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Final Report

NAG9-796

The Diagnostics of the External Plasma for the Plasma Rocket

NASA

Graduate Student Researchers Program

Johnson Space Center

Houston, TX 77058

Contract Number: NGT9-5

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The NASA contract number NAG9-796 was changed to NGT9-5 as per mod. 1 of the contract. This contract provided funding for Mr. Todd Jack to perform work under the NASA Johnson Space Center, Graduate Student Researchers Program. Mr. Todd Jack prepared the report of his work on the diagnostics of the external plasma for the plasma rocket which follows.

Mr. Todd Jack has left the University of Alabama in Huntsville and is now pursuing a degree in Physics at the University of Houston. He is continuing to be funded under the GSRP program and is continuing to work on the plasma rocket at Johnson Space Center.

NASA Joh ı Space Center Training Grant Progr
by Todd M. Jack

Participation in the training grant was initiated with a literature search and review of the plasma rocket. This process was collimated by a visit to the Johnson Space Center/Clear Lake facility to view the plasma rocket and its operation. In addition, my plan of research, academics, and the future conferences I should attend were discussed. My plan of research is included with the renewal package. It was revised to clarify my planned activities. In addition, it makes allowances for a summer '96 gap in funding.

The Fall began by the investigation of glow discharge and charged particle dynamics. This investigation led into the study of electrode ionization. Applying the acquired knowledge, a thermal ion source / plasma discharge tube has been designed and built (see schematic). To allow the thermal plasma to be directed at various angles, a tilting stand/holder was designed and constructed.

As stated in the attached plan of research, the focus of my research on the plasma rocket was determined to be the investigation of the plasma with a retarding potential analyzer (RPA). The high temperature resistant RPA will measure plasma parameters at the edge of the contained plasma and in the plume of the rocket. The RPA is capable of direct measurements of the plasma energy and density profiles.

Three regions of plasma temperature/energy are being investigated to understand fully the behavior of the plasma created by the propulsion device and the operation of the RPA. Each type of plasma has a RPA associated with it; i.e. a thermal RPA, a collimated RPA, and a high temperature RPA. Through the process of developing the thermal and collimated RPAs, the proper knowledge and experience has been gained to not only design a high temperature RPA for the plasma rocket, but to understand its operation, results, and uncertainty.

After completing a literature search for, reading published papers on, and discussing the operation of the RPA with electric propulsion researchers, I applied the knowledge gained to the development of a RPA for thermal plasma. A design of a thermal RPA was made which compensates for a large Debye length and low ionized plasma (see schematic). From this design a thermal RPA was constructed. It consists of an outer stainless steel casing, a phenolic insulator (outgases slightly), and stainless steel mesh for the voltage screens.

From the experience and knowledge gained in the development of the thermal RPA, a RPA for collimated plasma was developed. A collimated RPA has been designed and constructed (see schematic). It compensate for a smaller Debye length and much higher ionization than that existing in the thermal plasma. It is 17% of the size of the thermal RPA. A stainless steel casing shields the detector from impinging electrons and ions. An insulating material, epoxy resin, was utilized which has a negligible outgassing. This material can be molded in styrofoam and machined quite nicely. It is capable of withstanding moderately high temperatures. Attached to this resin insulator are inconel screens attached by silver plated copper wire to a voltage supply. All the work on the RPAs and thermal ion source, I performed in the University of Alabama in Huntsville's (UAH) engineering machine shop.

Beginning in March, the thermal plasma source, thermal RPA, and collimated RPA will be operated and tested at Marshall Space Center in a vacuum chamber utilized for collimated plasma experiments. A collimated plasma source (up to 10 keV) will be available for my use. By working with NASA Marshall researchers, I will prepare for the IEEE ICOPS'96 poster session, acquire kn ›dge on the RPA and other diagnostics f ollimated plasmas, and obtain experience in the analysis of the resulting data.

Knowledge gained on diagnostics will be applied during a research visit to Stennis Space Center (Sensor and Development Technology Division). For one week in May, I will be participating in diagnostics activities/research on rocket plumes. Similar, if not like, diagnostic instruments will be utilized as that which can be used on the plasma rocket.

I have begun to apply the experience and knowledge gained in the development of the thermal and collimated RPAs to the development of a high temperature RPA. I have initiated the gathering of information on a RPA capable of operating in the hostile environment of a Tokamak containment unit. A high temperature RPA has been used by researchers at the Massachusetts Institute of Technology on a Tokamak plasma.

For several weeks, I observed and learned from individuals involved with the Marshall Space Center vapor plasma source (VPS). The purpose of my activities here was to acquire knowledge on the behavior of plasma (material science environment). In addition, at the Marshall facility and at UAH, I familiarized myself with vacuum systems and their operation. Rocketdyne employees assigned to the VPS operations assisted me in this endeavor.

