MEASURING THE FULL VELOCITY GRADIENT AND DISSIPATION RATE TENSOR IN HOMOGENEOUS TURBULENCE USING SHAKE-THE-BOX AND FLOWFIT

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We present measurements of the full velocity gradient and dissipation rate tensor based on dense fields of fluid particle trajectories in homogeneous turbulence at Re_λ~270 and ~350 in a von Kármán flow between two counter-rotating propellers. Applying the *Shake-The-Box* (STB) particle tracking algorithm [1], we are able to instantaneously track up to ~100.000 particles in a measurement volume of 50 x 50 x 15 mm³. The mean inter-particle distance is lower than 7 Kolmogorov lengths. The data assimilation scheme *FlowFit* [2] with continuity and Navier-Stokes- constraints is used to interpolate the scattered velocity and acceleration data by continuous 3D B-Splines in a cubic grid, enabling to recover (locally) the smallest flow scales. In the presentation, we show Lagrangian velocity, acceleration and jolt statistics, as well as the Eulerian counterparts on velocity and pressure gradients with respective Q-R-diagrams, compute the energy dissipation rate directly by using local velocity gradient information gained by FlowFit at midpoints of particle tetrahedra in close proximity of a few Kolmogorov lengths and compare it to known indirect approaches.

At relatively low seeding densities, Lagrangian particle tracking (LPT) has been used in turbulence research for more than two decades [e.g. 3]. At this low seeding density, multi-particle statistics can be assessed in the inertial range, however, events where particle pairs or tetrahedra [4] reach small distances of the order of the Kolmogorov length are rare. Here, we aim for volumetric time-resolved measurements with the maximally feasible seeding density at high positional accuracy by applying the STB technique and FlowFit subsequently.

The experimental setup at the GTF3 of MPI-DS in Göttingen consists of a cylindrical water tank (500 mm diameter) with two counter-rotating propellers at the top and at the bottom, generating a von Kármán flow with a homogeneous turbulent region in the center (at least in radial directions). From earlier experiments [5], the expected Kolmogorov length for the lower Re_λ is $\eta \sim 100$ µm at a propeller frequency of 0.5 Hz. The Kolmogorov time is $\tau \sim 10$ ms, i.e., temporal oversampling by a factor of 12.5 at 1.25 kHz frame rate. Spherical monodisperse and nearly neutrally buoyant polystyrene particles (20µm diameter) are illuminated by a fibre-coupled 150 W Nd:YAG high frequency laser (IB Chronos 400 MM IC SHG) in the center of the tank. Four CMOS cameras (Phantom v640, 2560 x 1600 pixel, 1250 Hz) equipped with 100 mm Zeiss macro lenses ($f_\# = 16$) and Scheimpflug adapters record the particles in ~45° forward scattering. Prisms attached to the tank avoid astigmatism of particle images.

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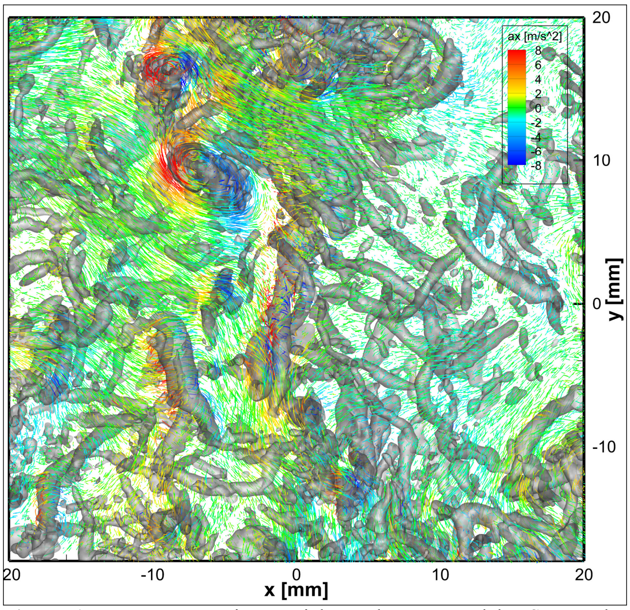

Figure 1. Dense Lagrangian particle tracks measured by STB, color coded by x-component of acceleration and iso-surfaces of Q-criterion, Q= 2500 s⁻² from FlowFit. $Re_\lambda \sim 270$, Kármán flow at GTF3 at MPI-DS, Göttingen.

References

[1] Schanz D, Gesemann S, Schröder A: „Shake-The-Box: Lagrangian particle tracking at high particle image densities“, Exp. Fluids 57:70,
[2] Gesemann S, Huhn F, Schanz D, Schröder A: " From Noisy Particle Tracks to Velocity, Acceleration and Pressure Fields using B-splines and Penalties", 18th Lisbon Symposium, Portugal, (2016)
[3] La Porta A, Voth GA, Crawford AM, Alexander J, and Bodenschatz E: "Fluid particle accelerations in fully developed turbulence" Nature 409, 1017-1019, (2001).
[4] Xu H, Pumir A, Bodenschatz E: "The pirouette effect in turbulent flows", Nature Physics 7, 709-712, (2011).
[5] Jucha J, Xu H, Pumir A, Bodenschatz E: "Time-reversal-symmetry Breaking in Turbulence", Phys. Rev. Lett. 113, 054501, (2014).