boltzplatz
numerical plasma dynamics

Flow Simulation of Atmospheric Entry at Titan

PICLas

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

Direct Simulation Monte Carlo

The Direct Simulation Monte Carlo (DSMC) 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 the 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.

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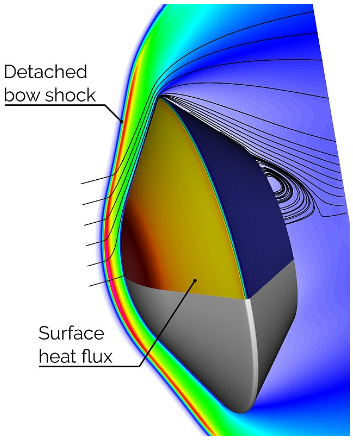
Saturn's moon Titan is of great to interest to the scientific community due to the thick nitrogen atmosphere with traces of methane. Spacecraft travelling to Titan utilize its atmosphere to decelerate upon arrival. During this maneuver, spacecraft must withstand an extreme thermal environment. Through numerical simulations of the atmospheric entry, the conditions and the incident heat flux are approximated to support the design of the thermal protection system.

Hypersonic, high-enthalpy flow

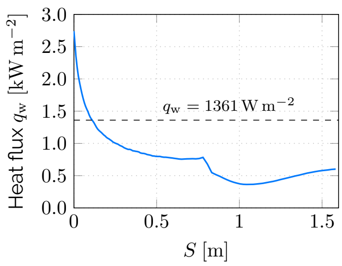


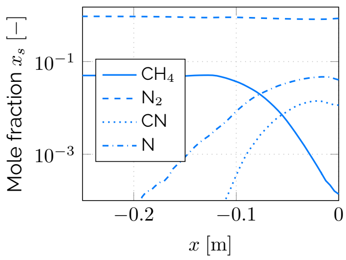
For this application, a generic spacecraft geometry is simulated with the Direct Simulation Monte Carlo (DSMC) module of PICLas. The incoming free-stream conditions are derived at the point of peak heating from an exemplary aerocapture trajectory. The hypersonic flow at a Mach number of 20 results in high-enthalpy conditions with a detached bow shock and a rarefied region behind the capsule. The figure shows the translational temperature in the symmetry plane and flow streamlines.

Complex chemistry modelling

The simulations utilize a complex species and chemistry model consisting of 13 species (including methane, nitrogen and the respective reaction products) and 24 reactions paths. Internal energy exchange is considered by rotational, vibrational and electronic excitation.

Simulation results on the right show the species composition of the gas mixture in front of the capsule and the incident heat flux on the back cover. This data can be utilized during the design of the heat shield to find the optimal solution with regard to the minimization of the total spacecraft mass.





Sources:

- Pfeiffer, M., Nizenkov, P., Mirza, A., & Fasoulas, S. (2016). Direct simulation Monte Carlo modeling of relaxation processes in polyatomic gases. *Physics of Fluids*, **28**(2), 027103.
- Nizenkov, P., Pfeiffer, M., Mirza, A., & Fasoulas, S. (2017). Modeling of chemical reactions between polyatomic molecules for atmospheric entry simulations with direct simulation Monte Carlo. *Physics of Fluids*, **29**(7), 077104.