Waves, Turbulence and Diffusion in Beta-Plumes: Rotating tank experiments at TurLab, Turin

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1 Overview

This dataset provides horizontal flow fields (velocity, relative vorticity, divergence, and shear strain rate) from nine rotating turbulence experiments carried out at TurLab at the University of Turin between November 2016 and February 2017.

The experimental device was a rotating cylinder 5 m in diameter filled with fresh water to a depth of 56 cm. The tank had a conical bottom, sloping upwards towards the centre from the outer edge over a radius of 2.25 m at an angle of 11.1°.

The flow was mechanically forced by a moving comb of vertical paddles partially immersed in the water, which moved backwards and forwards along a near-radial line over 100–150 s. The resulting flow was visualised using a laser sheet and microscopic particles, imaged using two cameras, and then processed into horizontal velocity fields and derived quantities using UVMAT/CIV (http://servforge.legi.grenoble-inp.fr/projects/soft-uvmat).

The main quantity varied between the experiments included in this dataset is the rotation period of the tank. There were minor differences in the comb configuration at each rotation period.

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2 Dataset contents

The dataset contains ten files. There is one `.tgz` file for each experiment, plus this file `readme.pdf`.

File	Experiment	Date acquired	Rotation period (seconds)	First image number	Last image number	Image number interval	Number of fields	Duration (h:mm:ss)
`EXPT01_161130.tgz`	EXPT01	30/11/2016	40.4	2	8502	20	426	1:11:00
`EXPT02_161201.tgz`	EXPT02	01/12/2016	40.4	1	38521	30	1285	3:34:10
`EXPT03_161201.tgz`	EXPT03	01/12/2016	40.4	1	33121	30	1105	3:04:10
`EXPT04_161202.tgz`	EXPT04	02/12/2016	119	1	18391	30	614	1:42:20
`EXPT05_161202.tgz`	EXPT05	02/12/2016	119	1	61201	30	2041	5:40:10
`EXPT06_170207.tgz`	EXPT06	07/02/2017	119	32	38462	30	1282	3:33:40
`EXPT07_170208.tgz`	EXPT07	08/02/2017	61	49	42589	30	1419	3:56:30
`EXPT08_170209.tgz`	EXPT08	09/02/2017	119	96	71166	30	2370	6:35:00
`EXPT09_170210.tgz`	EXPT09	10/02/2017	30.3	18	64788	30	2160	6:00:00

The MD5 checksums for each `.tgz` file are as follows:

File	Size (GB)	Checksum
`EXPT01_161130.tgz`	0.6	a6049bfb764e94d5d7b095ecfc4522e7
`EXPT02_161201.tgz`	2.0	73a9d23926e784b0194f865ae213a3e5
`EXPT03_161201.tgz`	1.7	59154f69e00eb90aa031f5867ddeb20d
`EXPT04_161202.tgz`	1.0	b948d5d72a347f1522ef8c2c89412a95
`EXPT05_161202.tgz`	3.2	ae730b2a6daa153525f6db68787f01b2
`EXPT06_170207.tgz`	1.9	b49bf4d0683bfeca7d2d40100a456740
`EXPT07_170208.tgz`	2.1	06fe7770e9bc8902c4605887087b9e76
`EXPT08_170209.tgz`	3.5	2045cfbe678d704437e88d50f07f377d
`EXPT09_170210.tgz`	3.3	38ed23e13dbf2dd83aedef4716421c73

Each `.tgz` file is a compressed and zipped `tar` archive that contains three directories:

- `merged.civ1/` containing CIV1 gridded flow fields in netCDF-4/HDF5 format.
- `merged.civ2/` containing CIV2 gridded flow fields in netCDF-4/HDF5 format.
- `movies/` containing animations visualising the data.

