Paper ID: 3686
student

SPACE PROPULSION SYMPOSIUM (C4)
Advanced Propulsion : Non Chemical, Non Electric (6)

Author: Mr. Yuuki IWAKI
Hokkaido University, Japan, yu-iwaki@mech-me.eng.hokudai.ac.jp

Prof. Tsuyoshi Totani
Hokkaido University, Japan, tota@eng.hokudai.ac.jp
Mr. Syunya Satoh
Hokkaido University, Japan, sh13un@yahoo.co.jp
Mr. Tetsushi NAGANUMA
Hokkaido University, Japan, t040481a@ec.hokudai.ac.jp
Dr. Masashi Wakita
Japan, m-wakita@eng.hokudai.ac.jp
Prof. Harunori Nagata
Hokkaido University, Japan, nagata@eng.hokudai.ac.jp

IMPROVEMENT OF THRUST AND SPECIFIC IMPULSE BY CONVECTIVE HEAT TRANSFER IN LAVAL NOZZLE

Abstract

Effects of the heating of a propellant in Laval nozzle have been obtained analytically. The analysis has been performed under the assumptions that the propellant flows in one-dimensional steady state and the propellant is heated by convective heat transfer.

Recently, there has been an increase in the development of microsatellites by universities and small-medium businesses. A piggyback system is the most practical launch system for microsatellites. The piggyback satellites cannot have any flammable propellants, because they might have an adverse effect on the performance of a main satellite. Resistojets or gas thrusters are suitable for the piggyback satellites because nonflammable propellants can be used. In the case that resistojets or gas thrusters are adopted in microsatellites, the propellant has the low enthalpy at the inlet of a nozzle. The convective heat transfer from the nozzle wall to the propellant becomes relatively large and cannot be neglected.

In the traditional nozzle theory used in a variety of propulsion systems involving rocket boosters, the influence by the heat transfer to the propellant has been neglected. In the small nozzle used in piggyback satellites, the traditional nozzle theory is not suitable. Heating a supersonic flow causes decrease in velocity and pressure increase. The nozzle can convert the enthalpy into the kinetic energy by the expansion of propellant. Hence, the heat supplied to the propellant at the nozzle is also converted to the kinetic energy and could improve the thrust and the specific impulse. The heating in the nozzle can expand a possibility of a thermal design of a propulsion system. Evaluation of the effect of the heating is required to obtain an optimal nozzle design.

The analysis program consists of two main parts that calculate the one-dimensional thermal conduction of the wall of the nozzle and one-dimensional steady continuous flow without a chemical reaction of the propellant. The boundary conditions of the former part are the constant temperature at the inlet of the nozzle, the convective heat transfer between the wall and the propellant and the radiative heat transfer between the wall and the surrounding. The boundary conditions in the latter part are the constant temperature at the nozzle inlet, a constant expansion ratio and the convective heat transfer between the wall and the propellant.

The analysis objects are the nozzle made of aluminum alloy and nitrogen as propellant. Dimensions of the nozzle are selected for various thrust level of the thruster.

Comparing 20 mN class nozzle with 100 mN class nozzle, the 20 mN class nozzle has a larger effect of the heat transfer in the nozzle. The inlet temperature of the propellant is 310 K and inlet pressure is 1 MPa about both nozzles. By heating the propellant by convective heat transfer in the nozzle, the specific impulse of the 20 mN class nozzle improves from 79 s to 86 s, and the specific impulse of the 100 mN class nozzle improves from 79 s to 84 s. The difference of the improvement ratio between the two nozzles is caused by the difference of the obtained heat per unit volume rate of the propellant.