boltzplatz
numerical plasma dynamics

Nozzle Expansion in a Cold Gas Thruster

Plasma Kinetic Code PICLas STUTTGART

boltzplatz offers engineering and consulting services around the open-source simulation software PICLas, which allows the prediction of rarefied gas and plasma dynamics under the influence of electromagnetic forces.

Bhatnagar-Gross-Krook

The Bhatnagar-Gross-Krook approximation allows the efficient simulation of denser gas flows, where the DSMC method becomes computationally expensive. While the particle-based method in PICLas is continuously extended, key features have already been implemented:

- 2D, axisymmetric (including a radial weighting), and 3D
- Single species simulations with polyatomic molecules using quantized vibrational energy treatment
- Simulation of gas mixtures with multi-species modelling of atomic & diatomic species

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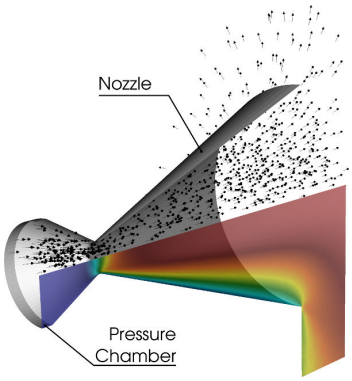
Cold gas thrusters are typically employed in satellites due to their reduced complexity, reliability and low cost. Due to plume impingement, the exhaust of the thruster can pose a contamination risk for mission critical components. If an array of thrusters is utilized, the plume-plume interaction becomes of interest for the performance characterization. Therefore, numerical simulations are used to predict the effect of the thruster plume on its surroundings.

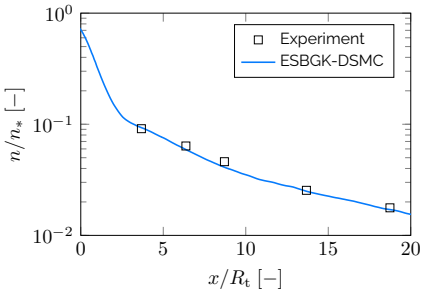
Large density gradients

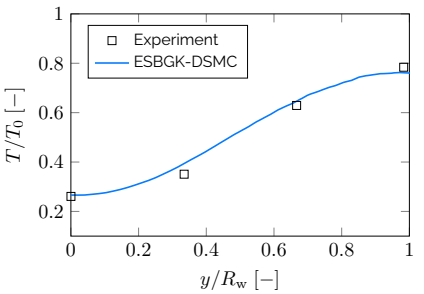


Large density gradients within the cold gas thruster ranging from continuum flow in the pressure chamber up to free molecular flow in the far wake of the nozzle pose a great challenge for a single numerical method. For this purpose, the Direct Simulation Monte Carlo (DSMC) module and the particle-based ellipsoidal statistical Bhatnagar-Gross-Krook (ESBGK) method of PICLas were coupled to exploit the advantages of both methods. While the DSMC method offers accurate results in rarefied flows, the BGK method enables a substantial increase in computational performance in high density regions.

Coupled ESBGK-DSMC simulation

The geometry of the micro thruster is based on an experimental setup available in literature. The thruster uses nitrogen as propellant, which is fed into the pressure chamber at a pressure of 474 Pascal and a temperature of 300° Kelvin. The excellent agreement between the experimental measurements and the numerical simulation enables the use of PICLas as a predictive tool for future thruster development. Through the coupled ESBGK-DSMC approach, where ESBGK was used only in the pressure chamber as well as the converging nozzle part, the simulation time could be drastically reduced by a factor of 20 000 as compared with conventional DSMC simulations. This allows to simulate the complete cold gas thruster (or an array of thrusters) within a single simulation.





Sources:

- Pfeiffer, M., Mirza, A., & Nizenkov, P. (2019). Evaluation of particle-based continuum methods for a coupling with the direct simulation Monte Carlo method based on a nozzle expansion. *Physics of Fluids*, **31**(7), 073601.