Large Eddy Simulation of Turbulent Swirling Flow Through a Sudden Expansion

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Project

Part of Ph.D project

- Numerical Investigations of Unsteady Flow in Draft Tubes

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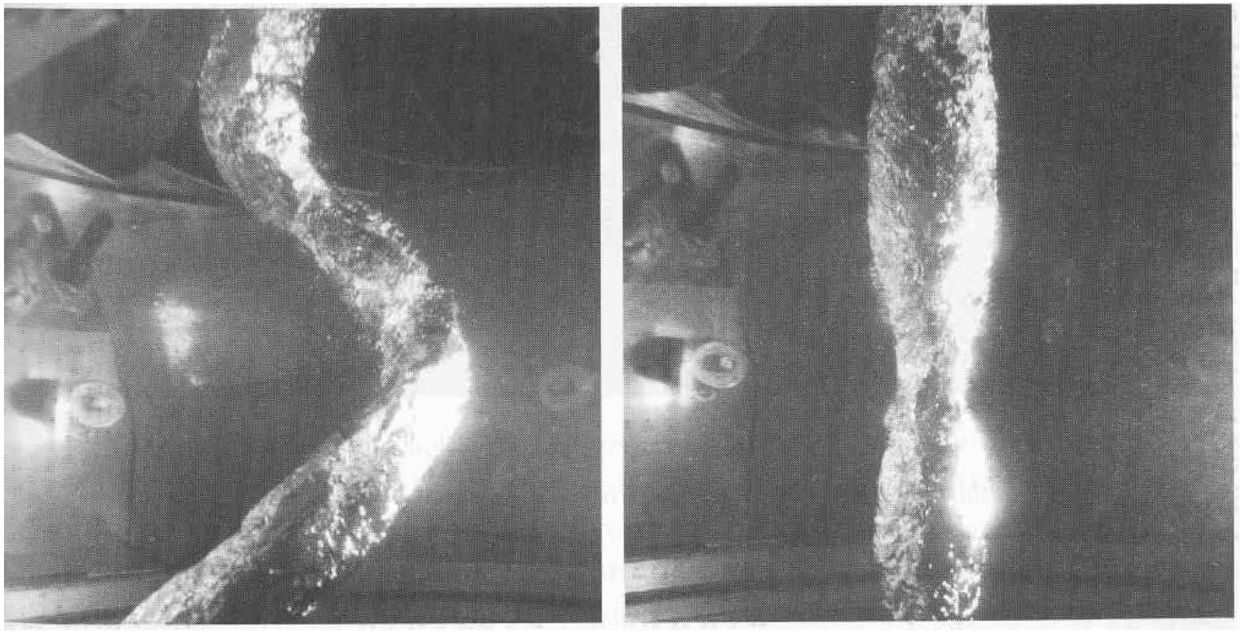
Background and motivation



When a turbine is operating at part load a swirling flow will exit the runner. This gives rise to an oscillating vortex core that cause vibrations and a decrease in efficiency.

