Test Methodology and Analysis of Faraday Probes with Application to Plasma Plumes for Spacecraft Electric Propulsion

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Abstract: Accurate measurement of ion charge flux in the plume of spacecraft electric propulsion is required to quantify key performance loss mechanisms and global plume properties. Although Faraday probe design and implementation is relatively straightforward, the data analysis is complicated by several factors, including: ion collection area of the probe, systematic error associated with the measurement geometry and coordinate system, and facility effects. At the direction of the Committee on Standards (CoS) for Electric Propulsion Testing, a Guide was jointly developed by members of the electric propulsion community to establish experimental methods, analysis techniques, and recommendations on the implementation of Faraday probe diagnostics in spacecraft electric propulsion plumes. The Guide is applicable to time-averaged plasma properties in electric propulsion plumes, with a focus on Hall effect thrusters and ion thrusters. A community standard in Faraday probe diagnostics will increase the quality of comparisons between different electric propulsion devices and facilities, thereby broadening the acceptance of measurement results and enhancing the fidelity for on-orbit predictions and modeling validation. A recommended Faraday probe design was designed and characterized. This paper outlines the standard methods and recommended practices described in the Guide titled "Test Methodology and Analysis of Faraday Probes with Application to Plasma Plumes for Spacecraft Electric Propulsion".

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I. Introduction

THE Electric Propulsion Technical Committee (EPTC) of the American Institute of Aeronautics and Astronautics (AIAA) and the Spacecraft Propulsion Subcommittee (SPS) of the Joint-Army-Navy-NASA- Air Force (JANNAF) Interagency Propulsion Committee tasked the electric propulsion communitee to assemble a Committee on Standards (CoS) for Electric Propulsion Testing. The assembled CoS was tasked with developing Standards, Guides, and Recommended Practices for select diagnostic techniques used in the evaluation of plasma thrusters. This paper provides an overview of the Guide established for experimental methods, analysis techniques, and recommendations on the implementation of Faraday probe diagnostics in spacecraft electric propulsion plumes.

Faraday probes are a common plasma diagnostic utilized to determine the local ion charge flux in electric propulsion plumes. The measurements may be integrated throughout the plume to quantify thruster performance loss mechanisms and global plume properties, including: plume divergence, ion beam current, and ionization mass fraction. Although Faraday probe design is straightforward, the data analysis is complicated by several factors, including the determination of the ion collection area and the influence of background particles inherent in ground vacuum facilities. The influence of facility background pressure has been well documented in the literature, but is difficult to characterize and had not been standardized prior to the CoS efforts. Mitigating these factors to evaluate quantitative plasma properties necessitates probe design considerations, plume characterization with facility background pressure, and judicious selection of the measurement region.

A joint effort between government, industry, and academia led to agreement of common test methodologies, a standard diagnostic design, and detailed analysis techniques for time-averaged plasma properties in electric propulsion plumes, with a focus on Hall effect thrusters and ion thrusters. The Guide titled "Test Methodology and Analysis of Faraday Probes with Application to Plasma Plumes for Spacecraft Electric Propulsion" encompasses a broad body of knowledge due to the complicated nature of Faraday probe measurements, and differentiates between recommendations that may be considered, guidelines that should be implemented, and standard methods. The document provides standards, guidelines, and recommended practices that minimize measurement uncertainty and enable accurate comparison of laboratory data with on-orbit measurements and computational plume simulations. Widespread use of the Guide on Faraday probe diagnostics will facilitate comparison of quantitative electric propulsion plume properties between laboratory users, satellite designers, and other interested parties. This paper describes the results of these efforts to standardize Faraday probe diagnostics for electric propulsion plumes.