4th International Seminar on ORC POWER SYSTEMS
ORC 2017
13 - 15 September
MILANO, Italy

Numerical CFD simulations on a small-scale ORC expander using a customized grid generation methodology

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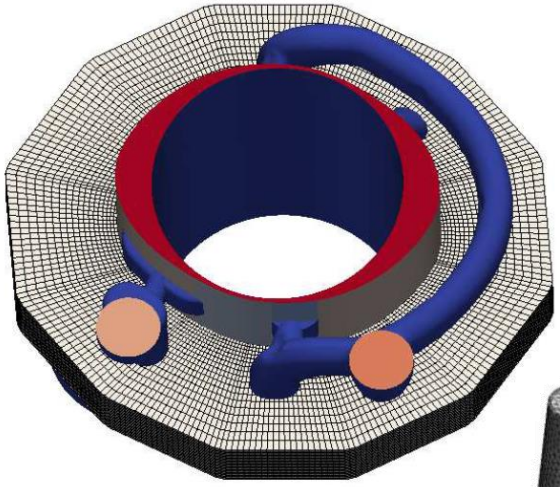
Need of advanced design tools in vane machines

Performance improvement

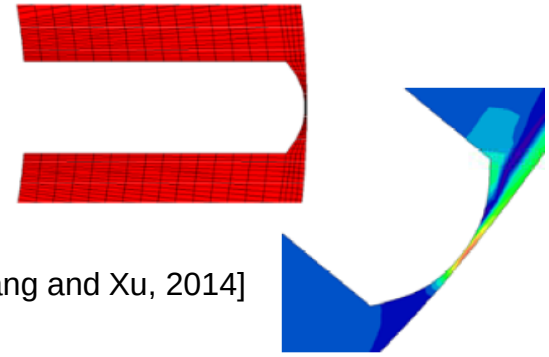
- Leakages (gaps in the order of tens of μm)
- Friction power
- Optimal expansion ratio
- Expansion phase



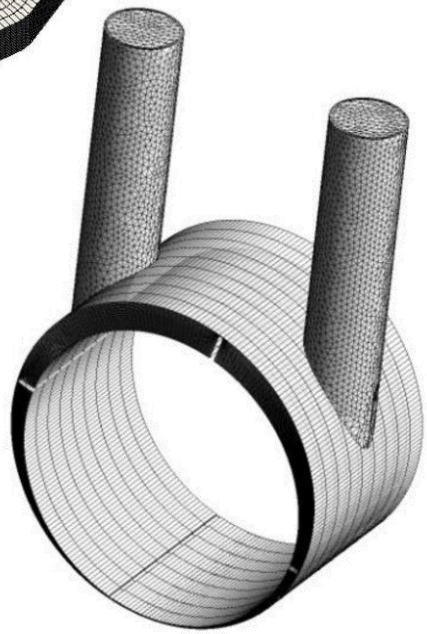
[Montenegro et al., 2014]

Challenges

- Moving and deforming grids
- Multiphase simulations required
- Scarce know-how availability



[Zhang and Xu, 2014]

