

DLR Vacuum Test Facilities for Thruster Plume Investigation

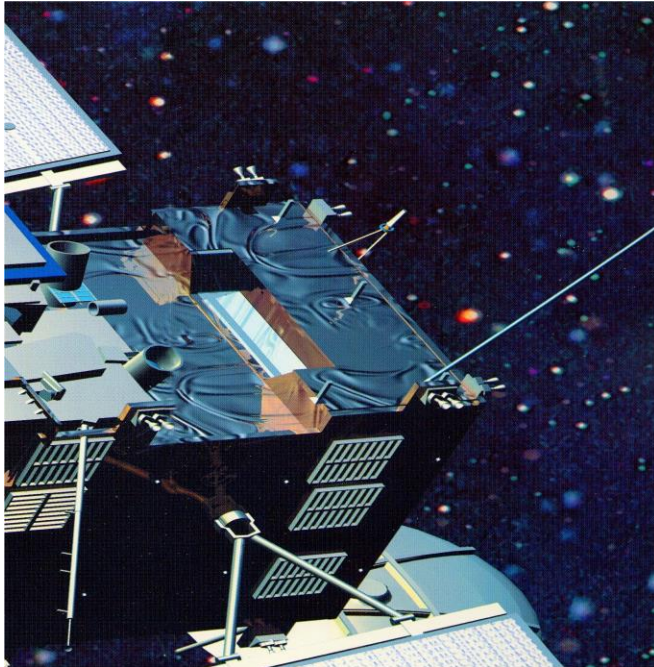
Martin Grabe

Spacecraft Department
Institute of Aerodynamics and Flow Technology
DLR Göttingen
martin.grabe@dlr.de



