National Aeronautics and Space Administration

FY24 Topic Areas Research and Technology Development (TRTD)

Fundamental Investigation of the Role of Facility Effects in Electrospray Thruster Wear Tests

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Strategic Focus Area: Micro-propulsion

Objectives: The objectives were to investigate the role of facility effects in electrospray thruster wear tests with ionic liquid (IL) and indium propellants with experiments and modeling, mitigate them to enable successful electrospray thruster life tests for high delta-V JPL missions in vacuum facilities and then verify the mitigation approaches with successful long duration testing.

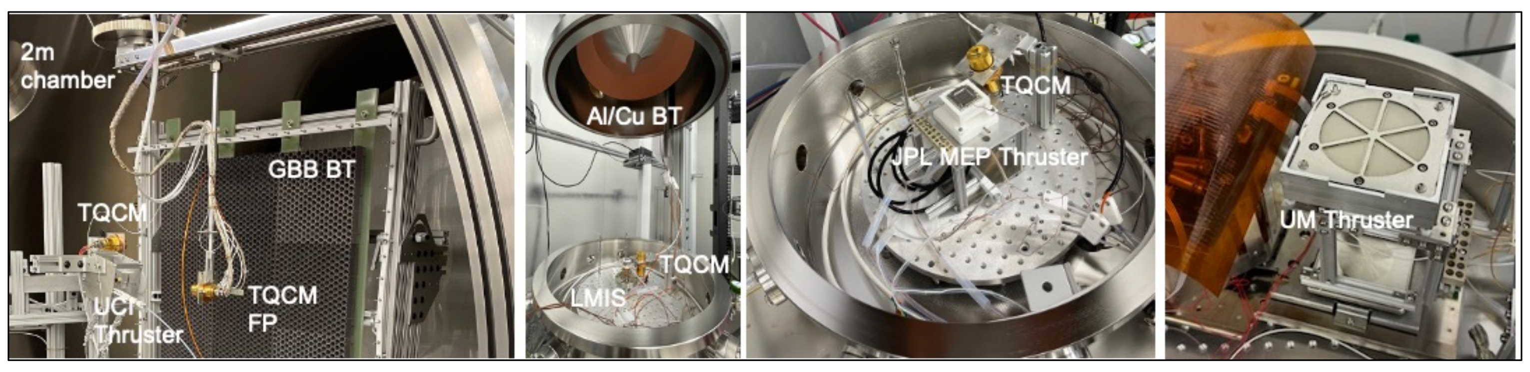

Figure 2. Three electrospray test facilities, diagnostics, beam targets and several electrospray sources tested on ionic and liquid metals.

