FY23 Topic Areas Research and Technology Development (TRTD)

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

Principal Investigator: Colleen Marrese-Reading (353); **Co-Investigator:** Steven Arestie (353)
Graduate Student Intern: Saba Shaik (Massachusetts Institute of Technology)

Strategic Focus Area: Micro-propulsion

Objectives: The objective is to develop a fundamental understanding of the role of facility effects in electrospray thruster wear tests with ionic liquid (IL) and indium propellants with experiments and modeling to enable successful electrospray thruster life tests for high delta-V JPL missions in vacuum facilities. The measurements include the mass flux, current and charged particle specific charge from thrusters and beam targets towards the electrosprays with indium and ionic liquid through a relevant range of beam current and voltage for propulsion systems. The measurements also include beam current and mass flux distribution and divergence sensitivity to vacuum facility pressure and beam targets. The modeling includes beam scattering and backflow of charged particle trajectories for different beam target configurations using COMSOL Multiphysics software. In year 2, the objective is to apply the results from year 1 to conduct successful long duration ionic liquid and indium electrospray micro and macrofabricated thruster tests to verify the developed understanding, predictability and controllability of facility effects on electrospray thruster wear tests for more than 500 h.

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 and there has been a lack in 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 to contaminate the thruster and cause premature failures. This work is critical to enabling successful flight qualification for JPL missions. It is especially important to JPL because JPL missions have high delta-V requirements or long duration missions requiring long duration qualification testing.

Approach and Results: The fundamental investigation of facility effects in electrospray thruster wear tests includes multiple electrospray sources in multiple vacuum chambers with a suite of novel diagnostics and multiple beam targets in the unique Micro Propulsion Laboratory (MPL) class 100 cleanroom. The 3 electrospray test facilities are in Fig. 1. 3 different electrospray sources were included in this study: 1) a single capillary emitter electrospray for ionic liquid propellant, 2) a UCI microfabricated 64 capillary emitter thruster for ionic liquid and 3) a single indium liquid metal ion source needle emitter with indium propellant. 3 beam targets were included: 1) a standard stainless steel plate target, 2) a novel porous aluminum (p-Al) geometric black body (GBB) target and 3) an indium and tungsten target, to characterize how they could impact thruster wear tests. Faraday probes (FP) and 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 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 and biases. Some of the data are included in Figs. 2 and 3. The propellant species coming off of the beam target were detected with a residual gas analyzer mass spectrometer. They show that the complex propellant 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ($C_8H_{11}F_6N_3O_4S_2$), EMI IM, is breaking down at the beam target into atomic and molecular constituents. Faraday probes and TQCM were swept through the plume facing the thruster to measure the current density distribution and mass flux distribution, respectively, in the thruster plume with different beam target distances and voltages and facility pressures to characterize their impact on the mass and current distribution in the plume. Some of the results are in Fig. 3. They show that increasing the facility pressure from 5×10^{-7} Torr to 10^{-5} Torr resulted in a increase in beam divergence. The test results showed that the facility beam target biasing significantly affected the beam divergence and could affect thruster lifetime. The results suggest several improvements that can be made in electrospray test facilities to reduce facility effects, including using our novel porous-Al GBB beam target to capture beam propellant and minimize accumulation on the thruster, facility walls and experimental apparatus. For the first time, secondary species time-of-flight (TOF) was conducted on an ionic liquid electrospray thruster beam target. The charged particle TOF measurements with the primary beam target and on the secondary species from the beam target are included in Fig. 4. Measurements of mass flux from an indium and tungsten beam target with an indium electrospray are also included in Fig. 2.

Significance/Benefits to JPL and NASA:
This work will enable the successful qualification of electrospray thrusters for successful NASA/JPL science missions for the first time. These test results are directly applicable to enable flight qualification of several ionic liquid electrospray thrusters: Busek CMNT, Busek BETMAX, ACCION and MIT iEPS (microfabricated) and the UCI (microfabricated) thrusters for a broad range of smallsat missions.

