

Cryogenic Heat and Mass Transfer
4th - 5th November 2019
University of Twente

TWO-PHASE FLOWS INVESTIGATIONS IN LIQUID PROPULSION SYSTEMS: “TRL BOOSTER” RESEARCH AT THE VON KARMAN INSTITUTE

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**von KARMAN INSTITUTE
FOR FLUID DYNAMICS**



Prometheus engine
(ArianeGroup)

Two-Phase Flows Investigations in Liquid Propulsion Systems

Work closely since 2012 with Space Industry and ESA to increase Europe's capability in designing and operating various liquid propulsion systems (**storable, cryogenic and hydrocarbon propellants**)



Orion spacecraft (NASA)

TRL 1...4

2012

2016

2018

2020

2022

Multiphase Fluid Hammer

Water hammer in liquid propulsion systems (satellites, cryogenic upper-stage)

Cavitation

Cavitation / flashing in components (e.g. valves, metering orifices, inducers...)

Cavitation /flashing in propellant-assisted valves

Flow Boiling

Chilldown in cryogenic upper-stages

Liquid film cooling in small scale thrusters

Nucleate boiling in ALM cooling channel

Propellant Management in Tanks

Isothermal sloshing (prediction methods for Propellant Management Devices)

Non-isothermal sloshing (short term maneuvers, long duration coasting)

New propellants

Densified cryogenic propellants (slush)

New test capabilities in Methane

H2O, HFE

LN2

+ LCH4

Rocket Reusability

Green propellants

Space re-fueling

Deep space exploration

...

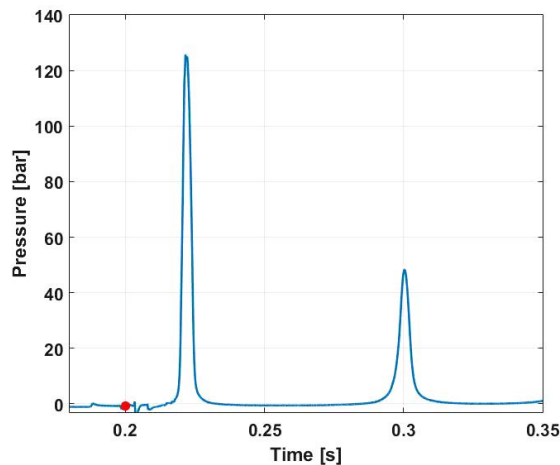
Multiphase Fluid Hammer

monopropellant propulsion system: priming phase

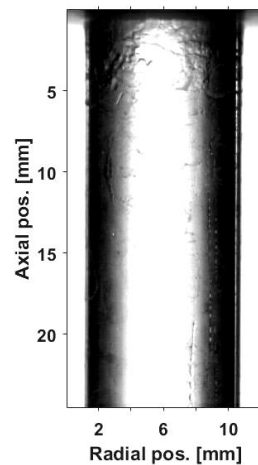


Instrumented flow visualisation module

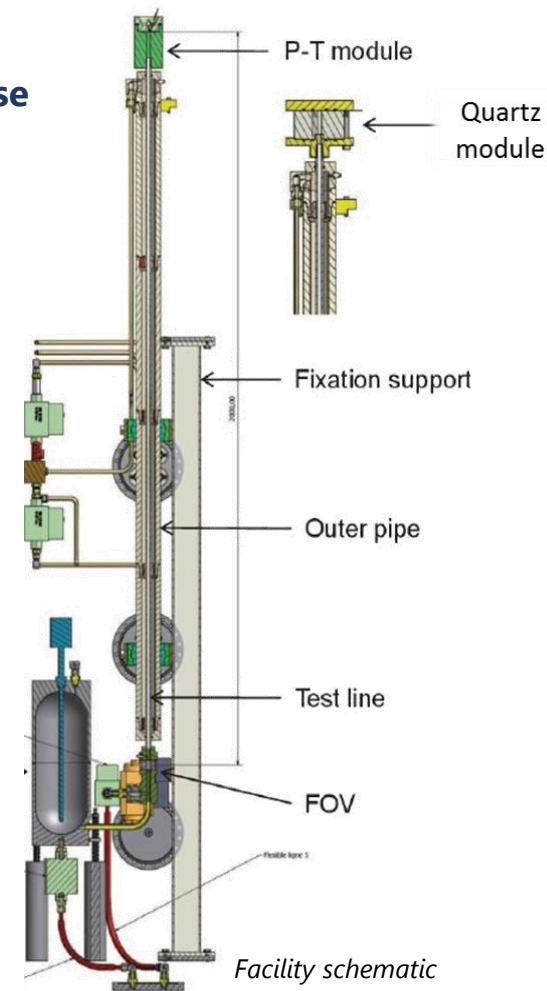
Fluid Hammer Facility (Chamber closed / opened)