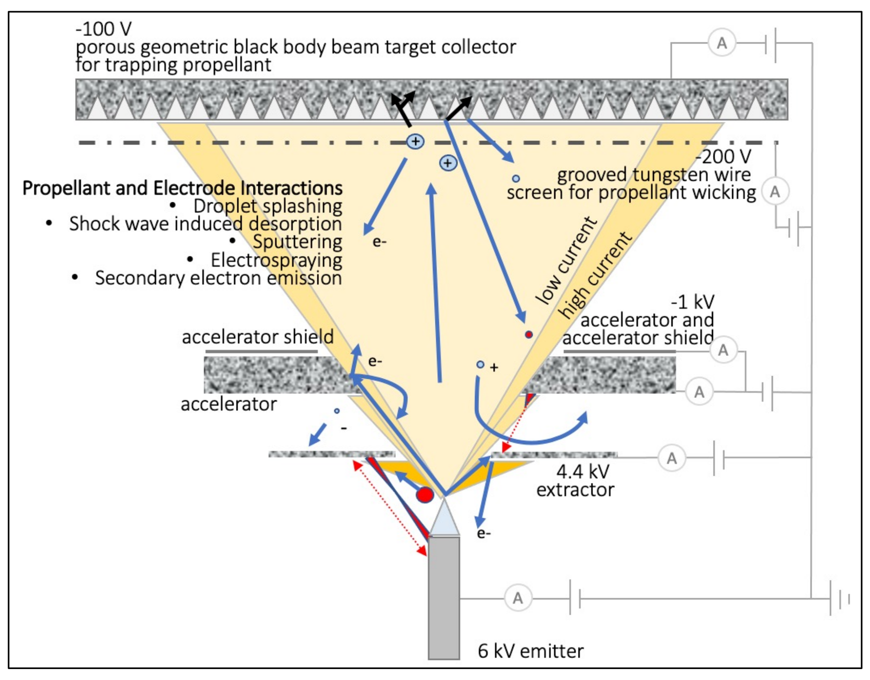

Figure 1. Illustration of charged particle and electrode and facility beam target interactions.

Background: Electrospray propulsion is under development to enable revolutionary new control capabilities for small and large spacecraft. However, missions are flying systems that have not been flight qualified because failures in ground tests (not at JPL) have been attributable to facility effects. There has been a lack in a fundamental understanding of how facility effects cause premature failures and how to prevent them. Due to this approach, there have been electrospray thruster failures on non-JPL flights. In ground testing, the conductive liquid propellants can splash and spray back from the facility and sputter the facility to contaminate the thruster and cause premature failures, as shown in Fig.1. Addressing this problem is important to JPL because our missions have high delta-V requirements or long duration missions requiring very long duration successful qualification testing.

Approach and Results: This investigation includes testing electrospray sources with a suite of novel diagnostics and multiple beam targets in the unique Micro Propulsion Laboratory (MPL) class 100 cleanroom. Test facilities, beam targets and electrospray sources tested are in Fig. 2. Seven different electrospray sources were included in this study: 1) a Busek single capillary emitter electrospray, 2) a Univ. of CA, Irvine microfabricated 64 capillary emitter thruster, 3) a Univ. of MI 6000 porous emitter thruster, 4) a single indium liquid metal ion source needle emitter, 5) an indium-fueled 400 emitter microfabricated array chip, 6) an indium-fueled 5-emitter microfabricated emitter array and 7) an indium-fueled Microfluidic Electrospray Propulsion (MEP) thruster. Four beam targets were included in this study to characterize how they could impact and improve thruster wear tests: 1) a standard stainless steel plate and screen, 2) a novel porous aluminum (p-Al) geometric black body (GBB) beam target, 3) an indium and tungsten can-shaped beam target and 4) an aluminum and copper conical target with a mesh baffle. Particle trajectories from the beam targets were modeled with COMSOL Multiphysics software for design optimization, as shown in Fig.3. A Faraday probe (FP) and a Temperature Controlled Quartz Crystal Microbalance (TQCM) were set-up facing the electrospray sources and the facility beam targets. The electrosprays sprayed at the beam target while the FP and TQCM also measured the current density and mass flux, respectively, from the beam targets back towards the thruster. Measurements were taken with the beam targets at different distances, biases and chamber pressures. Some of the data are included in Figs. 4 and 5. A residual gas analyzer mass spectrometer revealed that the propellant species coming off of the beam target were atomic and molecular constituents of the complex propellant 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ($C_8H_{11}F_6N_3O_4S_2$), EMI IM. Current density and mass flux distribution measurements, in Fig. 4., revealed that the facility beam target biasing significantly affected the beam divergence, which could affect thruster lifetime. Measurements of mass flux from two different beam targets with indium electrosprays with beam current and voltage are included in Fig. 5. These and other test results show orders of magnitude decreases in mass backflux from our beam targets with the proper design and voltage biasing. The results of this study suggest several improvements that can be made in electrospray tests and test facilities to reduce facility effects, even in small chambers, including:

1. Using a novel porous-Al GBB with a screen (for ionic liquid propellant) and conical Al-Cu (for indium propellant) beam target with improved biasing to capture beam propellant and minimize accumulation on the thruster, facility walls and experimental apparatus.
2. Positioning a beam target to collect 99.9% of the beam or to collect a beam half angle of 45°.
3. Outgassing propellant and beam targets before testing.
4. Operating in vacuum chamber pressures less than 1e-5 Torr.

