README: Turbulent Jet Large Eddy Simulation

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Overview

This README described the turbulent jet large eddy simulation dataset that is part of "A database for reduced-complexity modeling of fluid flows" [4]. 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

G. A. Brès, P. Jordan, V. Jaunet, M. Le Rallic, A. V. G. Cavalieri, A. Towne, S. K. Lele, T. Colonius, and O. T. Schmidt. Importance of the nozzle-exit boundary-layer state in subsonic turbulent jets. *J. Fluid Mech.*, 851:83–124, 2018

Flow conditions

This dataset corresponds to a subsonic turbulent jet issued from a contoured convergent-straight nozzle [3]. The dimensionless parameters are:

- Mach number: $M_j = U_j/c_j = 0.9$
- Reynolds number: $Re_j = \rho_j U_j D/\mu_j \approx 1,018,400$
- Jet temperature ratio: $T_j/T_\infty = 1.0$
- Nozzle pressure ratio: $NPR = P_0/P_\infty = 1.7$
- Nozzle temperature ratio: $NTR = T_0/T_\infty = 1.15$

Here, U is the mean streamwise velocity, c is the speed of sound, ρ is the density, D is the nozzle diameter, μ is the viscosity, T is mean temperature, P is the mean pressure, and the subscripts j, ∞, and 0 indicate nozzle exit, far-field, and stagnation conditions, respectively.

Data collection

The jet is investigated via high-fidelity large eddy simulation (LES) using the compressible flow solver "CharLES" developed at Cascade Technologies [1], which solves the spatially filtered compressible Navier-Stokes equations on unstructured grids using a finite volume method. The round nozzle geometry (with exit centered at the origin) is explicitly included in the axisymmetric computational domain, which extends from approximately $-10D$ to $50D$ in the streamwise direction and flares in the radial direction from $20D$ to $40D$. Several meshes were considered as part of a grid resolution study, and the one considered here contains approximately 16 million control volumes. The LES methodologies, numerical setup, and comparisons with

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experimental measurements are described in more detail in Ref. [3], wherein the available dataset is labeled *BL16M_WM_Turb*.

The LES database contains 10000 snapshots of the jet sampled every 0.2 acoustic time units (tc_∞/D), after the initial transient is removed. To facilitate post-processing, the data have been interpolated from the original unstructured LES grid onto a structured cylindrical grid output grid that extends to $0 \le x/D \le 30$, $0 \le r/D \le 6$ and contains $(626, 138, 128)$ points in the streamwise, radial and azimuthal directions, respectively. The streamwise and radial grids approximately mirror the underlying LES resolution (see Ref. [2] for details), while points are equally spaced in the azimuthal direction. Flow fields are stored as single-precision arrays, while other variables are stored in double-precision format.

Nondimensionalization

The LES data use the following nondimensionalization:

$$\rho = \frac{\rho^*}{\rho^*_\infty}, \qquad p = \frac{p^*}{\rho^*_\infty {c^*_\infty}^2} = \frac{p^*}{\gamma p^*_\infty}, \qquad T = \frac{T^*}{T^*_\infty}, \qquad \boldsymbol{u} = \frac{\boldsymbol{u}^*}{c^*_\infty}, \qquad \boldsymbol{x} = \frac{\boldsymbol{x}^*}{D^*}, \qquad t = \frac{t^* c^*_\infty}{D^*}.$$

Here, the superscript $*$ refers to the dimensional quantity. The nondimensionalization is based on an ambient speed of sound $c_\infty = \sqrt{\gamma p_\infty/\rho_\infty}$, where $\gamma = 1.4$. The resulting form of the ideal gas law is $p = \rho T/\gamma$.

File inventory

The database contains the following files and variables:

- `jet_example.zip`: zip archive containing a representative subset of the following data and scripts as an entry point for users
- `jet_read.m`: Matlab script showing how the data can be read and manipulated
- `jet_parameters.h5`: hdf5 file containing flow and data parameters
  - `M`: Mach number
  - `Re`: Reynolds number
  - `dt`: time step between snapshots
- `jet_grid.h5`: hdf5 file containing grid information
  - `x`: streamwise grid
  - `r`: radial grid
  - `theta`: azimuthal grid
  - `WeightMat`: volume associated with each grid point
- `jet_3D_t#####.h5`: hdf5 file containing a snapshot of the three-dimensional flow field at time index `#####` $\in [00000, 10000]$
  - `rho`: density at each (`x`, `r`, `theta`) grid point
  - `ux`: streamwise velocity at each (`x`, `r`, `theta`) grid point
  - `ur`: radial velocity at each (`x`, `r`, `theta`) grid point
  - `uth`: azimuthal velocity at each (`x`, `r`, `theta`) grid point
  - `p`: pressure fluctuation $p - 1/\gamma$ at each (`x`, `r`, `theta`) grid point
- `jet_3D_t#####.zip`: zip archive of `jet_3D_t#####.h5` files, each containing 1000 snapshots

- jet_mXX_t#####.h5: hdf5 file containing a snapshot of the XX azimuthal Fourier mode at time index ##### $\in [00000, 10000]$
  - rho: density at each (x, r) grid point
  - ux: streamwise velocity at each (x, r) grid point
  - ur: radial velocity at each (x, r) grid point
  - uth: azimuthal velocity at each (x, r) grid point
  - p: pressure fluctuation $p - 1/\gamma$ at each (x, r) grid point
- jet_mXX.zip: zip archive of jet_mXX_t#####.h5 files
- jet_mean.h5: hdf5 file containing the mean flow field
  - rho: mean density at each (x, r) grid point
  - ux: mean streamwise velocity at each (x, r) grid point
  - ur: mean radial velocity at each (x, r) grid point
  - uth: mean azimuthal velocity at each (x, r) grid point
  - p: mean pressure fluctuation $p - 1/\gamma$ at each (x, r) grid point
- calc_POD.m: A minimal Matlab implementation of proper orthogonal decomposition

References

[1] G. A. Brès, F. E. Ham, J. W. Nichols, and S. K. Lele. Unstructured large eddy simulations of supersonic jets. *AIAA J.*, 55(4):1164–1184, 2017.

[2] G. A. Brès, V. Jaunet, M. Le Rallic, P. Jordan, A. Towne, O. T. Schmidt, T. Colonius, A. V. G. Cavalieri, and S. K. Lele. Large eddy simulation for jet noise: azimuthal decomposition and intermittency of the radiated sound. AIAA paper 2016-3050, 2016.

[3] G. A. Brès, P. Jordan, V. Jaunet, M. Le Rallic, A. V. G. Cavalieri, A. Towne, S. K. Lele, T. Colonius, and O. T. Schmidt. Importance of the nozzle-exit boundary-layer state in subsonic turbulent jets. *J. Fluid Mech.*, 851:83–124, 2018.

[4] 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.