Computational Modeling of Transonic Flow in a Thermo-Electric Propulsion System

R. Groll, S. Reichel, T. Schadowski and H. J. Rath
Center of Applied Space Technology and Microgravity,
University of Bremen, Am Fallturm,
D-28359 Bremen,
Germany

Overview

Future micro-satellite mission have to be planned for minimized fuel need with a maximum of specific impulse. Optimizing this specific Impulse of a thermo-electric micro-thruster with coupled methods of trans-sonic flow solvers and thermo-electric heating/plasma generating methods are an efficient way analyzing the thermo-fluid dynamic behavior of the thrust efficiency depending on the generated heat inside an electric plasma generator.

This work deals with the computational and dimensional analytic modeling of the heat and production rate inside the investigated micro-thruster. Describing new ways of computational modeling trans-sonic electro-thermal flows the efficiency of future micro thruster devices will optimized using parameter studies of computation simulation results before producing the first prototype.

1. INTRODUCTION

Developing the computation method of electric propulsion devices compressible flows expanding in a vacuum chamber are simulated. Additionally source terms for heat implementation and electric forces included in the used transport equations.

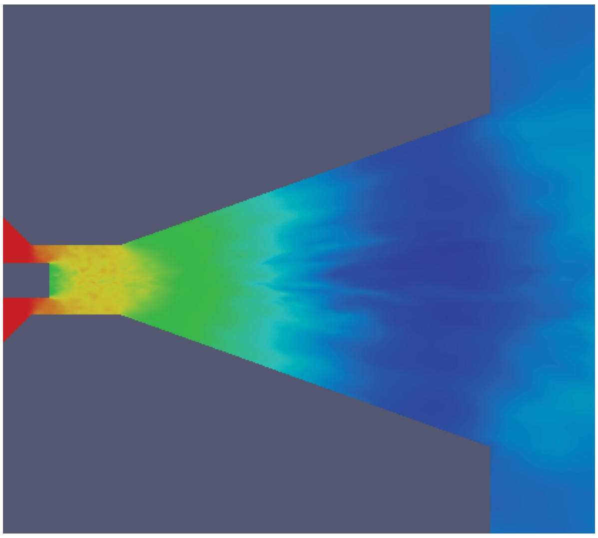

FIGURE 1. Pressure distribution of a DSMC simulation in the diffuser region of a transonic nozzle

Modeling the electric flux transport equation for electric potential are developed. Basically the heating of the electrodes by the electric discharge introduce the form and the position of the plasma discharge region.

2. EXPERIMENTAL SETUP

FIGURE 2. Vacuum chamber with mass flow controller and turbo-molecular vacuum pump

The experimental set-up is used inside a small vacuum chamber. The small volume has the advantage of a very high vacuum pump mass flow performance for very low pressures.

3. ELECTRO-THEMAL MODELING PROCESS

Modeling the plasma flow through the hypersonic nozzle of the micro thruster compressible transport equations are used describing mass, momentum and heat transfer in the diffuser region of the thruster nozzle.

$$\frac{\partial}{\partial t}(\rho)+\frac{\partial}{\partial x_j}(\rho u_j)=0$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_i}{\partial x_i}-\frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right)\right]+F_{ion}$$

$$\frac{\partial}{\partial t}(\rho e)+\frac{\partial}{\partial x_j}(\rho e u_j)=\frac{\partial}{\partial x_j}\left[\rho\alpha\frac{\partial h}{\partial x_j}\right]-p\frac{\partial u_k}{\partial x_k}+\dot{Q}_{ion}$$

These equation describe the interaction the expansion level with the temperature dependent electric conductibility during the ionization coupled electric discharge of the introduced noble gas.

