boltzplatz
numerical plasma dynamics

Plume Impingement on a Flat Plate of a Single & Dual Thruster Configuration

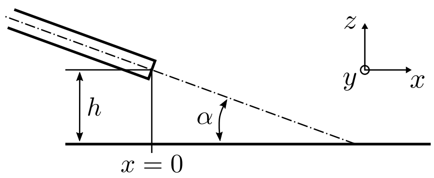
Plume impingement plays a major role in the development of spacecraft systems due to the possible contamination of mission critical elements such as solar panels or scientific instruments by a thruster exhaust.

Numerical simulations estimate the area of effect of a single or a system of thrusters and help in the optimization of the spacecraft configuration. The application case presented in the following validates two particle-based methods within PICLas:

- Direct Simulation Monte Carlo (DSMC)
- Ellipsoidal Statistical Bhatnagar-Gross-Krook (ESBGK)

Both methods are introduced in the information boxes on the left.

Experimental & numerical setup

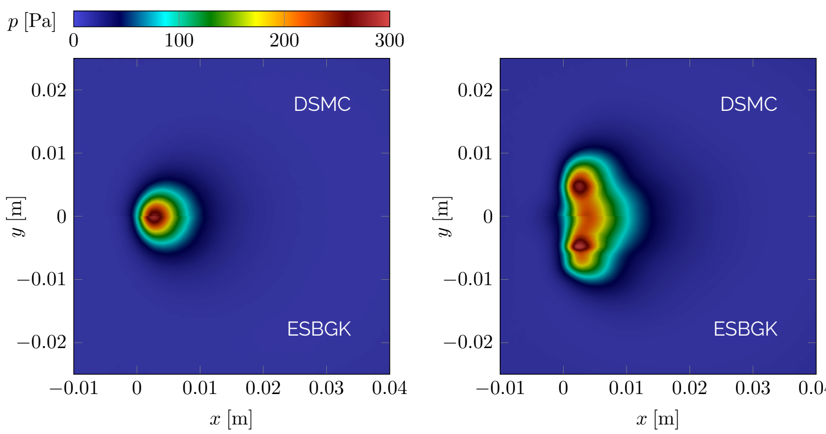


A schematic of the experimental setup by Wu (2017) is shown on the left, where $h = 5\,\mathrm{mm}$ denotes the distance to the center of the nozzle exit area. The angle $\alpha = 20°$ is relative to the rotational axis of the nozzle. The dimensions of the flat plate are $60\,\mathrm{mm} \times 60\,\mathrm{mm}$ $(x \times y)$ and the computational domain additionally expands into z by $10\,\mathrm{mm}$. The inner nozzle diameter is $0.6\,\mathrm{mm}$. In the dual configuration, the nozzles were separated by $9.6\,\mathrm{mm}$ with $y = 0$ at the centre. Only half of the computational domain was simulated, exploiting the symmetry in the xz-plane. The flow conditions of an air mixture ($\chi_{\mathrm{N}_2} = 0.79$, $\chi_{\mathrm{O}_2} = 0.21$) at the nozzle exit plane are given below. The velocity vector is parallel to the nozzle symmetry axis.

n_{in} $[\mathrm{m}^{-3}]$	T_{in} [K]	v_{in} $[\mathrm{m\,s^{-1}}]$
$8.95 \cdot 10^{24}$	230.4	376.99

Surface pressure due to plume impingement

Both methods DSMC and ESBGK are compared in terms of the surface pressure in the following qualitative figures. Very good agreement can be observed between the two methods.



(a) Single (b) Dual

Plasma Kinetic Code PICLas STUTTGART

boltzplatz offers services around the simulation software PICLas, developed by the University of Stuttgart at the Institute of Aerodynamics and Gas Dynamics and the Institute of Space Systems. It allows the prediction of rarefied gas and plasma dynamics under the influence of electromagnetic forces. It is available under the GNU General Public License v3.0.

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 simulations
- Single species simulations with diatomic and polyatomic molecules using quantized vibrational energy treatment
- Simulation of gas mixtures with the multi-species modelling for atomic and diatomic species

The goal of the on-going development is to reach the same feature level as within the DSMC method to allow a bidirectional coupling for applications such as atmospheric entry and in-space propulsion. Coupled BGK-DSMC simulations show great promise in terms of computational time reduction.