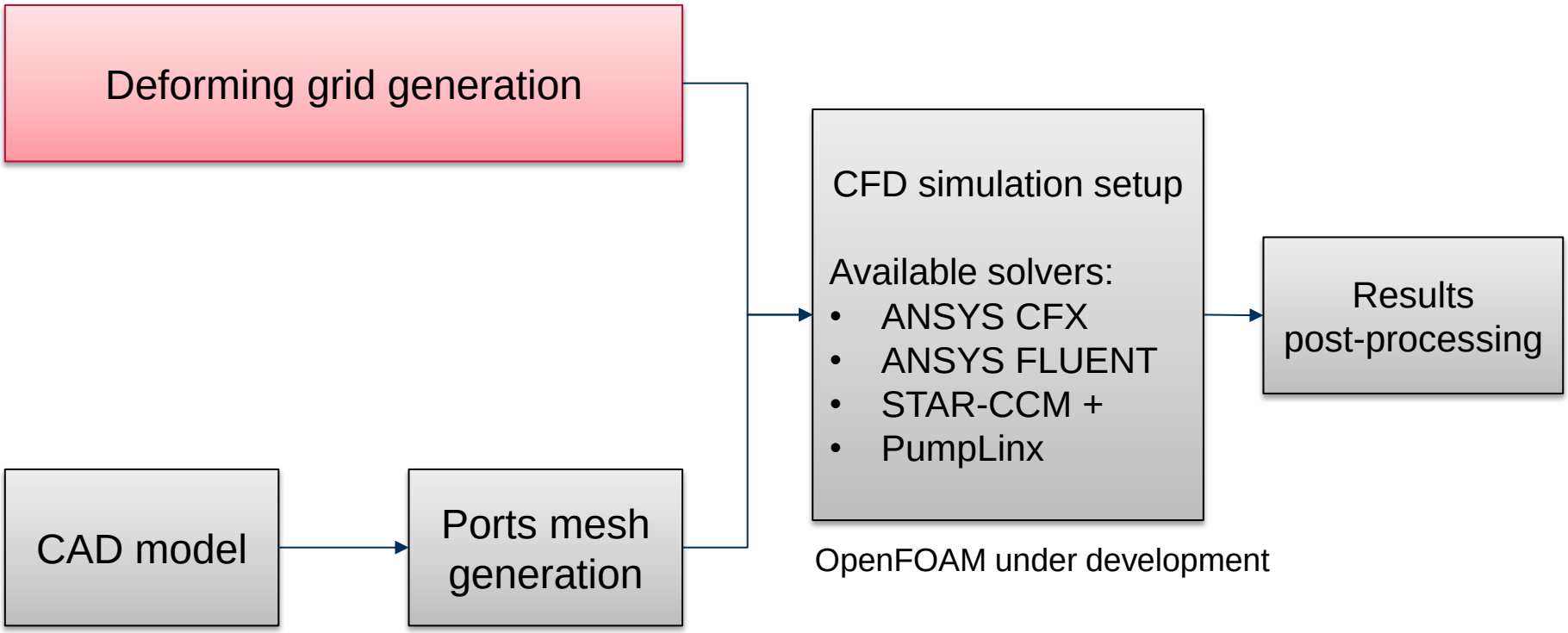


[Kolasiński and Błasiak, 2015]

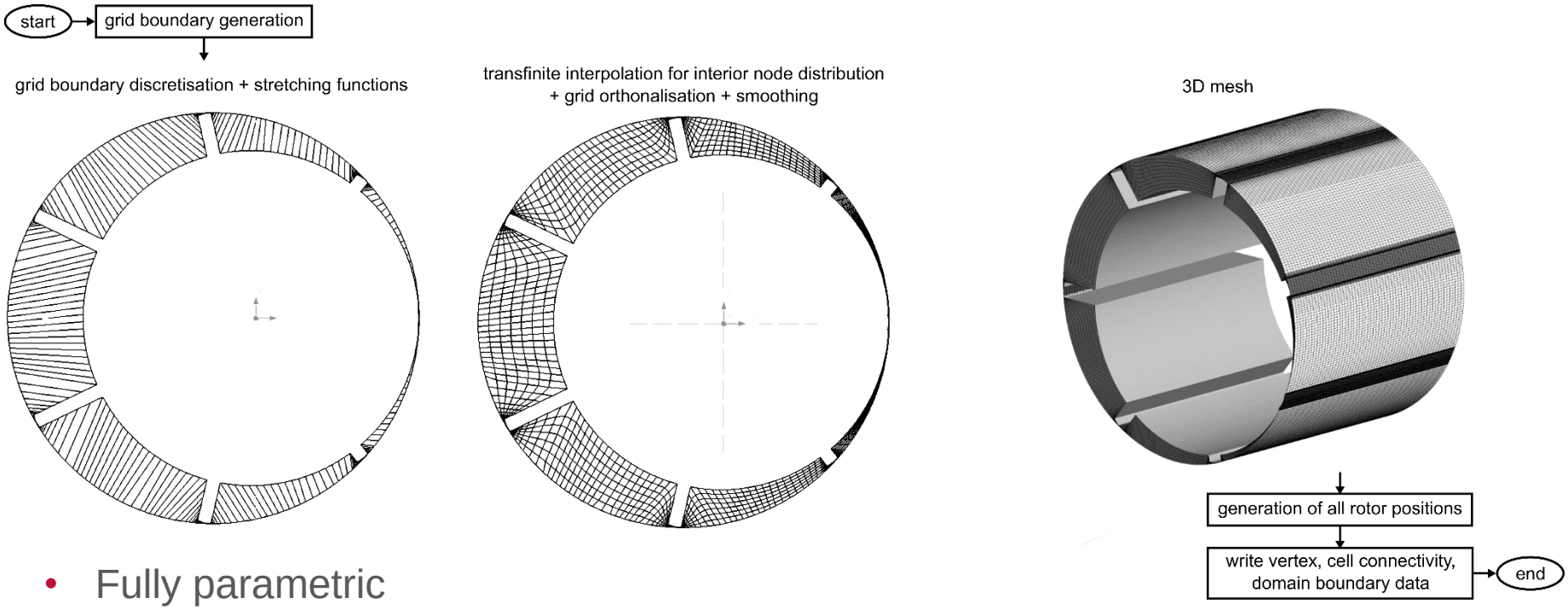
Outline

- ✓ Motivations
- ❑ Deforming grid generation procedure
- ❑ Simulation setup
- ❑ Results
- ❑ Experimental validation
- ❑ Next challenges

