Cooperation Activities between IRS and the University of Tokyo in the Field of Pulsed Plasma Thruster Development

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Tony Schönherr* and Kimiya Komurasaki†
The University of Tokyo, Kashiwa, Chiba, 277-8561, Japan

Matthias Lau‡ Georg Herdrich§ and Hans-Peter Röser¶
Universität Stuttgart, Stuttgart, Baden-Württemberg, 70569, Germany

and

Shigeru Yokota‖ and Yoshihiro Arakawa**
The University of Tokyo, Bunkyo, Tokyo, 113-8656, Japan

Abstract: Being part of the Stuttgart Small Satellite Program, the two missions Perseus and Lunar Mission BW1 will provide a test-bed for new technologies comprising two different kinds of electric propulsion systems. The Pulsed Plasma Thruster (PPT) project, initiated at IRS, named SIMP–LEX will provide one of the thrusters installed. For an improved research and development of the system, international cooperation was aimed with help of a coalescent PPT community and direct research programs. This paper will give a brief overview about past cooperations and justifications for a research cooperation as well as some information about the PPT working group and it will explain the research plan for the combined effort between the universities in Stuttgart and Tokyo.

Nomenclature

B	= magnetic field
ΔL	= change in inductance caused by the plasma propagation
I	= discharge current
x, y, z	= coordinates in the space between the electrodes
x_p	= position of the plasma sheet along the electrodes

*Ph.D. Candidate, Department of Advanced Energy, schoenherr@al.t.u-tokyo.ac.jp.
†Professor, Department of Advanced Energy, komurasaki@k.u-tokyo.ac.jp.
‡Ph.D. Candidate, Institute of Space Systems (IRS), lau@irs.uni-stuttgart.de.
§Section Lead, Institute of Space Systems (IRS), herdrich@irs.uni-stuttgart.de.
¶Director, Institute of Space Systems (IRS), roeser@irs.uni-stuttgart.de.
‖Assistant Professor, Department of Aeronautics and Astronautics, yokota@al.t.u-tokyo.ac.jp.
**Professor, Department of Aeronautics and Astronautics, arakawa@al.t.u-tokyo.ac.jp.

I. Introduction

The Institute of Space Systems (IRS) is undergoing the challenge of realizing several small satellites within the Stuttgart Small Satellite Program[1–3]. Two of these missions - Perseus and Lunar Mission BW1 - will have electric propulsion systems installed. Scheduled to be placed in a low Earth orbit (LEO), the satellite Perseus is intended to have a mass of less than 150 kg comprising one arcjet thruster named TALOS[4] and one pulsed plasma thruster (PPT) named SIMP-LEX[5]. One mission objective is the profound evaluation of the electric propulsion systems in regard of operativeness, compatibility and reliability. After the in-orbit validation of the performance characteristics and the operational behavior, the then refined thrusters will be applied to Lunar Mission BW1 and will serve as main propulsion in order to send the satellite to the Moon.

The development of SIMP-LEX towards a thruster for the satellite missions was supported by national and international cooperation, eventually leading to a new improved thruster design[6]. The further research and development of the thruster system was considered to be of higher value by combining the expertise of different facilities. Following the ideas evoked at the First International PPT & iMPD Workshop at the IRS and based on previous researches conducted in cooperation between the IRS of the Universität Stuttgart and the Department of Advanced Energy of the University of Tokyo, the scientific potential within a cooperative PPT project was realized and the related exchange of personnel and information envisaged. In order to establish and consolidate development methods for space propulsion systems and to improve the quality level of future thrusters, a research plan for the PPT was sought to realize a successful and thoroughgoing project.

II. Preceding research activities

International cooperation for research has a long history at IRS. Several projects were conducted in the past by means of a vivid exchange of researchers and close communication between research facilities all over the world. Starting in 2000, first experimental investigations as part of a research cooperation together with the Department of Advanced Energy at the University of Tokyo were conducted in the area of plume characterization of a plasma generator[7]. Following this initial step, several academic exchanges between the two institutes, including visiting researchers as well as students, were undertaken in different space-related research fields. These comprise energy transmission by microwaves[8], optical and probe measurement methods applied to plasma generator flows[9–13] and electric propulsion systems[14] as well as numerical investigations of the latter[15]. Based on the close national cooperation between the University of Tokyo and JAXA, projects were also expanded to combine the equipment and experience, e.g., in the field of plasma characterization[16].

