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Numerical simulation of vortex induced pressure fluctuations in the runner of a Francis turbine at deep part load conditions

Motivation

Francis turbines are more and more used to compensate fluctuations in the electrical grid

- ➢ Increased share of operation outside of designed operating range, where complex flow phenomena exist (see Fig. 1)
- ➢ Higher structural loads that have a negative impact on the lifetime of the turbine

Overall-project goal:

Derive a workflow to obtain reliable load evaluations at off-design conditions that is feasible for the application in the design process

Goal of the HPC investigations:

Provide highly resolved CFD results that serve as a reference to derive more simplified simulation setups (e.g. larger time step, reduction of simulation domain) for the design process

Numerical setup

- Simulations performed with commercial software ANSYS CFX
- Turbulence model: SBES (hybrid RANS-LES)
  → WALE model in LES region and SST model in RANS region
- Investigated meshes: 25 million cells (25M), 56M and 82M
- Time step is selected to fulfil that the RMS Courant number is below one ($\Delta t = 0.4°$ for mesh 25M and 0.2° for 56M and 82M)
- Simulated runner revolutions: 70
  - 20 runner revolutions for initialization process
  - 50 runner revolutions for averaging

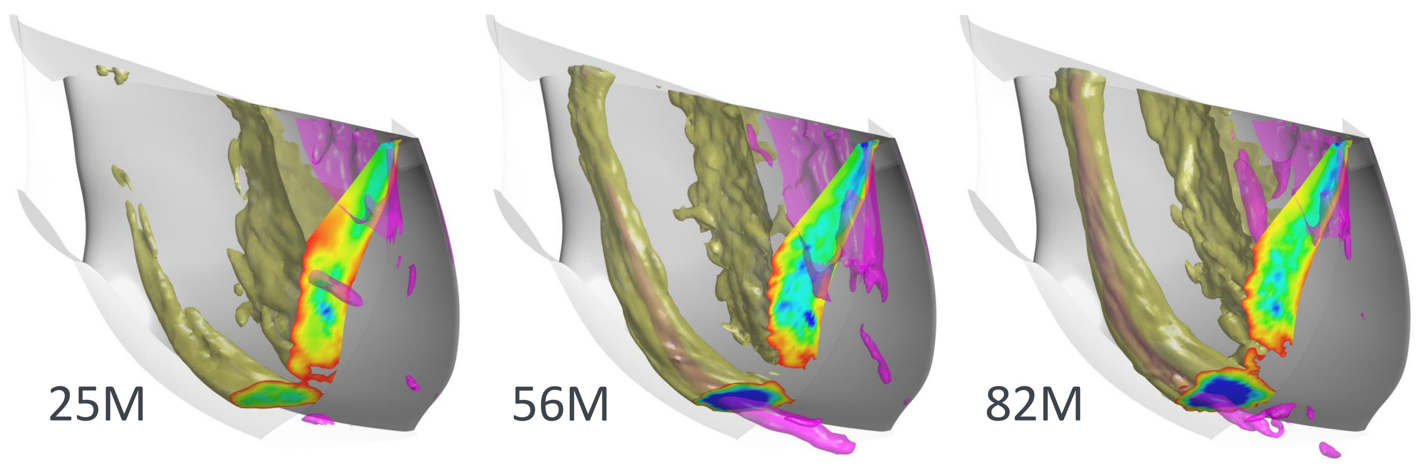

Fig. 2: Vortex movement in one runner channel. The movement is visualized by an isosurface (gold) that captures the region where the pressure is falling below vapor pressure for at least one time step within the simulated 50 runner revolutions. Furthermore, an isosurface of the pressure (threshold set to vapor pressure) for a randomly chosen time step is displayed in purple.