Goals

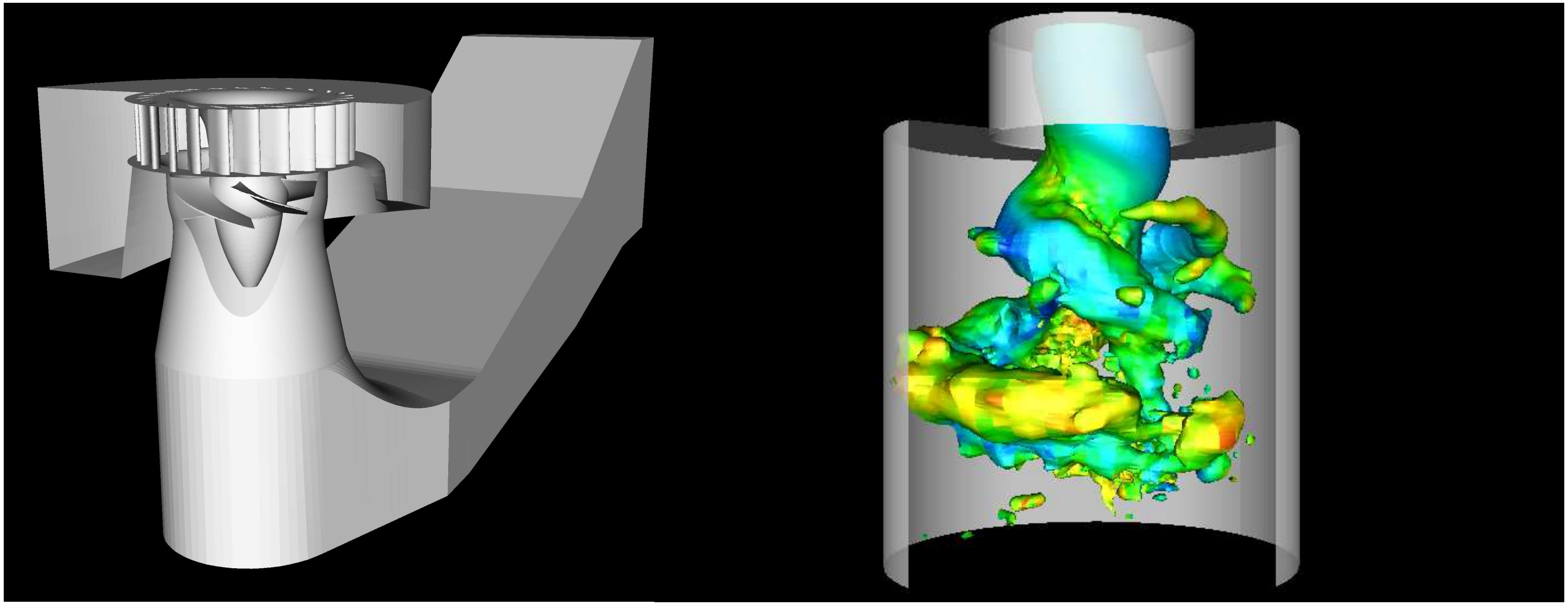
of the present work:

- To acquire an understanding of the physics of swirling flow in general and unsteady swirling flow in draft tubes of water turbines in particular.
- To learn which features of the flow that are most crucial to simulate - and how to do it properly.

of future work:

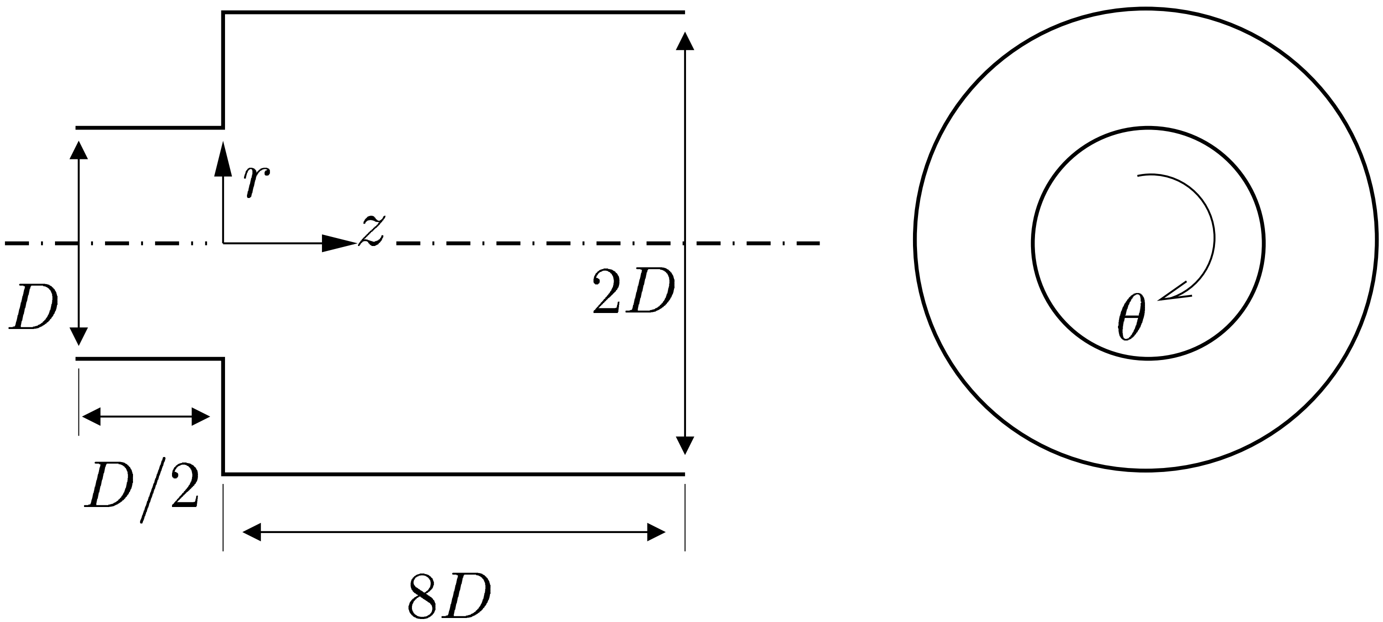
- To improve numerical simulations and turbulence modeling of unsteady swirling flow in draft tubes.

