EUROPA LANDER CONCEPT MISSION MONOPROPELLANT PLUME-INDUCED CONTAMINATION TESTING C. E. Soares [1], W. A. Hoey [1], A.T. Wong [1], M. Grabe [2]. [1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, [2] German Aerospace Center (DLR - Deutsches Zentrum für Luft- und Raumfahrt), Bunsenstraße 10, 37073 Göttingen, Germany.

Introduction: Space mission science objectives and evolving scientific instrumentation place ever more challenging constraints on the control and characterization of contamination, in particular for upcoming and proposed missions focused on the detection of organics and life. In general, spacecraft plume-induced contamination is a major contamination vector for all types of space exploration missions: orbiters, lander, rovers and sampling missions. [1] Therefore, as part of the proposed Europa Lander technology development and maturation activities, we identified the need for further development in thruster plume testing and modelling and developed a road map to improve plume induced contamination predictive capabilities by lowering model uncertainties through testing.

Background: Spacecraft that use descent engines to land onto airless moons are at risk of inadvertently contaminating both their landing sites and instrument suites, even if they employ measures like the proposed Europa Lander's Sky Crane that would mitigate landing site contamination in denser, continuum atmospheres. Landings onto 'airless' bodies – bodies without continuum, collisional atmospheres at their surface, e.g. Europa and Earth's moon – instead generate ephemeral, rarefied 'atmospheres' composed primarily of propulsion byproducts and surface materials (i.e. entrained dusts, sublimed frosts) above landing sites for at least the duration of powered landing. These spacecraft-induced environments would be many orders of magnitude more dense than unperturbed ambient environs, and could have contamination impacts to mission science and engineering objectives. [2]

Key vectors for such contamination include the gas- and liquid-phase byproducts of chemical propulsion that constitute descent engine plumes, and the surface materials (e.g. regolith) entrained within the ephemeral, plume-induced rarefied environs generated on airless bodies by such plumes. Mission science objectives may be undesirably affected by powered landing events, particularly if landing sites to be sampled are eroded or ablated by descent engines, or are seeded with droplets of unreacted propellant. Likewise, spacecraft instruments or other sensitive surfaces (i.e. radiators or solar panels) may be impacted by the direct impingement or ballistic fallout of particles removed from the landing surface by descent engine plumes. For these reasons, JPL has pursued a multi-disciplinary effort to experimentally characterize and computationally simulate the contamination effects of powered descent onto Europan and lunar surfaces. [1,2] As part of the proposed Europa Lander technology development and maturation activities, the NASA Jet Propulsion Laboratory (JPL) and the German Aerospace Center (DLR - Deutsches Zentrum für Luft- und Raumfahrt) will be conducting a test program to characterize monopropellant plume induced contamination. These measurements will be used in the development of plume-induced contamination models in support of the proposed Europa Lander mission.

Experimental Facilities: DLR Göttingen currently operates two test facilities dedicated to research into plume impingement effects from chemical attitude control thrusters: the mechanically pumped Contamination Chamber Göttingen (CCG), and the sophisticated DLR High-Vacuum Plume Test Facility for Chemical Thrusters (STG-CT). With STG-CT, DLR built and operates a unique vacuum facility, whose test section is entirely surrounded by a 30m2 cryo-wall, which is kept at a temperature of about 4.2K by using liquid helium as a cooling agent. This low temperature is necessary to cryo-pump hydrogen, which is a major plume constituent. In order to keep the background pressure below 10-5mbar during thruster tests, one must maintain all cryo-surfaces below 4.7 K. Fig. 1 offers a view inside the copper-lined test section, with a thermally insulated thruster pack in the foreground.

