Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(7) (2020) 443-446
DOI: 10.22060/mej.2019.15369.6104

New Development in Direct Simulation Monte Carlo Algorithm for Asymmetric Complex Geometry

R. Zakeri[1]*, R. Kamali-moghadam[2], M. Mani[3]

[1] Department of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran
[2] Aerospace Research Institute, Ministry of Science, Research and Technology, Tehran, Iran
[3] Department of Aerospace, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: In this paper, the development of the direct simulation Monte Carlo algorithm has been carried out for flow analysis around axial symmetric complex geometries in rarefied conditions with consideration of reduction in computational cost compared to a full three-dimensional state, appropriate accuracy of the results compared to related available references, as well as the proper selection of particles. In this paper, the algorithm is presented that involves studying different modes of motion and collision of particles with each other or the wall for axial symmetric complex geometries in such a way that the least computations are applied for achieving a high-efficiency solution. In the results section, various geometries such as simple geometry for first case and complex geometry for second case study is investigated and the results are compared with the validated results. The results show the proper accuracy of the proposed algorithm compared to the three-dimensional solvers. Also, the selection of the smallest number of suitable particles is one of the issues that has been studied for selecting the appropriate number of particles. It has been shown that in the first and second test cases, the 30000 and 500000 particles are at least number of particles with consideration of accuracy of results.

Review History:

Received: 04/12/2018
Revised: 29/03/2019
Accepted: 14/04/2019
Available Online: 07/07/2019

Keywords:

Direct simulation Monte Carlo algorithm
Asymmetric
Complex geometry

1. INTRODUCTION

Direct Simulation Monte Carlo (DSMC) method [1], due to the accuracy of solution in dilute environments in various industries, such as turbomachinery and discharge pumps design and construction of reentry vehicles in the aerospace industry, design and construction of mechanical-electrical micro-systems, the nuclear industry has been widely used. One of the most important applications of the DSMC in the aerospace industry is the investigation of gas properties at high velocities, which will be examined in this paper. Due to the high accuracy of this method, several research centers have been tried to develop this technique and produce software applications such as SMILE [2], DAC [3], DS2V /3V [1], MONACO [4].

2. DEVELOPMENT OF THE DSMC METHOD

The DSMC algorithm is based on the motion and collision which is presented in reference [1]. In order to develop this method, general grid generation is required which is extracted by GAMBIT software as input files as well as other input parameters. Then all input information is analyzed and all the required information, such as cells, angles of elements, area (two dimensions) or cell volume (for axis symmetry) is calculated and stored. In the next step, each particle must be placed in a suitable cell and stored in the cell and sub cellular position. In the further development of the DSMC code number, the code has been promoted to symmetric-domain mode. Simulation of flow in symmetric geometries has many applications in the flow analysis around reentry bodies with zero-angle In general, the coefficients of axis symmetry have been extracted by Maple software in general mode and have been implemented in code for the first time.

*Corresponding author's email: r_zakeri@shahroodut.ac.ir

3. RESULTS AND DISCUSSION

The first problem, which is considered as a precise example of validation in the field of simulation of axial flow, is to study the changes in gas flow properties over the cylindrical geometry. The geometry data and the initial properties of the flow are given in Table 1. The geometry of the cylinders is due to horizontal and vertical lines as simple geometries, and the aim is to examine the accuracy of the code developed compare to available Bird code, which is usable only for simple geometries.

