README: Turbulent boundary layer planar particle image velocimetry

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Overview

This README describes the experimental turbulent boundary layer dataset that is part of "A database for reduced-complexity modeling of fluid flows" [1]. Users of these data should cite the following references:

A. Towne, S. Dawson, G. A. Brès, , A. Lozano-Durán, T. Saxton-Fox, A. Parthasarthy, A. R. Jones, H. Biler, C.-A. Yeh, H. Patel, and K. Taira. A database for reduced-complexity modeling of fluid flows. *AIAA Journal*, 61:2867–2892, 2023

Flow conditions

This dataset corresponds to a nominally zero pressure gradient subsonic turbulent boundary layer at five Reynolds numbers. The dimensionless parameters are:

- Friction Reynolds numbers: $Re_\tau = \frac{u_\tau \delta}{\nu} = 600, 980, 1370, 1780, 2220$
- Reynolds number based on distance from the leading edge: $Re_x = \frac{U_\infty X}{\nu} = 5.9 \times 10^5, 1.2 \times 10^6, 1.9 \times 10^6, 2.7 \times 10^6, 3.5 \times 10^6$

Here, u_τ is the friction velocity, δ is the 99% boundary layer thickness, ν is the kinematic viscosity, U_∞ is the free stream velocity, and X is the distance from the leading edge of the flat plate.

Data collection

The data were collected using planar particle image velocimetry in a low-speed wind tunnel at the Aerodynamics Research Laboratory at the University of Illinois Urbana-Champaign. The boundary layer was tripped at the leading edge of a flat plate held in the center of the test section. The boundary layer developed for 2.5 meters in a nominally zero pressure gradient environment. Particle image velocimetry was performed using a Phantom high-speed camera and a Continuum laser and was processed using DaVis software from LaVision.

The data have a spatial field of view of between 3 and 4 boundary layer thicknesses in the streamwise direction. The spatial resolution varies between 4 viscous units between vectors to 23 viscous units between vectors, depending on the Reynolds number of the case in question. The data sets include time-resolved velocity fields at the 5 Reynolds numbers and non-time-resolved fields at $Re_\tau = 980$. For the time-resolved cases, data were recorded at a rate of 3.75 kHz to yield temporal resolutions between 0.4 and 12 viscous units, depending on the Reynolds number. 6170 consecutive velocity fields of streamwise and wall-normal velocities are provided for each Reynolds number. For the non-time-resolved case, data were recorded at a

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rate of 0.2 kHz. 10,000 streamwise and wall-normal velocity fields are made available for this case. The data are formatted with double precision.

For all cases, particle image pairs are provided as TIFF files. The image acquisition rate was exactly 7510.7296 fps for the time-resolved cases, and the camera exposure was set to 133.82 μs. For the non-time-resolved case, the acquisition rate was 400 fps, and the exposure was 2495.72 μs. The time interval, dp, between two laser pulses (in the double-pulsed operation for frame straddling) was 220μs, 110μs, 70μs, 50μs, and 40 μs in order of increasing Reynolds number. A particle displacement of 7 pixels was targeted when choosing dp.

Nondimensionalization

The x and y vectors, specifying the streamwise and wall-normal coordinate, respectively, are non-dimensionalized by the boundary layer thickness in the center of the field of view: $x = x^*/\delta$ and $y = y^*/\delta$. The streamwise and wall-normal velocity components, u_x and u_y, and their time averages, $u_{x,mean}$ and $u_{y,mean}$ are not non-dimensionalized and are provided in m/s.

File inventory

The database contains the following files and variables:

- `expBL_example.zip`: zip archive containing a representative subset of the following data and scripts as an entry point for users
- `expBL_read.m`: Matlab script showing how the data can be read and manipulated
- `expBL_Re###_parameters.h5`: hdf5 file containing flow and data parameters
  - `Rex`: Reynolds number based on the distance from the leading edge
  - `dt`: time step between subsequent vector fields in seconds
  - `delta`: 99% boundary layer thickness in meters
- `expBL_Re###_grid.h5`: hdf5 file containing grid information
  - `x`: streamwise grid
  - `y`: wall-normal grid
- `expBL_Re###.h5`: hdf5 file containing the two-dimensional instantaneous velocity fields
  - `ux`: instantaneous streamwise velocity field at each (`x`, `y`) grid point and at each time `t`
  - `uy`: instantaneous wall-normal velocity at each (`x`, `y`) grid point and at each time `t`
- `expBL_Re###_mean.h5`: hdf5 file containing mean velocity field information
  - `ux_mean`: time-averaged streamwise velocity field at each (`x`, `y`) grid point
  - `uy_mean`: time-averaged wall-normal velocity field at each (`x`, `y`) grid point
- `expBL_Re###_RawData.zip`: zip archive containing the particle images as TIFF files in the format `expBL_Re###_t#####_image(n).tif`. `t#####` ranges from t00001 to t06170 for the time-resolved data and from t00001 to t10000 for the non-time-resolved data, while (n) takes the value of 1 or 2 for each `t#####` to denote the image number of each image pair.
- `expBL_Re###.zip`: zip archive containing the above files for each `###` $\in [600, 980, 1370, 1780, 2220]$

A tag of `_NTR` is added to the filenames that correspond to the non-time-resolved data at $Re_\tau = 980$. For example, the grid file is named as `expBL_Re980_NTR_grid.h5` and the particle images as `expBL_Re980_NTR_t#####_image(n).tif`

References

[1] A. Towne, S. Dawson, G. A. Brès, , A. Lozano-Durán, T. Saxton-Fox, A. Parthasarthy, A. R. Jones, H. Biler, C.-A. Yeh, H. Patel, and K. Taira. A database for reduced-complexity modeling of fluid flows. *AIAA Journal*, 61:2867–2892, 2023.