Non-Chemical Space Propulsion Research Activities at Nagoya University

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Abstract: Nagoya University reinitiated non-chemical space propulsion researches including on steady-state, applied-field magnetoplasmadynamics thruster and laser propulsion. This paper introduces its infrastructure and recent research activities.

I. Introduction

NAGOYA university was active in experimental and numerical investigations on electric propulsion; publication started from 1984 IEPC in Tokyo. Recently, its infrastructure and research topics have renewed, and non-chemical space propulsion activities have newly started. This paper reports recent related research activities in Ionized Gas Dynamics Laboratory, Department of Aerospace Engineering, Nagoya University.

II. Steady-state, applied-field MPD thruster

In 2006, a 2.0-m-dia., 4-m-long, stainless-steel vacuum chamber, see Fig. 1, was installed in Department of Aerospace Engineering, Nagoya University. It has a turbo-molecular pump backed by a rotary pump. The chamber was manufactured primarily for electric propulsion research. However, it is also utilized as a dump tank for an in-draft supersonic wind tunnel.

Using this vacuum chamber, experimental study of steady-state, applied-field magnetoplasmadynamics (MPD) thruster was re-initiated. The thruster head is schematically illustrated in Fig. 2. The design is basically the reproduction of 1980s University of Tokyo work. It comprises a cupper anode and a 2%-thoriated tungsten cathode rod of 3 mm diameter. The anode is shaped as a Laval nozzle. Boron-nitride is used as the insulator in-between. A water-jacketed solenoid coil surrounds the anode, and is directly water cooled. The anode contacts the water jacket of the solenoid coil, being cooled only through heat transfer through the contact.

The thruster head is mounted on a pendulum type thrust stand (Fig. 3). The thruster electrodes were connected with a commercially available welding power supply. However, it did not cover high-voltage mode operation. Therefore, recently another power supply was introduced and its high-voltage performance was improved. The solenoid coil is connected with another DC power supply.

Fig. 4 shows an example of exhaust plume of argon propellant. Thrust is measured from a deflection angle of the thrust stand arm, which is measured using a differential transformer set outside of the vacuum chamber, about 1 m from the pendulum fulcrum.
III. Laser propulsion

One of currently-most-active research topics in the laboratory is laser propulsion. We have two highly repetitive pulse lasers:

- TEA (Transversely-Excited Atmospheric) CO₂ laser: Wavelength; 10.6 µm, energy; 10 J/pulse, pulse width 200 ns (FWHM), repetition frequency; 50 Hz at a maximum.

- Nd:YLF laser: Wavelength; 1047 nm, average power 80W, pulse width 10 ns (FWHM), repetition frequency; 10 kHz at a maximum.

Moreover, another RP laser is planned to be introduced March, 2010:

- Repetition frequency; 100 kHz, average power; 400 W, pulse width; 10 ns.

Using these RP lasers, various propulsion studies can be done.

Sasoh et al. demonstrated that laser propulsion performance can be improved by ‘in-tube’ configuration. They developed ‘laser-driven, in-tube accelerator (LITA),’ and demonstrated projectile vertical launch operation. Figure 5 shows an example of LITA vertical launch operation. In this case, an aluminum-alloy(A7075-T6)-made projectile has an laser ablator rod made of polyacetal on its center. The projectile is set in an acrylic launch tube of 25 mm in inner diameter. Laser pulses are sent from through a ZnSe window at the bottom of the launch tube. The launch tube is connected to a 0.7-m-dia., 2-m-long vacuum chamber, and evacuated. The lower part of the projectile is shaped as a parabolic mirror, focuses a laser pulse onto the centric polyacetal ablator. Using the TEA CO₂ laser listed above, the projectile is launched.

Figure 6 shows a schematic illustration of an advanced LITA, the wall-ablative LITA. In this device, the propellant (polyacetal) is not on board a projectile, but is placed on the launch tube wall. Since the projectile does not carry propellant on board, a high payload ratio can be achieved. The original idea of placing a propellant off board comes from the ‘ram accelerator.’ In the ram accelerator, the launch tube is filled with combustible mixture, which is ignited with a shock system generated by the projectile itself. However, the ram accelerator has a serious problem in its practical usage; with a high projectile speed exceeding 2.5 km/s, the projectile material starts directly reacting oxygen in the mixture, thereby disintegrating the projectile. Higgings proposed synchronized ignition of
explosive to the projectile motion. However, such system is technically very difficult. So far, the WA-LITA is the unique device in which this kind of propulsion concept is really demonstrated.

Along with the device development, basic research on mechanisms of generating laser-ablative impulse has been conducted.\textsuperscript{7,8} Figure 7 shows a velocity interferometer for any reflector, which is known as ‘VISAR’\textsuperscript{9} in shock in condensed mater research field. This is a Michelson type interferometer; the reflected beam is split into two paths of different optical lengths, interfering between them yields a beat signal the phase of which has a linear relation with the reflector velocity. The system has a time resolution of 4 ns; the impulse generation process, that is the time variation of laser-pulse induced thrust, can be resolved. Figure 8 shows the example of time variations of laser-pulse induced impulse onto polyacetal propellant.\textsuperscript{8}

**IV Plasma actuation**

Another activity is to use laser plasma for modulating pressure field over a supersonic body. In the Mach 1.9 wind tunnel it was experimentally demonstrated that irradiation of repetitive laser pulses significantly reduce the supersonic drag with an efficiency of energy deposition exceeding unity.\textsuperscript{10} It is expected that with the newly-introduced 100 kHz RP laser even higher drag reduction performance will be obtained.

**Summary**

We have just re-initiated electric propulsion research. Together with other non-chemical propulsion research activities, we are currently emphasizing the related activities.

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**References**


(a) Principle

(b) Photograph of the VISAR

Figure 7. VISAR for time-resolved thrust measurement

Figure 8. Time variations of local impulse measured using VISAR