Draft tube and a simplified geometry



Kaplan turbine of Hölleforsen and a slightly simplified model. The swirling flow in the simplified model resembles the flow in a turbine working at part load.

LES

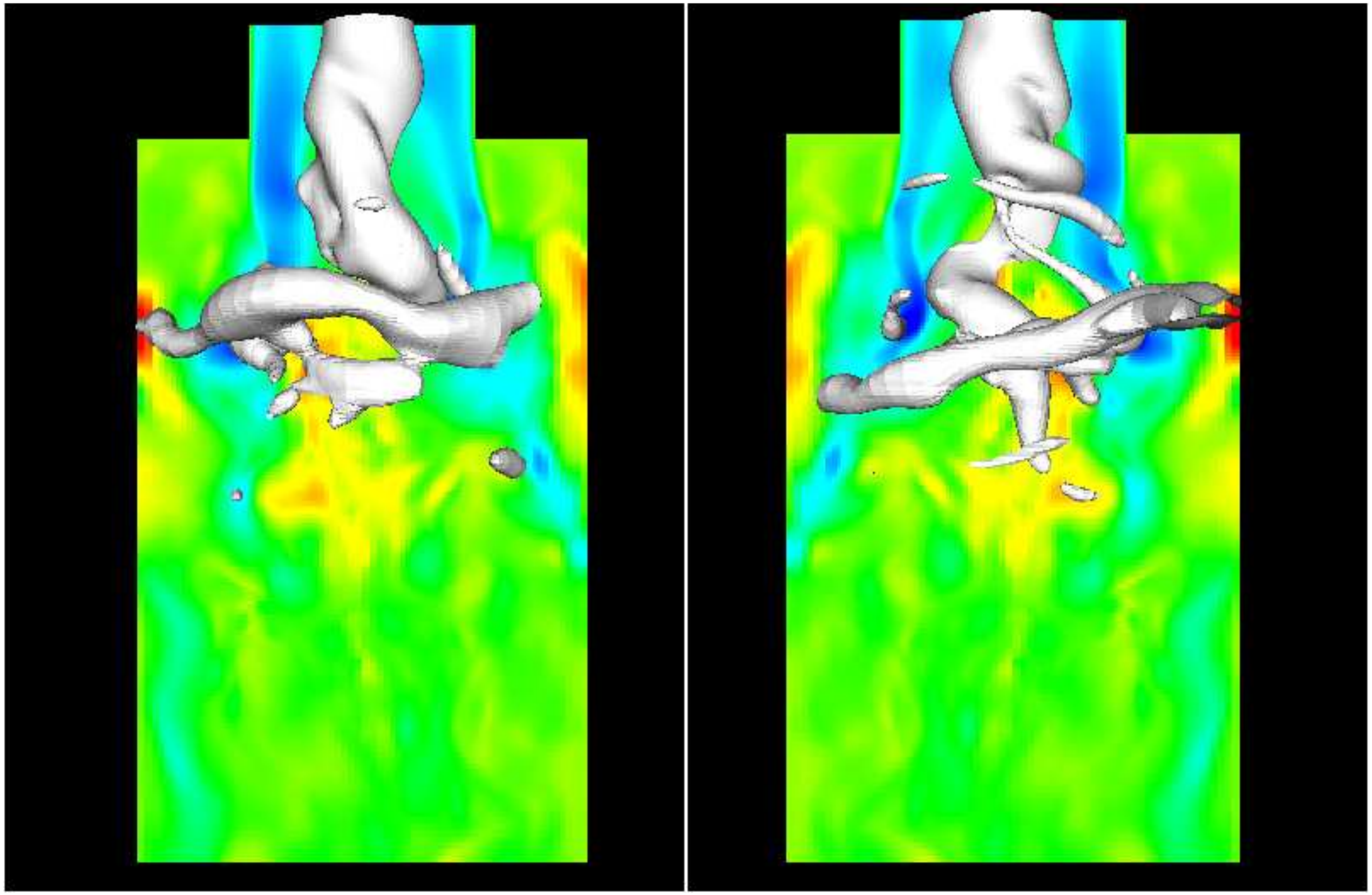


LES of swirling flow through a sudden expansion at Re=40000