Modeling the momentum and the thermal diffusion rate the temperature dependence is modeled by the Sutherland procedure:

$$T=\frac{e-e_0}{c_v}\ ,\ \frac{p}{\rho}=\frac{R_0 T}{M}\ ,\ \mu=\frac{A_s T^{1.5}}{T+T_s}$$

Modeling the electric flux density inside the plasma flame the plasma is heated and the electric conductibility is increasing. The mass flux is restricted because of the temperature dependent exit velocity of the transonic nozzle. During the subsonic gas acceleration the plasma is heated by the electric discharge

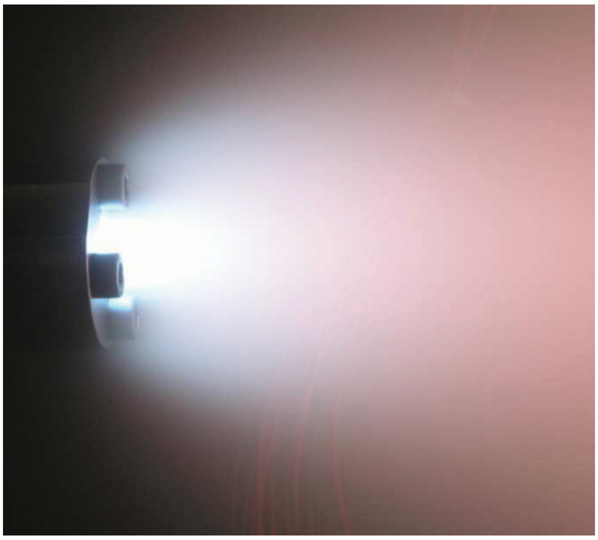

FIGURE 3. Xenon plasma thruster in service

4. CONCLUSIONS AND OUTLOOK

With the computational set-up of the electric propulsion device the electric discharge of the ionized noble gas is simulated. The computational results are validated with experimental data.

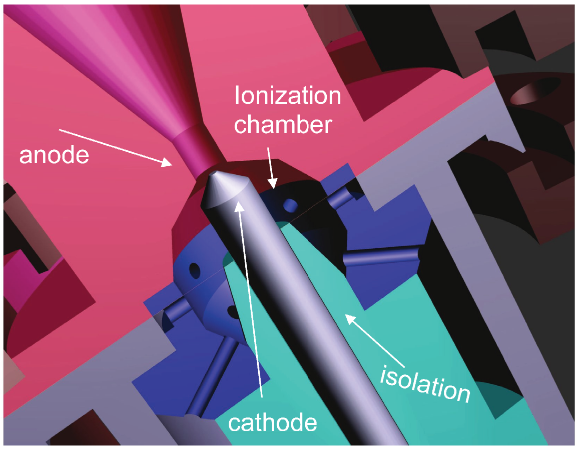

FIGURE 4. Geometrical set-up of the ionization chamber

During the discharge process the electrodes are heated by the electric discharge near the smallest gap inside the ionization chamber.

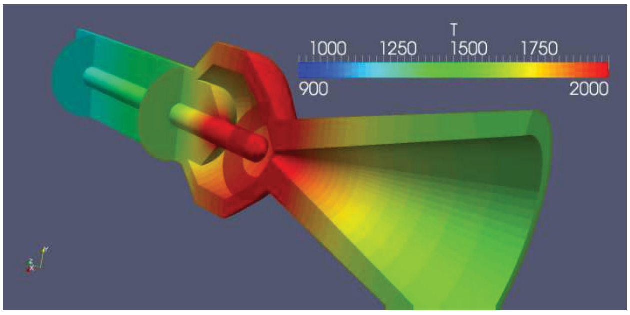

FIGURE 5. Temperature distribution in the nozzle case

Optimizing the outer diffuser shape for maximum heat radiation power the best electric performance for highest gas exit velocities is reached.

REFERENCES

[1] E. Choueiri, On the Thrust of Self-Field MPD Thrusters IEPC-97-121, Electric Propulsion and Plasma Dynamics Laboratory (EPPDyL) Princeton University; 1997

[2] A. Fruchtman Limits on the effciency of several electric thruster configurations, Physics of Plasmas, Vol. 10, MAY 2003; Department of Aeronautics and Astronautics University of Southampton, Highfield, Southampton, Hampshire, SO17 1BJ, UK; August 1997

[3] S. Reichel, R. Groll, H.J. Rath, Numerical Simulation of an electric charged compressible gas flow with en electric mesh refinement, European Conference on Computational Fluid Dynamics, ECCOMAS CFD, 2010

[4] T. S. Sheshadri, Anode surface temperature profile in MPD thrusters, Vacuum, Vol. 59, 2000, Holon Academic Institute of Technology P.O. Box 305, Holon 58102, Israel; January 2003