Table 1: Setting parameter of the cylindrical problem

Parameter	**Time Step (s)**	**Density Number (m^{-3})**	**Temp. (K)**
value	10^{-6}	10^{21}	100
Parameter	**Velocity (m/s)**	**Length (m)**	**Diameter (m)**
value	1000	1	0.005

Table 2: Setting parameter of double cones problem

parameter	Time Step (s)	Mach number	Temp. (K)
value	10^{-6}	15.6	42.61
parameter	Velocity (m/s)	angle	-
value	2076	25 &55 °	-

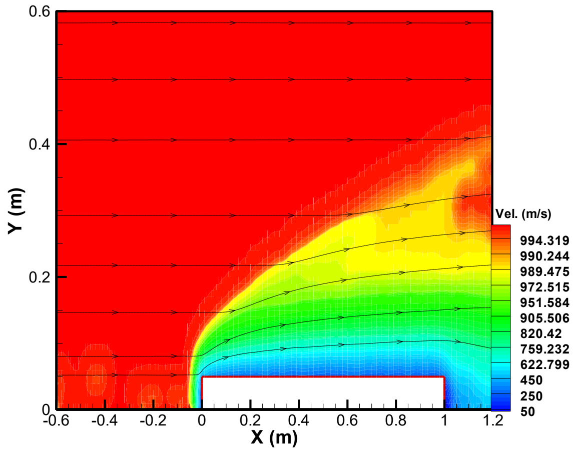

Fig. 1. The velocity contours of the cylindrical problem

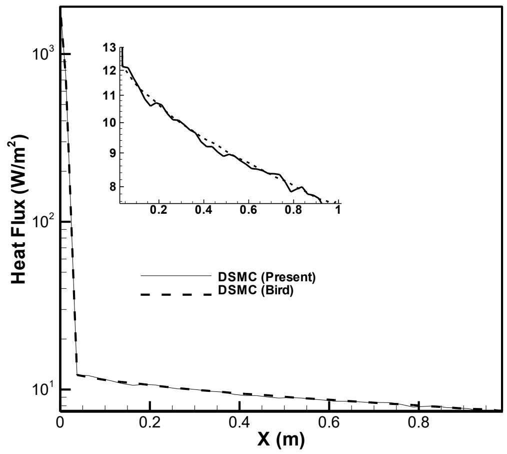

Fig. 2. Heat flux distribution on the cylindrical problem

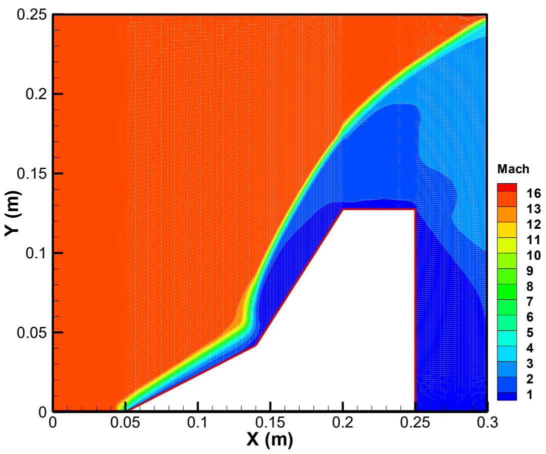

Fig. 3. Mach contours of double cones problem

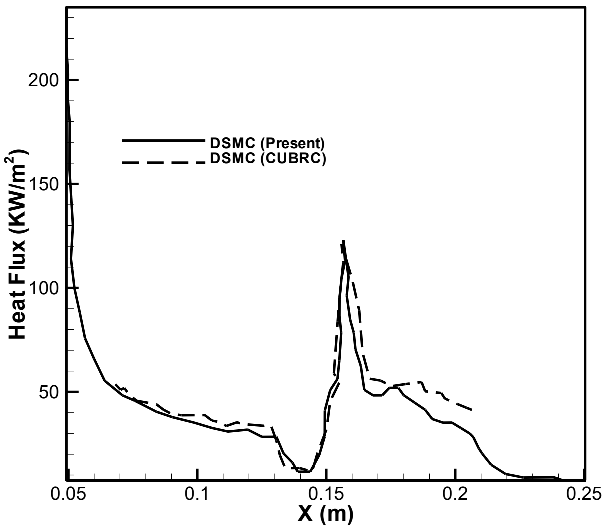

Fig. 4. Heat flux distribution on the double cones problem

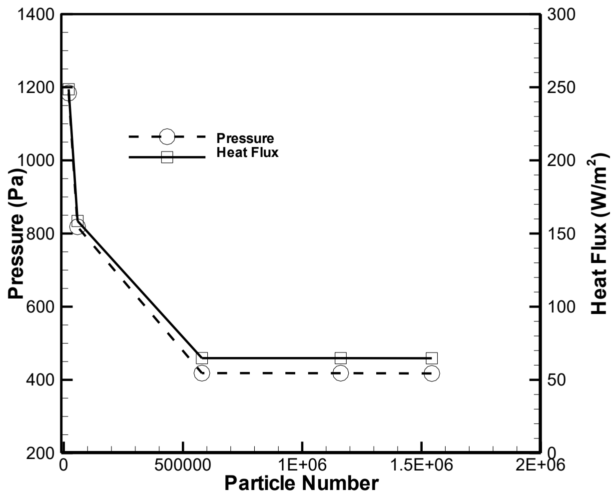

Fig. 5. Proper particle numbers for the double cones problem

The desired problem is to study the properties of nitrogen gas flow in passing through double cone geometries with angles of 25 and 55 [5]. The geometry is based on the Ref. [5], including complex geometries, due to the existence of incline line in geometry and interaction of the shock and boundary layer and this geometry are examined by various researchers for the validation of numerical codes. The setting condition is presented in Table 2.

One of the issues that should be considered in the DSMC approach is to select the correct number of particles. Since the DSMC method is based on a particle-based method, provided that the size of the cell is smaller than the size of a third of the free particle size, the results are not affected by the grid type, while the correct selection of particles affects the accuracy of the results [6]. To properly simulate the DSMC, enough particles should be placed in all cells [6]. This value depends on the type of problem which is analyzed, but in general, it should not be less than 5 particles in each cell. In the two preceding problems, the cylinder of the two convex cones of this study has been carried out.

