README: Turbulent airfoil wake large eddy simulation

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Overview

This README described the airfoilLES dataset that is part of "A database for reduced-complexity modeling of fluid flows" [2]. 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.

C.-A. Yeh and K. Taira. Resolvent-analysis-based design of airfoil separation control. *Journal of Fluid Mechanics*, 867:572–610, 2019.

Flow conditions

This dataset corresponds to the turbulent separated flow over an NACA 0012 airfoil at $6°$ angle of attack. The dimensionless parameters are:

- Free-stream Mach number: $M_\infty = U_\infty / a_\infty = 0.3$
- Reynolds number: $Re = \rho_\infty U_\infty L_c / \mu_\infty = 23,000$

Here, U_∞ is the free-stream velocity, a_∞ is the speed of sound, ρ_∞ is the density, L_c is the chord length, μ_∞ is the viscosity.

Data collection

The dataset is generated from the wall-resolved large-eddy simulation (LES) of a spanwise-periodic flow over the airfoil using the finite-volume compressible flow solver *CharLES* [1]. The computational mesh is designed based on a C-shape structured grid adaptively refined in the wake region, resulting in a hybrid topology with structured sub-domains and unstructured regions at the interface of adaptive refinement. The domain size for the LES is $x/L_c \in [-19, 26]$, $y/L_c \in [-20, 20]$ and $z/L_c \in [-0.1, 0.1]$ respectively in the streamwise, transverse and spanwise directions, with the leading edge of the airfoil positioned at the origin. Additional information on the boundary conditions, grid convergence, and validations with respect to aerodynamic forces and pressure distribution can be found in [3].

The dataset has $n_t = 16,000$ time-resolved snapshots along the mid-span slice and the spanwise-averaged velocity fields extracted over a near-wake region of $x/L_c \in [-0.5, 6]$ and $y/L_c \in [-2.5, 2.5]$. These snapshots are collected at a constant convective time increment of $\Delta t U_\infty / L_c = 0.0104$, spanning across a time window of $tU_\infty/L_c \in [0, 165]$. This time span is equivalent to approximately 248 vortex shedding cycles. For each snapshot, all velocity components (u_x, u_y, and u_z) are provided in single precision at the mid-span and for three spanwise Fourier modes, the first of which corresponds to the spanwise-average. In addition to the time-resolved snapshots, the time- and spanwise-averaged velocity field is also provided. The three velocity

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components are individually formatted as a column vector $\boldsymbol{u} \in \mathbb{R}^n$ for each snapshot, where $n = 222,210$ is the number of grid points residing inside the chosen near-wake region. Also, a vector $\boldsymbol{w} \in \mathbb{R}^n$ for the cell sizes is also provided to appropriately weight each element in the velocity vectors when performing modal analyses.

Nondimensionalization

The LES data includes three components of the velocity fields and use the following nondimensionalization:

$$\boldsymbol{u} = \frac{\boldsymbol{u}^*}{U_\infty^*}, \quad \boldsymbol{x} = \frac{\boldsymbol{x}^*}{L_c^*}, \quad t = \frac{t^* U_\infty^*}{L_c^*}.$$

where the superscript $*$ refers to the dimensional quantity.

File inventory

The database contains the following files and variables:

- `airfoilLES_example.zip`: zip archive containing a representative subset of the following data and scripts as an entry point for users
- `airfoilLES_parameters.h5`: hdf5 file containing flow and data parameters
  - `Re`: Reynolds number
  - `dt`: time step between snapshots
- `airfoilLES_grid.h5`: hdf5 file containing grid information
  - `x`: streamwise grid
  - `xa`: x-coordinate of points defining airfoil geometry
  - `y`: cross-stream grid
  - `ya`: y-coordinate of points defining airfoil geometry
  - `w`: volume associated with each grid point
- `airfoilLES_snapshots_kzXX.zip`: zip archive containing all `airfoilLES_kzXX_t#####.h5` files
- `airfoilLES_kzXX_t#####.h5`: hdf5 file containing the `XX`-th spanwise Fourier modes of the 3D flowfield at time index `#####` $\in [00001, 16000]$ with `XX` $\in [00, 01, 02]$. The corresponding spanwise wavenumbers are $k_z L_c = [0$ (snapwise mean), 10π, $20\pi]$
  - `ux`: x-component of velocity for mid-span slice at each (`x`, `y`) grid point
  - `uy`: y-component of velocity for mid-span slice at each (`x`, `y`) grid point
  - `uz`: z-component of velocity for mid-span slice at each (`x`, `y`) grid point
- `airfoilLES_snapshots_midspan.zip`: zip archive containing all `airfoilLES_t#####.h5` files
- `airfoilLES_t#####.h5`: hdf5 file containing snapshots of the mid-span slice at time index `#####` $\in [00001, 16000]$
  - `ux`: x-component of velocity for mid-span slice at each (`x`, `y`) grid point
  - `uy`: y-component of velocity for mid-span slice at each (`x`, `y`) grid point
  - `uz`: z-component of velocity for mid-span slice at each (`x`, `y`) grid point
- `airfoilLES_mean_zavg.h5`: hdf5 file containing the mean flow field for spanwise averaged slice

- `ux_zavg_mean`: x-velocity for time- and spanwise-averaged flow at each (`x`, `y`) grid point
- `uy_zavg_mean`: y-velocity for time- and spanwise-averaged flow at each (`x`, `y`) grid point
- `uz_zavg_mean`: z-velocity for time- and spanwise-averaged flow at each (`x`, `y`) grid point

■ `airfoilLES_mean_midspan.h5`: hdf5 file containing the mean flow field for midspan slice

- `ux_mean`: x-velocity for time-averaged mid-span slice at each (`x`, `y`) grid point
- `uy_mean`: y-velocity for time-averaged mid-span slice at each (`x`, `y`) grid point
- `uz_mean`: z-velocity for time-averaged mid-span slice at each (`x`, `y`) 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 Journal*, 55(4):1164–1184, 2017.

[2] 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.

[3] C.-A. Yeh and K. Taira. Resolvent-analysis-based design of airfoil separation control. *Journal of Fluid Mechanics*, 867:572–610, 2019.