In this project, new beam targets and faster propellant drying procedures were developed, automated data acquisition and test control was developed to enable unattended operation for long duration testing, and new diagnostics were developed for the required measurements. An electrospray thruster was tested for >470 hours to validate our beam target and test approach.

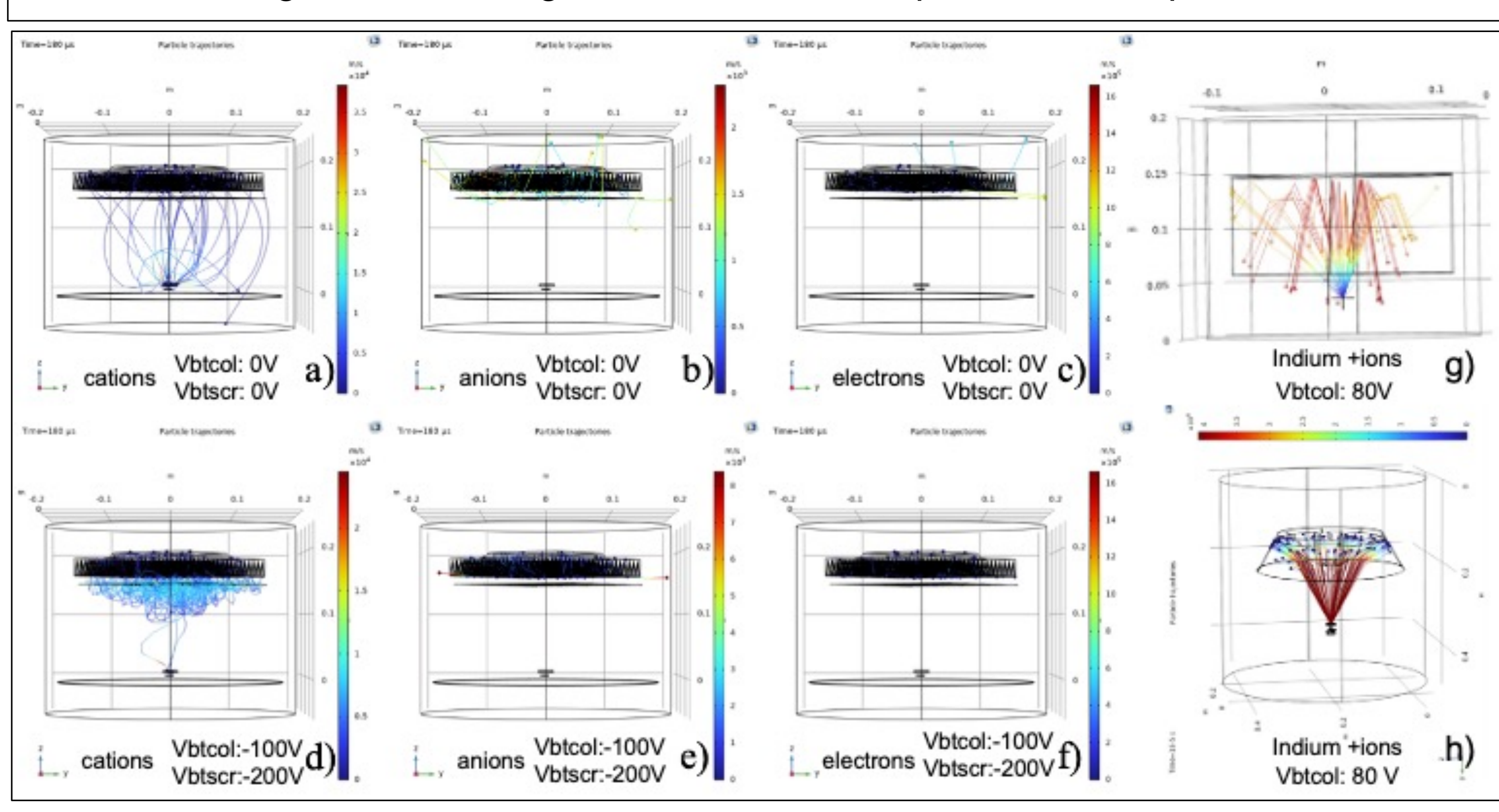

Figure 3. COMSOL Multiphysics modeling results for ionic liquid electrospray particle trajectories with 1 eV thermal energy that are released from the GBB surface (a-f) and two the indium electrospray beam targets (g-h).