4. CONCLUSION

This paper studies the development of numerical software for the axial symmetry conditions for complex geometries. The new DSMC algorithm has been developed for using the complex geometries, taking into account computational cost reduction in axial symmetry mode. The algorithm involves tracking particle and applying boundary conditions as well as applying the axial symmetry condition for any geometry. To evaluate and validate the developed software, the supersonic gas flow was investigated around cylindrical and two cone geometries and the results were compared with existing valid data. The accuracy of the results of the present method compared to other references (intermediate error Less than 10%) in both cases. Also, studying the number of suitable particles (30,000 particles for the first one and 500,000 for the second case) for proper simulation by the DSMC method has been carried out.

REFERENCES

[1] G.A. Bird, *Molecular gas dynamics and the direct simulation of gas flow*, Oxford University Press, 2nd Edition, 1994.

[2] M.S. Ivanov, G.N. Markelov, S.F. Gimelshein, Statistical simulation of reactive rarefied flows: Numerical Approach and Applications, *7th AIAA/ASME Joint Thermophysics and Heat Transfer Conference AIAA*, (1998) 2669.

[3] G. J. LeBeau, A Parallel implementation of the directs monte carlo method, *Journal of Computer Methods in Applied Mechanics and Engineering*, 174 (3) (1999) 319-337.

[4] I.D. Boyd, Modeling of associative ionization reactions in hypersonic rarefied flows, *Journal of Physics of Fluids*, 19 (9) (2007) 096-102.

[5] J. Moss, DSMC computations for regions of shock/shock and shock/boundary layer interaction, *in Proceedings of the 39th AIAA- Aerospace Sciences Meeting and Exhibit*, Reno, NV, USA, (2001) 1027.

[6] R. Zakeri , R. Kamali-Moghadam, M. Mani, A new approach for chemical reaction simulation of rarefied gas flow by DSMC method, *Journal of Computers & Fluids*, 140 (2016) 111-121.140, PP. 111-121.