LPT Case 03

The experimental dataset comprises images of Helium-filled soap bubble within a Rayleigh-Bénard convection cell, captured by four (out of six) 5.5 MegaPixel SCMOS cameras (Bosbach et al. 2021, Godbersen et al. 2021, Weiss et al. 2024). The experiment was conducted at DLR Göttingen and consisted of a electrically heated aluminum plate and a water-perfused cooling plate, which allows for illumination from the top using an assortment of LED arrays (see Fig. 1). A total of six PCO edge 5.5 SCMOS cameras (2560 × 2160 pixels with a 6.5 µm pitch) was installed and equipped with Zeiss Distagon 35 mm lenses. They were installed at the height of the upper cooling plate and slightly tilted downwards to view the full cell Despite the strong reflection on the black bottom plate, bubbles are still visible in this region. The flow was recorded at a repetition rate of 30 Hz for over 30 minutes. The images captured by all six cameras over 54528 time-steps were used to reconstruct Lagrangian Particle Tracks using the DLR Shake-The-Box implementation; these results will serve as a Ground Truth for the evaluation of the LPT challenge results. For the challenge data, the four inner cameras of the in-line camera setup are selected (marked in red in Fig. 1, right), all viewing the entire volume within the cell. The omission of the two outer cameras severely aggravates the reconstruction problem, allowing the six-camera solution to be regarded as a Ground Truth.

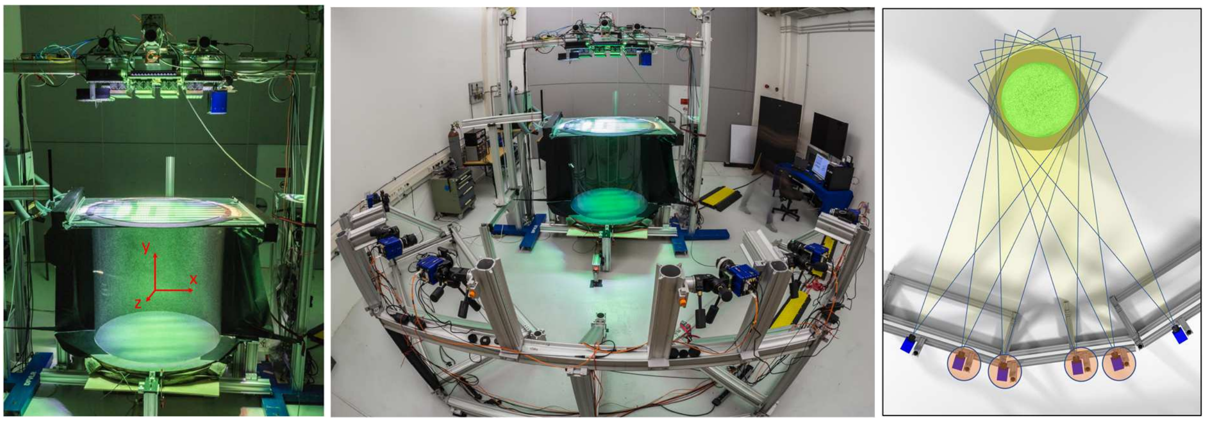

Figure 1: Left: The 1.1m high and wide RBC sample, filled with HFSBs and illuminated by the LED array, Coordinate system indicated in red; Middle: Image of the full lab setup with the six cameras on X95-mount; Right: Rendering from top of the camera setup and field-of-views. The cameras available within the LPT challenge are marked by red circles

The use of Helium-filled soap bubbles with limited lifetime leads to an ever-diminishing particle density over the measurement. This allows to extract short time-series of images at arbitrary particle image density. At the beginning, the six-camera evaluation is able to track around 550,000 bubbles, corresponding to over 0.13 ppp at an assumed active image area of around 4Mpix, at the end of the time-series 2385 tracked bubbles remain (see Fig. 2 right). Please note that the visible particle image density varies greatly over the image due to the circular shape of the sample, therefore the given ppp-values represent averages over the active image.

For the reconstructions with only four cameras we supply time-series of 50 images at 0.01, 0.04 and 0.07 ppp and 100 images at 0.1 ppp. Two-pulse-cases are available at 0.005, 0.015, 0.045, 0.06 and 0.075 ppp (see Table 1). The disjoint values for TR and TP are chosen to avoid an overlap of flow situations and images between the two modes. For each case, a sliding minimum image is provided for image preprocessing, created by taking for each pixel the minimum over +/- 10 images of the first image (see Fig. 2).