- Isolate the most important physics.
- Weak dependence on turbulence model.
- Will be used to validade the (URANS/VLES) turbulence models that must be used for the real application.

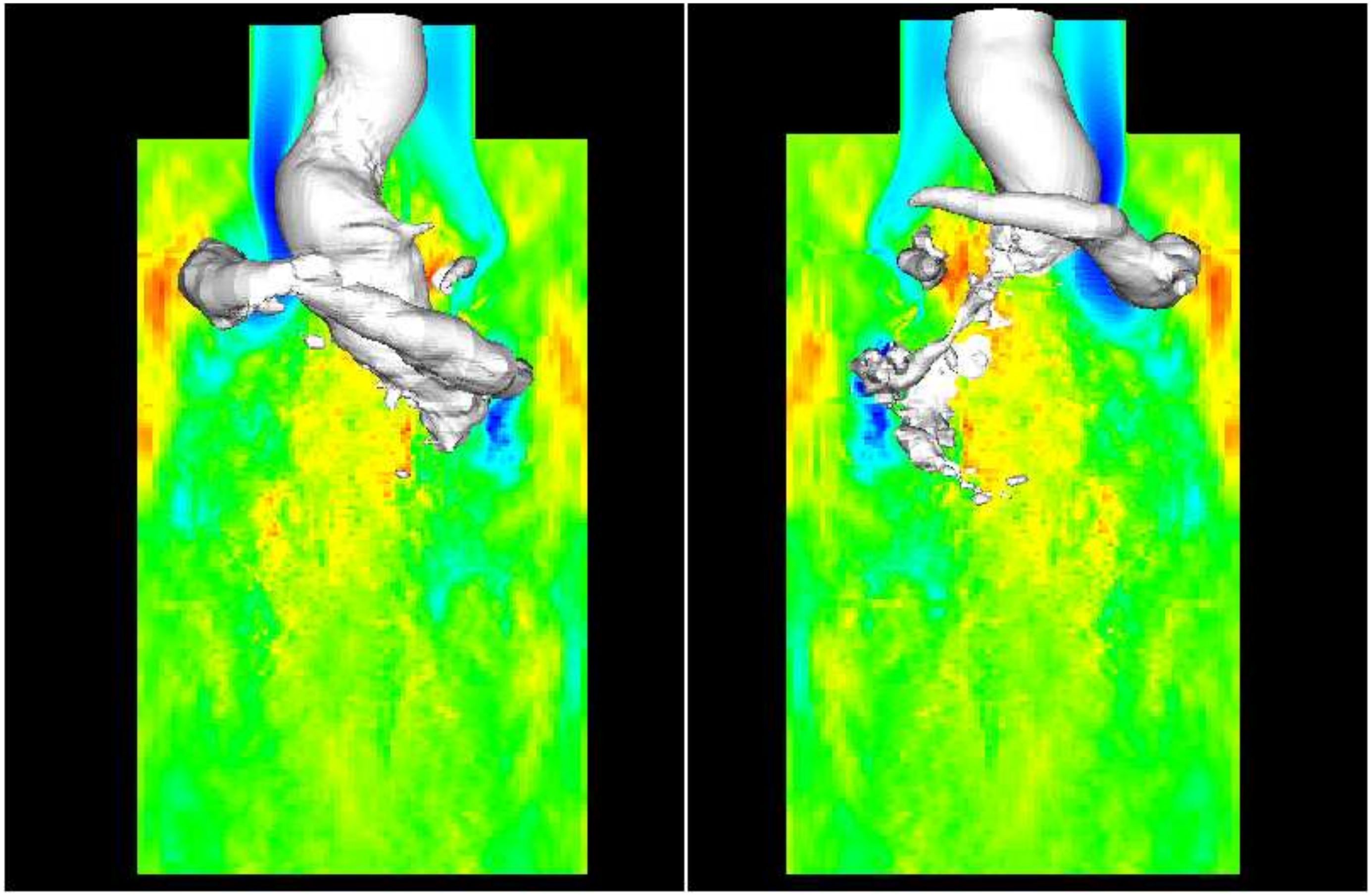
Experimental data courtesy of P. A. Dellenback, USA.

