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Interface Issues for On-Board Propulsion Systems

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Overview

Integration issues associated with the use of new chemical and electric propulsion technologies are a primary concern to the user community. Experience indicates that integration impacts must be addressed to the satisfaction of both spacecraft builders and operators prior to the acceptance of new propulsion systems. The NASA Lewis Research Center (LeRC) conducts an aggressive program to develop and transfer new propulsion technologies and this includes a major effort to identify and address integration issues associated with their use (Refs. 1,2). This paper provides an overview of integration issues followed by a brief description of the spacecraft integration program at LeRC.

Discussion

On-board propulsion systems are a major mass driver in a broad range of space missions. Because of this, the application of high performance propulsion technologies can provide significant benefits which can be used to reduce launch vehicle requirements, increase spacecraft life, and/or improve payload capabilities. Acceptance of new propulsion technologies requires both high mission benefit and technology demonstrations sufficient to reduce the perceived risks of potential users to acceptible levels. In addition to performance, reliability, and manufacturing considerations, these demonstrations must include tests to show that the new system will not adversely impact spacecraft systems or functions. A schematic showing the interrelationships between a spacecraft and an electrothermal arcjet system are shown in Figure 1. This example was chosen for its timeliness. The arcjet was developed through a joint NASA/industry program and first flown in a commercial application in December 1993. Many of the integration issues shown in the figure can be addressed via straightforward engineering changes in electrical, propellant delivery, and other spacecraft systems. Several, however, are unique to advanced propulsion systems as shown in Figure 2. These can further be broken into thermal impacts and issues associated with the plasma plume. The former, while problematic, are well defined and will not be discussed in detail here. The latter are often not well characterized and so not amenable to standard treatments and will be the primary focus of this paper. Plumes from both chemical and electrical thrusters represent sources of contamination/degradation of sensitive spacecraft sensors and surfaces. With chemical thrusters, the major contamination source is unburned fuel which can condense on unprotected surfaces during thruster operation. Degradation due to electric thruster plumes is by and large caused by sputtering due to high energy particles. The effects of both thermal loading and momentum exchange due to direct impingement of plume flows must also be considered. In contrast to chemical thrusters, high performance electric rocket plumes are often highly ionized and associated particles and fields present issues related to communication signal transmission and electromagnetic interference unfamiliar to many spacecraft designers and users.

To directly address user concerns associated with plume flows, the LeRC On-Board propulsion program supports extensive efforts aimed at characterizing both small rocket plume flows and their impacts on spacecraft systems. The program is composed of three major elements - fundamentals, testbed development, and specific technology transfer efforts. These are designed to encompass both near- and far-term development programs and are illustrated in Figure 3.

As shown in the figure, the LeRC program in fundamentals includes both theoretical and experimental efforts to characterize plume flows. This part of the program is structured to provide the tools necessary to address integration issues both now and in the future. A major fraction of program resources are directed toward the development of sophisticated numerical plume models based on Direct Simulation Monte Carlo (DSMC) techniques. Early goals of the effort are to develop and validate models of simple non-ionized flows and the impacts of ground test facilities on experimental results. To date, numerical results have been shown to match well with experimental data obtained from small resistojet thrusters. It is hoped that anticipated advances in computational capabilities can be leveraged in the near future to develop codes for charged flows based either on DSMC or other advanced techniques.

In addition to the DSMC work, the LeRC program also funded the development of a plume/communications impacts model which has now been used in industry to evaluate the effects of arcjet plumes on satellite communications links for realistic configurations.

The diagnostics effort includes both intrusive and non-intrusive diagnostics for the evaluation of plume flows. Many of these have found application both in the direct assessment of specific integration issues, as noted below, and in plume code validations.

A major part of the integration effort at LeRC has focused on the development of high fidelity testbeds for space propulsion related research. These testbeds have been used extensively in cooperative programs associated with program technology transfer efforts. Examples of existing capabilities are shown in Figure 4. In addition to direct thrust measurements, installed diagnostic capabilities include intrusive probes for plume measurements such as electron number density and temperature, current density profiles and ion energy distribution, and contamination/degradation effects. Non-intrusive diagnostics to evaluate both axial and azimuthal ion velocity profiles are available as are capabilities to directly monitor communications impacts. The major propulsion testbed is located in the Electric Power Laboratory. The facility itself is a large vacuum chamber approximately 5 m in diameter and 20 m in length. This chamber is pumped both by a large gaseous helium cryopanel and a set of 20 oil diffusion pumps backed by a mechanical pumping system.