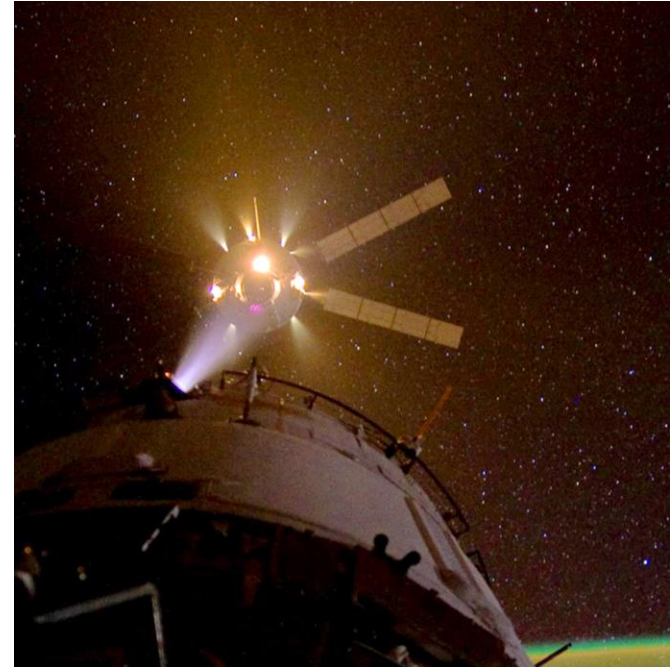
Knowledge for Tomorrow

Impingement Scenarios



ESA

twin RCT's on "Rosetta" spacecraft

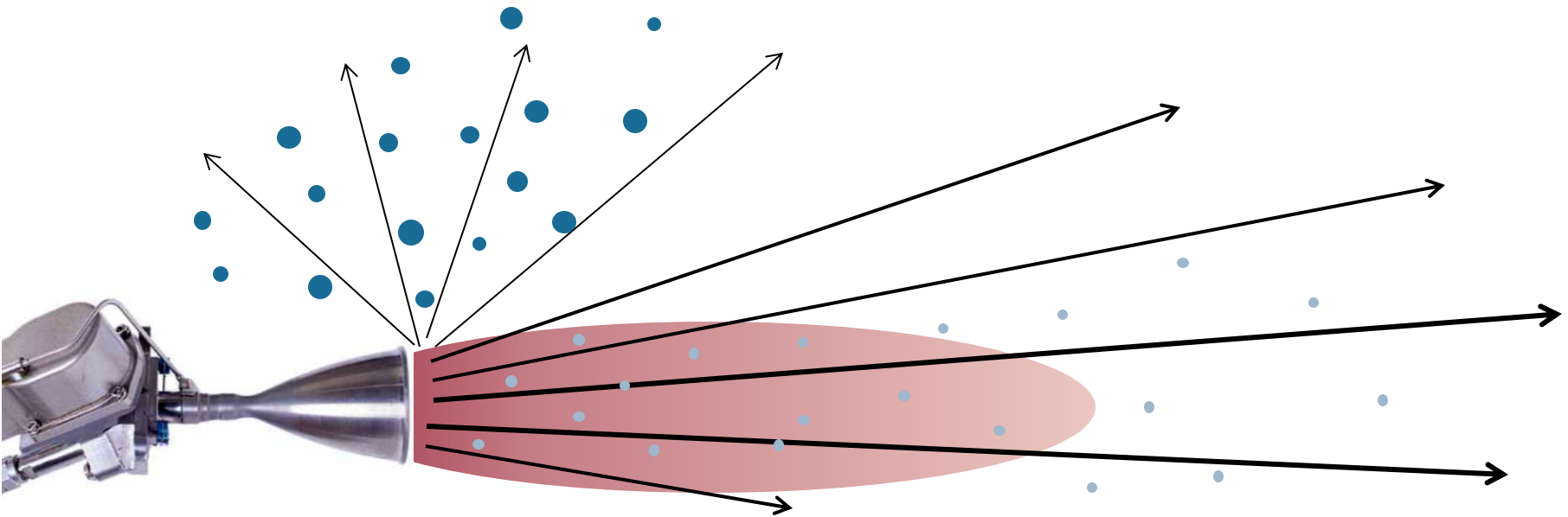


NASA

ATV approaching ISS



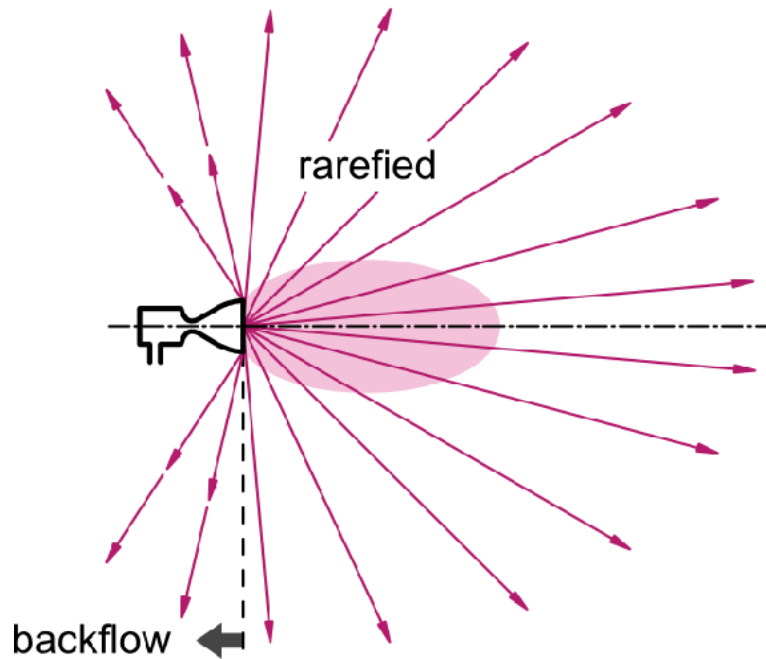
Plume Investigation



- distribution of
 - plume species (also traces of fuel impurities)
 - mass- / momentum- / energy flux
- presence & distribution of droplets
- impact on impinged surfaces



Test Facility Requirements



contradictory situation:

- high-vacuum required for free plume expansion ($p_b \sim 10^{-6}$ mbar)
- "venting" the chamber with a few grams/second!

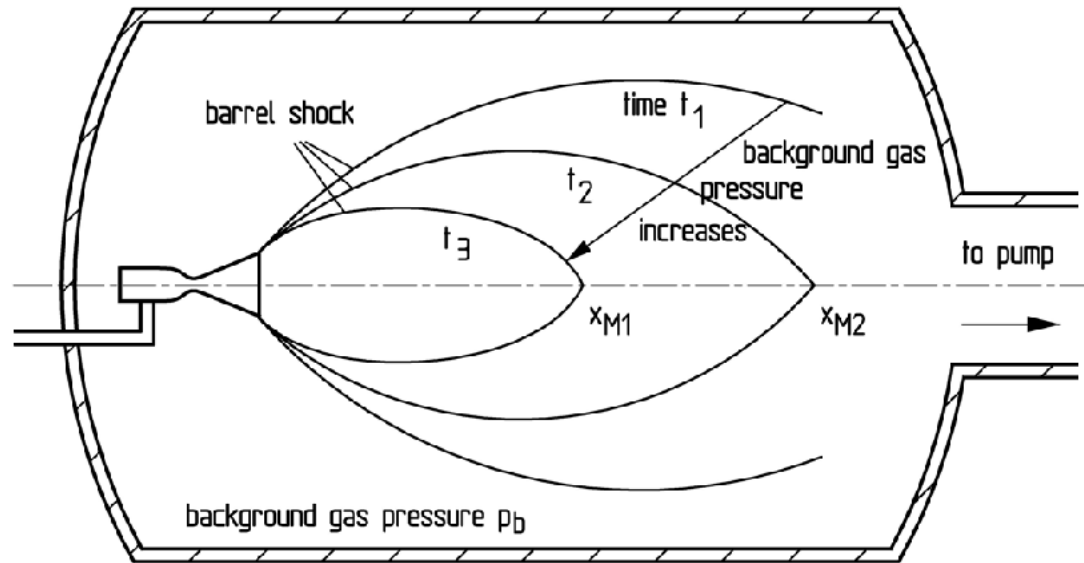
EXAMPLE

- chamber volume: 10 m^3
- mass flow rate: $\sim 3 \text{ g/s}$ (typ. 10N)
- $\Delta p/\Delta t \sim 0.4 \text{ mbar/s}$

→ $\Delta p = 4 \times 10^{-2} \text{ mbar}$ in 100 ms!



