Breakdown of Sensitivity Analysis in Chaotic, Turbulent Fluid Flows[1] QIQI WANG, PATRICK BLONIGAN, MIT, JUNHUI GAO, BUAA — Sensitivity analysis is a class of algorithms for calculating derivatives of output quantities with respect to input parameters in computational fluid dynamics simulations. It is an essential ingredient for data assimilation, aerodynamic design, uncertainty quantification and flow control. Sensitivity analysis in high fidelity simulations of turbulent flows (DNS or LES) is challenging. These simulations are true to the chaotic nature of turbulence: instantaneous flow fields are very sensitive to perturbations in parameters and geometry; while long time averaged, statistical quantities are often well behaved functions of parameters and geometry. Consequently, sensitivity of statistics cannot be computed by taking the statistics of sensitivity. For example, averaging the sensitivity of instantaneous drag over a long time do not give the sensitivity of the mean drag. This talk first discuss the mathematical reason of the breakdown of sensitivity analysis of statistical quantities in chaotic systems. We then demonstrate the breakdown on a number of examples, including airfoil at high angle of attack, a cylinder in crossflow, and a turbulent jet in a cross flow. We show that positive Lyapunov exponents in these systems lead to divergence of the conventional sensitivity analysis.

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