One example of a joint NASA/industry cooperative program is illustrated in Figure 5. The participants in this program were General Electric's Astro-Space Division (GE - now Martin Marietta), the spacecraft manufacturer, and the Rocket Research Company (now Olin Aerospace), the arcjet suppliers. Similar programs with industry and other government agencies have addressed integration issues associated with other advanced propulsion systems. The objective of this particular test was to retire risks perceived both by GE and AT&T, the end user of the spacecraft. Concerns centered on plume impacts on spacecraft surfaces, electrostatic discharge phenomena, and EMI. Samples of typical spacecraft materials were supplied for the test by GE along with experimental equipment for electrostatic discharge tests. GE also made available a flight-type brassboard PPU which was developed under their program with RRC. RRC provided arcjet hardware and support. The testing was performed in the large space propulsion testbed at LeRC with an array of antennas for radiated EMI measurements installed. Spacecraft materials samples were arranged so that exposure to the plume would approximate on-orbit conditions. Detailed comparisons of pre- and post-test measurements of critical physical properties of the spacecraft materials samples showed that no significant degradation resulted from plume exposure during the test. Similarly, the effects of electrostatic discharge phenomena were found to be negligible. EMI levels in regions of interest to the commercial satellite user community were within acceptable limits. EMI above standard limits was still measured in low frequency ranges and this remains an open issue.

As noted above, new high performance propulsion systems often present non-standard interface issues which require unique treatments. Integration issues are a major concern to the aerospace community and these concerns are expected to grow as time passes and more invasive systems are considered. The LeRC program will continue to develop the tools and testbeds required to identify and address critical integration concerns.