Simultaneous time-resolved pressure measurements and flow visualization at impact (water)



Pressure signal attenuation and speed of sound strongly affected by NCG (cushion effect)



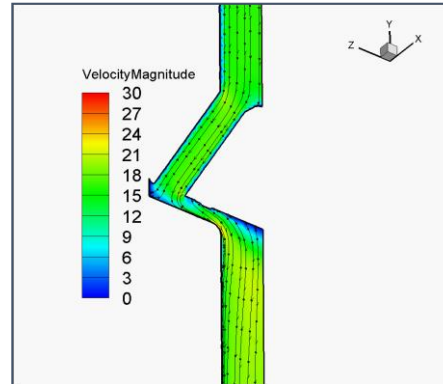
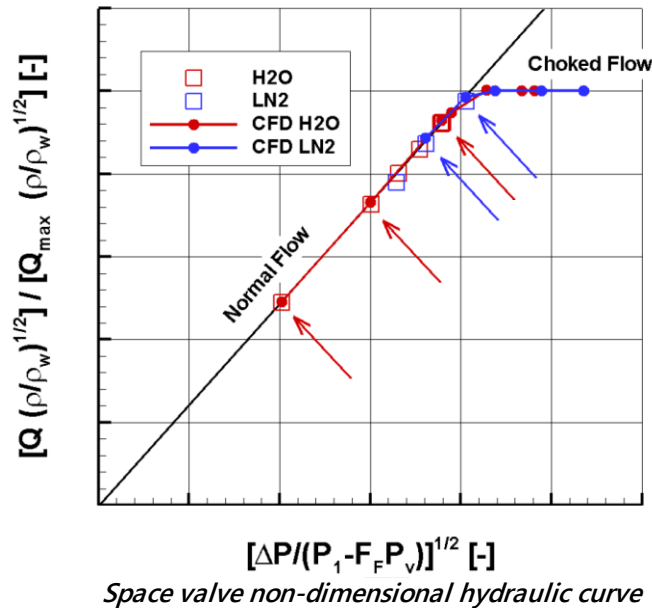
Facility schematic

Water, Ethanol, Acetaldehyde and LN2, applied research

- Unsteady P and T measurements
- High-speed visualization of the 2-phase flow
- Identification of multiphase phenomena
- Calibration of EcosimPro/ESPSS

Cavitating Flows

propulsion system feedline valve: hydraulic characterization



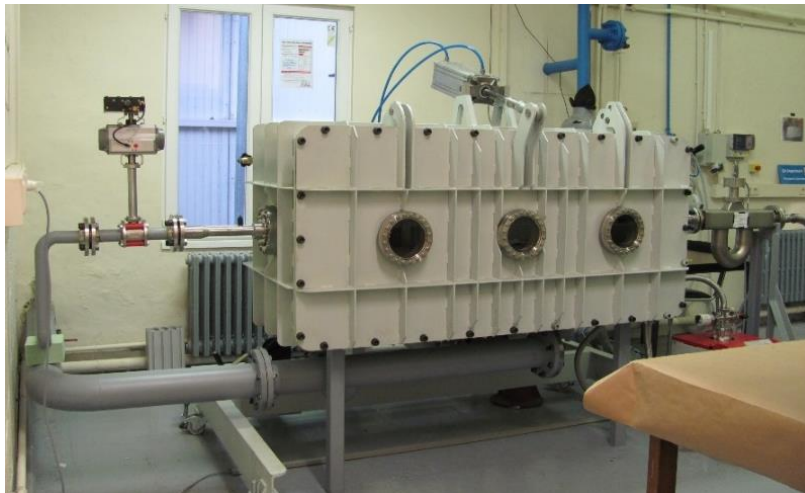
Velocity magnitude and streamlines along a 2D section