To obtain general knowledge of Tokamak plasma (the plasma rocket is the linear section of a Tokamak fusion reactor), I have read "Tokamak Plasma: A Complex Physical System" by B. B. Kadomtsev. The knowledge gathered from reading this book is not only applicable to my plasma rocket research but also to a planned summer of research at a Tokamak fusion facility this summer. The U.S. Department of Energy (DoE) has eliminated the funding of the Tokamak fusion program. I have contacted several representatives of Tokamak fusion facilities in Europe expressing my interest in participating in an international research visit. The Joint European Torus (JET) program in England has expressed in writing its interest to have me perform plasma diagnostics with them. Presently, the Imperial College, as an associate member of JET, is seeking funding to support me during my stay. Not only will I obtain experience using plasma diagnostics at JET, but I will construct a theory on the use and results of a magnetic field wiggle to break away the plasma from the magnetic lines of force.

I have contacted individuals from the U.S. Department of Energy in an attempt to obtain information on the magnetic wiggle operation used on DoE light sources (x-ray). The magnetic field of the accelerator was wiggled at the point of particle extraction to break the charged particles from the magnetic field lines and allow for their unhindered departure from the accelerator. I am obtaining a computer code that can be built upon to simulate the magnetic wiggle effect on the plasma rocket's plume. The simulation will provide the parameters that should exist in the plasma which I will confirm or refute by the RPA measurements.

In November, I attended the 37th American Physical Society Division of Plasma Physics (DPP) conference in Louisville, Kentucky. I obtained an understanding for the operations of a U.S. scientific/engineering conference, learned about international plasma research, and discussed plasma diagnostics activities with investigators. Attendance at the DPP conference prepares me for the environment I can expect at the IEEE ICOPS'96 Plasma Science conference in Boston, MA (June 2 - 6). At the ICOP'96 conference, I will be involved in a poster session, presenting my research on the retarding potential analyzer (RPA).

Description of Proposed Research and Methodology

Three phases of research will be used to understand, design, and utilize a high temperature retarding potential analyzer (RPA). It will be used to characterize the plasma existing in both the plume and at the edge of the magnetically contained plasma of the plasma rocket. The characterization is necessary in order to verify that the wiggling of the magnetic field can have the ability to break the plasma from the magnetic field lines and provide the necessary information to properly develop the plasma rocket.

Phase I of the research project consists of designing, building, and testing a RPA for low temperature plasmas; i.e. thermal and collimated. The RPA of Phase I will be prototypes for the purpose of understanding its operation and responses to a wide range of energies and densities. The retarding potential analyzer measures the energy and density of the ions or electrons entering into its solid angle of collection. Testing will involve the determination of the output parameters and sensitivity of the device. Each grid will be tested individually by changing only its voltage and observing the output from the RPA. To verify that the RPA is providing proper output, it is compared to the output from a Langmuir or Faraday probe. It will occur in year one of the research program.

A tentative plan exists for the partially supported summer of 1996 to develop a theory for the detachment of the plasma from the magnetic field lines by wiggling the magnetic field at the plasma's exit. This will be accomplished as part of a summer research program with the Imperial College (London, England) who is involved in fusion research with the Joint European Torus (JET) Tokamak fusion program. If it is not possible to participate in summer research abroad, research will be undertaken in the U.S. It is at JET that I would obtain experience with plasma diagnostics on a Tokamak fusion reactor's magnetically contained plasma (unattainable in the U.S).

Phase II of the research project involves the design, building, and testing of a retarding potential analyzer for high temperature plasma. The actual RPA will utilize the knowledge and understanding gained in Phase I of the research project. The high temperature RPA must be machined from a ceramic material to withstand the high temperatures of the magnetically contained plasma. Testing will involve the determination of the RPA's operating parameters and uncertainty. Phase II will occur during year two of the research program.

Phase III of the research project is the most important and intense. Diagnostics of the plasma in the plume and magnetic containment component will be performed. The RPA determines the energy and density of ions at specific locations in the plume and magnetic confinement component of the plasma rocket. Correspondingly, Langmuir probes measure the electron energy and density averages. Phase III will be performed in the third year of the research program.

In the second half of year two, the Ph.D. dissertation will be begun. The interpretation and presentation of the data will be included in the text. Also, it will include the theory for the detachment method proposed and how well this method is supported by the measurements taken of the plasma. An uncertainty analysis will be presented on all equations used for calculations that were performed.

Place abstract within the 4.5 inch by 10.5 inch (11.5 cm by 27 cm) brackets of this form or of a photocopy of this form

Plasma Diagnostics with a Retarding Potential Analyzer

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The plasma rocket is located at NASA Johnson Space Center. To produce a thrust in space, an inert gas is ionized into a plasma and heated in the linear section of a tokamak fusion device to 1×10^4 - 1.16×10^6K ($\rho = 10^{10}$ - 10^{14} cm^{-3}). The magnetic field used to contain the plasma has a magnitude of 2 - 10 kGauss. The plasma plume has a variable thrust and specific impulse.

A high temperature retarding potential analyzer (RPA) is being developed to characterize the plasma in the plume and at the edge of the magnetically contained plasma. The RPA measures the energy and density of ions or electrons entering into its solid angle of collection. An oscilloscope displays the ion flux versus the collected current. All measurements are made relative to the facility ground.