1. Bennett, G. L., et al., "An Overview of NASA's Electric Propulsion Program," IEPC-93-006, September 1993.

2. Curran, F. M., et al., "The NASA Low Thrust Propulsion Program," AIAA-92-3703, July 1993.

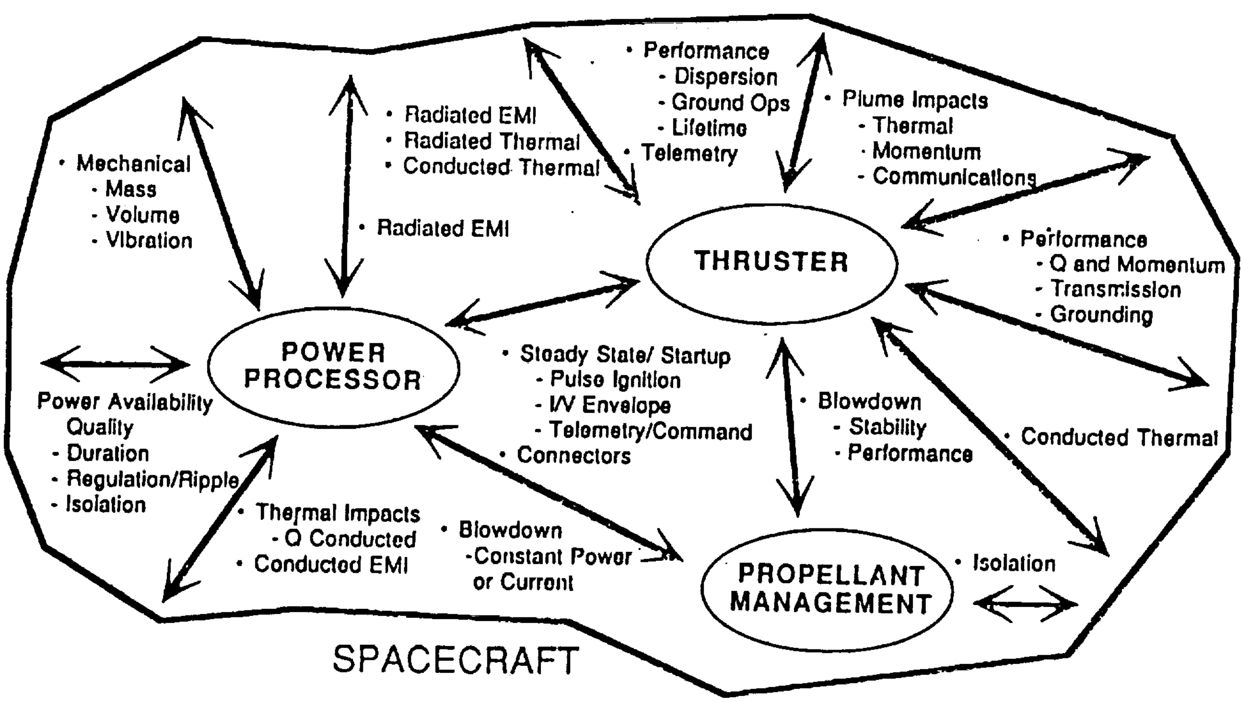


Figure 1. Arcjet System/Spacecraft Interrelationships.

ON-BOARD PROPULSION INTERFACES

ELECTRIC | **CHEMICAL**

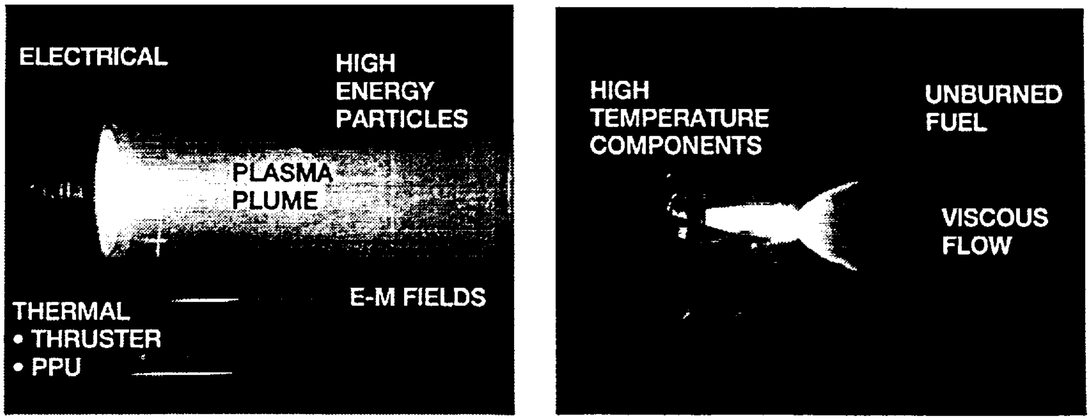
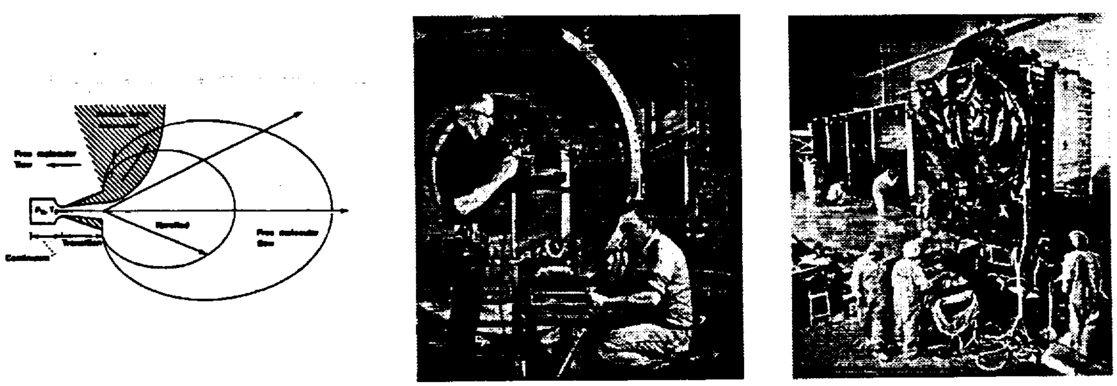


Figure 2. Interface Issues Unique to High Performance Propulsion Systems.