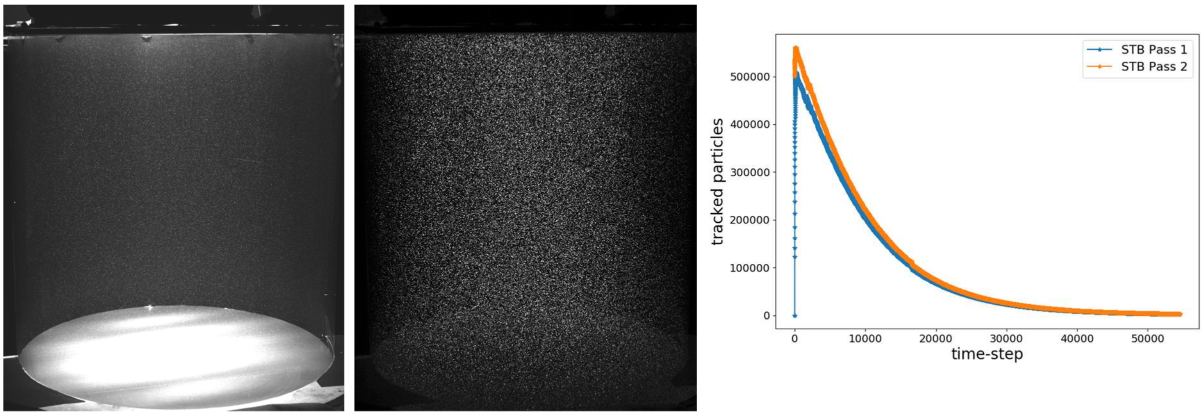

Figure 2: Left and middle: exemplary camera image at 0.04 ppp without and with subtraction of a sliding minimum image; Right: Number of tracked particles over the full time series for both passes of the six-camera STB evaluation

For calibration, two options are available – either a total of around 75.000 random points within a slightly enlarged reconstruction volume ('LPT_CASE03_CalibPoints.txt') or a version with around 14.000 points on several x-y-planes at different z-depths ('LPT_CASE03_CalibPoints_on_grid.txt'). The point correspondences were created using the fully calibrated two-plane camera model (initial plate calibration, volume self-calibration and finally a B-spline based 2D correction field which accounts for the curvature of the plexiglass) that was used within the six-camera STB evaluation. Participants can either just use these points to calibrate their camera models or additionally perform a Volume-Self-Calibration using the supplied time-series.

The coordinate system is approximately centered in the sample, with X, Y and Z within (-550 to +550, -610 to 500, -550 to +550) mm. The dynamic range of the velocity is rather high, with low particle shifts in some regions, while the highest velocities can reach around 0.35 m/s, corresponding to a particle shift of around 20 pixels (these values have not been checked for all data points, so they should not be used as absolute limits).

Participants can choose whether they want to process the TR or the TP data, or both. For TR, results have to be submitted at least up to ppp = 0.07 and for TP up to ppp = 0.045. Processing the higher seeded cases is of course encouraged.

For **TR**, the tracked particles for time step 25 (images '_I0024', ppp ≤ 0.07) or 50 (images '_I0049', ppp = 0.1) need to be supplied for each processed seeding density in the following format: ASCII-file with first line *X Y Z Xfit Yfit Zfit VX VY VZ AX AY AZ*, followed by one line for each tracked particle with raw position (in mm), fitted position (temporal fit of participants choice to dampen position noise and to determine velocity and acceleration; in mm), the velocities VX, VY, VZ (in m/s) and the accelerations AX, AY, AZ (in m/s^2), all calculated at time step 25 or 50 depending on the seeding density of the case. In their accompanying description, participants should describe how fitted position, as well as velocity and acceleration, are computed. The naming of the files should follow the convention: "ZZZZ_LPT_CASE03_TR_ppp_0_AAA_PartFieldNN.zip", with ZZZZ being the participant identification name (free number of characters), AAA fractional ppp and NN the time-step index (24 or 49).

Additionally, for the 0.04 ppp-case, the raw positions should be supplied for all time-steps in the form of 50 separate ASCII files with the naming scheme "ZZZZ_LPT_CASE03_TR_ppp_0_040_RAW_PartFieldNN.zip" (with NN from 00 to 49). Each file should contain a header line *X Y Z TrackID,* followed by one line for each particle track with the raw position (in mm) and a unique number for each track that will allow identifying connected trajectories within the 50 supplied files.

For **TP**, the single computed flow field needs to be supplied for each processed seeding density in the following format: ASCII-file with first line *X0 Y0 Z0 X1 Y1 Z1,* followed by one line for each particle with the two measured particle positions X0, Y0, Z0, and X1, Y1, Z1 (in mm) for time steps 0 and 1 of all identified two-pulse tracks. The naming should be "ZZZZ_LPT_CASE03_TP_ppp_0_AAA_PartField00.zip", with ZZZZ being the participant identification name (free number of characters), and AAA fractional ppp.

Table 1: Supplied cases for the experimental RBC data

Case	ppps	# of images
TR	0.01, 0.04, 0.07	50
TR	0.1	100
TP	0.005, 0.015, 0.03, 0.045, 0.06, 0.075	2

Contact in case of questions: daniel.schanz@dlr.de

Literature

Bosbach J, Schanz D, Godbersen P, Schröder A (2021) Spatially and temporally resolved measurements of turbulent Rayleigh-Bénard convection by Lagrangian particle tracking of long-lived helium-filled soap bubbles, *14th International Symposium on Particle Image Velocimetry*

Godbersen P, Bosbach J, Schanz D, Schröder A (2021). Beauty of turbulent convection: a particle tracking endeavor. *Physical Review Fluids*, 6(11), 110509.

Weiss, S., Schanz, D., Erdogdu, A. O., Schröder, A., & Bosbach, J. (2024). On Lagrangian properties of turbulent Rayleigh–Bénard convection. *Journal of Fluid Mechanics*, 999, A90.