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Uncertainty Quantification Applied to Direct Noise Computation of Cavity Oscillation Mechanisms

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Noise emitted by flow over cavities has in recent years become a major concern in automobile exterior aerodynamics. Different noise generation mechanisms have been identified in cavities, such as Helmholtz resonance and Rossiter feedback, which can both lead to tonal noise. Rossiter feedback is characterized by a two-way interaction between aeroacoustics and hydrodynamics. This necessitates the use of direct noise computation, where acoustic sources are directly resolved in a compressible LES (as opposed to hybrid simulations, where hydrodamics and aeroacoustics are treated in two consecutive steps). To achieve the necessary multi-scale resolution and low numerical dissipation, a high-order method is advantageous. Both frequencies and noise levels are highly sensitive to the simulation setup. The dominant acoustic modes can switch abruptly. Applying uncertainty quantification (UQ) to the problem setup is therefore a promising way to gain a more complete insight into the factors influencing the generated noise spectra. In UQ, uncertain input parameters (here, for example, uncertain inflow conditions and cavity geometry) are treated as random variables.

Our deterministic simulations are carried out using a discontinuous Galerkin spectral element method. Turbulence is generated with a random Fourier mode initial condition and a recycling-rescaling domain at the inflow. We have implemented both Multilevel Monte Carlo and non-intrusive collocation methods to treat uncertain input to the aeroacoustic problem. These methods will be briefly presented and some algorithmic and implementational aspects will be mentioned.

In a first step, we recreate an existing computational two-dimensional laminar cavity noise reference case. Subsequently, we add a UQ analysis. Apart from a stochastic evaluation, we investigate under which circumstances certain frequencies become dominant and how the noise level responds to changing input. Finally, an extension to a three-dimensional case with a turbulent upstream boundary layer is presented.

In the laminar case, very distinct Rossiter modes are observed. The results of Multilevel Monte Carlo and non-intrusive collocation methods match very well. Input parameters such as cavity length and depth, inflow Mach number and boundary layer thickness each have a considerable effect on the emitted frequency spectra. Peak frequencies and peak noise levels vary. Also, abrupt mode switching between different dominant rossiter modes can be observed. In certain cases, the aeroacoustic feedback vanishes completely.

Rossiter modes in the turbulent case are less clearly pronounced, and the feedback mechanism shows more intermittency than in the laminar case, as the instabilities in the shear layer above the cavity interact with random turbulent fluctuations. Moreover, turbulent eddies impinging on the downstream cavity edge create additional broadband noise.

With our results, we hope to contribute to a deeper understanding of cavity noise generation and to advance the application of UQ to aeroacoustics.