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Computational Aeroacoustics Using the Generalized Lattice Boltzmann Equation

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PROJECT SUMMARY

The overall objective of this SBIR project is to develop a computational aeroacoustics (CAA) technique based on solution of the generalized lattice Boltzmann equation (GLBE), which incorporates multiple relaxation times, for airframe noise (AFN) problems at low Mach numbers. Phase I of the SBIR assesses the feasibility of using the GLBE formulation for computing near-field turbulence by comparison with selected CAA benchmarks. These consisted of tone generation by flow over a circular cylinder, a pair of side-by-side cylinders and feedback-generated sound in cavity flows, considered as canonical problems for AFN. In Phase II, in addition to further development of the GLBE, near-field solutions will be coupled to far-field acoustics prediction methods.

For large eddy simulations (LES) of near-field turbulent flows, a subgrid scale (SGS) model with a wall-damping function was introduced into the GLBE through a set of relaxation times that determine its hydrodynamic behavior. The rest of the relaxation times can be adjusted to enhance numerical stability at high Reynolds numbers. Optimization strategies were also introduced to speed up solution of the GLBE, and parallelized using Message Passing Interface (MPI) to handle larger CAA problems. Finally, variable grids and a consistent initialization procedure for GLBE suitable for acoustics problems were also developed and implemented.

In more detail, the approach based on GLBE was initially assessed for LES prediction of wall turbulence in channel flows. Various turbulence statistics, including pressure fluctuations as well as pressure-strain correlations, were found to agree well with DNS and experimental data. Computational accuracy, stability and cost of the GLBE for LES were also compared with the single-relaxation time (SRT) LBE, demonstrating that the GLBE was markedly more stable numerically – by at least a factor of 3 in Reynolds number, and with similar run times for the problems considered. Thus, significantly higher Reynolds number LES appear to be possible with GLBE than with SRT-LBE. The parallel performance tests carried out with up to 16 processors showed near-linear scalability for the GLBE method. Furthermore, the GLBE was about 3 times faster, and of similar accuracy, compared to a finite-difference LES for the same problem with same nodalization and time step (Courant number ~ 0.4).

Parallel 3D GLBE simulations of the CAA benchmarks indicated high fidelity reproduction of tonal frequencies for cross-flow over a single, and a pair of cylinders, and feedback-generated tonal frequencies in both deep and shallow cavities, resulting from shear layer instability modes. The Strouhal numbers of the oscillations and the details of vortical flow structures in each case agreed well with previous data. The computed amplitudes of turbulent fluctuations in the mixing layer of the shallow cavity are also in the range of existing data.

The Phase I project has accomplished its proposed objectives and demonstrated competitive computational costs, excellent parallel scalability, and the superior stability characteristics and accuracy of the GLBE for solution of CAA benchmarks. Phase II continuation would further develop the GLBE approach for very high Reynolds number flows using wall layer models with enhanced fidelity to address AFN problems in realistic conditions, e.g., in high-lift systems, such as slats and flaps, and landing gear.