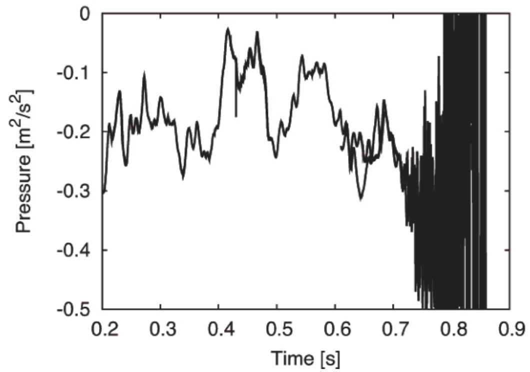
k-ω SST



k-ω SST SAS



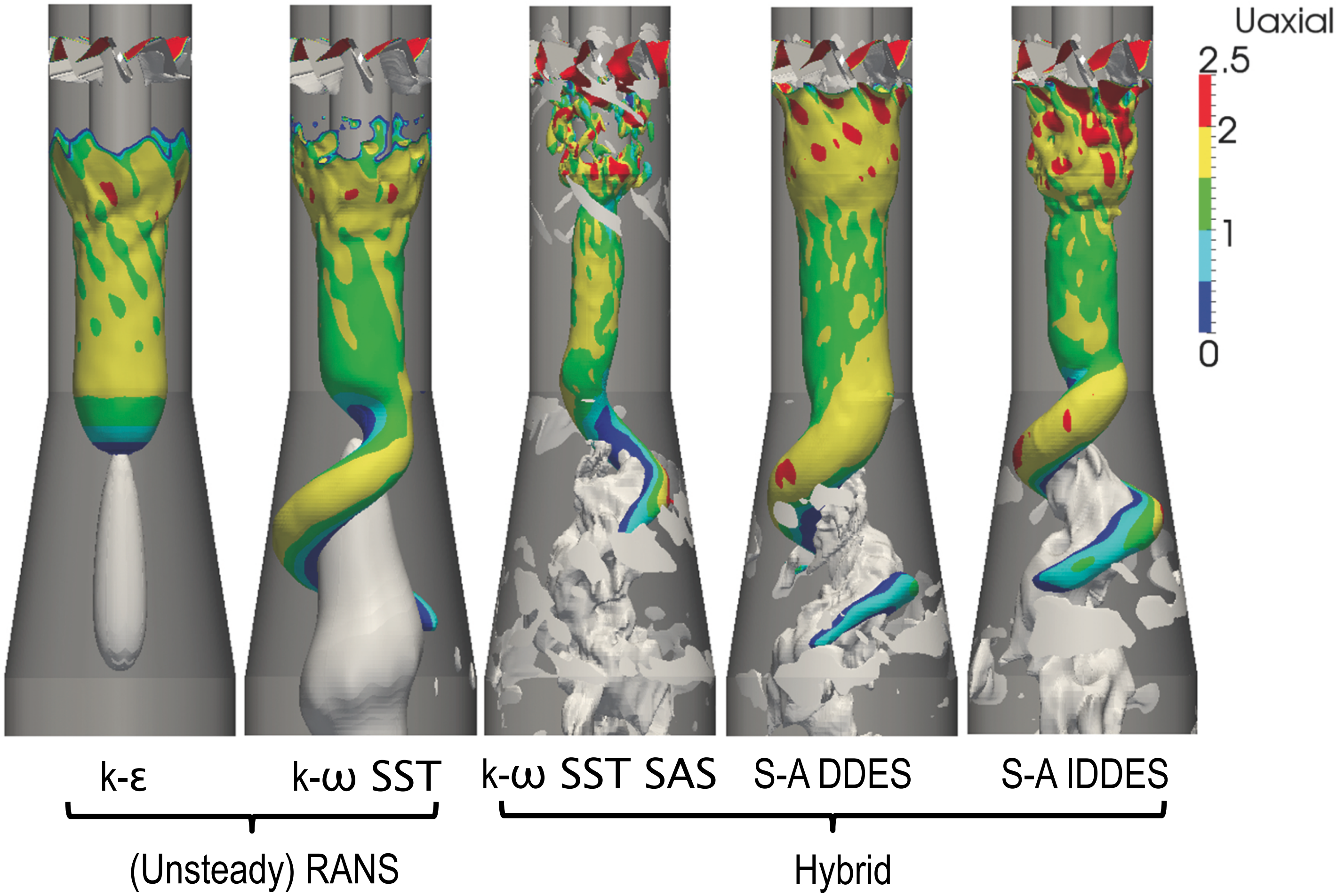
S-A DDES