Numerical CFD simulations in positive displacement machines



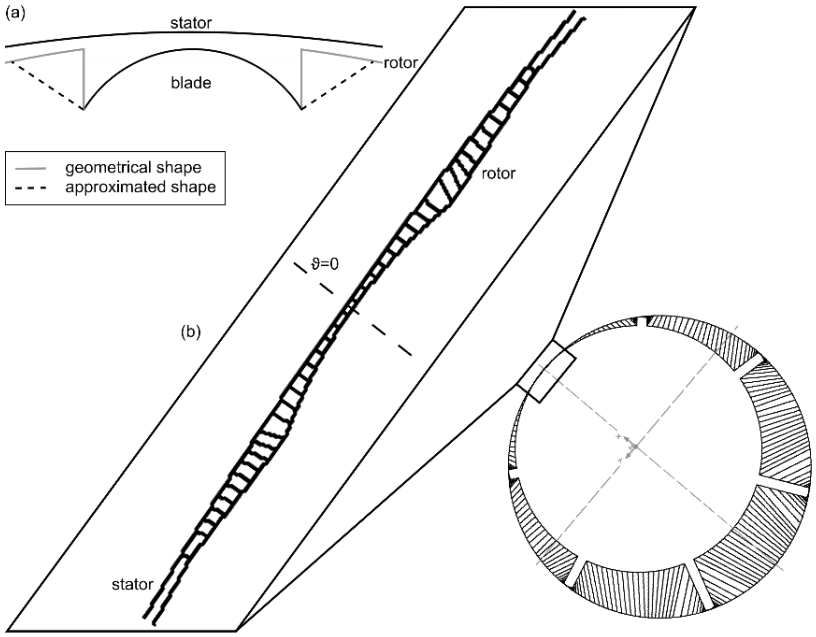
Grid generation procedure



- Fully parametric
- Easy to use
- Functional with most of the CFD solvers

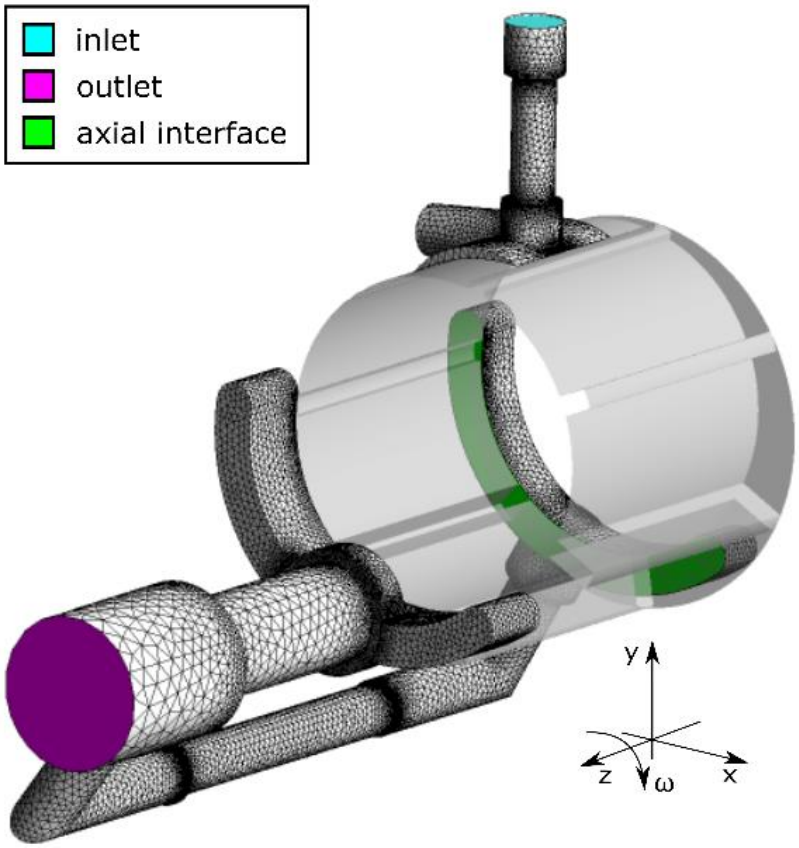
Mesh generation

- Different clearances (10, 25, 50μm)



- 20 nodes on rotor, stator and blade tip boundaries

- 10 nodes on blade walls



	Ports	Rotor (10μm)
Cell type	tetrahedral	hexahedral
Node count (Million)	0.135	0.157
Maximum aspect ratio	23	228
Minimum orthogonality	10.0	11.6

