DSMC SOLUTIONS OF HYPERSONIC FLOW OVER A PLANETARY PROBE USING FULLY AUTOMATED ADAPTIVE MESH REFINEMENT AND CUT-CELL ALGORITHMS

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ABSTRACT

Aerobraking and aerocapture techniques involve the precise use of drag generated at the outer edge of a planetary atmosphere to tailor the orbital or entry trajectory of a spacecraft. Numerical simulation tools capable of accurately predicticting drag and heating rates are vital to spacecrat design and trajectory optimization for a given mission. Such low density and high velocity conditions result in highly non-equilibrium flow over the spacecraft that lies in the transitional regime between continuum and free-molecular flow. The direct simulation Monte Carlo (DSMC) particle simulation method [1] is both accurate and efficient model in this flight regime. For example, NASA has used the DSMC Analysis Code (DAC) [2] to support a number of aerobraking and aerocapture missions. As parallel computing resources continue rapid growth, new missions may utilize increasingly larger DSMC simulations. This work presents results obtained from a “next-generation” DSMC code [3] developed at the University of Minnesota. The code employs an embedded 3-level Cartesian mesh, accompanied by a cut-cell algorithm to incorporate triangulated surface geometry into the adaptively refined Cartesian mesh. Such an approach enables decoupling of the surface mesh from the flow field mesh, which is desirable for flows with large density variations and also for adaptive mesh refinement (AMR). A simple and efficient AMR algorithm that maintains local cell size consistent with the local mean-free-path and therefore a constant number of particles in each cell will be detailed. The 3-level embedded Cartesian mesh combined with fully automated AMR allows precise control of local mesh size and time-step while requiring little-to-no user time. Validation of the code will be provided, and DSMC results for 3-D hypersonic flows over a planetary probe with large density variations will be presented.

[1] Bird, G. A., Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford Univ. Press, New York, 1994.

[2] LeBeau, G.J., “A parallel implementation of the direct simulation Monte Carlo method”, Comp. Meth. Appl. Mech. Engrs., Vol. 174, pp 319.

[3] Gao, D., Zhang, C., and Schwartzentruber, T.E., “A Three-Level Cartesian Geometry-Based Implementation of the DSMC Method”, AIAA Paper 2010-0450, Jan. 2010, presented at the 48th AIAA Aerospace Sciences Meeting, Orlando, FL.