LN2, applied research

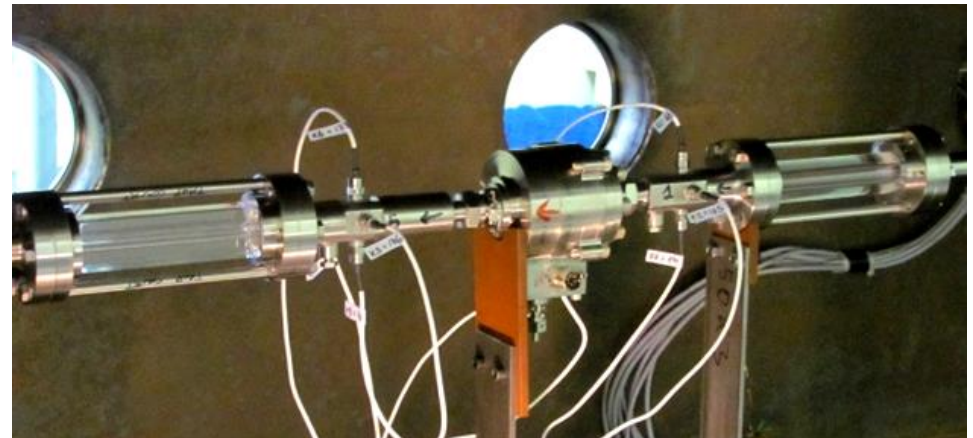
- T, DP vs. Q measurements
- High-speed flow quality preliminary visualizations
- 3D CFD simulations (CFD ACE+)



Demonstrated hydraulic similitude between testing fluids in linear regime



CryoLine Facility



Cryogenic valve installed on the measurement section

Cavitating Flows

orifices: hydraulic characterization

Cavitation (conical orifice)

Water, fundamental research

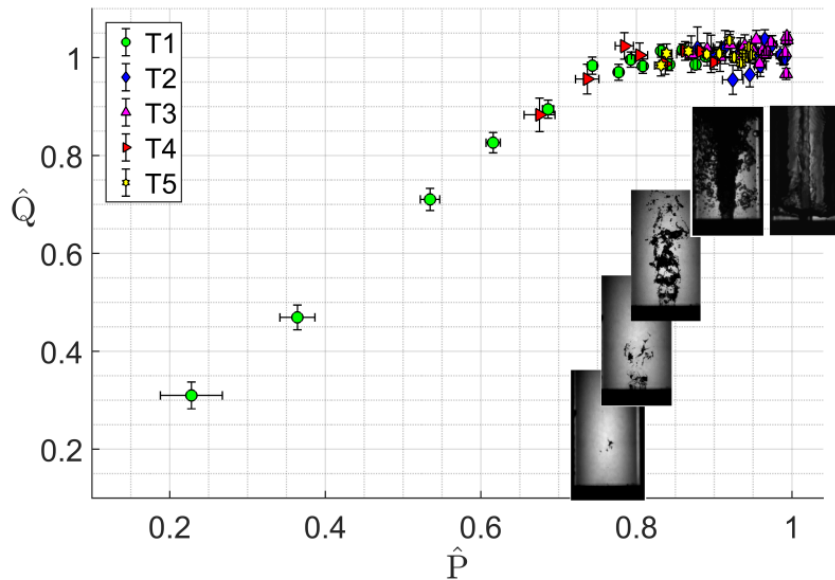
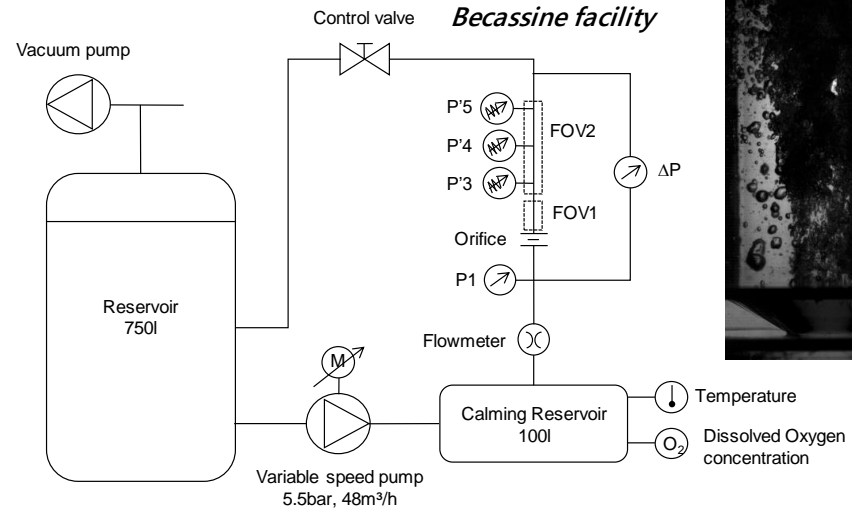
- T, DP vs. Q measurements
- High-speed flow high quality visualizations
- EcosimPro/ESPSS validations



