INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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Thesis Title: A Boundary Condition-based Machine Learning Algorithm for Fast Prediction of Hypersonic Flows

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SHORT ABSTRACT

A new deep neural network-based machine learning algorithm has been developed for predicting the flow field around a reentry vehicle in supersonic and hypersonic conditions for the entire trajectory from 85 km to 40 km. The gas flow field depends on the geometry, inlet conditions (ICs), and boundary conditions (BCs). In the conventional approach, the compressible Navier-Stokes-Fourier (NSF) equations are solved on a discretized computational domain with appropriate initial and boundary conditions, using either the Riemann or the Boltzmann approach, which is a computationally intensive task. At higher altitudes, the alternative particle-based direct simulation Monte Carlo (DSMC) is used to study the flow physics. The proposed approach is our first attempt to predict the flow field using deep neural networks without explicitly solving the NSF equations or running DSMC simulations. Further, the proposed "boundary condition-based machine learning algorithm (BCML)" falls under the category of physics-guided neural network. The training data for the low-altitude BCML model is generated using an in-house Riemann flux solver-based NSF code and OpenFoam-based hy2Foam solver, and converted into a BCML-compatible format. An in-house DSMC solver was used to generate data for the high-altitude BCML framework. After appropriate training, it was found that the BCML models were able to capture shock structures and other related wave patterns in the flow around an arbitrarily shaped bluff body, with arbitrary initial and boundary conditions at any altitude within the extrema to a reasonable accuracy. The computational time required by the BCML models was orders of magnitude lower than that of conventional NSF-based CFD simulations and even lower than the DSMC simulations. The BCML models could predict flow fields almost instantaneously (less than 20 s), whereas the NSF-based CFD simulations and DSMC often needed several hours to days on a parallel architecture. In addition to fast prediction of flow fields, BCML models can improve the overall efficiency of traditional solvers. Two examples, one for the continuum-based NSF solver and the other related to the particle-based DSMC solver, have been focused on in the present thesis. The BCML-generated flow fields can be used as initial conditions for the NSF solver, thereby improving the simulation's convergence. Also, the BCML-generated optimized mesh for the DSMC was found to be approximately 2 times faster than a general mesh.