Test Facility Requirements

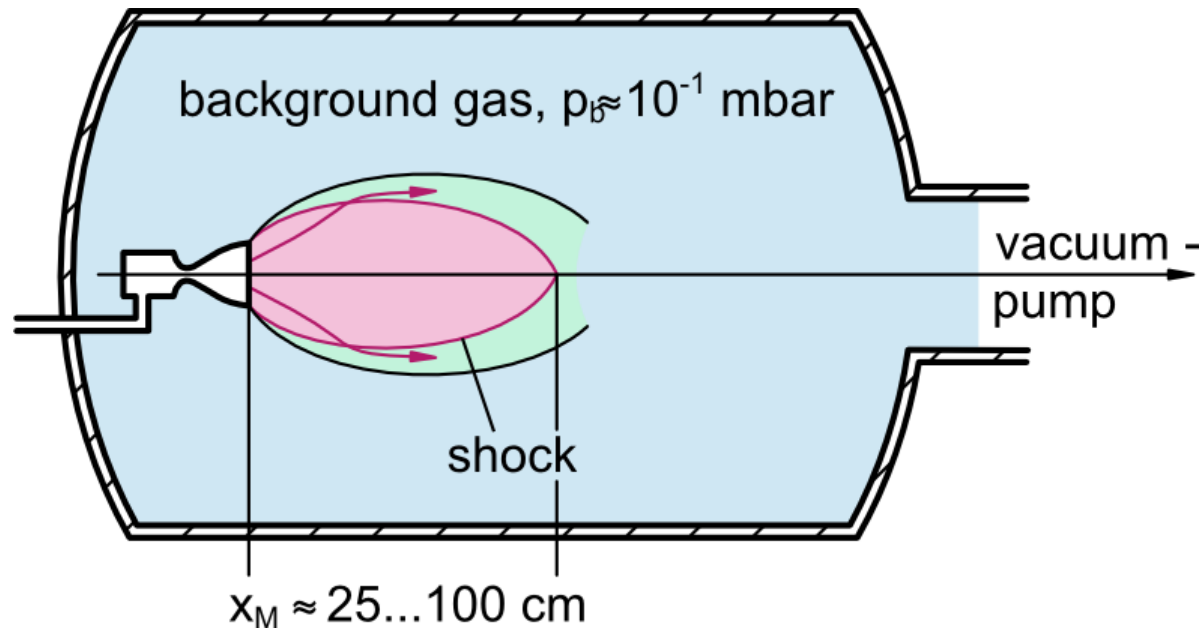


“Conventional” vacuum chamber, equipped with roots blowers:

- Initially acceptable vacuum collapses rapidly
- Supersonic plume reduces to confined core
- **EXAMPLE:** axial plume dimension: $x_M \sim 1$ m after 100ms



Test Facility Requirements



- plume expansion differs from pulse to pulse (req. pumping time $\ll t_{\text{off}}$)
- no analysis of gas flow beyond the barrel shock
- analysis of *droplet* contamination may be possible



DLR Plume Test Facilities

“Contamination Chamber Göttingen” (CCG)

Dimensions

- Diameter 2.2 m
- Height ~ 3 m

Pumping System

- 2 parallel pump sets
- Pumping speed 13'000 m³/h
- Final Pressure: 3×10^{-4} mbar
- Chamber pressure operating a 10N biprop. thruster (PMF): ~ 0.1 mbar

Time scale

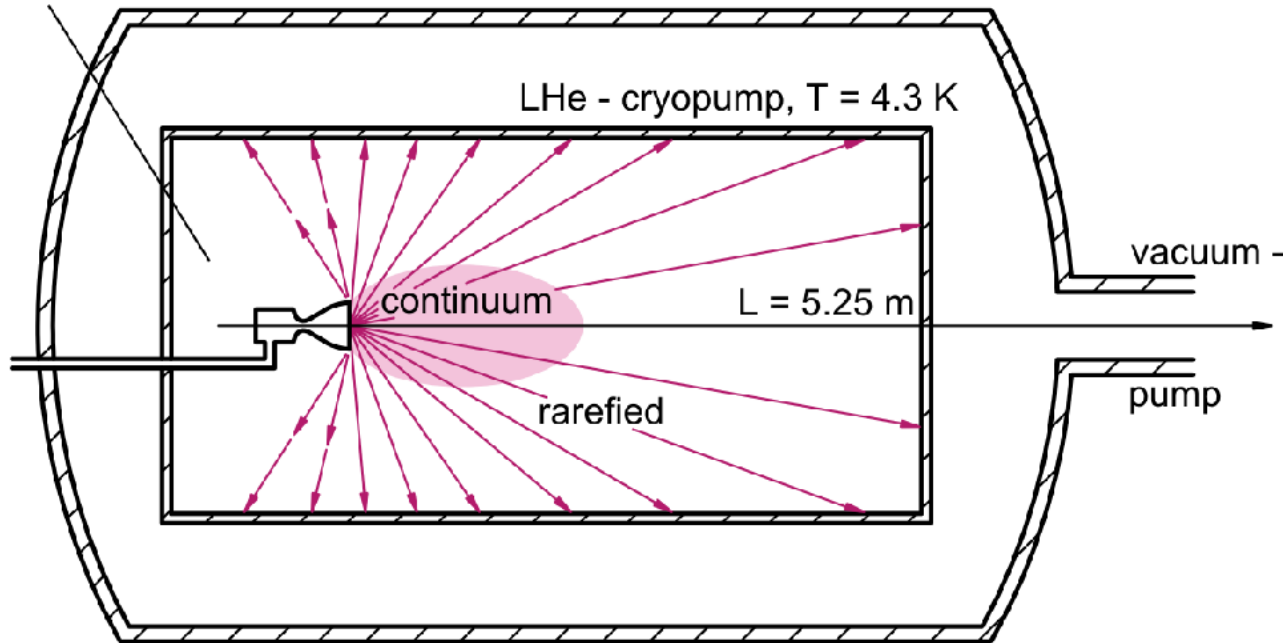
- Pump-down to final pressure: ~ 1 h,
- Venting: ~ 1 h