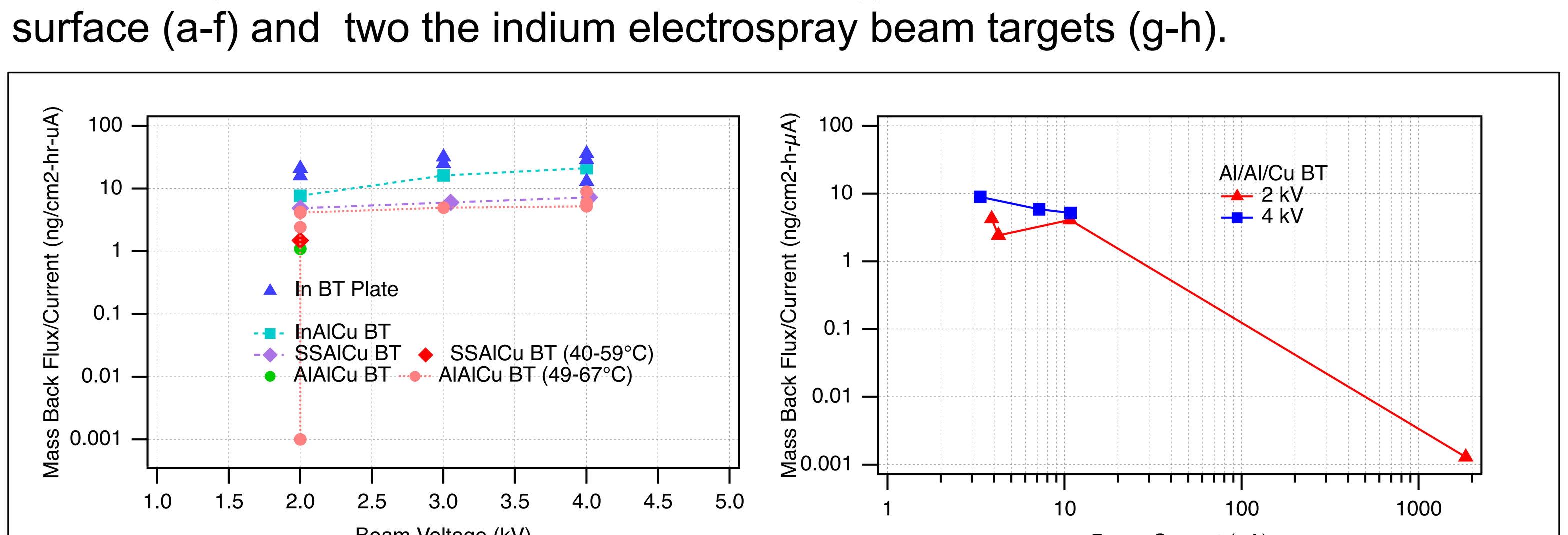

Figure 5. Mass back flux from different beam targets and beam target materials with indium electrospray sources revealing that the conical aluminum beam target traps the propellant better than a flat plate beam In BT Plate.

Table 1. Mass back flux and current density, I_{fp}, from the beam targets (BT) for indium (in ion mode (i) and ionic liquid (EMI-Im electrosprays in droplet mode (d)) per μA of beam current, Ib. Current density, I_{fp}, units are pA/cm^2-μA).