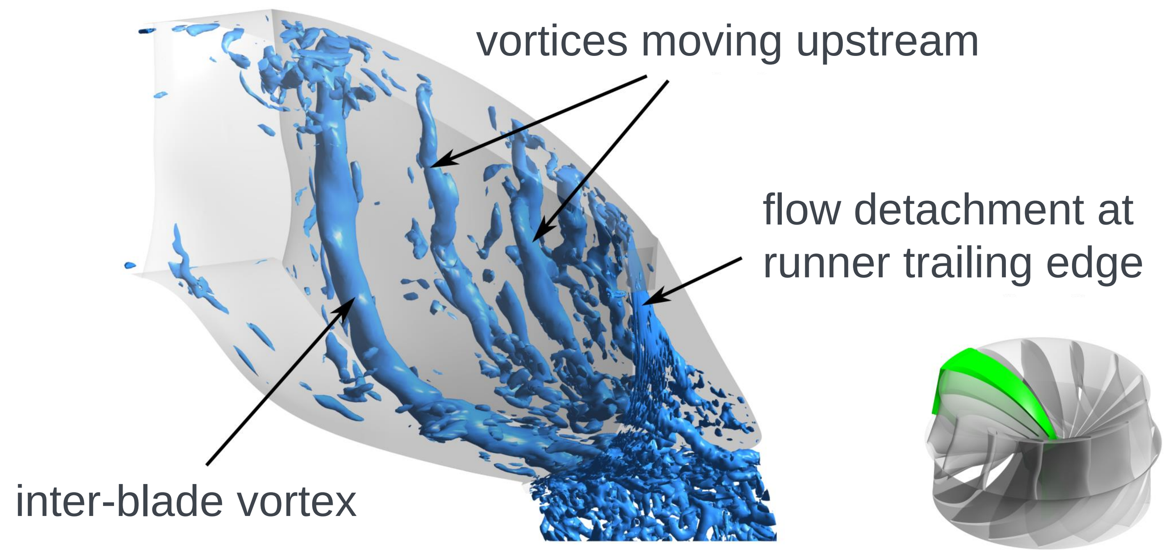

Fig. 1: Vortex structures in one runner channel.

Results

- Significantly better resolution of the pressure minimum in the vortex core of the inter-blade vortex by meshes 56M and 82M
  - ➢ Pressure isosurface in Fig. 2 (purple color)
  - ➢ Golden isosurface that visualizes the regions, where the pressure is falling below vapor pressure in at least one time step within the 50 runner revolutions
- Significantly higher pressure fluctuations on the suction side (see Fig. 3)
  - ➢ Inter-blade vortex located closer to the suction side
- Qualitatively similar results of the standard deviation for the different meshes. Nevertheless, differences in the region close to the leading edge and in the region of high pressure fluctuations caused by the upstream moving vortices

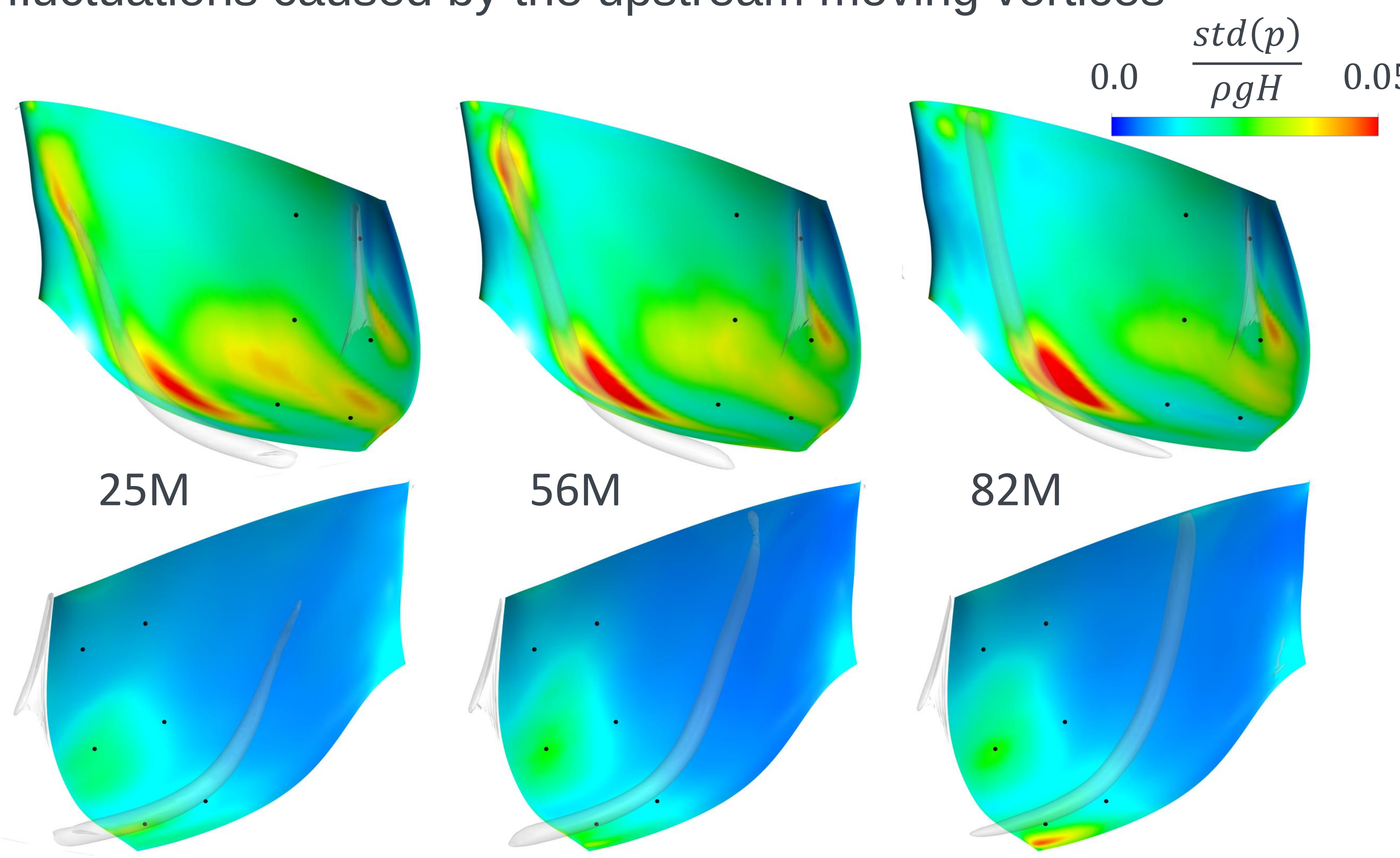

Fig. 3: Standard deviation of pressure on the suction side (top) and pressure side (bottom) of a runner blade. The standard deviation is calculated from 50 runner revolutions.