Results



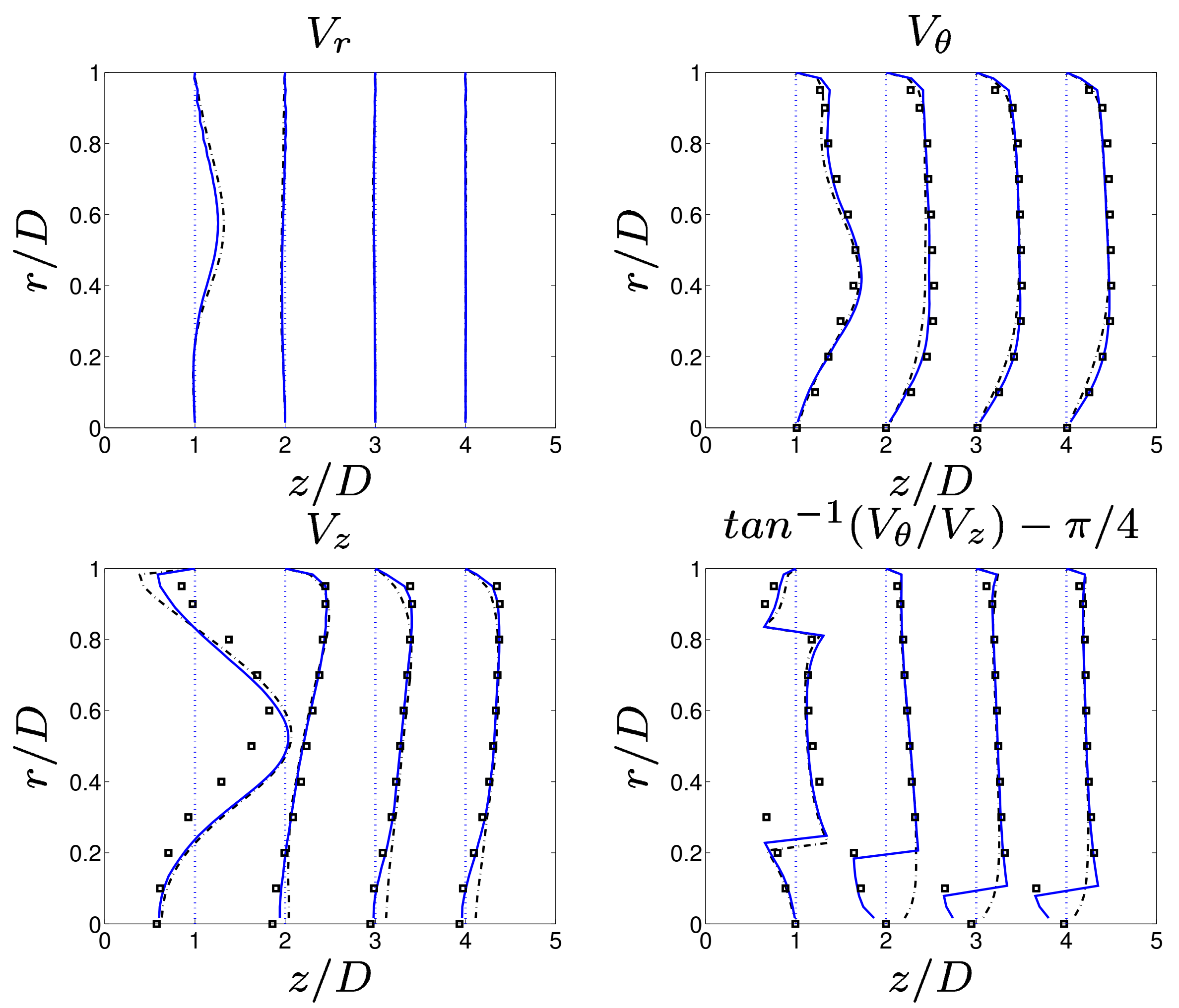
Snapshot of iso-pressure surface and axial velocity in a plane (vL).

