DETECTING DETERMINISTIC CHAOS IN TURBULENCE AROUND AN AIRFOIL

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Abstract The Navier-Stokes equations for fluid flow are far from being amendable to conventional mathematical analysis. Simulation results, in the absence of a feasible analytical treatment of the equations, demand the output be analyzed by means of nonlinear time series analysis methods. While deterministic chaos in turbulence has been observed and reported by several researchers, there are still benefits to outlining a systematic procedure that would enable to do the analysis in a conclusive and generally applicable way. The goal of this study is to introduce minimal standards and procedures by means of which deterministic chaos can be established from simulation and experimental data. As an example, we study the turbulence around an airfoil based on simulation data, first using the mutual information method and the false-nearest-neighbor method to reconstruct the attractor from the time series. Next we employ a determinism test to verify whether the observed irregular behavior is indeed deterministic, as well as a stationarity test to verify that the systematic parameters were held constant during data acquisition. Lastly, after establishing conclusively that the data stems from a deterministic process, we calculate the maximal Lyapunov exponent. Based on the fact that the later is positive, we conclude in favor of deterministic chaos in the turbulence around an airfoil. We argue that the outlined analysis constitutes the first step towards meaningful further analyses, such as for example the determination of the whole spectra of Lyapunov exponents, and we propose it as the minimal standard when dealing with irregular time series, stemming either from measurement or simulation. To facilitate the adoption of our proposal, we also provide user-friendly programs for all employed methods at matjazperc.com/ejp.

EXPERIMENTAL: DENSITY SERIES

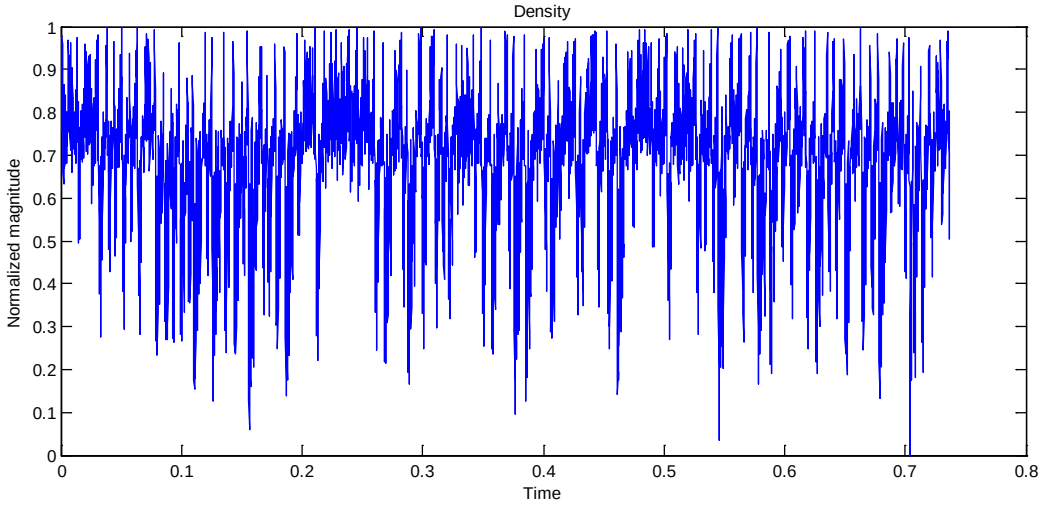

Figure 1. Density series extracted from turbulence around an airfoil.

CHAOS ATTRACTOR

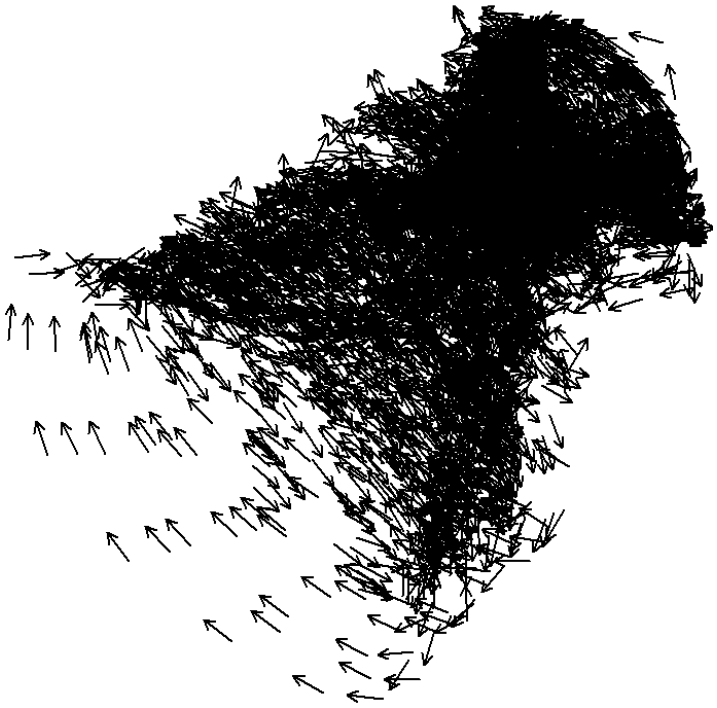

Figure 2. Reconstructed attractor from density series.

References

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