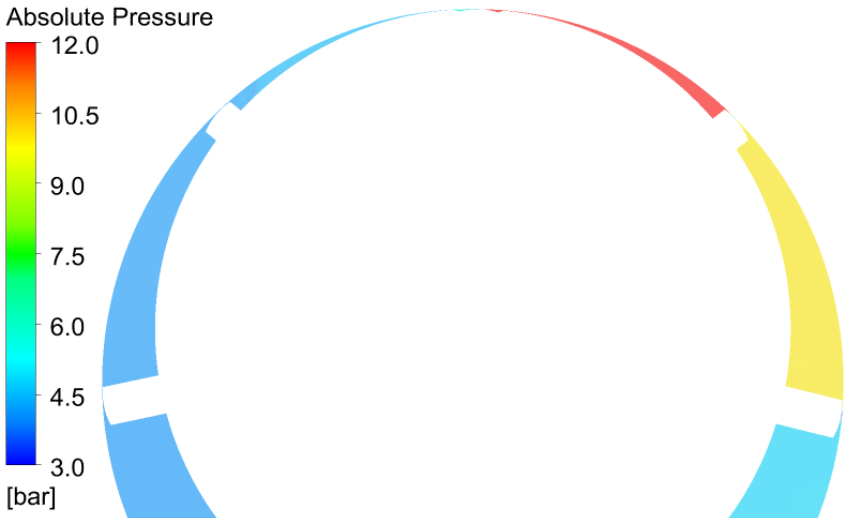
Simulation setup in ANSYS® CFX

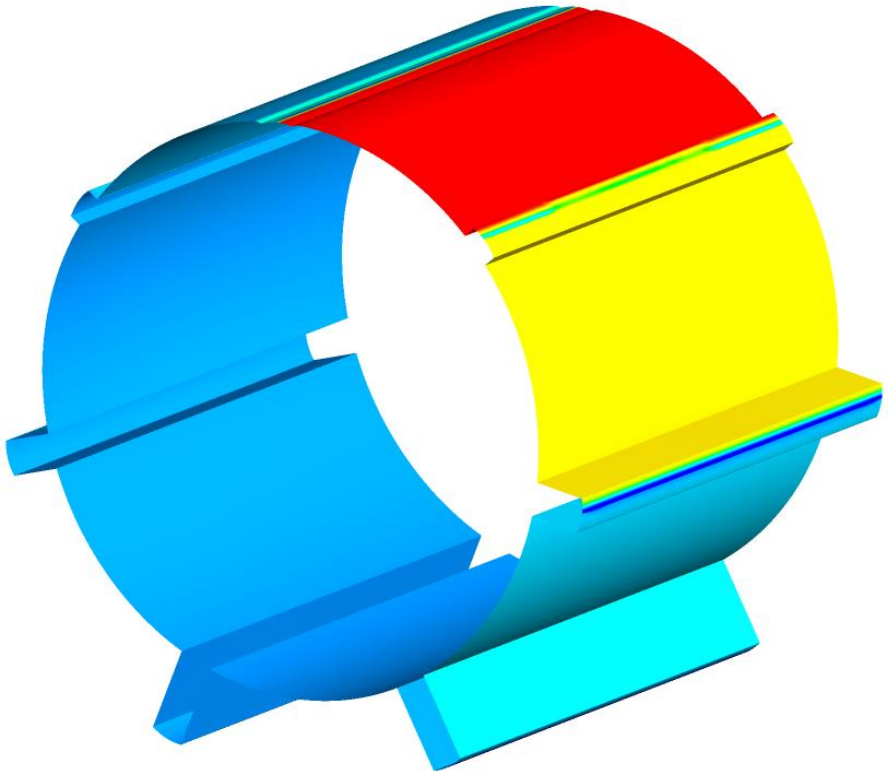
Mesh deformation	User defined nodal displacement via **junction box routines** in FORTRAN	**Advection scheme**	Upwind
Mesh in ports	Tetrahedral with boundary layer refinements (Generated by ANSYS pre-processor)	**Pressure-Velocity coupling**	Co-located layout (Rhie and Chow 4th order)
Turbulence model	SST – k Omega (Standard Wall Functions)	**Transient scheme**	Second order (Fully implicit Backward Euler)
Inlet boundary condition	Opening (Specified total pressure and temperature)	**Transient inner loop coefficients**	Up to 20 iterations per time step
Outlet boundary condition	Opening (Static pressure In case of backflow used as total pressure and temperature)	**Convergence criteria**	r.m.s residual level 1e-03
Control volume gradients	Gauss divergence theorem	**Relaxation parameters**	Solver relaxation fluids (0.4)

- Aungier Redlich Kwong real gas model for superheated R236fa
- 0.5° crank angle step
- Boundary conditions:

