THREE DIMENSIONAL VELOCITY FIELD OF VORTICES IMPINGING ON A WALL OBTAINED BY SCANNING PARTICLE TRACKING VELOCIMETRY.

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MOTIVATION

Vortex wall interactions are omnipresent in wall-bounded turbulent flows and are therefore of fundamental interest for understanding such flows. In this study SPTV was used to quantitatively measure the rapid changes in flow topology of vortex rings directed towards a rigid boundary. The 3D velocity vector fields generated on impact are dependant on the angle of the vortex propagation direction to the wall. If the vortex ring approaches the wall perpendicularly the vortex first stretches due to the mean strain induced from the stagnation point type flow, then builds up a shear layer of opposite sign close to the wall. This shear layer rolls up into vortices while being subject to the induction from the still strong original vortex. Subsequently, the first of the rolled up shear layer vortices is entrained into the original vortex in a complex three dimensional fashion which leads to multiple breakdown events along the vortex core and to the very rapid destruction of the originally coherent vortex. This is in contrast to the case when the angle of propagation is inclined with regard to the wall. Here, upon approach of the vortex ring to the wall, this interaction also first stagnates in the region of closest contact, and a similar shear layer entrainment develops locally. Now, since this interaction originates where the vortex is close to the wall, two symmetric vortex breakdown events develop and travel along the vortex core towards the less perturbed part of the vortex ring which has not jet felt the presence of the wall. During this process, strong flows develop along the vortex core due to the pressure gradient between the strongly rotating and weakly rotating regions. Chang et al.[1] (1997) have numerically simulated a similar setup, where an elliptical vortex propagated parallel to the wall and interacted when first approaching with the long principal axis.

Two main questions are addressed in this study.

First, for vortices that impact with an inclined angle, we want to focus the attention on the region initiating the symmetric vortex breakdown to obtain estimates for the increase in the local maximum vorticity, and azimutal strain rate. Since the symmetric vortex breakdown can be interpreted as a “terminal” Kelvin wave, this type of vortex wall interaction is relevant to turbulent transition and energy exchange. It is speculated that turbulent drag reduction by addition of polymers is caused by interference with this breakdown process. Kerr[2] (1993) shows evidence for a developing singularity in vorticity magnitude when simulating such an event using the incompressible Euler equations.

Second, for vortices impacting a wall perpendicularly we want to elucidate the complex mechanisms at work when we have the main ingredients of a turbulent flow (e.g. vortex filament, shear layer, and strain) interacting in a strongly dynamic fashion and leading to the rapid dissipation of the introduced energy.

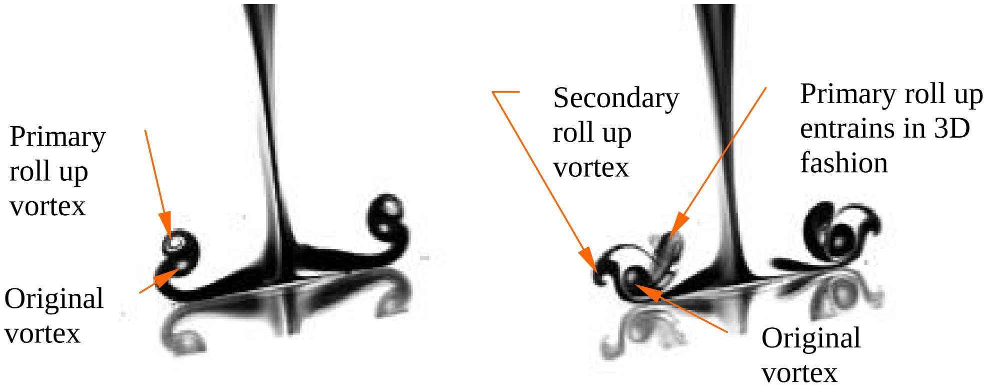

Figure 1: Flow visualization using Laser Induced Fluorescence in the center plane of a vortex ring impinging <u>perpendicular</u> onto a wall. The light sheet is 4 mm thick and the diameter of the original vortex torus ca 50 mm wide. Two instances in time are shown. Left image is shortly before 3D breakdown; right image is at the instant of the 3D entrainment of the primary roll up vortex into the original vortex.

METHODS

3D Particle Tracking velocimetry[3,4] has been developed as a full flow field measurement tool at our institute in collaboration with the Institute of Geodesy and Fotogrammetry over the last decade and has yielded numerous publications and dissertations. In the classical system, a four-camera setup records images of tracer particles being convected through an illuminated observation volume with similar dimensions in the three spatial directions. Stereoscopic matching identifies a number of individual particles in the different image frames, and allows determining the 3D position in physical space from the previously in situ calibrated setup. A tracking algorithm then repeatedly identifies and follows the individual particles in time to obtain the particle paths. The system however has an inherent limit to the seeding density because of the long optical path through the observation volume. Practically an upper limit to the number of particles is of $O(10^3)$ independent on the absolute size of the observation volume. Applying a higher density leads to an unacceptable number of overlapping particles in each image space so that the yield of stereoscopic matches decreases and the overall performance degrades.

