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PIV Measurements of Compressible Vortex Rings Generated by a Shock Tube

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Vortex rings are interesting fluid dynamic phenomena that can be either generated artificially or that appear in nature. Important physical characteristics of vortex rings are the propagation velocity, growth rate, and vorticity. To date, many studies were conducted with incompressible vortex rings for which corresponding theoretical models have been developed. Compressible vortex rings, which move at considerably higher velocities than incompressible vortex rings, have not been studied to the same extent as incompressible vortex rings so that it is interesting to compare their characteristics with existing theoretical models.

In this study, fast propagating compressible vortex rings were generated with a small shock tube 47 mm in diameter (Fig. 1). The shock tube creates an impulsively started flow with a leading shock resulting in an unsteady boundary layer separation at the tube exit. Further on, the boundary layer rolls up and forms a separated vortex ring that is accelerated up to 100 m/s by the accelerated flow issuing from the tube. The vortex ring was visualized by the laser light sheet and the instantaneous velocity field was measured by a 2D-PIV system (Fig. 1).

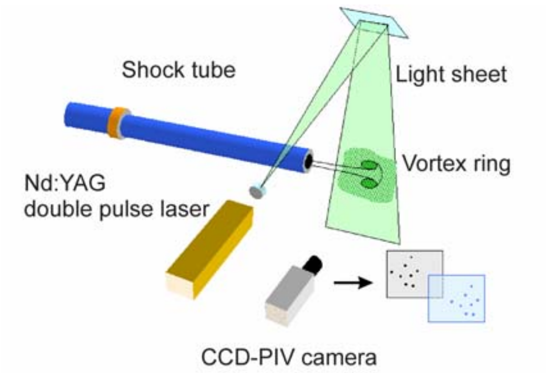

Fig. 1: Shock tube facility for the generation of vortex rings and PIV system.

Both the shock tube and the ambient air were seeded with fine smoke particles. A visualization of a generated vortex ring with a high level of seeding particles is shown Fig. 2. The particles were seeded only inside the tube for this picture. The vortex cores are clearly seen as dark disks surrounded by a high amount of particles. At this stage, the vortex ring was not yet pinched of from the jet flow emanating from the tube exit. The experiments were repeated to determine the velocity field in and around the vortex ring at several defined positions x of the propagation trajectory. The experimental results showed that the vortex ring keeps its structure even at a longer propagation distance of 1.5 m from the tube exit.

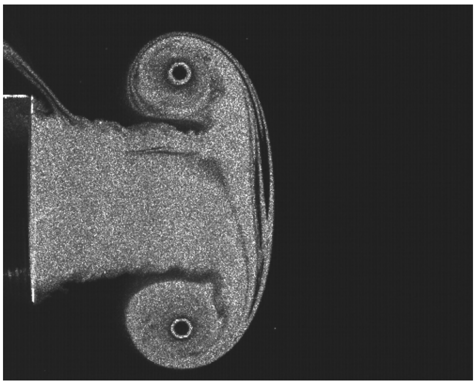

Fig. 2: PIV-picture of a vortex ring moving from left to right.

The vortex core can be well defined and the streamlines in the vortex ring are visible from the velocity field measurement (Fig. 3). The measurements also yield information about the vorticity and the kinetic energy within the vortex ring. The evolution of these values along the ring's propagation path can be compared with existing theories of incompressible vortex rings.

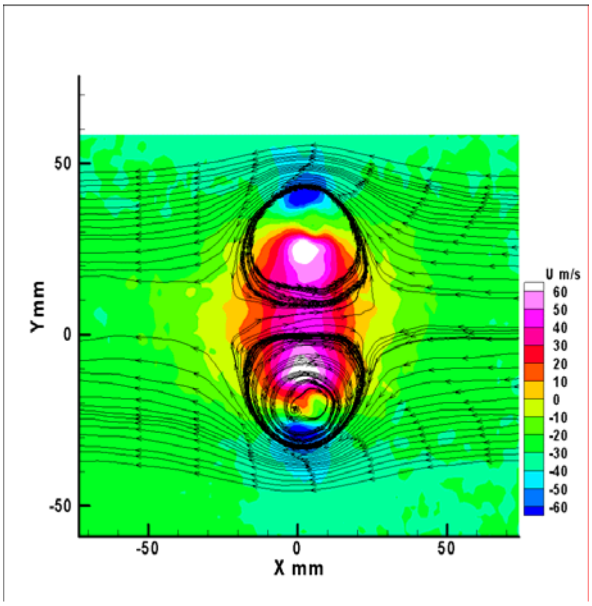

Fig. 3: Velocity distribution and streamlines in and around a vortex ring determined by PIV at a propagation distance of 1.5 m.