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開放端磁場で膨張加速する希薄弱電離アークジェットのDSMCシミュレーション

DSMC Simulation of Flowing Characteristics of Rarefied Weakly-Ionized Arc-Jet Expanding along Open-Field-Line

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We have been studying fluid dynamic characteristics of arc-jet helium plasma flowing along open-field-line experimentally [1 – 3]. However, it is still difficult for us to understand the rigorous physics of acceleration/deceleration of ions in the plasma flow as well as variation in space potential. We should carry out numerical simulation by modeling the plasma flow to understand the plasma flow entirely. The objective of the present study is to understand the plasma flow at the open-magnetic field by numerical simulation.

The plasma has low ionization degree, which indicates that we must solve the flow of neutral particles simultaneously. We must also treat the ion flow as a rarefied dynamic flow since the Knudsen number of the ion flow Kn is larger than about 0.15. Consequently, we applied the Direct Simulation Monte Carlo (DSMC) method to solve the Boltzmann equation stochastically. We solve the problem as an axi-symmetric problem, where particle movement is treated as 3-D while the collision as 2-D [4, 5]. To overcome the statistical fluctuation of ions as minor species, we applied weighting factor method and solved the neutral particles simultaneously [4]. Although we should solve electrons simultaneously, we supposed that the electron density, velocity and temperature are the same with those of ions, respectively, for simple analysis. We also assumed that the space potential was already given as the values observed experimentally [1– 3]. We applied maximum collision number method to simulate collisions, where we considered elastic and charge-transfer collisions between an ion and a neutral particle, and elastic collisions between neutral particles [4, 5].

Figures 1(a) – 1(c) show dependence of number density, Mach number and temperature of both ions and neutral particles, respectively, calculated for the on-axis r = 0. It was found that the larger ionization degree results in the larger maximum Mach number in the vicinity of diverging magnetic field, and that it causes the further extension of the acceleration domain. It was also found that the lower ionization degree makes the maximum ion temperature higher. We found that the numerical results of Mach number and temperature qualitatively agree with our previous experimental results, where the best agreement was for the assumption of ionization degree 10^{-2}.

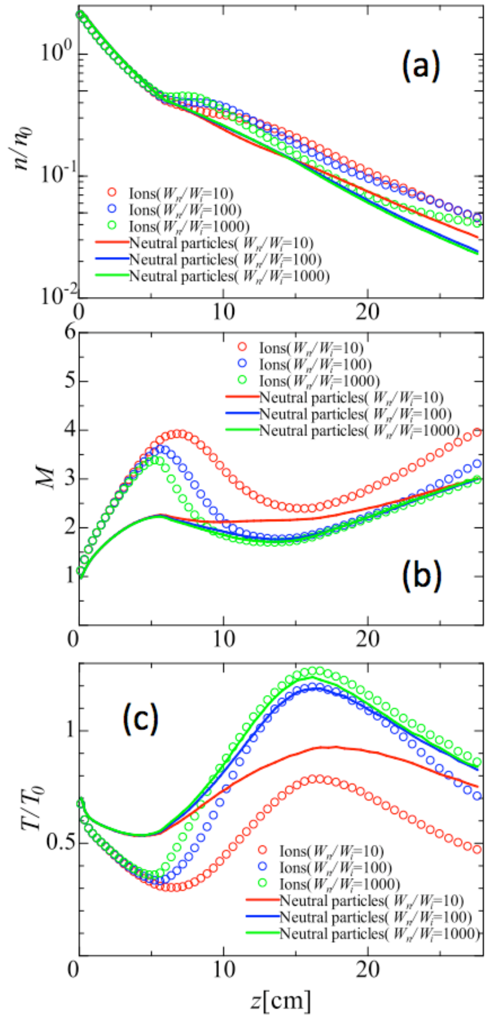

Fig. 1. Numerical results calculated for on-axis (r =0) condition; (a) number density, (b)Mach number and (c) temperature. Weighting factor is the reciprocal ionization degree, which were set to be 10, 100 and 1000.

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