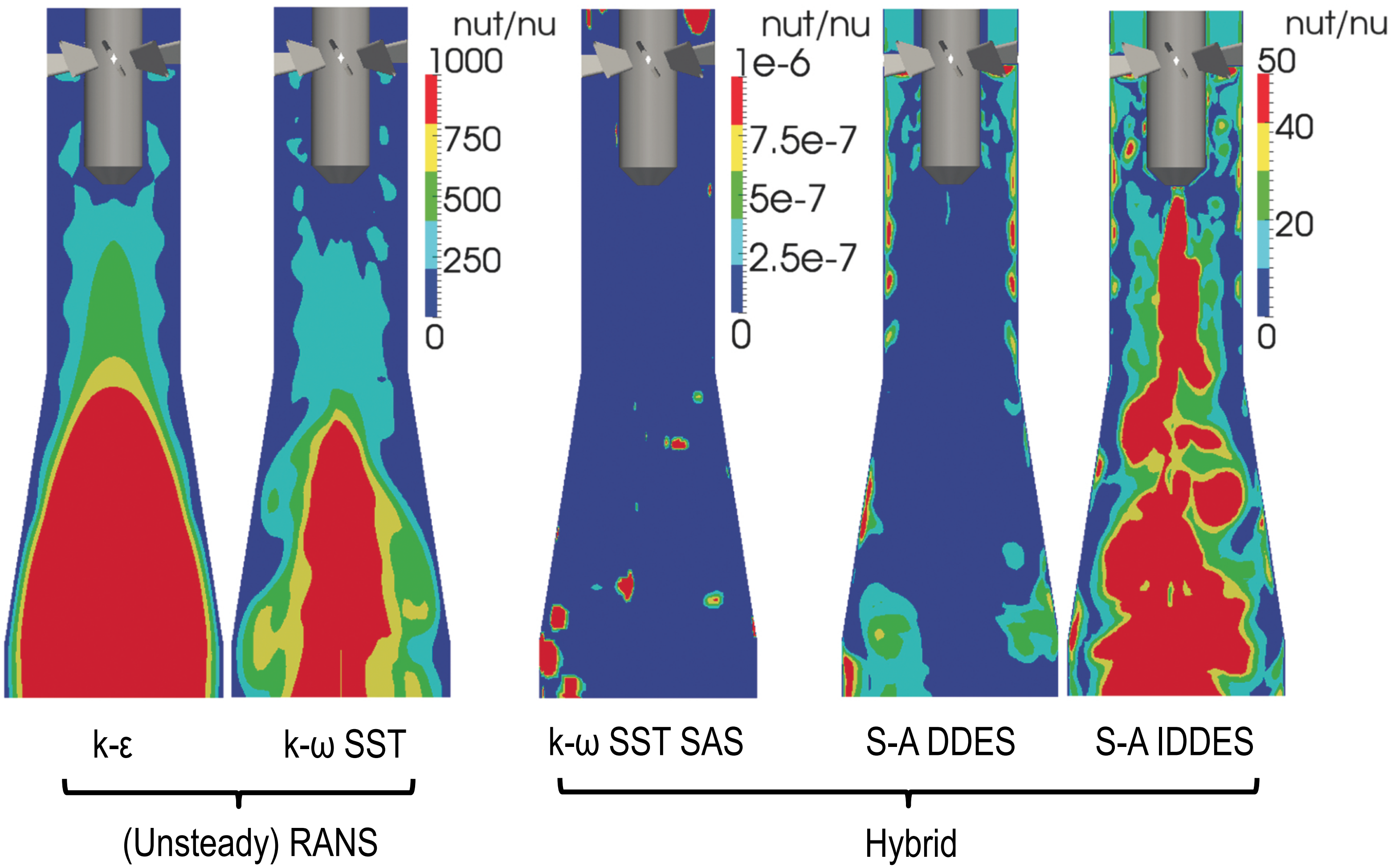
S-A IDDES

General Evaluation of the Simulations

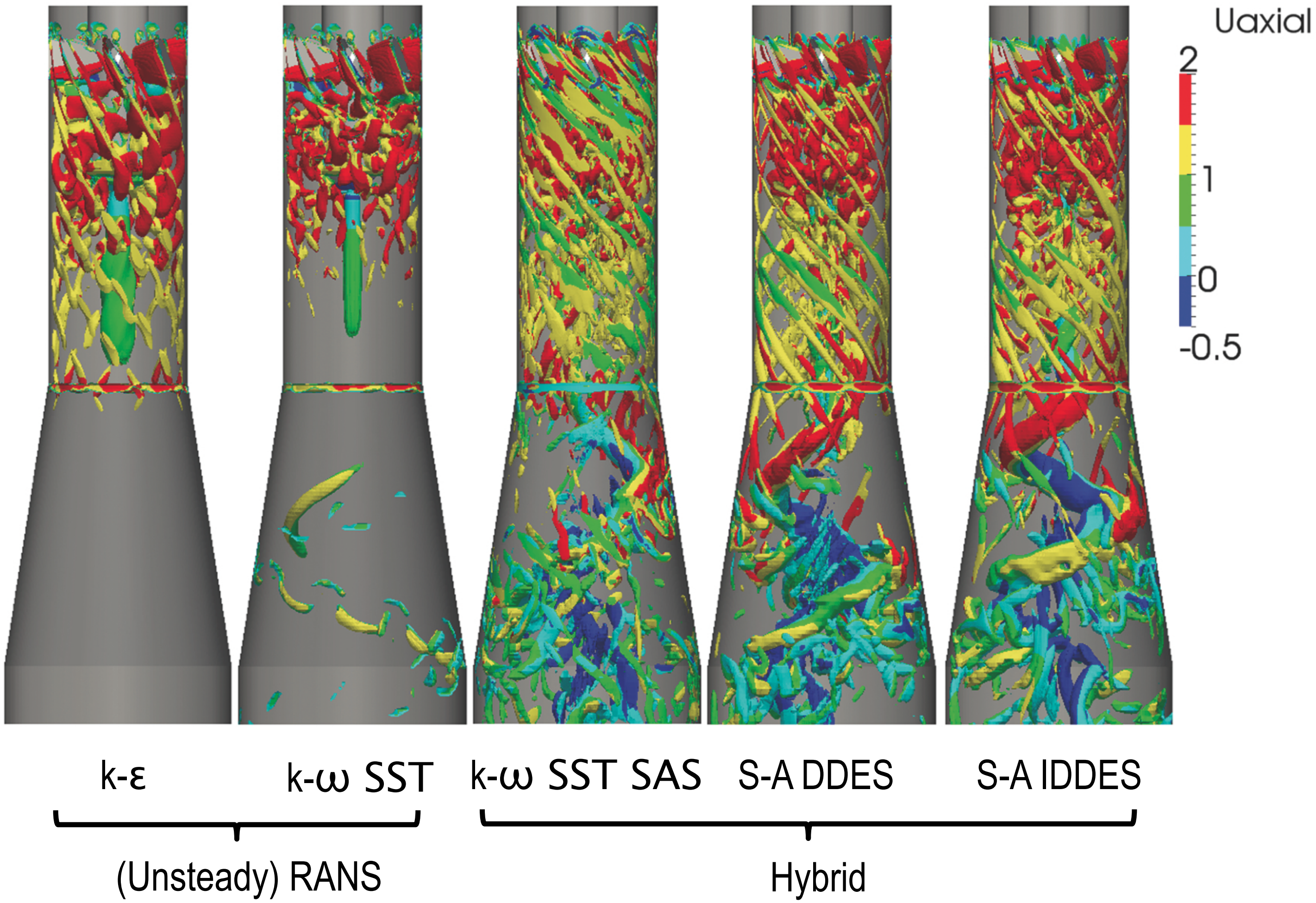
- Isosurface of pressure (colored by axial velocity) and axial velocity Ua = -0.001 m/s (solid color)