DLR Plume Test Facilities

Plume Expansion in High-Vacuum

background gas,
 $p_b < 10^{-5}$ mbar



- Cryo-deposition of molecules at the chamber walls permits free plume expansion
- **Boiling helium** temperature needed to pump hydrogen



DLR Plume Test Facilities

High-Vacuum Plume Test Facility for Chemical Thrusters (STG-CT)

Dimensions

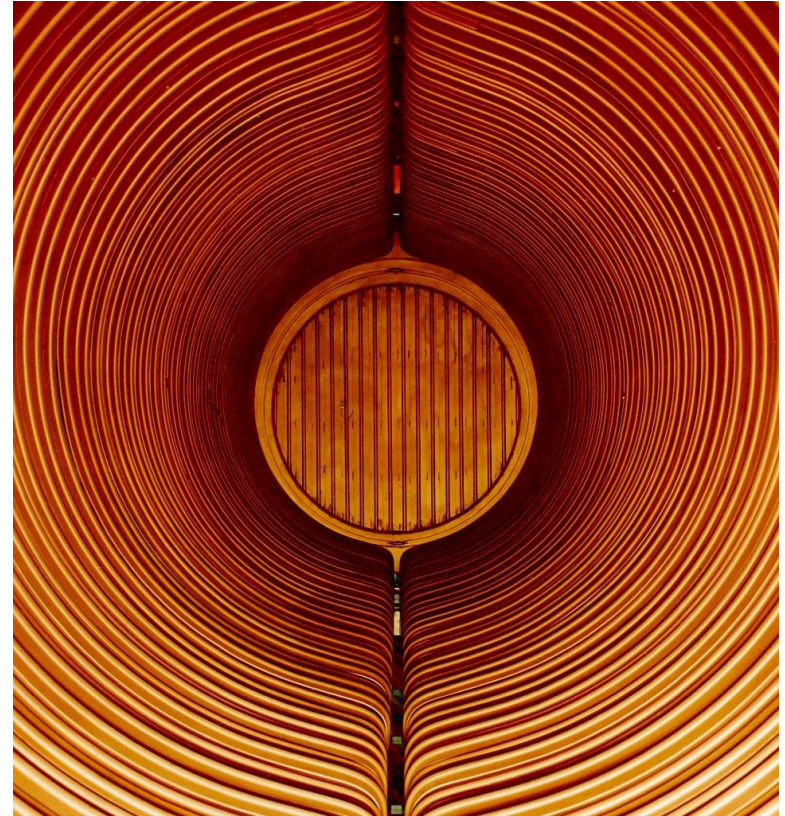
- Vacuum vessel: 7.6 m × ø3.3 m
- Test section: 5.2 m × ø1.6 m