Results



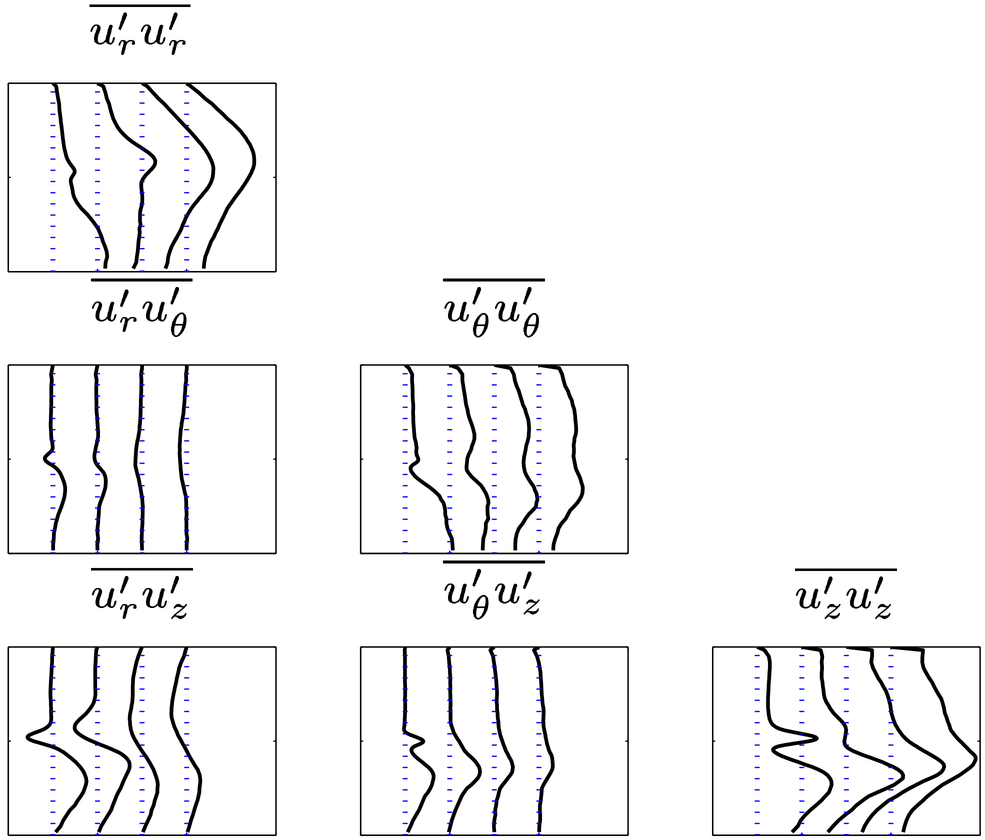
Snapshot of iso-pressure surface and axial velocity in a plane (CD).