In the field of PPT development, cooperation and exchange of research ideas and information was sought by means of an International PPT & iMPD Workshop that took place at IRS in 2007. With participants from 5 countries, the workshop was a success that yielded the founding of the PPT & iMPD Working Group[a] and ameliorated the research connections between the universities and research centers. As a result of the coalescent community during the workshop, the project SIMP-LEX was considered to strongly benefit from combined experience and experimental facilities at IRS as well as at the University of Tokyo. That is, a concept was figured out to enable a cooperation based on 2 PhD theses, namely Matthias Lau for the lifetime and operativeness research at the IRS and Tony Schönherr, former student of the IRS, for the plasma diagnostic and thruster discharge research at the University of Tokyo.

III. PPT research cooperation

III.A. General goals

The technical aim of the cooperative work is the development, research and successful testing of a thruster system eligible for space application. This not only includes the thruster head itself, but the on-board sensor units to monitor the performance and the health of the propulsion system as well as the equipment necessary for operation. Further, it has to be guaranteed that the thruster does not affect the adjacent satellite systems either electromagnetically nor by plasma sediment contamination. The challenge to go to the Moon, faced by Lunar Mission BW1, implies unprecedented lifetime requirements that have to be verified within the

[a] http://impd.irs.uni-stuttgart.de

project SIMP-LEX. In regard of further projects and missions, the behavior of the thruster and the resulting performance should evidently be studied to improve the design tools there are. This can be conducted by measuring the plasma and thruster characteristics during the discharge and obtain feedback information for the modeling.

Additionally, the exchange of researchers and the promotion of intercultural experiences is a further and important goal of the PPT development cooperation. Acquiring new knowledge about testing methods and exchanging ideas about systems development will eventually improve the quality of the thruster, and the intensity of the cooperation for further joint projects.

III.B. IRS contributions and development

The IRS features a long and extensive heritage of electric propulsion development, covering a broad spectrum of thruster systems. As mentioned in Chapter II, the PPT SIMP-LEX, developed at IRS was agreed at the First International PPT & iMPD Workshop to encourage a strong cooperation between IRS and the University of Tokyo. The potential in both technical and institutional cooperation are rooted in the successful research work and equal interests of both partners in the development of reliable and flexible PPT propulsion system solutions.

The IRS joins in the common approach to boost research and interdisciplinary cooperation by providing and exchanging resources, by offering support and expertise. Further contributions are the experimental evaluation of research data provided by the University of Tokyo as well as the development of technical solutions for the implementation of the results achieved. To ensure an equal basis for testing, investigations and data acquisition for both research partners and because of IRS capabilities and experience with the thruster design, all stages of the thruster hardware are built and provided by IRS. Development efforts at IRS for the thruster SIMP-LEX are ongoing and continuously carried out in parallel to the cooperation but maintain constant consideration of possible synergies.

The exchange of resources includes every aspect of personnel and data transfer, not only in reference to the SIMP-LEX development project but also in related projects and fields of plasma research and diagnostics covered by both the facilities at IRS and in Tokyo. The focus with personnel lies on encouraging students for project works at the corresponding partner facility as well as the continuous exchange of research associates and visiting scientists. A common handling and discussion of research data improves the accuracy of data achieved and therefore ensures faster, more reliable and verified results. This is realized in an unprecedented way of open cooperation and data management between IRS and the University of Tokyo and goes hand in hand with efforts for granting access to constant support and expertise in all relevant fields of work. At IRS this goal is realized in an early phase of work by strongly supporting the set-up of a new test facility at the University of Tokyo for performing the joint investigations. In return, the University of Tokyo provides hands-on expertise on measurement techniques and test equipment.

A significant contribution of IRS for processing and implementation of data from numerical or experimental investigations at the University of Tokyo is done by means of evaluation campaigns within the test facilities at IRS. This includes the technical integration of thruster modifications, building, facility integration and extensive testing and characterization of optimized thruster designs. The resulting data on improvements and operational behavior is made available for both partners for deeper analysis and further utilization. However, scientific and technical outputs of the cooperation will be presented in common publications to reflect the joint approach in research. Updates of the thruster hardware are provided by the IRS if necessary.

The extensive development program of the SIMP-LEX thruster system is - as mentioned above - partly to be fulfilled in the scope of an ongoing PhD thesis at IRS. The roadmap comprises the thruster characterization, thruster optimization, subsystems development and integration, as well as on-ground life testing and studies on spacecraft compatibility and contamination. The two latter studies are planned to be carried out in a cryogenic test facility of the *Deutsches Zentrum für Luft- und Raumfahrt* (DLR) in Göttingen, Germany to investigate the operation capability of SIMP-LEX under simulated thermal space conditions. The on-ground life testing will be conducted in a currently set up test facility at IRS. The investigations will provide information on the thruster's operational behavior and reveal life-limiting mechanisms for subsequent optimization and evaluation of the operational life. Further the testing program for the in-orbit demonstration mission of SIMP-LEX on-board of the PERSEUS thruster technology demonstration testbed will be developed.