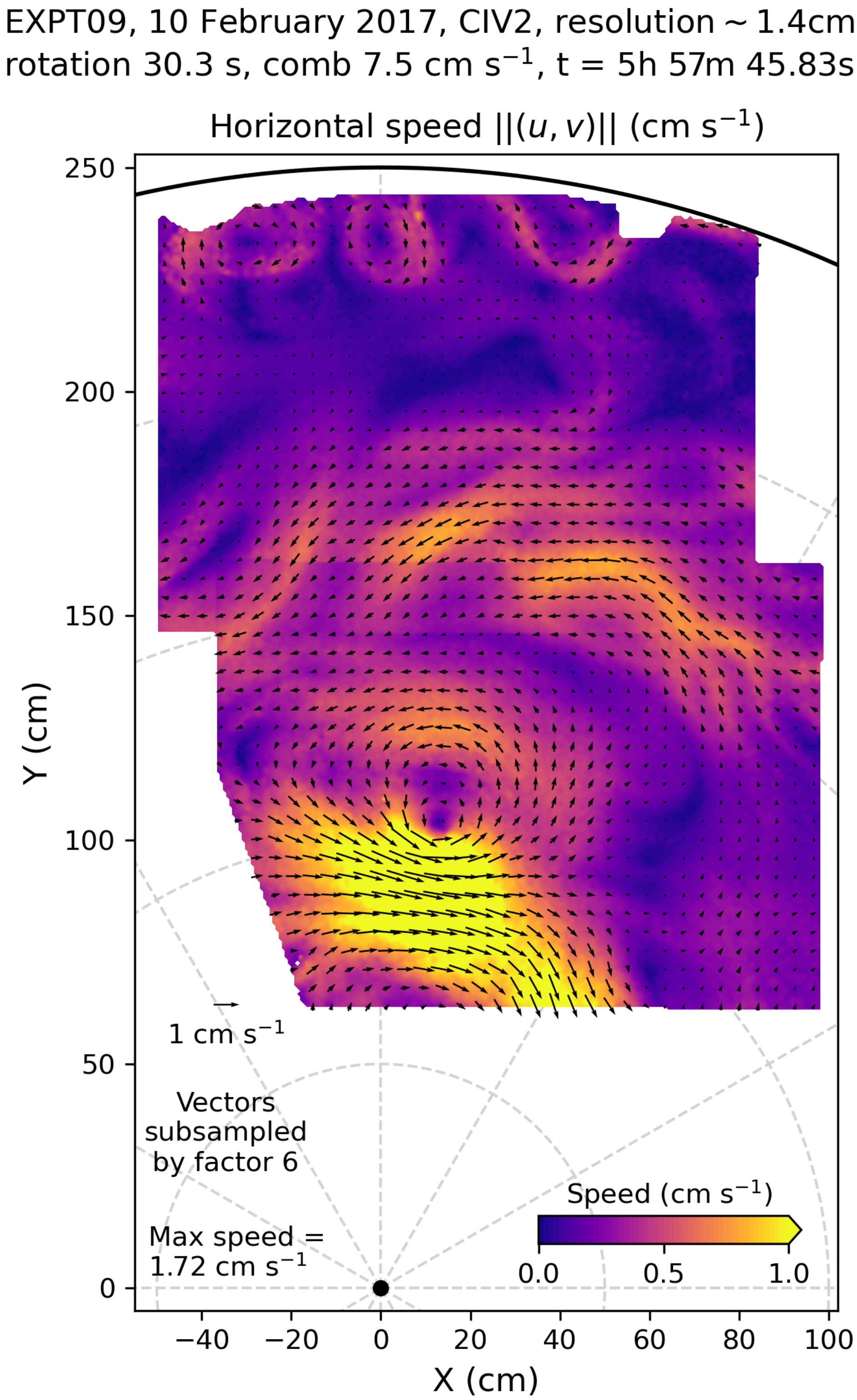
3 Gridded horizontal velocity data and derived fields

Horizontal velocity data and derived scalar fields are stored in the `merged.civ1/` and `merged.civ2/` directories. Files are in netCDF-4/HDF5 format. Each file contains one instantaneous horizontal velocity field and its derived scalar fields (relative vorticity, divergence, and shear strain rate).

The file naming convention is `fig_N.nc`, where `N` is the image number of the reference image used in the CIV processing. `N` is not zero-padded. The table above gives the range of image numbers for each experiment. Files are numbered with an interval of 30, except for EXPT01, where the interval is 20. In each case this corresponds to 10 seconds of real time between each file. $t = 0$ for each experiment is approximately when the initial spin-up of the rotating tank from rest began.

The data are on a uniform right-handed Cartesian grid. The y-axis of the grid is aligned along a radius of the tank, with the origin at the centre of the tank. This grid is the same for all experiments, and does not change within each experiment. There are some small differences between the CIV1 and CIV2 grids.

The figure below shows an example of a single flow field, illustrating the Cartesian grid and the spatial extent of the data. The centre of the tank is the large dot at the bottom, and the circular edge of the tank is the curved line at the top. Radial and azimuthal grids are also shown in the figure for reference, but we do not include these in the dataset. Note the velocity field in the figure is subsampled by a factor six in both directions.



Two datasets are included for each experiment:

- `merged.civ1/` contains data after the CIV1 / FILTER1 / PATCH1 stages of processing. CIV1 accounts for translation between images, but no other transformations. The CIV1 fields are on a 133×166 grid. The grid spacing is 1.15 cm in both directions. The effective resolution is 2.36 cm, which is set by the correlation box size in the CIV1 step.
- `merged.civ2/` contains data after the CIV2 / FILTER2 / PATCH2 stages. CIV2 uses CIV1 as a first guess horizontal velocity field, and then accounts for shearing and rotation in addition to translation between images. The CIV2 fields are on a 221×272 grid. The grid spacing is 0.69 cm in both directions, and the effective resolution is 1.44 cm.