Pumping System

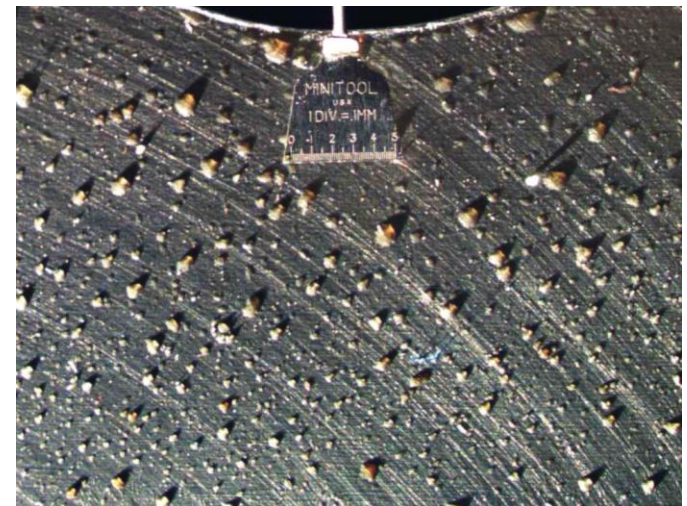
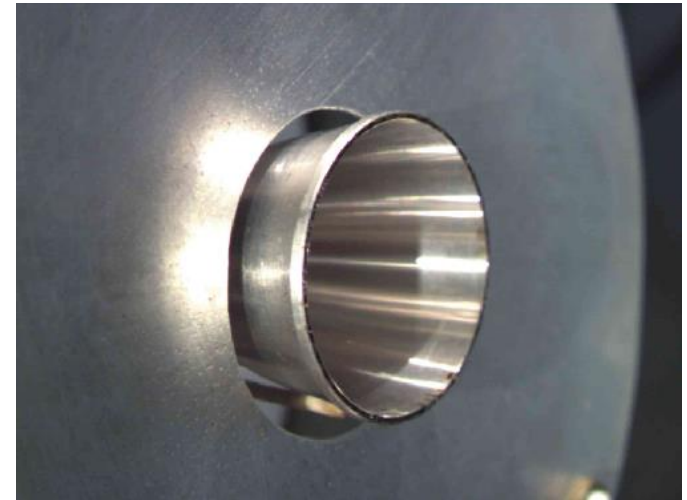
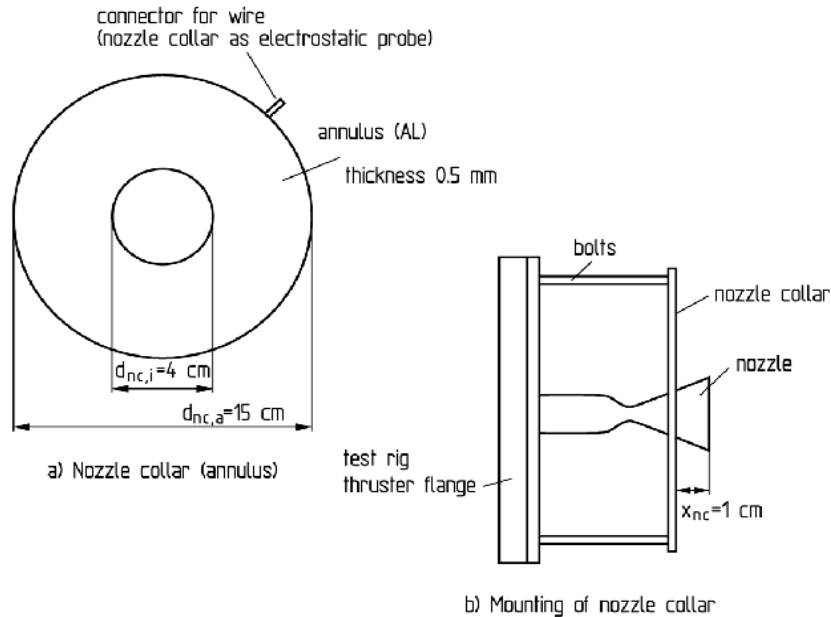
- LHe-Cryopump: 30 m²
- Wall temperature: $T_w \sim 4.3$ K
- Pressure in test section:
 - $p < 10^{-5}$ mbar (w. thruster on!)
 - $p < 10^{-7}$ mbar (w/o H₂)
- 500 W heat load continuous
- 25 kW w. pulsed loads

Time scale

- cooling: ~ 3 d
- test time: 6 to 12 h
- warming: ~ 7 d



Example: Droplet Contamination

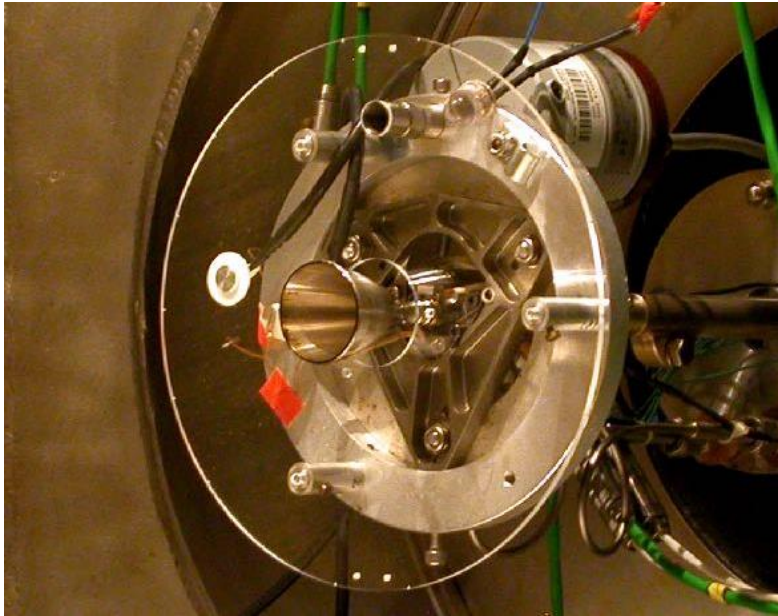


- Witness surface (“nozzle collar”) to capture upstream droplets from MMH/MON biprop