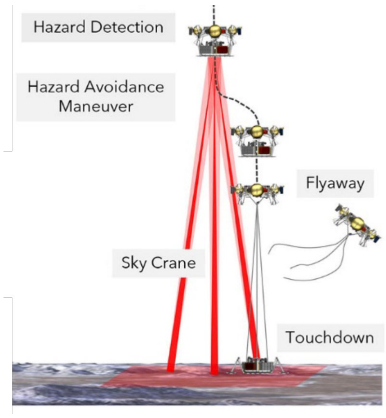
Fig. 1. Test section of DLR High-Vacuum Plume Test Facility STG-CT

Measurements: As part of the test program, measurements of plume contamination composition and quantity will be made for two monopropellant thrusters, of 5-N and 18-N class. The measurements will characterize:

- Plume composition (through mass-spectrometry).
- Contaminant flux (through use of cryogenic quartz crystal microbalances).
- Contaminant deposition and mechanical erosion (onto select witness materials samples).
- Contaminant penetration into icy simulants.
- Plume structure (via high-resolution imaging).

Modeling Approach: The empirical data generated through this testing campaign is applied in the development of physics-based plume contamination models used in landing simulations. The modeling approach makes use of Computational Fluid Dynamics (CFD) coupled with Direct-Simulation Monte Carlo (DSMC) to generate physics-based plume flowfields. Modeling of particulate (liquid and solid) transport in the flowfields is accomplished though a particle-in-cell method. Figure 2 illustrates the results of a conceptual analysis for a Lander mission concept. Several critical features emerge in the exhaust flow field when plume-plume and plume-vehicle interactions are considered. Note the dense region between parallel pairs of descent engines and the dense core formed along the descent *Z*-axis. This would impinge upon the Lander during bridled descent, forming a *steady shock* that would drape over the vehicle and ultimately drive into a separate, distinct shock layer formed over the Europan surface. Streamlines projected onto the *XZ* plane demonstrate the formation of *recirculation zones* both underneath the Lander vehicle and as the Lander and surface shocks interact. This result is 'blanked' where plume flow field mean free paths exceed 1 cm, but even the edges of this density field are thousands of times more dense than Europa's ambient atmosphere. Sky Crane engine plumes would support an 'atmosphere' of exhaust byproducts over the Lander and landing site for at least the duration of bridled descent. The JPL/DLR experimental test campaign will provide critical, novel data about the effects of this induced environment on relevant spacecraft materials and icy simulants that will inform future iterations of this model.

Conclusions: The JPL/DLR plume induced contamination test program described here will be critical to the development of the next generation of plume contamination models in support of technology development maturation for the proposed Europa Lander, and for other future space exploration lander missions.



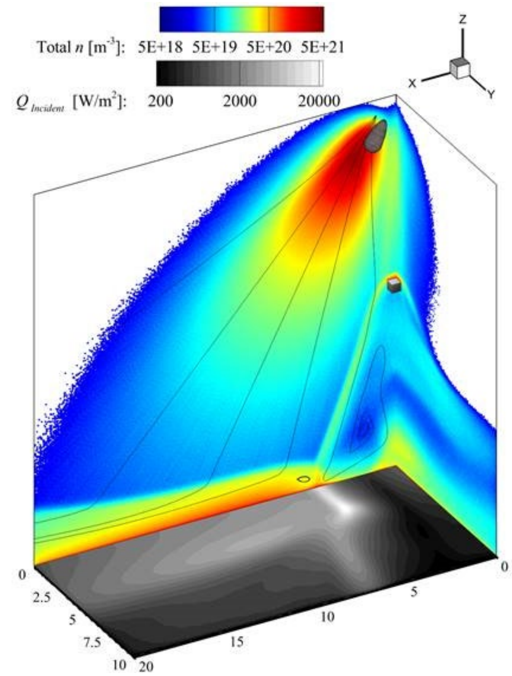


Fig. 2. DSMC modeling of plume-induced flowfield effects for a Europa Lander mission concept.

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References: [1] M. Grabe and C.E. Soares, "Status and Future of Research on Plume Induced Contamination," 71st International Astronautical Congress. [2] W. A. Hoey, R. Lam, A. T. Wong, and C. E. Soares, "Europa Lander Engine Plume Interactions with the Surface and Vehicle," 2020 IEEE Aerospace Conference.