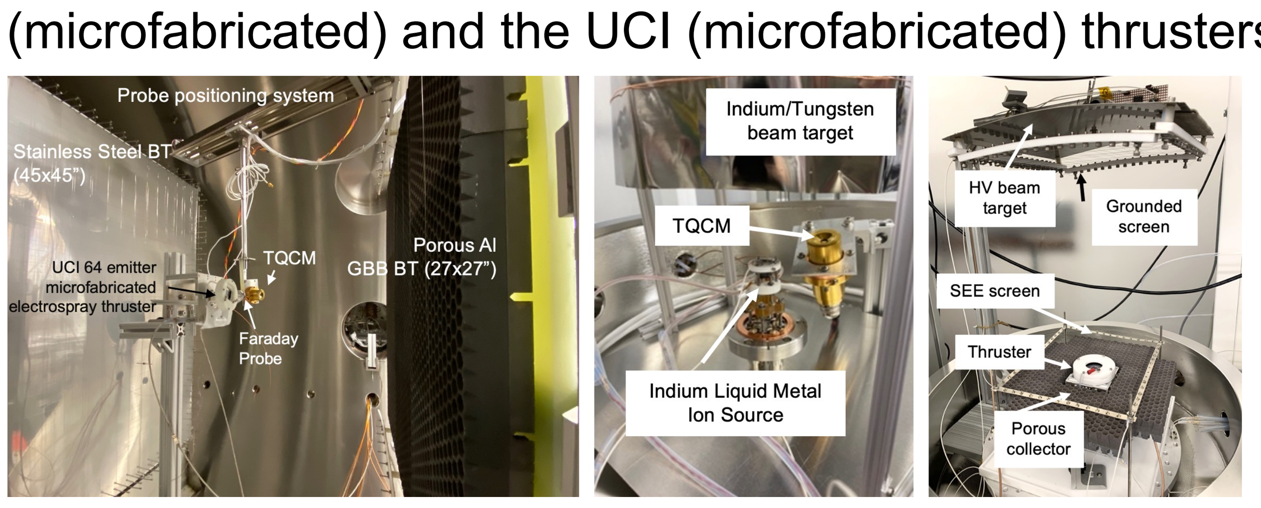

Figure 1. 3 test facilities and electrospray sources used.

Figure 2. Beam target test results.

Electrospray	Beam Target (BT)	BT collector /screen voltage (V)	I_B (μA)	V_B (kV)	Mass Flux from BT (ng/cm²-h)	Current Density from BT (pA/cm²) at -100V|0V|100V	I_{ex} (nA)	I_{ac} / I_{acs} (nA)
			Ionic liquid propellant – EMI IM					
Single Emitter	SS plate	0/0	0.35	6	1.4	94.5 | -1.6 | 802	0.14	-1.08/-0.52
Single Emitter	SS plate	0/-30	0.35	6	1.4	-22.8 | 11 | 16.5	0.5	-1.47/-0.2
Single Emitter	SS plate	-100/-200	0.35	6	1.7	0.8 | 3.9 | 11	0.11	-0.65/0
Single Emitter	SS plate	0/0	0.6 (0.771)	6	2.8	20 | 11 | 607	25	-0.9/-0.14
64 emitter thr	SS plate	0	18.28	2	11.6	-35.4 | 39.4 | 9449	-0.013	
64 emitter thr	SS plate	0/-30	18.93	2	5.5	-58.3 |-45.7 | 198.4	-0.072	
64 emitter thr	SS plate	-100/-200	18.95	2	16.5	-48 | -22 | 20	-0.094	
64 emitter thr	SS plate	-100/-200	18.55	1.8	8.3	-59.8 | -21.2 | 6.6	-0.104	
Single Emitter	p-Al GBB	0/0	0.60 (0.64)	6	10.1	12.6 | 23.6 | 59	77	-0.82/-0.65
Single Emitter	p-Al GBB	-100/-200	0.35	6	6.5 – 11.3	0.2 | 2.4 | 5.8	0.36	-1/-0.5
Single Emitter	p-Al GBB	-100/-200	0.35	2	0.5			
64 emitter thr	p-Al GBB	-100/-200	19.0	2	12.7-36	-160 | -98.4 | -49	-0.38	
			Liquid metal propellant - Indium					
Single emitter	In/W	80	8	2	124			
Single emitter	In/W	80	8.7	3	218			
Single emitter	In/W	80	8	4	291			