Propellant	Vb (kV)	Ib (μA)	Beam Target	BT Bias (V)	BT Screen Bias (V)	Mass back flux(ng/cm2-h-uA)	Ifp (-100V)	Ifp (0V)	Ifp (100V)
EMI-Im (d)	6	0.35	SS plate	-100	-200	4.1 +/- 0.1	2.2	11	32
EMI-Im (d)	6	0.35	SS plate	0	0	2.8 +/-0.2	-269	-4	2286
EMI-Im (d)	6	0.35	pA GBB	-100	-200	14.5 +/- 0.1	1	7	17
EMI-Im (d)	6	0.35	pA GBB	0	0	14.1+/- 0.1	-32	-21	69
EMI-Im (d) [wet]	6	0.39	pA GBB	-100	-200	90.1 +/- 0.2			
Indium (i)	2	11.1	In/W pl	-80		16			
Indium (i)	2	1845	Al/Al co	-80		0.004			

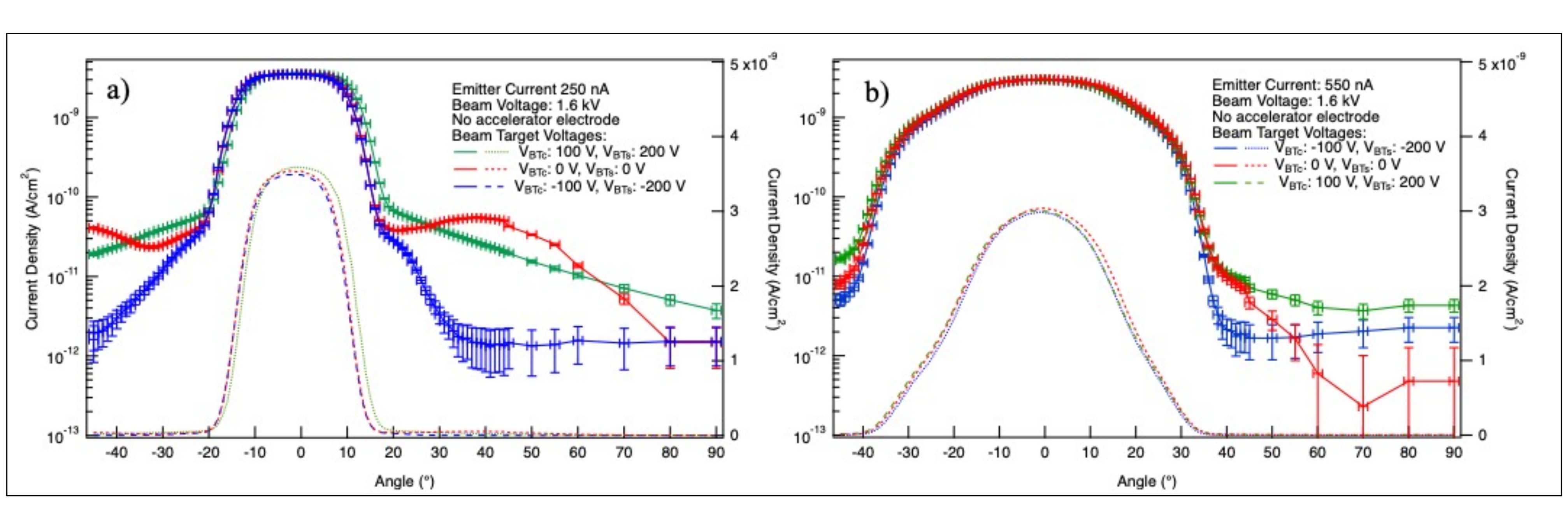

Figure 4. Current density distributions in the plume of a single emitter ionic liquid electrospray operating at 250 nA (a) and 550 nA (b) and 1.6 kV at different GBB beam target biasing. The current is plotted on a log axis (solid curves) and linear (dotted curves) to reveal differences at high angles.

Significance/Benefits to JPL and NASA:

The results of this investigation will enable successful electrospray thruster qualification testing for several thousands of hours for JPL and NASA mission infusion for a broad range of science missions with small and large spacecraft.

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