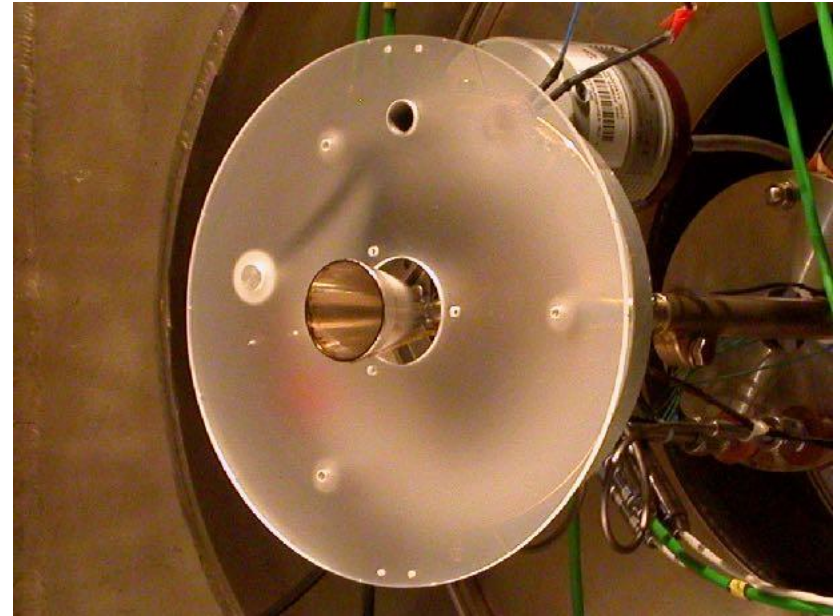


Example: Droplet Contamination

upstream contamination on transparent collar in CCG (MMH/MON biprop):



before

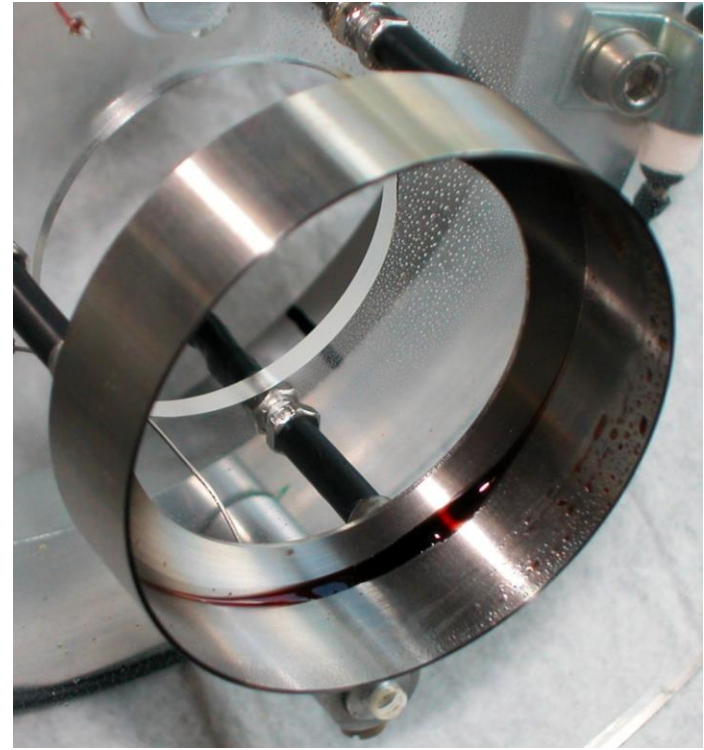
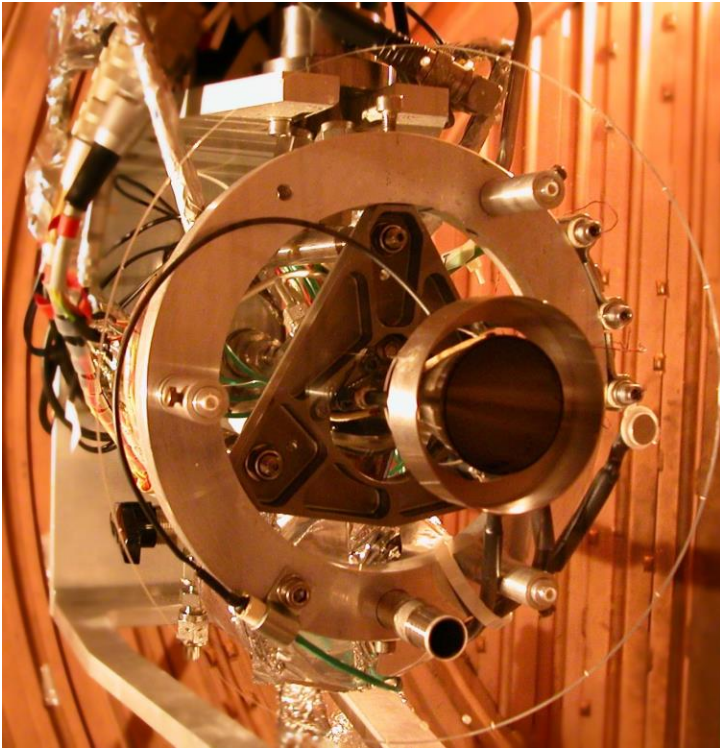