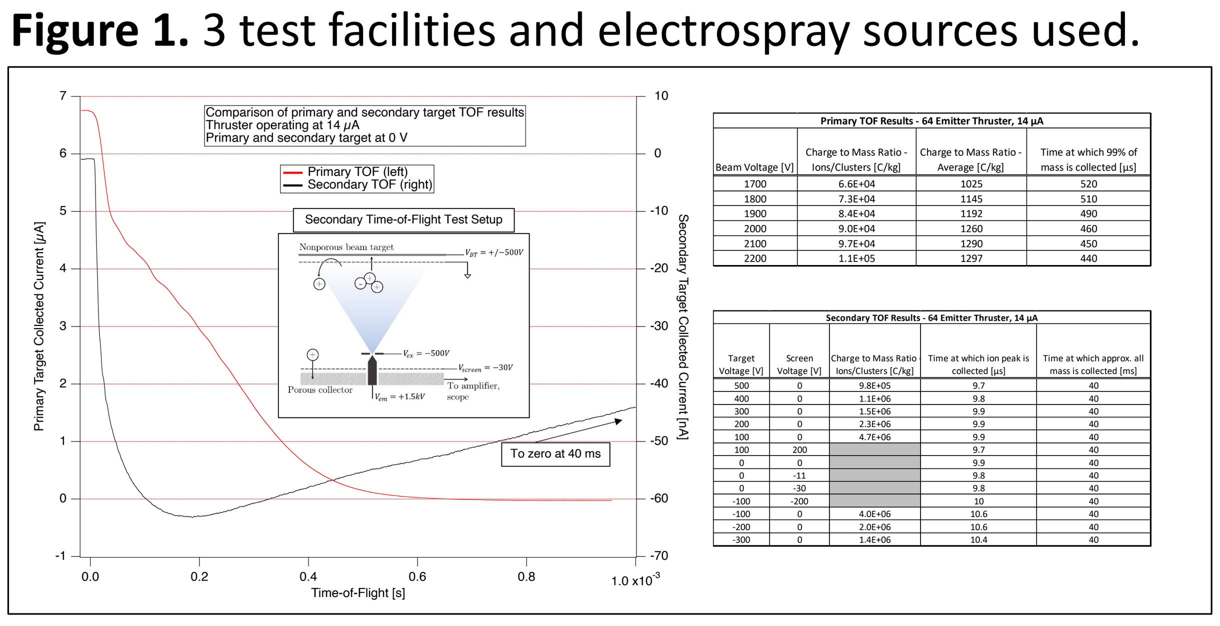

Figure 4. Primary and beam target secondary species time-of-flight data for a UCI 64 emitter thruster operating on EMI IM propellant.

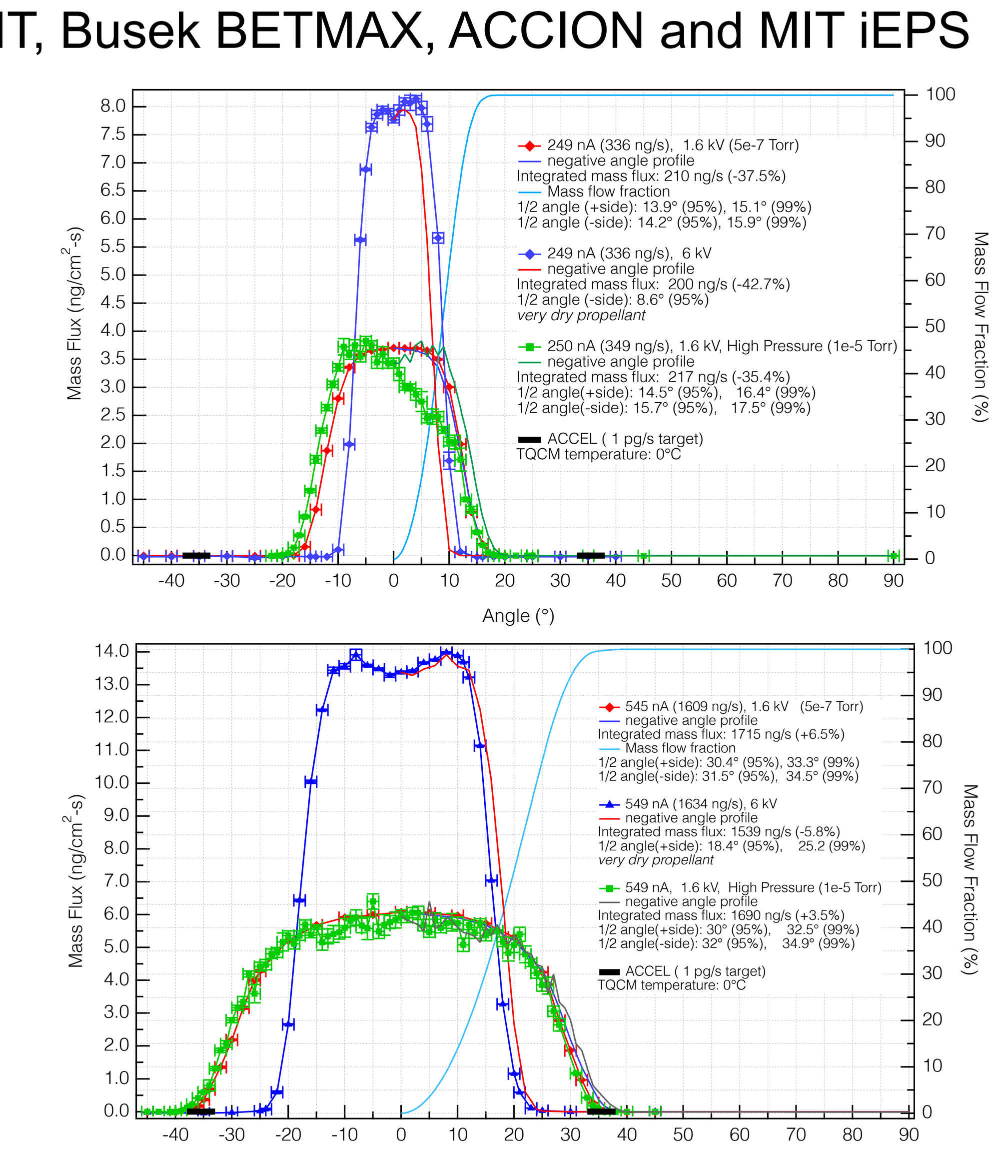

Figure 3. Mass flux distribution in the plume of a single emitter spraying EMI IM at 2 current and facility pressure levels.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

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PI/Task Mgr. Contact Information:
C. Marrese-Reading: cmarrese@jpl.nasa.gov
S. Arestie: sarestie@jpl.nasa.gov
S. Shaik: sshaik@mit.edu