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ON DSMC CALCULATIONS OF HIGH SPEED GAS FLOWS ON ADAPTIVE MESHES

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KEY WORDS

Transient Adaptive Sub-cells (TAS) technique, Simplified Bernoulli Trials (SBT) collision scheme, No Time Counter (NTC) collision scheme

ABSTRACT

The adaptive meshes increase the computational efficiency of the numerical algorithms especially in zones with significant gradients such as shock waves. In the present paper, a modification of Transient Adaptive Sub-cells (TAS) technique [1] is proposed to improve the DSMC space accuracy. It follows fluid flow nature and uses a finer mesh where the local density increases. Compared are the results obtained by using two collision schemes - Bird's No Time Counter (NTC) collision scheme [2] and Stefanov's Simplified Bernoulli trials (SBT) (see for details [3]).

TAS condition, results and considerations

The considered test problem is a gas flow past a square in a narrow channel at supersonic speed 900[m/s] (M=2.43) and Knudsen number 0.02 (see Fig. 1 a)). The fluid flow is complex that makes it convenient for testing the quality of schemes. The position of the shock wave in front of the square is a very sensitive characteristic of the considered supersonic flow and we focused to analyze the results obtained from DSMC calculations by using both NTC and SBT collision schemes on a computational grid with TAS refinement.

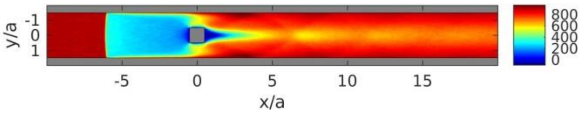
The proposed here Transient Adaptive Subcells technique consists of two elements. First, the cells of the basic grid are divided into subcells using a local uniform Cartesian mesh. The condition for dividing cells into subcells is determined by the requirement of a minimal average number of particles per subcell within a time step , which reads as follows:

$$l_i \le \sqrt{N_i / N_{\min}}\ , \tag{1}$$

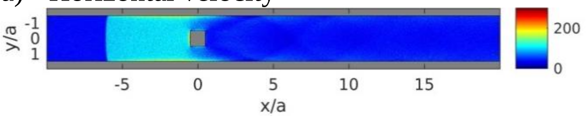
where l_i is a level of divisions – an integer number that denotes the number of subcells in each of directions of a cell i, i.e. for 2D case the local mesh is $l_i \times l_i$ cells, N_i is the number of particles in basic cell i, $N_{\min}$ is the minimal average number of particles per subcell.

Second, the maximum l ($l_{\max}$) is set at the beginning of calculations and the time step is adjusted to the minimal subcell size. The l array is evaluated once every $l_{\max}$ time step. The value of the next time step is chosen to be in agreement with Courant-Friedrichs-Lewy (CFL) condition i.e. the time step in each subcell to be equal in mean to the time of particle flight across the subcell. Thus, for a subcell

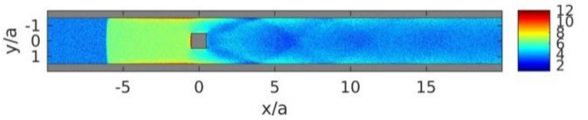
system with different levels of divisions, the global time step is the smallest value Δt calculated from the CFL condition for the smallest subcells. All particles in the computational domain are moving every time step Δt while the collision procedure is performed once every l_i time steps with collision time step $(l_{\max} - l_i + 1)\Delta t$. Thus, the time step in the collision procedure varies in each subcell according to the number of skipped time steps to balance the global time running.
Figure 1 a), b) and c) shows horizontal velocity field, number of particles in basic mesh cells and TAS level of computational domain, respectively. The level of divisions of the basic cells corresponds to number density of particles in each point of the computational domain.



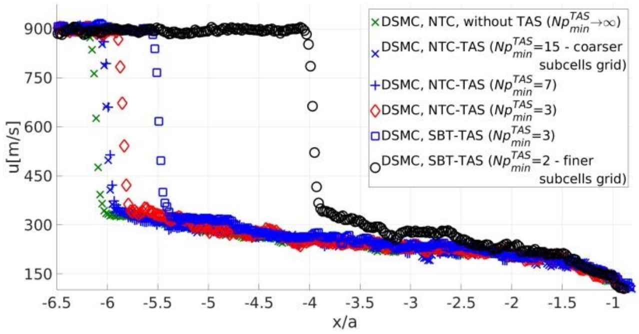
a) Horizontal velocity



b) Number of particles in basic mesh cells



c) TAS level



d) The profiles of horizontal velocity are given at the central line along the channel (y = 0).

Figure 1: DSMC SBT-TAS, basic mesh 1500x150 cells and 12 million particles, where a is a square size.

The usage of the described TAS technique showed a significant improvement of the DSMC space accuracy for both applied schemes: NTC and SBT. Fig. 1 d) shows a comparison between DSMC without TAS and with TAS by using different $N_{\min}$. The accuracy is rapidly improved with decrease of $N_{\min}$ ($N_{\min} = 15$ (coarser subcells grid) to $N_{\min} = 2$ (finer subcells grid)).

Conclusions

The TAS technique was applied in the DSMC algorithm to improve the space accuracy. Two collision schemes, NTC and SBT, have been used, and the results were compared showing a better accuracy of SBT when applied to finer TAS mesh. The DSMC method with included TAS technique has the same space accuracy as the DSMC on an uniform fine grid without TAS by using up to 18 times fewer number of particles in the computational domain.

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