Parallel Performance

- Simulations performed on the Hawk at HLRS in Stuttgart
- Strong scaling test performed for meshes 56M and 82M on the file system ws10 (see Fig. 4)
- Comparison of versions 19.5 and 21.1 does not show an improvement in parallel performance
- Acceptable scaling up to 1536 cores for mesh 56M and up to 2048 cores for mesh 82M
- Simulations that use the hypercube topology are not significantly faster
- Simulations with Open MPI are 16.5% faster compared to the use of HMPT MPI
- Using 64 cores per node instead of 128 is not reasonable
- Simulation time: approx. 2.5 months on 1536 (56M) or 2048 cores (82M)

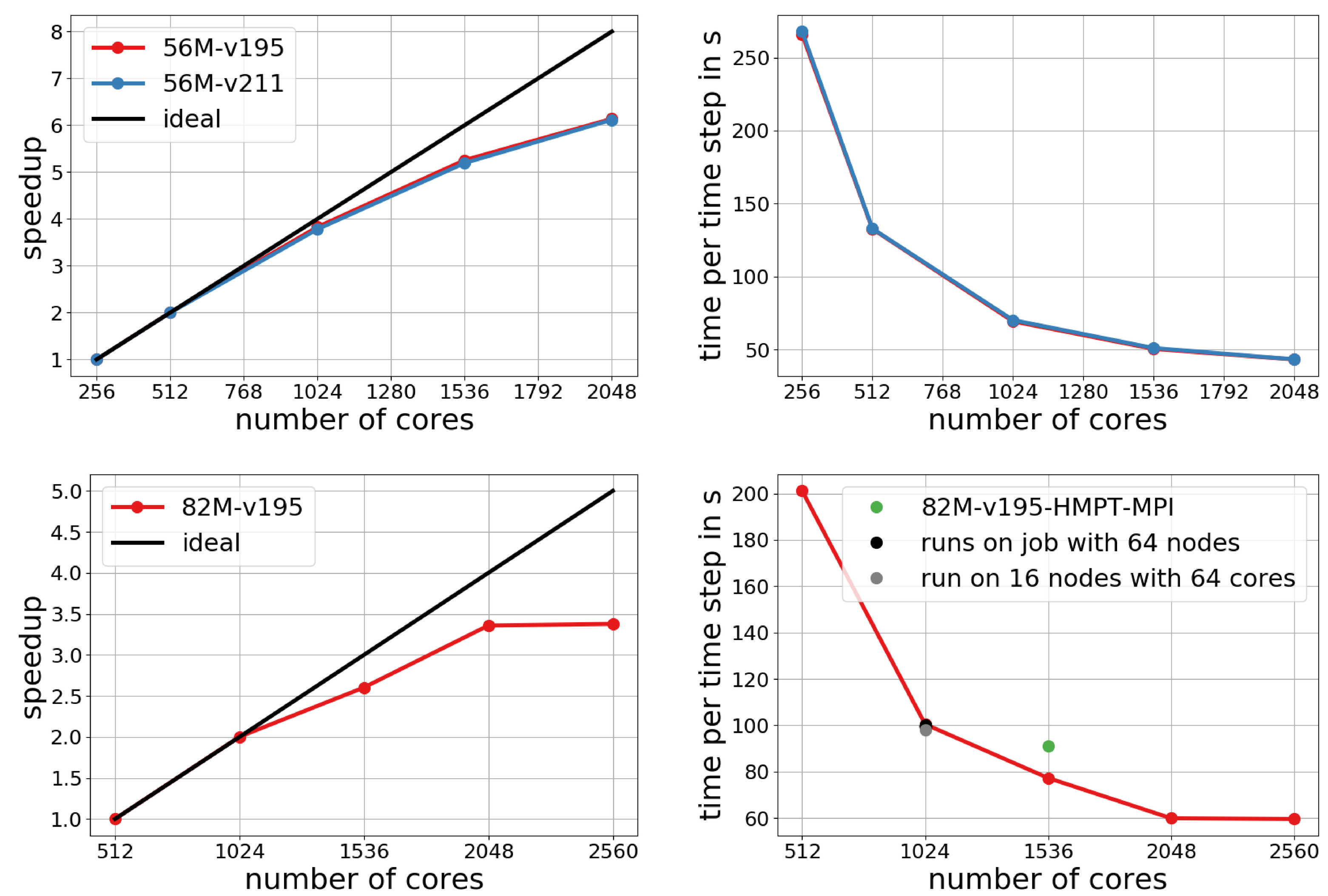

Fig. 4: Speedup and time per time step for mesh 56M (top) and 82M (bottom).

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