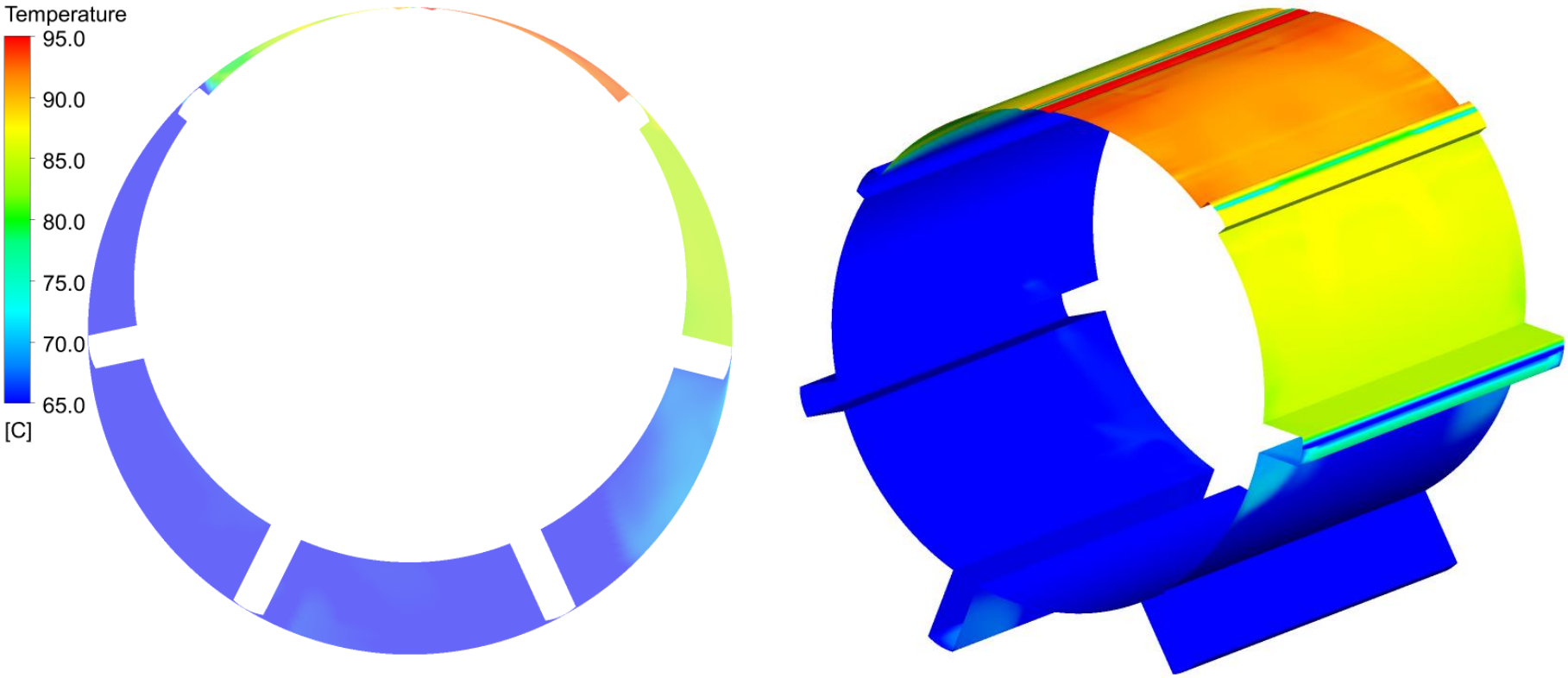
	Inlet	**Outlet**
Pressure [bar_a]	12.1	4.6
Temperature [°C]	90.5	69.4
Revolution speed [RPM]	1551	