III.C. Goals and research plan at the University of Tokyo

In order to investigate the PPT and its physics in detail several approaches are aimed. Following a preliminary study on the calculation and the measurement of the self-induced magnetic field[6], the goal will be to refine and expand this calculation model to the purposes and conditions of ameliorated SIMP-LEX models.

The result expected is the magnetic field of the thruster normalized by the total discharge current for an assumed plasma position, and the change in inductance created by the propagating plasma. The slug model[17] used to describe the discharge and acceleration processes of the plasma current sheet is also intended to be adapted to the conditions of SIMP-LEX, eventually leading to a progression of the plasma position and the discharge current in time. Combining these results yields an information on the magnetic field in time and space as is displayed in Figure 1.

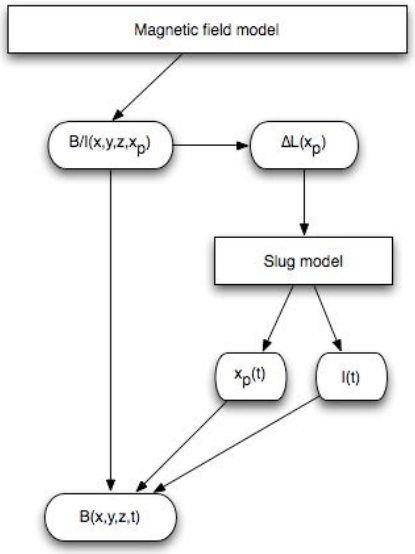

Figure 1. Roadmap for the magnetic field calculation

Experimental investigations with current and magnetic field probes are intended to compare with the analytical data found, and to give a feedback to the model for further enhancement. Moreover, the experimental usage of the high speed camera at the Department of Aeronautics and Astronautics of the University of Tokyo will eventually lead to comparable information about the plasma propagation and the divergence loss and will, thus, give more insight into the thruster's operation and comparison with the analytical model. Further, from the plasma picture, information about a possible contamination of close-by satellite components can be estimated. Consequently, the influence of the thruster's discharge on the satellite by means of its magnetic field information can be derived, and the design tool for the performance estimation be ameliorated.

To enable experimental data that conform with SIMP-LEX a twin thruster with identical components and an appropriate vacuum chamber was set up and successfully operated as can be seen in Figures 2 and 3.

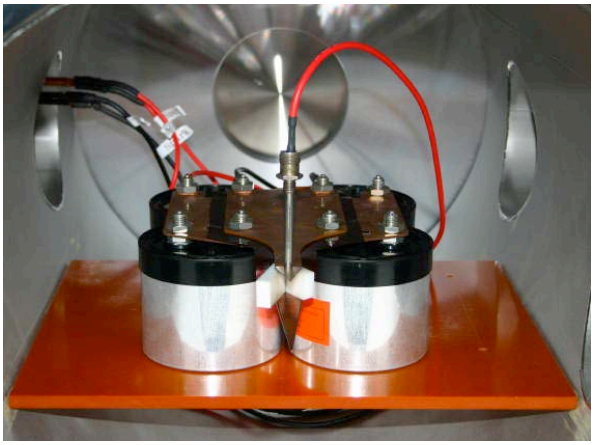

Figure 2. Twin SIMP-LEX setup.

Figure 3. Twin SIMP-LEX in operation.

Following the experience gathered in plasma plume diagnostics and high-speed measurements in Tokyo[18], experimental investigations in this field will be conducted on SIMP-LEX. Due to the short-time discharge, the application of optical measurement equipment is more complex and has to be conducted sophisticatedly. As a result of an emission spectroscopic study, information about the composition of the plasma are expected to be acquired. This is not only important to better understand the physics happening during the discharge

and the ablation and ionization of the propellant but also to investigate the possible erosion of the electrodes which play an important role for the lifetime expectation of the thruster.

Measurements with help of spectroscopic and interferometric means as demonstrated at RIAME[19] will result in information about the number densities and average temperatures of certain selected species, and by that it would be possible to estimate the ionization degree and the influence of certain thruster parameters on that value. Further, a comparison with the fully kinetic plasma model, being developed at IRS[6], will be enabled and will allow a feedback on this model.

IV. Conclusions

Based on successful international research cooperation between the IRS and several research facilities and universities worldwide, an additional partnership was sought in the field of PPT development. Following the First International PPT & iMPD Workshop and the related founding of the PPT & iMPD Working Group, the project SIMP-LEX was extended to a close cooperation between the IRS and the Department of Advanced Energy at the University of Tokyo. This cooperation includes the exchange of related personnel, e.g., a common PhD position as well as an allocation of research tasks towards an operating thruster suitable for space application between the two institutes. Subsequently, data and information transfer are enhanced to enable profound and effective development and research.

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