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Author: Mr. Michele Nava
Politecnico di Milano, Italy

Dr. Filippo Maggi
Politecnico di Milano, Italy
Mr. Davide Zuin
D-Orbit SpA, Italy

GASDYNAMIC EXPANSION MODELS AND PRELIMINARY HEAT TRANSFER AND THERMAL ANALYSIS FOR THE NOZZLE OF A MICROWAVE ELECTROTHERMAL THRUSTER USING DIFFERENT PROPELLANTS

Abstract

The Microwave Electrothermal Thruster (MET) is an emerging technology for space propulsion that uses microwave power to generate a plasma inside a cylindrical resonant cavity. The plasma heats a gaseous propellant flowing around it, and such gas is then expanded through a converging-diverging nozzle and accelerated to supersonic velocities, producing thrust. The nature of the gasdynamic expansion is crucial in determining the nozzle exit conditions and the propulsive performances of the thruster. Chemical reactions in MET nozzles may be favored by the high nozzle-inlet temperatures generated in the resonant cavity, but the high gas velocities and the small size of the nozzles themselves reduce the time available for chemical reactions to occur. Moreover, heat transfer to the nozzle walls and temperature limits of nozzle materials can impose severe constraints on the working conditions and maximum achievable thruster performance. Different models are applied and compared to describe the gasdynamic expansion of N_2, N_2O and H_2O for various nozzle inlet conditions: a frozen chemistry model, a chemical equilibrium model, and a hybrid model employing the Bray freezing criterion to identify a transition point from chemical equilibrium to frozen flow conditions. The quasi-1D inviscid Euler equations with chemical reactions are also solved for the case of N_2. Convective heat transfer from the expanding gas in chemical equilibrium to a radiatively cooled nozzle is modelled and simulated for H_2O, considering stagnation temperatures and pressures of $6000\,K$ and $1\,atm$, respectively. A wide performance gap is seen for all propellants between the frozen flow and the chemical equilibrium model, with the latter predicting higher exit velocities and thruster efficiencies. The Bray model predicts a freezing point in proximity of the nozzle throat and shifted towards the converging section for all the propellants, suggesting an expansion closer to the frozen flow one. This is confirmed by a good agreement with the Euler equations for N_2. The heat transfer model predicts nozzle throat wall temperatures and heat fluxes in the order of $4000\,K$ and $550\,W/cm^2$, respectively, suggesting the need for an appropriate nozzle cooling system design in high performance METs.