Simulation results

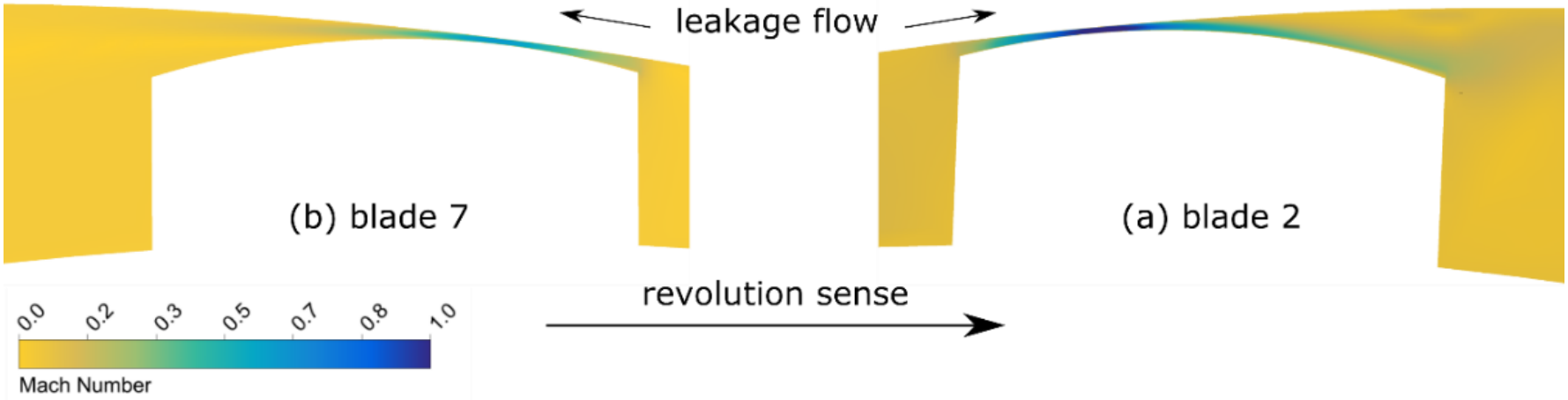




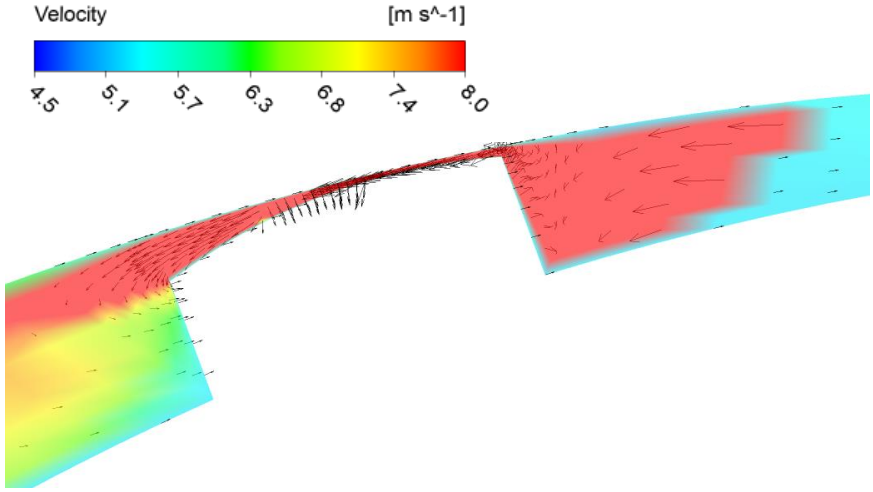
Simulation results

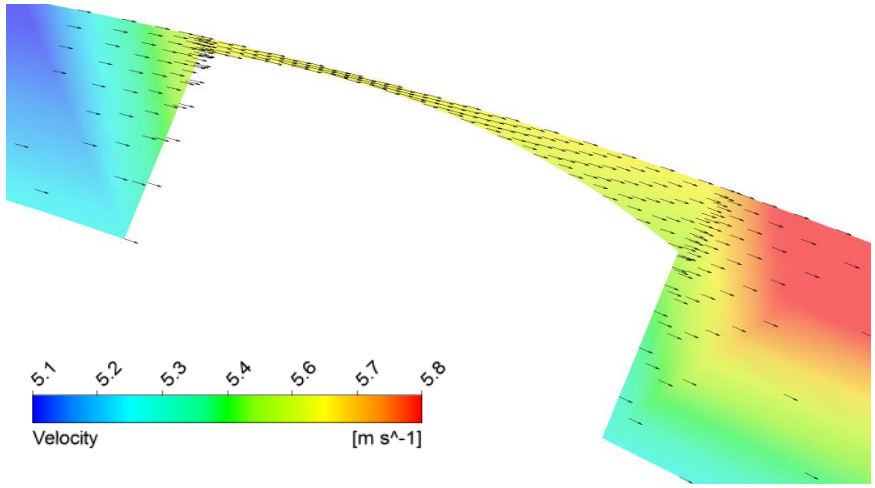


Simulation results



Mach number field at main tip clearance locations:
(a) between chambers 1 and 2, (b) between chambers 6 and 7