One possible solution is to scan a thinner illuminated volume (with regard to the optical path) through the region of interest and record images correspondingly faster. In a first approximation, one is able to increase the particle density linearly with the reduction in the thickness of the scanned volume. The motivation for the increase in particle density lies in the need to resolve small scales with sufficient accuracy while at the same time having a large enough observation volume to realize the large-scale flow topology.

A sketch of the scanning optical setup is given below. A laser light sheet is generated with appropriate thickness and scanned horizontally by passing through a quadratic prism. On the receiving end, a four-way image splitter projects the different views onto a single chip of a high-speed image acquisition system (Photron Ultima APX). The image trigger is provided by an optical gate together with a hole-disk mounted to the rotating prism.

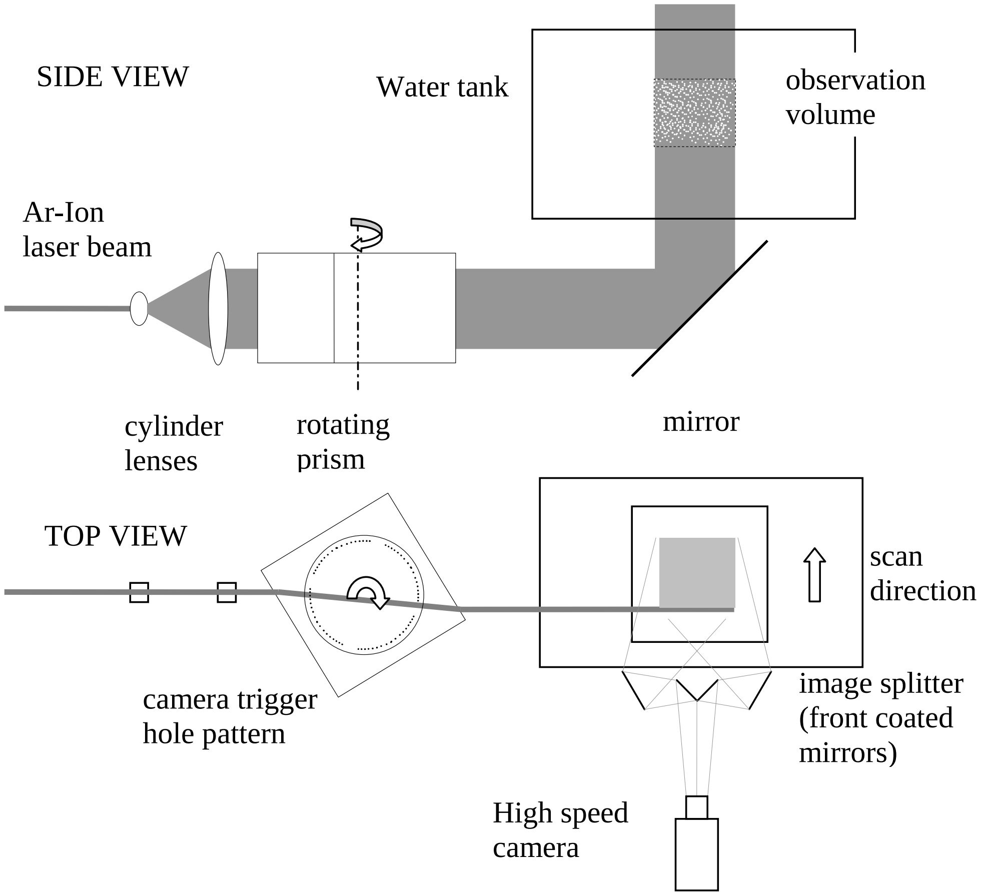

Figure 2: Optical setup of the scanning PTV system used to increase the particle density in the observation volume. The light sheet undergoes parallel displacement depending on the rotation angle of the prism.

It is planned to maximize the particle density sufficiently to obtain velocity gradient information throughout the observation volume and apply newly developed analysis through the availability of the velocity gradient tensor.

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[1] Chang et al., Three-dimensional vortex/wall interaction: Entrainment in numerical simulation and experiment, Phys. Fluids 9, 57 (1997)

[2] Kerr RM. 1993. Evidence for a singularity of the3-dimensional, incompressible Euler equations. Phys. Fluids A 7:1725–46

[3] Maas, H.-G., 1992: Digitale Photogrammetrie in der dreidimensionalen Stroemungsmesstechnik ETH Zurich - Dissertation Nr. 9665

[4] Marko Virant, Anwendung des dreidimensionalen "Particle-Tracking-Velocimetry" auf die Untersuchung von Dispersionsvorgängen in Kanalströmungen, ETH Zürich Dissertation Nr.11678, 1996