A RPA is being developed in a process which involves the investigation of several prototypes. The first prototype has been tested on a thermal plasma. The knowledge gained from its development and testing were applied to the development of a RPA for collimated plasma. The prototypes consist of four equally spaced grids and an ion collector. The outermost grid is a ground. The second grid acts as a bias to repel electrons. The third is a variable voltage ion suppressor. Grid four (inner grid) acts to repel secondary electrons, being biased equal to the first. Knowledge gained during these two stages are being applied to the development of a high temperature RPA

Testing of this device involves the determination of its output parameters, sensitivity, and responses to a wide range of energies and densities. Each grid will be tested individually by changing only its voltage and observing the output from the RPA. To verify that the RPA is providing proper output, it is compared to the output from a Langmuir or Faraday probe.

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Subject Topic: Plasma Diagnostics

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- ❒ **Prefer Oral Session**
- ☒ **Prefer Poster Session**
- ❒ **No preference**
- ❒ **Special requests for placement of this abstract:** ____
- ❒ **Special requests for equipment:** ____

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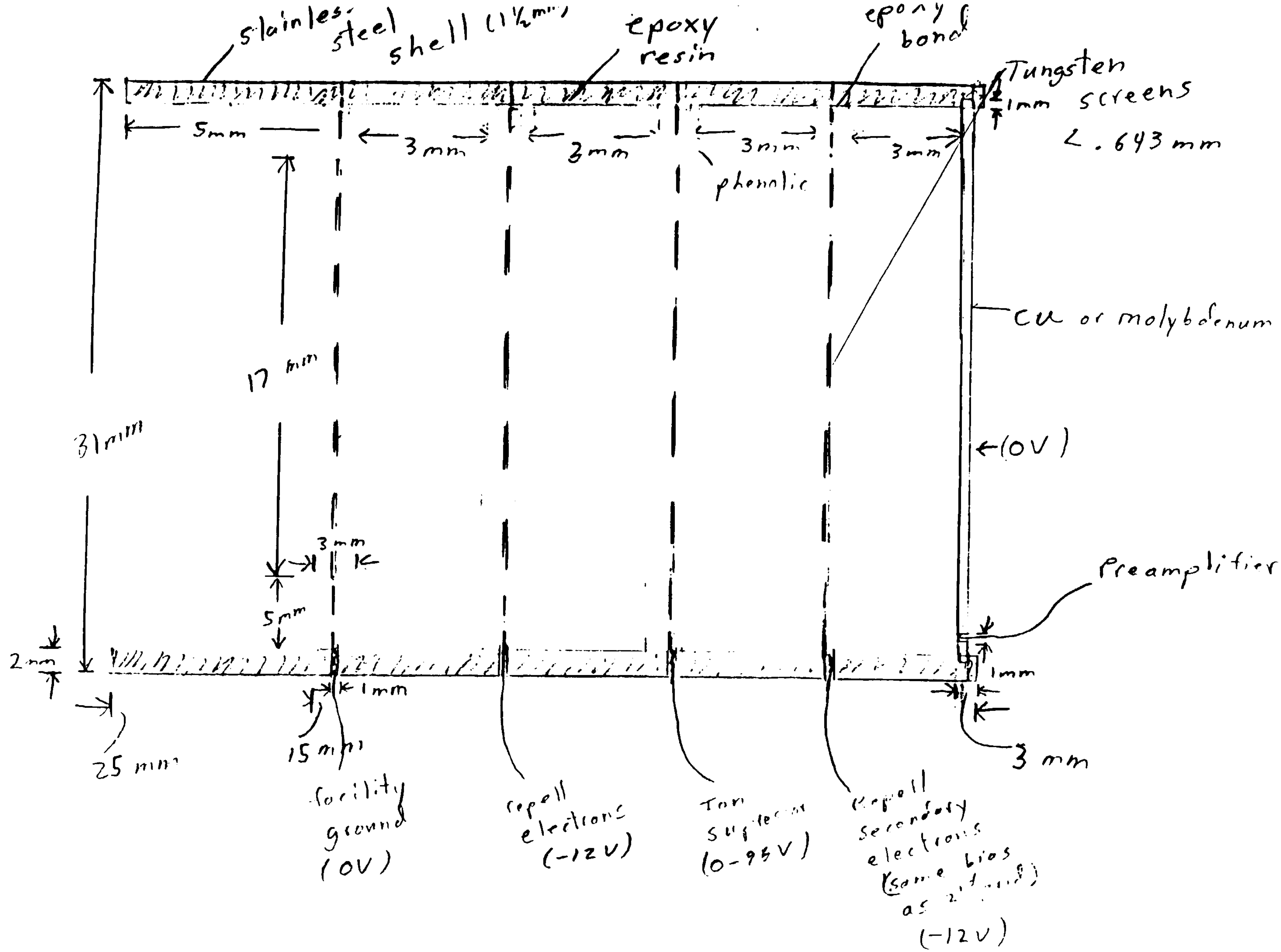
Abstract must be received no later than Friday, Feburary 9, 1996



Collimated RPA

Plasma Discharge Tube