Each netCDF-4/HDF5 file contains the following quantities:

Dimensions

Dimension	Description
`coord_x`	Number of grid points in x-direction
`coord_y`	Number of grid points in y-direction

Variables

Variable	Dimensions	Symbol	Description	Units
`coord_x`	1D	x	Positions of 2D field grid points in x-direction	m
`coord_y`	1D	y	Positions of 2D field grid points in y-direction	m
`U`	2D	u	Horizontal velocity in positive x-coordinate direction	m s^{-1}
`V`	2D	v	Horizontal velocity in positive y-coordinate direction	m s^{-1}
`curl`	2D	ζ	Relative vorticity $\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$	s^{-1}
`div`	2D	δ	Divergence $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$	s^{-1}
`strain`	2D	-	Shear strain rate $\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$	s^{-1}

Locations where no velocities were measured are given as not-a-number (`NaNf`) in each 2D field.

Selected global attributes

Attribute	Description
`NbCoord`	Number of physical coordinates
`NbDim`	Number of dimensions
`Time`	Time elapsed since start of experiment (s)
`ProjObjectCoord`	Location of the coordinate origin relative to the centre base of the tank (m)

Random uncertainties

In general, the random uncertainty in each horizontal velocity component is 0.04–0.09 mm s^{-1}, depending on the experiment and which camera the velocity is calculated from. In the merged fields provided in this dataset, this means there can be a difference in the uncertainties between the inner and outer halves (radially) of the velocity field. In the part of the velocity field where the two cameras overlap, the uncertainty will be somewhere between the two values. The table below summarises these uncertainties, to one significant figure:

Experiment(s)	Inner half (mm s^{-1})	Outer half (mm s^{-1})
EXPT01	0.06	0.06
EXPT02–EXPT08	0.09	0.04
EXPT09	0.09	0.09

4 Movies

Each experiment has a directory `movies/` that contains four animations of the data. Replace `#` with the experiment number in each case. All movies are in MP4 format:

- `EXPT0#_pv_vel_civ1.mp4`: Animation showing the potential vorticity field

$$q = \frac{2\Omega + \zeta}{h}$$

  where Ω is the rotation rate and h is the depth of the tank (varies with radius). This as shown as coloured contours, overlaid with the vector horizontal velocity (u, v), after the CIV1 / FILTER1 / PATCH1 stage.

- `EXPT0#_pv_vel_civ2.mp4`: Same as above but after CIV2 / FILTER2 / PATCH2.

- `EXPT0#_spd_vel_vort_div_civ1.mp4`: Animation showing three panels. From left to right:
  - Horizontal flow speed $||(u, v)|| = \sqrt{u^2 + v^2}$ overlaid with the vector horizontal velocity (u, v).
  - Relative vorticity $\zeta = \dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$.
  - Divergence $\delta = \dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y}$.

  These are after the CIV1 / FILTER1 / PATCH1 stage.

- `EXPT0#_spd_vel_vort_div_civ2.mp4`: Same as above but after CIV2 / FILTER2 / PATCH2.

5 Data processing

1. Raw images were taken using an outer and an inner camera.
2. Using the raw images we defined masked regions where data are excluded. For the outer camera this masked out the visible tank superstructure and the laser sheet where it intersected the wall. For the inner camera this masked out the region where a laser shadow fell. As the cameras moved slightly between the December and February experiments, separate masks were required.
3. In some experiments the image numbering for the outer and inner cameras was not synchronised. We computed the shift between the two, and chose the images to process from each camera accordingly.
4. We ran a filter to remove the background, using the UVMAT script `sub_background`. This processed a burst of 3–4 images every 10 seconds (every 30 images, with the camera taking three frames per second, except for EXPT01, where the camera took images at two frames per second, so every 20 images). The background subtraction used a 23-image running mean (only using the images every 10 seconds in the mean).
5. We ran the CIV software on each sequence of image pairs. Outer and inner cameras were processed separately.

6. Two sets of calibration images were used to calibrate the two cameras. One was taken before the December experiments EXPT01–EXPT05, and the other was taken after experiments EXPT06–EXPT09. For the outer camera, images with the calibration grid covering the outer camera, touching the outer wall, were used to estimate the intrinsic and extrinsic calibration parameters. For the inner camera, images with the calibration grid covering the inner camera were used to estimate the intrinsic parameters, then images with the calibration grid touching the outer tank wall were used to estimate the extrinsic parameters. This resulted in four sets of calibration data: one for each camera and for December and February separately.
7. The calibration images were used to calibrate the uncalibrated data to produce a raw horizontal velocity dataset in physical coordinates at a scattered but quasi-regular set of points. This was done for each camera separately.
8. The scattered horizontal velocity vectors were merged and interpolated onto a regular grid using the thin plate spline method. This was done using the UVMAT `merge_proj` utility. The `merge_proj` utility also dealt with the overlap between the cameras. The merge was done for CIV1 and CIV2 separately, so the final dataset contains both stages.

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