FUNDAMENTALS | TESTBED DEVELOPMENT | TECH TRANSFER



- THEORETICAL
- EXPERIMENTAL

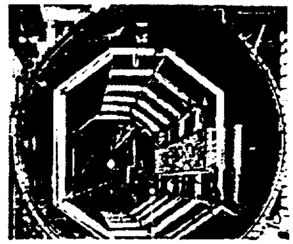
- FACILITIES
- DIAGNOSTICS

- COOPERATIVE PROGRAMS
- FOCUSED R&T
- OUTREACH
- FLIGHT EXPERIMENTS

EFFORTS ENCOMPASS NEAR- AND FAR-TERM THRUSTS
- FUNDAMENTALS THROUGH TECH INSERTIONS
- MULTIDISPLINARY TEAMS
- UNIQUE LERC CAPABILITIES
- INTENSE USER INTERACTIONS

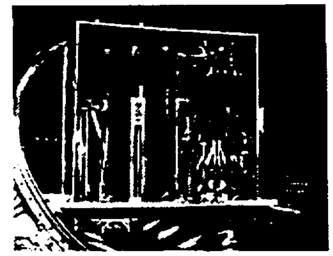
Figure 3. LeRC Spacecraft Integration Program.

PLUME/SURFACE INTERACTIONS

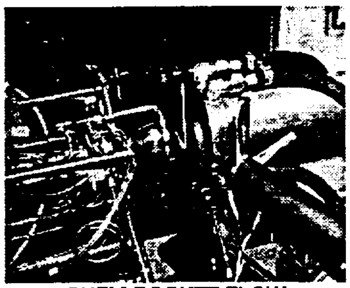


SPACE SIMULATION

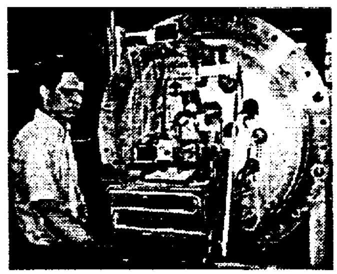
LeRC PROPULSION TEST BEDS
- UNIQUE CAPABILITIES
- ACCESSIBLE
- LOW COST



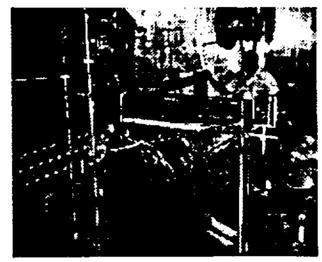
EMI



CHEM ROCKET FLOW DIAGNOSTICS



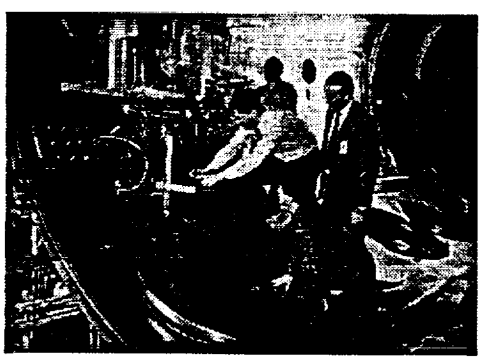
PERFORMANCE



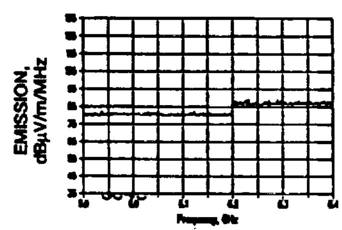
COMMUNICATIONS IMPACTS

Figure 4. Test Bed Capabilities at LeRC.

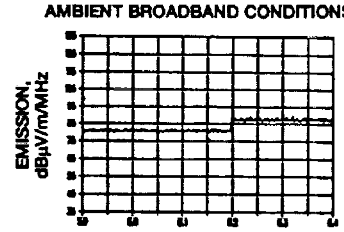
LERC–GE–RRC ARCJET COMPATIBILITY EVALUATION



DIRECT EXPERIMENTAL ASSESSMENTS



AMBIENT BROADBAND CONDITIONS



ARCJET/PPU BROADBAND EMISSIONS

- PLUME COMPATIBILITY WITH S/C DEMONSTRATED
  - RADIATED/CONDUCTED EMI
  - S/C CHARGING
  - CONTAMINATION/DEGRADATION
- REQUIRED FOR MAINTENANCE OF TELSTAR 4 DECISION

Figure 5. Joint Industry/NASA Cooperative Program Example.