Direct Simulation Monte Carlo

The Direct Simulation Monte Carlo method in PICLas for the simulation of non-equilibrium, high-enthalpy rarefied gas flows has a multitude of features including:

- 1D, 2D, axisymmetric (including a radial weighting) and 3D simulations
- Mesh independence with on-the-fly octree-based mesh refinement and a nearest neighbour algorithm
- Broad range of available species from electrons to polyatomic molecules such as methane and carbon-dioxide
- Treatment of chemical reactions & ionization processes using the different chemistry modelling

Application areas of the DSMC method range from atmospheric entry and in-space propulsion to terrestrial applications such as micro-channel flows and vacuum pumps.

About us

We are aerospace engineers from the University of Stuttgart and we worked together during our PhDs on the development of PICLas. As a result, our combined expertise is in the rarefied gas dynamics, electromagnetic phenomena and numerical simulation techniques.

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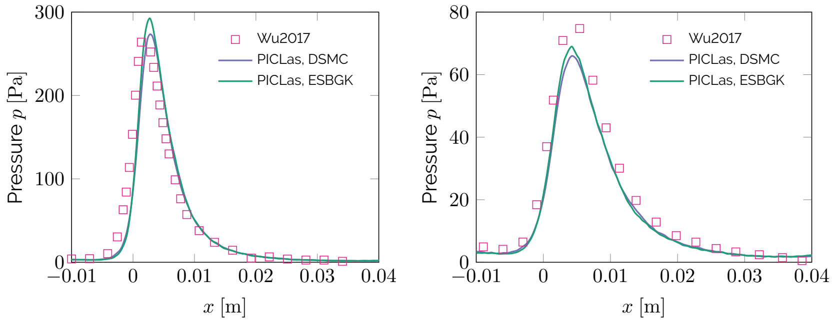
Comparison with experimental measurements

The simulation results are compared with experimental measurements obtained by Wu (2017) with pressure-sensitive paint. The figures below show the pressure along the center axis ($y = 0$) and an off-axis ($y = 4.8\,\mathrm{mm}$) of the plate for the single and dual configuration.

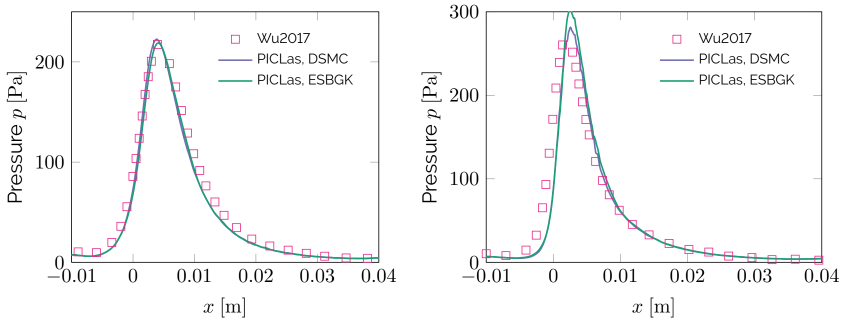
Single plume



(a) $y = 0$ (Nozzle axis)

(b) $y = 4.8\,\mathrm{mm}$

Dual plume



(a) $y = 0$

(b) $y = 4.8\,\mathrm{mm}$ (Nozzle axis)

Both simulation methods show very good agreement with the experimental results and thus demonstrate their capabilities for the predictive simulation of plume-plume interaction and plume impingement.

Sources:

- Wu, J., Bitter, M., Cai, G. B., He, B. J., & Kaehler, C. (2017). Investigation on aerodynamic force effect of vacuum plumes using pressure-sensitive paint technique and CFD-DSMC solution. *Science China Technological Sciences*, **60**(7), 1058–1067.
- Pfeiffer, M., Mirza, A., & Nizenkov, P. (2021). Multi-species modeling in the particle-based ellipsoidal statistical Bhatnagar–Gross–Krook method for monatomic gas species. *Physics of Fluids*, **33**(3), 036106.

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