after

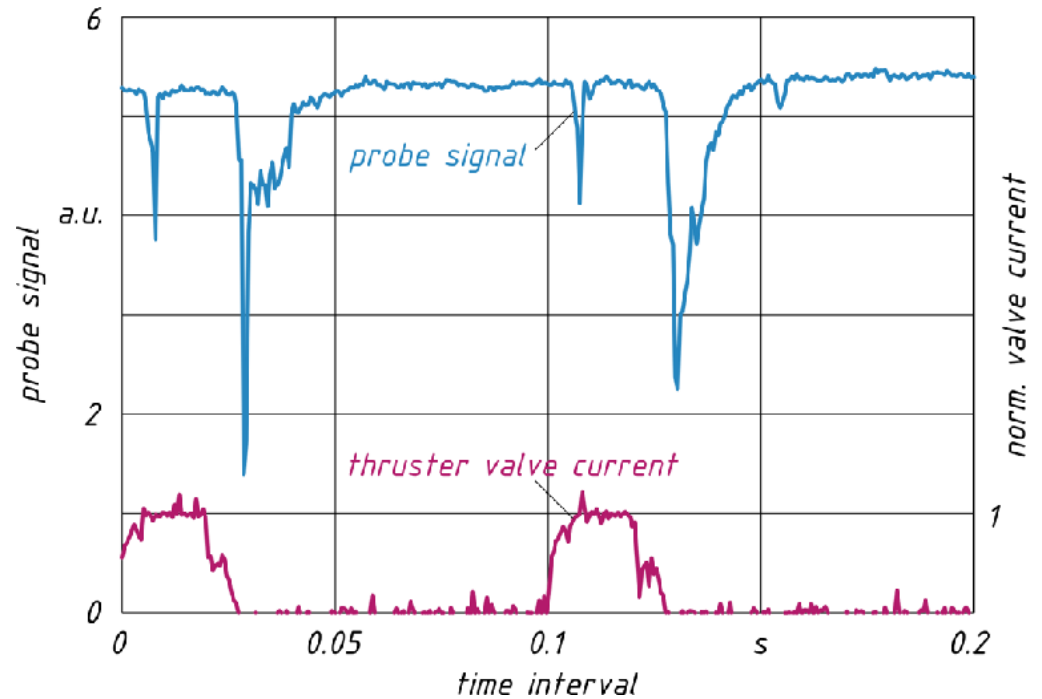
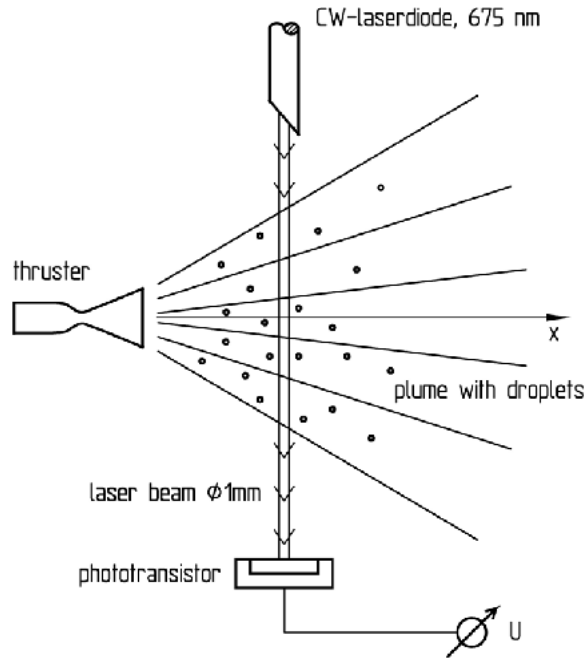


Example: Droplet Contamination

unburnt fuel collected in plume shield in STG-CT (MMH/MON biprop):