- Slice of the Swirl Generator (colored by the ratio of turbulent kinematic to molecular kinematic viscosity)

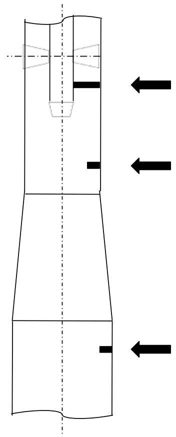


- Isosurface of the second invariant of the velocity gradient tensor



Comparison with Experimental Data

- Experimental data and corresponding measurement positions

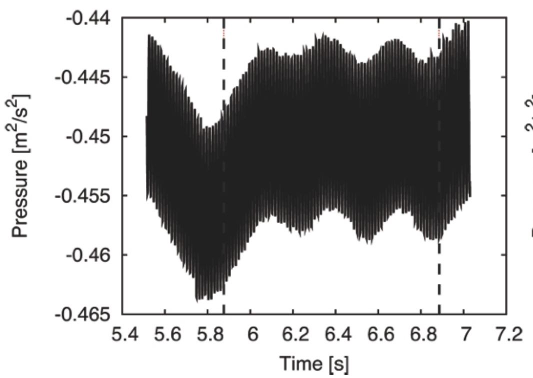


Laser Doppler Velocimetry lines (L1, L2, L3)
- Axial/tangential mean velocity

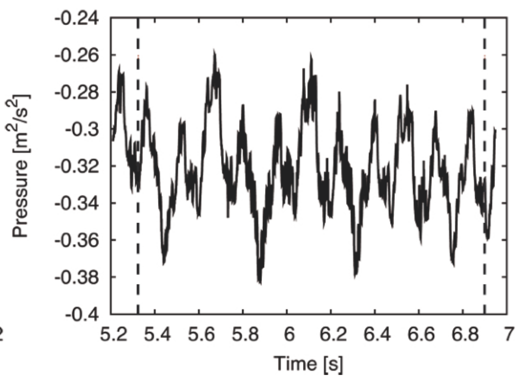
Pressure-sensor position (P1)
- Development of the simulation
- Frequency of the helical vortex
- Start/stop time-averaging

Pressure-sensor position (P2)
- Frequency of the helical vortex
- Mean pressure difference to P1

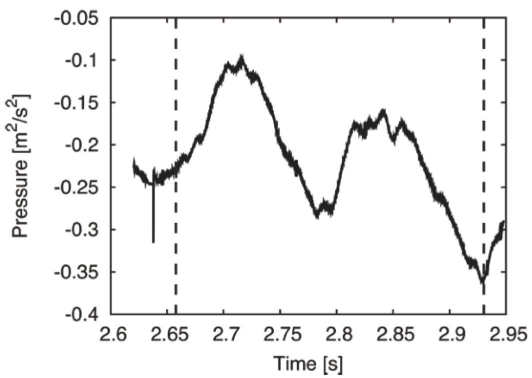
- Period of time averaging of the relevant properties