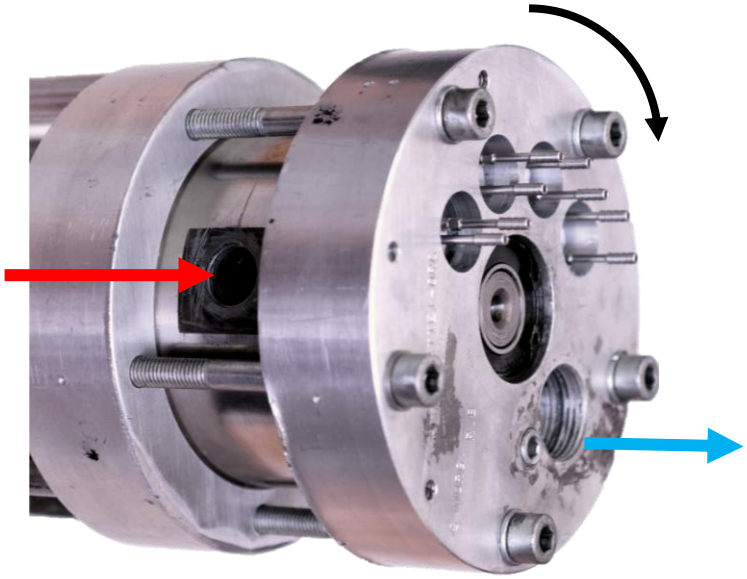




Experimental validation

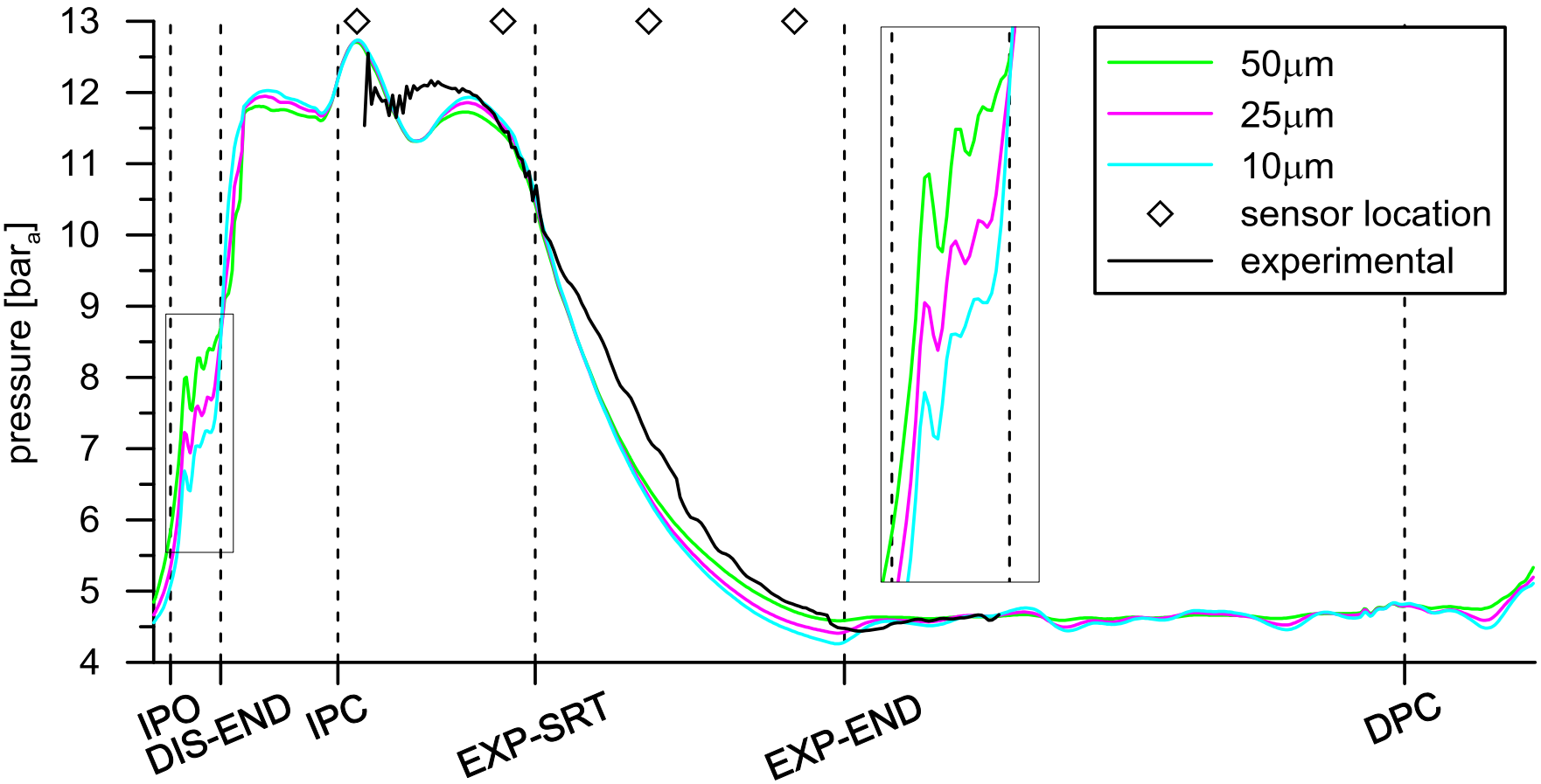
waste heat stream
(90-120°C)

electrical power
up to 3kW



- Pressure and temperature measurements across the machine
- Piezoelectric transducers along the expansion phase
- Speed and electrical power measurements