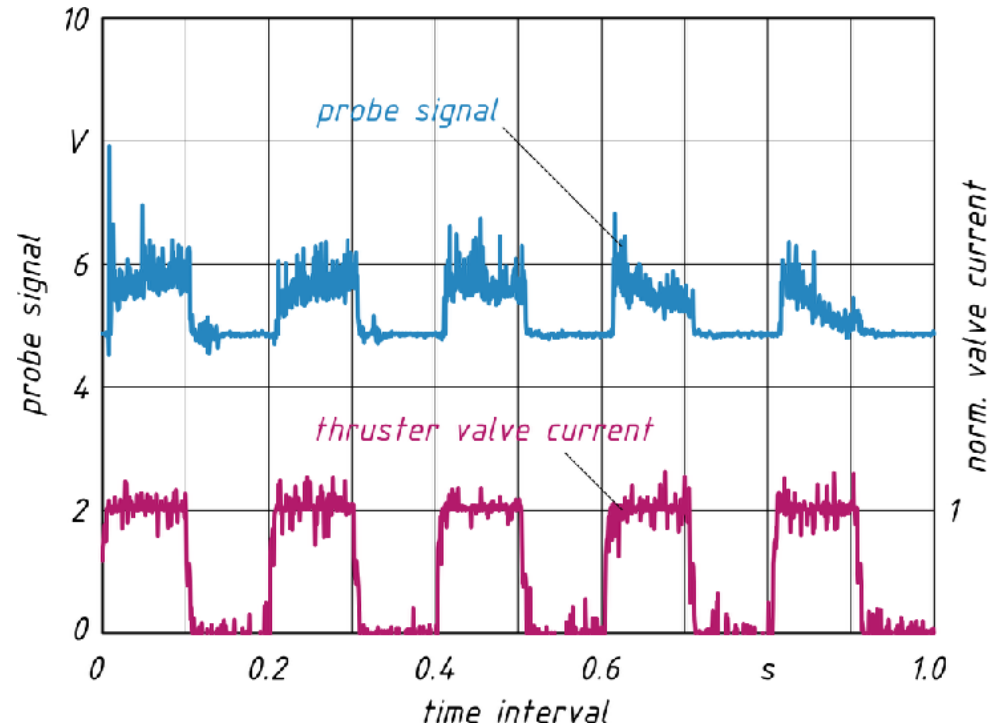
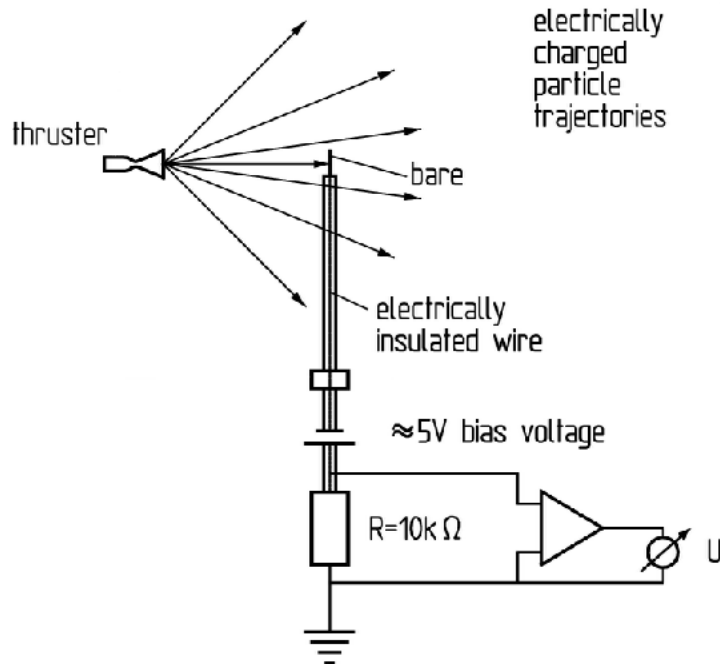
Example: Droplet Contamination



laser light attenuation: droplets are detected at beginning and end of pulse



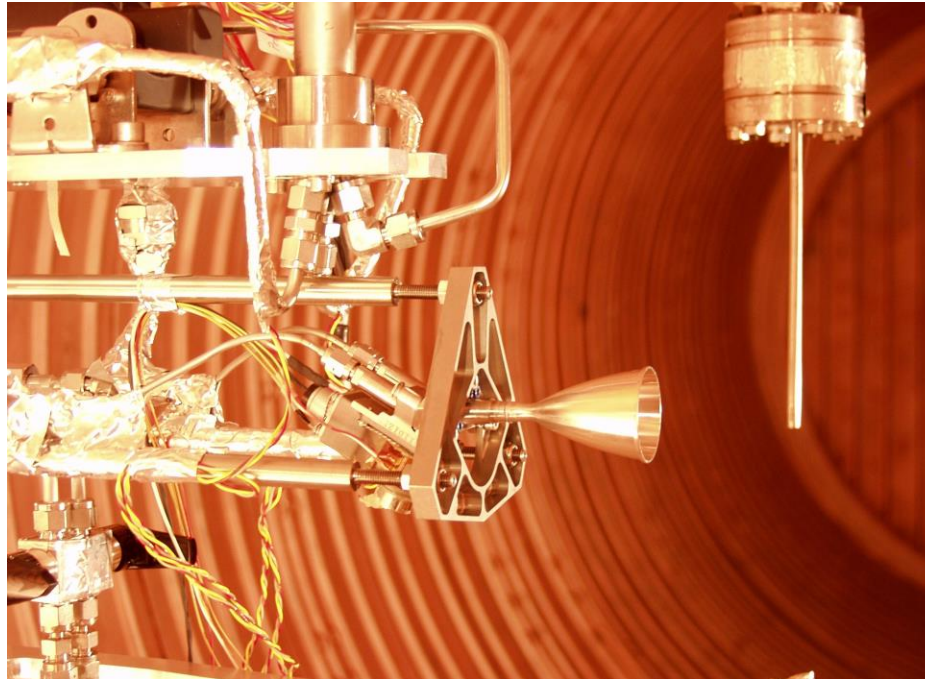
Example: Droplet Contamination



electro-static wire probe: charged droplets are detected *during* firing



Plume Research at DLR



For more information:

- NATO RTO-EN-AVT-194-12
- Journal of large-scale research facilities, 2, A86. <http://dx.doi.org/10.17815/jlsrf-2-139>
- talk to me