Experiment



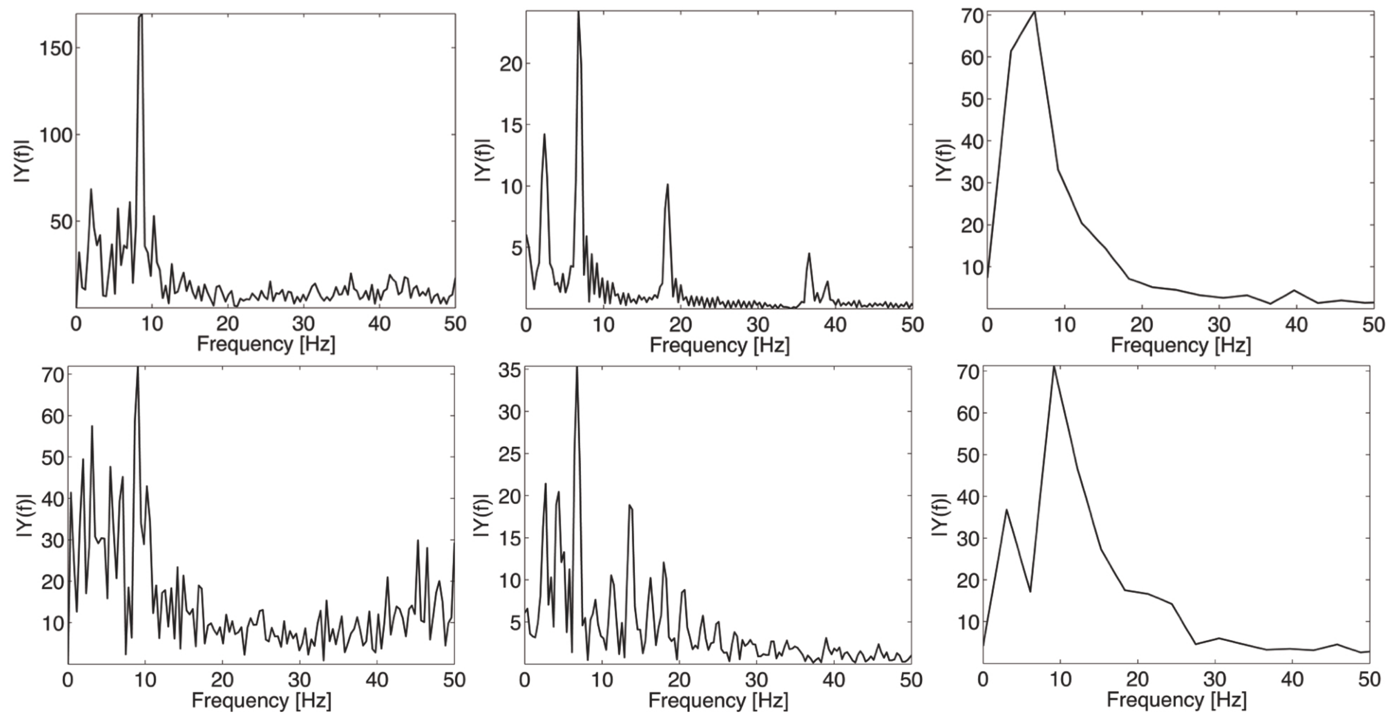
k-ω SST



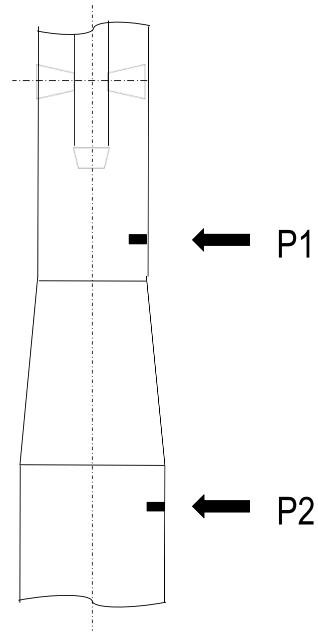
S-A DDES

Comparison with Experimental Data

- Frequency spectrum at P1 and P2 based on a Fourier transformed pressure signal

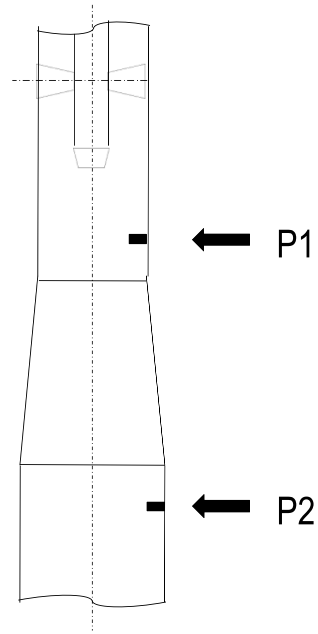


Experiment   k-ω SST   S-A DDES



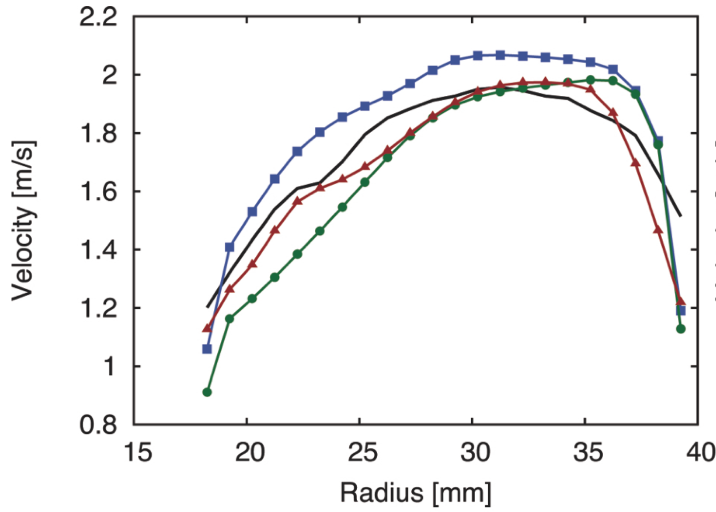
- Dominant frequencies at positions P1 and P2 and pressure difference between P1 and P2

	Experiment	k-ε	k-ω SST	S-A DDES
Frequency at P1 in [*Hz*]	8.7	-	6.8	6.1
Deviation from the experimental frequency in [%]	0	-	22	30
Frequency at P2 in [*Hz*]	9.1	-	6.8	9.2
Deviation from the experimental frequency in [%]	0	-	25	1
Pressure difference in [*Pa*]	237	437	269	263
Deviation from the experimental pressure difference in [%]	0	85	29	11