Time-averaged velocity



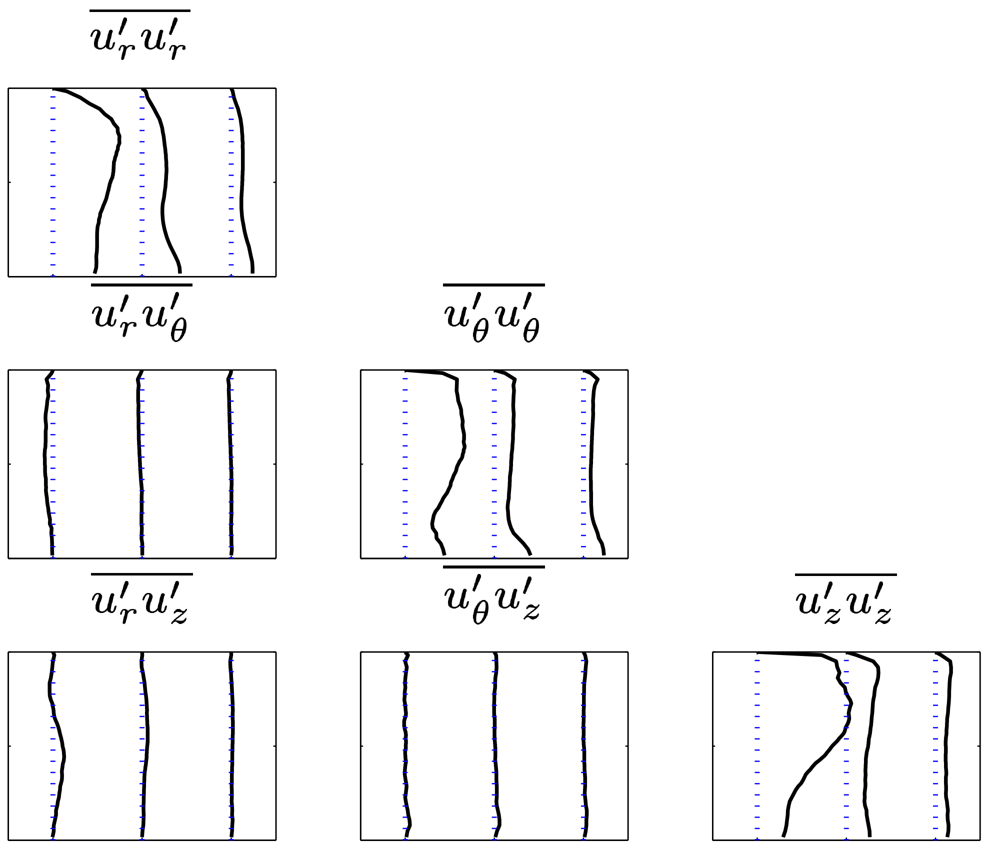
[−]: Central difference scheme. [·−]: Van Leer scheme. [□]: Experimental data.

