The Role of Analysis and Testing in Ion Engine Development Programs

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Adequate performance was achieved relatively early in the development of ion engines and most subsequent development programs have focussed on demonstrating adequate engine life. The primary threats to engine reliability over the required service life are damage accumulation failure modes such as accelerator grid failure due to sputter erosion from charge exchange ions, erosion of discharge chamber components by lower energy ion sputtering and grid shorting by flakes of sputter-deposited material. These types of failure may typically be observed only after thousands of hours of operation. The purpose of this paper is to provide a critical review of the approaches used in past ion engine development programs to characterize and control these wearout failure mechanisms.

Validation of engine life has traditionally relied primarily on testing. Engineering solutions to problems observed early in a development program are proposed and tested in a few long duration tests later in the program. This approach is rooted in the philosophy that one or two successful tests with a duration exceeding the required service life are adequate to demonstrate engine reliability, For damage accumulation failure modes however, this approach does not provide a statistically significant demonstration of reliability--performing enough tests to adequately characterize the failure probability distribution would be prohibitively expensive. In addition, problems encountered later in the development program often necessitate design changes, which then render the results of previous endurance testing inapplicable to the current design. In the absence of a complete understanding of how the failures occur, it becomes impossible to determine the impact of design changes except by additional costly testing.

Another approach is to invest in experimentally and analytically characterizing the physics of failure for the dominant modes discovered in long duration tests. Validation of engine life is then accomplished primarily through analysis, using models of failure that have been validated by testing. This approach has been used successfully in the gas turbine engine industry to control failure risk and is gaining acceptance in the rocket propulsion industry. Life validation by physics of failure analysis provides the tools necessary to evaluate the impact of design changes before embarking on costly test programs and the capability to quantitatively predict failure risk.

The characterization and analytical description of the dominant engine failure modes must be emphasized early in a development program, however. A review of the history of ion engine development reveals that problems have generally been treated empirically and that the tools for understanding why wearout failures occur generally do not exist. This will be illustrated for a number of failure modes encountered in various ion engine development programs, and the implications for NSTAR, a current NASA program to validate 30 cm xenon ion engine technology for planetary missions, will be discussed.