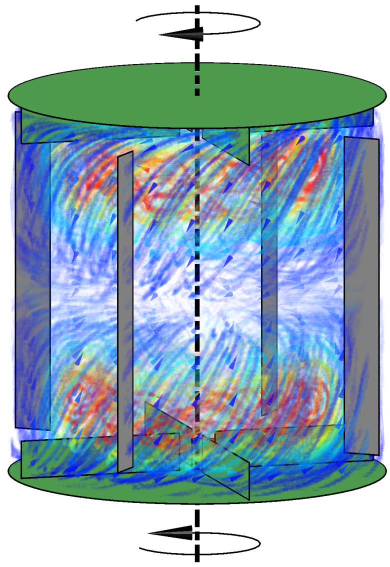
Exploration of large-scale structures in a baffled turbulent von Kármán swirling flow

The project aims to explore the properties of turbulent von Kármán swirling flow (VK flow). VK flow can be briefly described as flow within a vessel closed from both sides with impellers spinning in the opposite directions. The flow, visualised in the figure, exhibits a characteristic mean pattern consisting of two, same-size, toroidal cells inside which fluid continually circulates. On top of that, fluid spins around the vessel axis, and the rotation rate changes gradually along the axis to match angular velocities of the impellers. As a result of this composition, the flow velocity vanishes close to the vessel centre, forming a stagnant region.



Visualisation of a mean VK flow.

VK flow is one of the canonical flows in turbulence research. It has been a subject of multiple theoretical, experimental, and numerical works, spanning over a wide range of topics. There are a few features which make this flow configuration particularly appealing for researchers, e.g. highly energetic turbulent motion can be created in a relatively compact experimental apparatus. It is hardly arguable that VK flow is important for turbulence research, and the better it is understood, the better it can serve for all kinds of turbulence-related research (e.g. particles dispersion in turbulent flows). This forms the high-level motivation of the project.

The particular aspect of VK flow that the project aims to investigate is a recently observed feature of the flow field, which appears in the vicinity of its stagnant region. This feature can be characterised as a unidirectional, radially-oriented, velocity field with a significant spatial extent, which exists on top of the mean flow visualised in the figure. The feature is the strongest close to the vessel centre, where it accounts for more than half of the turbulence energy, and weakens progressively away from the centre. It undergoes rotation around the vessel axis with the angular velocity equal to roughly 10% of the impellers' angular velocity. The project goal is to address the following four research questions about the described flow feature: (i) is this phenomenon reproducible in different facilities, (ii) how sensitive is it to the history of the flow, (iii) how sensitive is it to the geometry of the vessel, (iv) can it be controlled via different stirring strategies. By answering these, the project is meant to broaden our understanding of VK flows.

Before the posed questions can be answered, an experimental facility, suitable for particular conditions of the project, is to be designed, built and equipped. In particular, it has to allow for the application of Particle Image Velocimetry (a non-intrusive measurement technique capable of capturing velocity fields over a planar or volumetric domains), which is meant as the primary experimental technique used within the project. The first of the research questions is self-explanatory. Reproducibility of a phenomenon, independently of the experimental apparatus, is the necessary condition for considering it as relevant. The second question looks into the potential effects of the flow history. For instance, different states of the investigated feature can be reached depending on how the flow was started. Such a behaviour has been observed in VK flows in the past regarding its other properties. The third question considers effects of the vessel geometry, focusing on the hight-to-diameter ratio, and the baffles layout (i.e. vertical plates attached to vessel sidewall to limit the spinning of the fluid, in the figure they appear in grey). This second focus is particularly important, as the investigated feature has not been observed in unbaffled VK flows, despite considerably larger scientific attention received by such flows. Finally, the last scientific question looks into possibilities of controlling, i.e. energising or de-energising, the structure through the application of specific stirring strategies. Two main stirring approaches are considered here, modulated stirring and random stirring.