Reynolds stress tensor - upstream



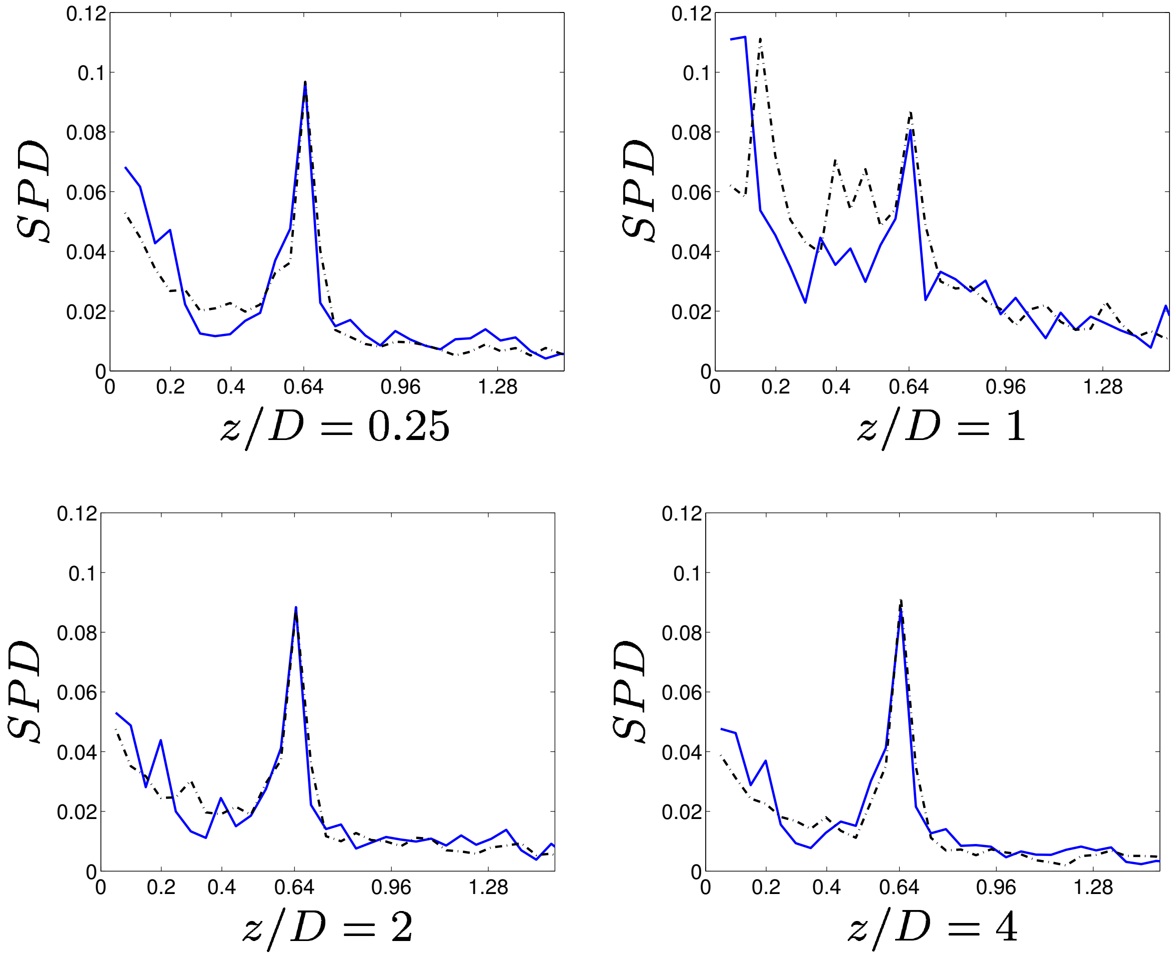
Reynolds stress tensor close to entrance, $r/D = \{0.25,\ 0.5,\ 0.75,\ 1\}$. The anisotropy is high in the vortex breakdown region.

Reynolds stress tensor - downstream



Reynolds stress tensor, $r/D = \{1,\ 2,\ 3,\ 4\}$. Downstream the vortex breakdown region, the anisotropy more or less vanish - despite the higher relative swirl.

Frequencies



[—]: Central difference scheme. [·—]: Van Leer scheme.

Conclusions

- The vortex rope frequency is not sensitive to the choice of discretization scheme.
- Other (especially lower) frequencies of the flow (which possibly originates from flow separation) are sensitive to numerical accuracy.
- The inlet boundary must probably be moved further upstream. Because of the presence of an oscillating vortex core, the flow is not expected to be instantaneously symmetric at the present location.

Conclusions

- The turbulent anisotropy is high only in the vortex breakdown region. It is likely that most of the anisotropy is created by the rotating vortex rope itself. If so, advanced turbulence models are superfluous if this structure is well resolved in time and space.

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