Jet Propulsion Laboratory
California Institute of Technology

Deutsches Zentrum für Luft- und Raumfahrt
DLR

EUROPA LANDER MISSION CONCEPT
MONOPROPELLANT PLUME-INDUCED CONTAMINATION TESTING

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Introduction

As space missions and mission science objectives grow in ambition – and especially as they aim to detect trace organics or biosignatures – understanding and controlling potential contamination vectors becomes ever more important.

- **Spacecraft plume-induced contamination** is a major contamination vector for all types of space exploration missions: orbiters, lander, rovers and sampling missions.
- Landings in near-vacuum – e.g. onto Europa and Earth's moon – would generate ephemeral, rarefied 'atmospheres' above their landing sites for at least the duration of powered landing.[2]
- Therefore, as part of the proposed Europa Lander technology development and maturation activities, JPL and DLR are working together to **improve plume-induced contamination predictive capabilities through experimental testing**. [1]

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** *(below)*.

Figure: *Artist's conception of the proposed Europa Lander Sky Crane descent, showing the Lander being lowered along its flexible bridle.[3]*

Plume Effects

Landing site plume impingement can have impacts to both project science and engineering, including:

- **Particle entrainment and removal** from the landing site.
- **Contamination** of the surface where sampling science will be conducted with plume byproducts (i.e. ammonia, hydrazine).
- **Heating and erosion** of the surface where sampling science will be conducted (i.e. through sublimation of surface frosts).

Engine plumes can also influence a Lander vehicle itself:

- Direct impingement > induced **vehicle torques** while bridled.
- **Heating to the vehicle** and its suite of scientific instruments.
- Molecular / particulate contamination of sensitive instrumentation, obscuration of surface imaging, etc.

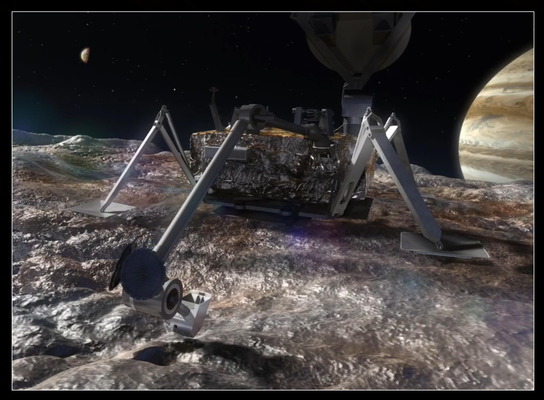


Figure: *Artist's conception of the proposed Lander on Europa.[3]*

Experimental Facilities and Planned Measurements

As part of this 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: *(further detail in the table below)*

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

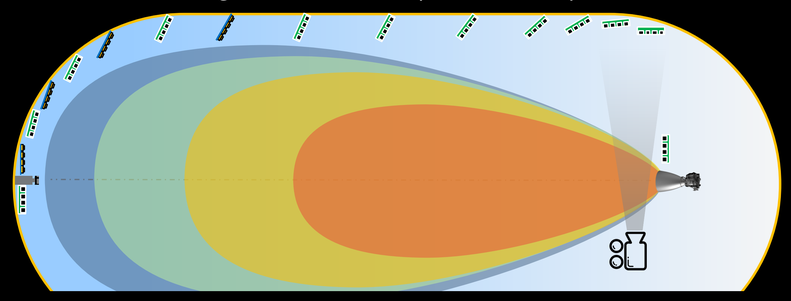
DLR Göttingen operates the **High-Vacuum Plume Test Facility for Chemical Thrusters (STG-CT)**. The STG-CT test section is surrounded by a 30 m^2 cryogenically-cooled wall kept at approximately 4.2 K with liquid helium. This is necessary to cryo-pump hydrogen, a major monopropellant plume constituent.

Background Image: *Copper-lined test section; thermally-insulated thruster pack at center.*

Plume Measurements	Contaminant Composition	Contaminant Deposition	Contaminant Sublimation and Evaporation Properties	Effects on Spacecraft Materials	Contaminant Penetration	Plume Visualization
Instrument / Measurement Type	• Quadrupole Mass Spectrometer • QTGA [4 CQCMs]	4 CQCMs	4 CQCMs [QTGA]	Witness materials: • Kapton • Aluminum • Fused Silica • Gold Mirror • StaMet coated black Kapton	Witness Materials: • Aerogel • Ice simulant	• Light attenuation (630nm red laser, and photo diode) • High-speed video & photographic imaging
Location in test chamber	Near plume centerline	4 locations from plume centerline	4 locations from plume centerline	20 locations per test, covering from plume centerline to backflow region	20 locations per test, covering from plume centerline to backflow region	Nozzle exit plane

Table: *Plume induced contamination test measurements.*

Figure: DLR *STG-CT plume test setup.*



Modeling Approach

The empirical data generated through this testing campaign is applied in the development of **physics-based models** used in landing simulations.

- Continuum near-engine flow: Computational Fluid Dynamics (CFD)
- Rarefied far-field flow: Direct-Simulation Monte Carlo (DSMC).

Results of a preliminary simulation are shown *below*, and illustrate important physical effects generated by engine plumes.

- Plumes form a **shock that drapes over the vehicle** and ultimately drives into a **separate shock layer over the Europan surface**.
- Streamlines demonstrate the formation of **recirculation zones** underneath the vehicle and as Lander and surface shocks interact.
- Incident convective heat fluxes onto the Europan surface peak in this shock interaction region, which may induce ice sublimation.
- 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, of order 1 minute. [2]

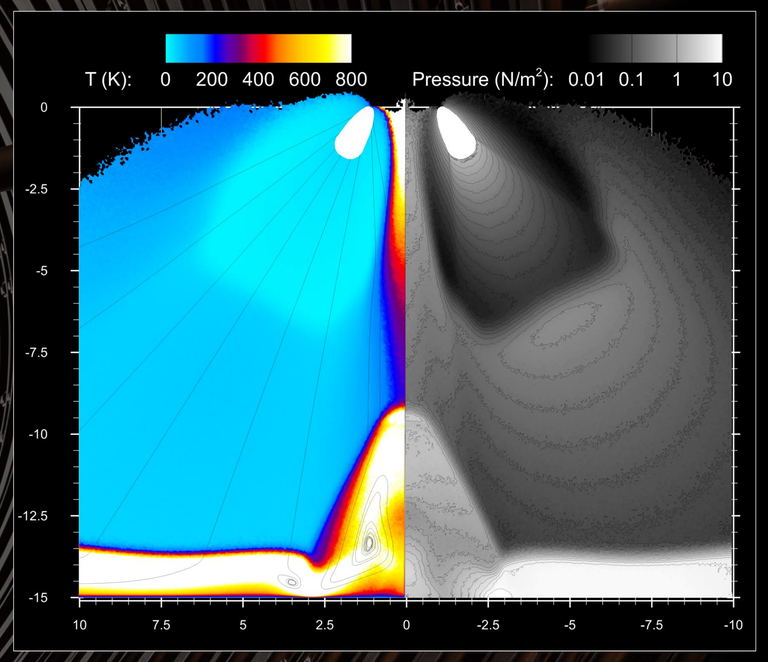


Figure: *Steady-state gas flow-field generated at 15 m above the surface by four 30°-canted engines at full-throttle during Sky Crane.[2]*

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 other future exploration missions.

Likewise, it will provide **novel data about the effects of this environment on spacecraft materials and icy simulants.**

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.

[3] K. P. Hand et al. and the Project Engineering Team, 2017. "Report of the Europa Lander Science Definition Team." Posted February 2017.

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