Experimental validation

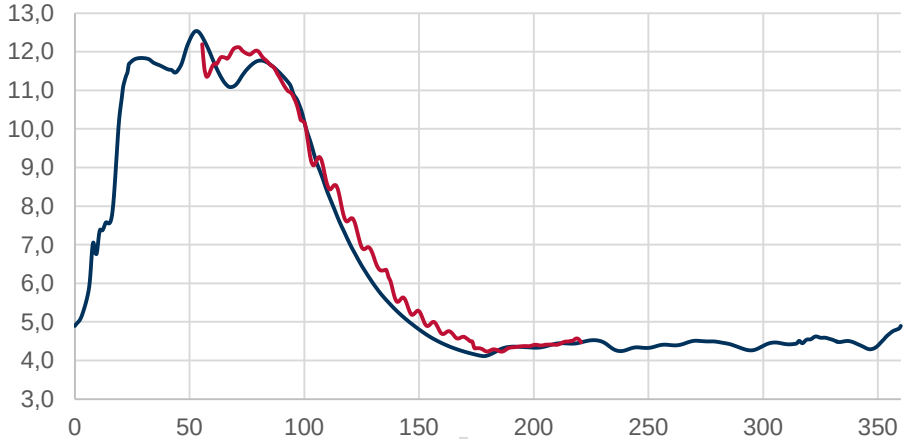


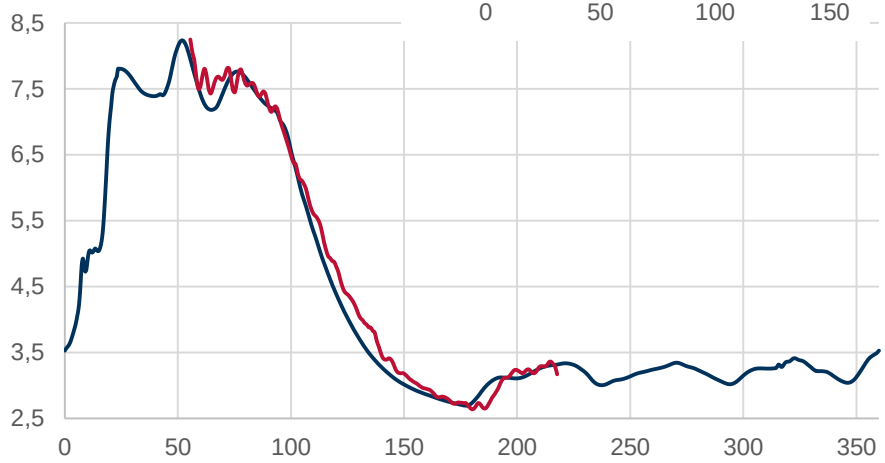
Experimental validation (ongoing)

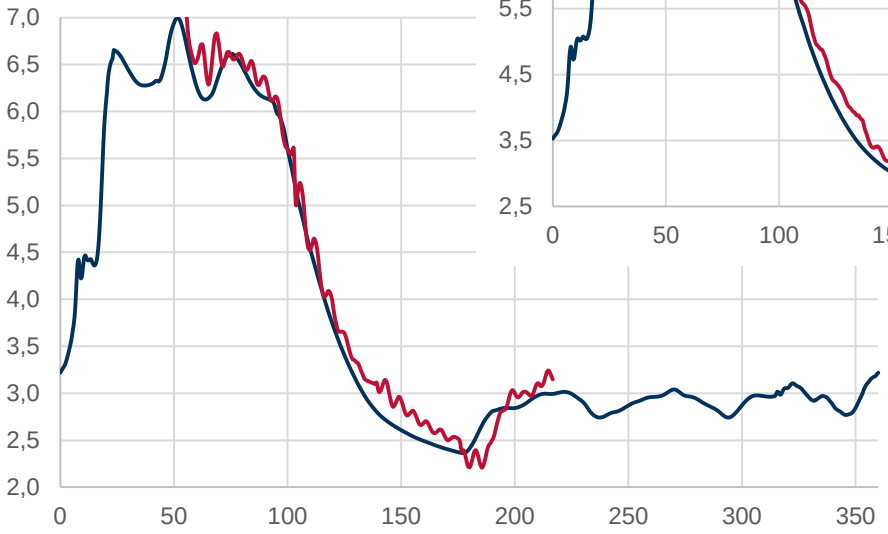
Multiple energy recovery regimes

- Pressure ratios (p_{max})
- Temperatures

Experimental dataset available at
https://doi.org/10.1533/9781782421702.3.183







Forthcoming experimental datasets

- Mattei's R&D labs (compressed air systems)
- University of L'Aquila (automotive)

Conclusions

- ✓ Development of a customized grid generation methodology for vane machines
- ✓ Single phase real gas simulations on a small-scale ORC expander
- ✓ Validation with indicating pressure data

Next challenges

- ❑ Grid sensitivity study
- ❑ Use of the numerical simulation to optimize the machine performance
- ❑ Multi-phase simulations
- ❑ Fluid-structure simulations to account for friction

Acknowledgements

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