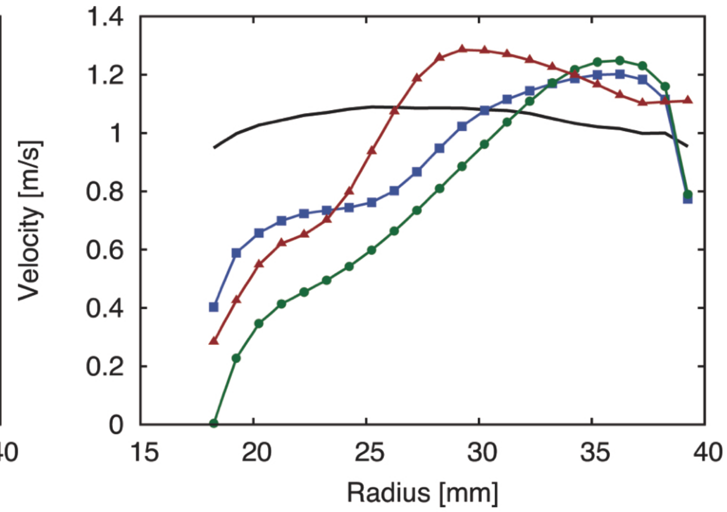


- Velocity profiles along the LDV line L2

Axial velocity



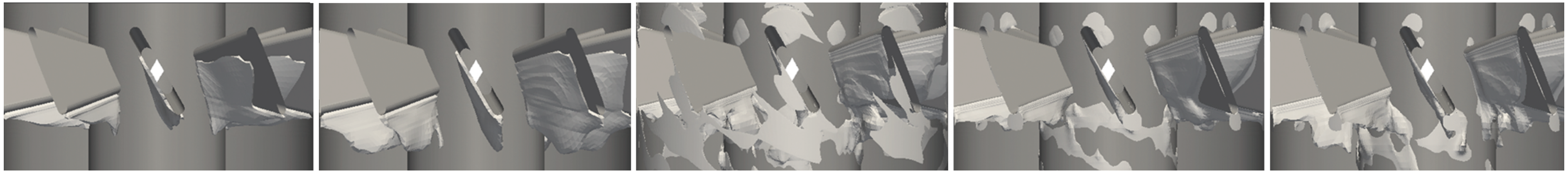
Tangential velocity



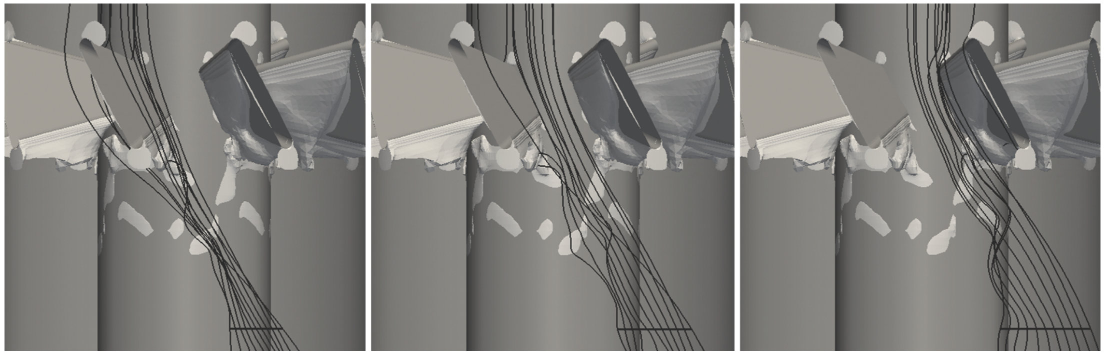
Experiment — kEpsilon — kOmegaSST — SADDES —

Possible Problems

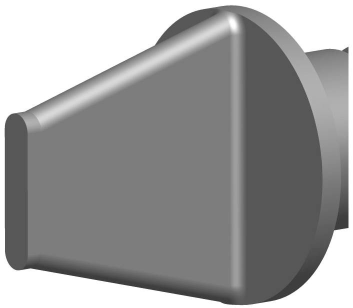
- Separation below the blades



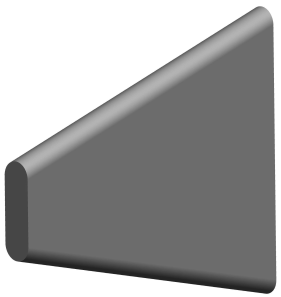
  - ➢ Streamlines through the LDV measurement lines



- Blade simplifications



Original blade



Simplified blade

Conclusion

- All turbulence models but the k-ε model predict the general flow field of the helical vortex
- Hybrid models:
  - ➢ Require significantly more time to simulate the flow
  - ➢ Give a more likely picture of the flow due to a higher resolution
- All simulations are not in sufficient agreement with the experimental data
- The separation below the blades might be a possible reason for the mismatch

Prospect

- Investigations of only the blade region
- Mitigation of the corresponding separation zones (design of curved blades)
- Further studies to exclude possible effects of the simplifications, mesh and numerical setup

Movies

- Velocity glyphs
- Isosurface of pressure and velocity

Thank you for your attention!

Any questions?