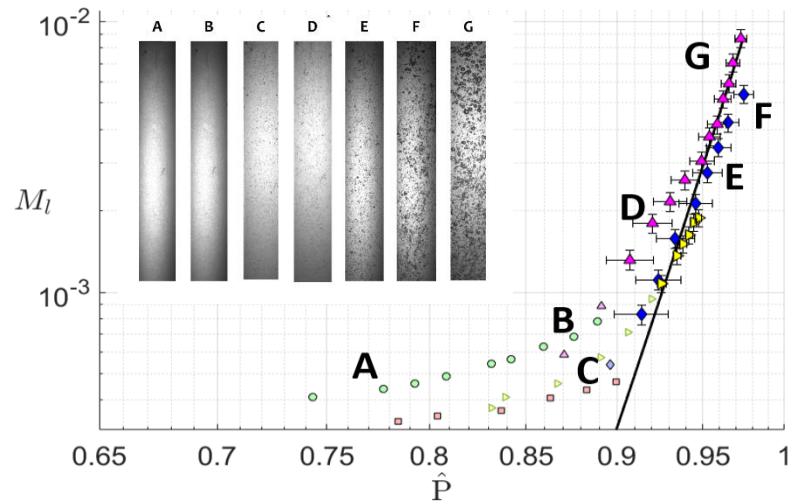
**Cavitation inception and development
synchronized with flow regime**



**3 pressure sensors method for speed of
sound and void fraction detection**



Hydraulic curve with examples of flow topology



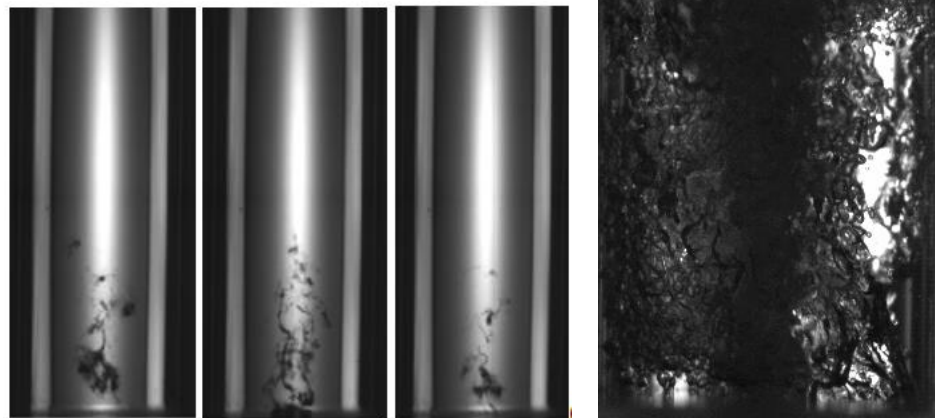
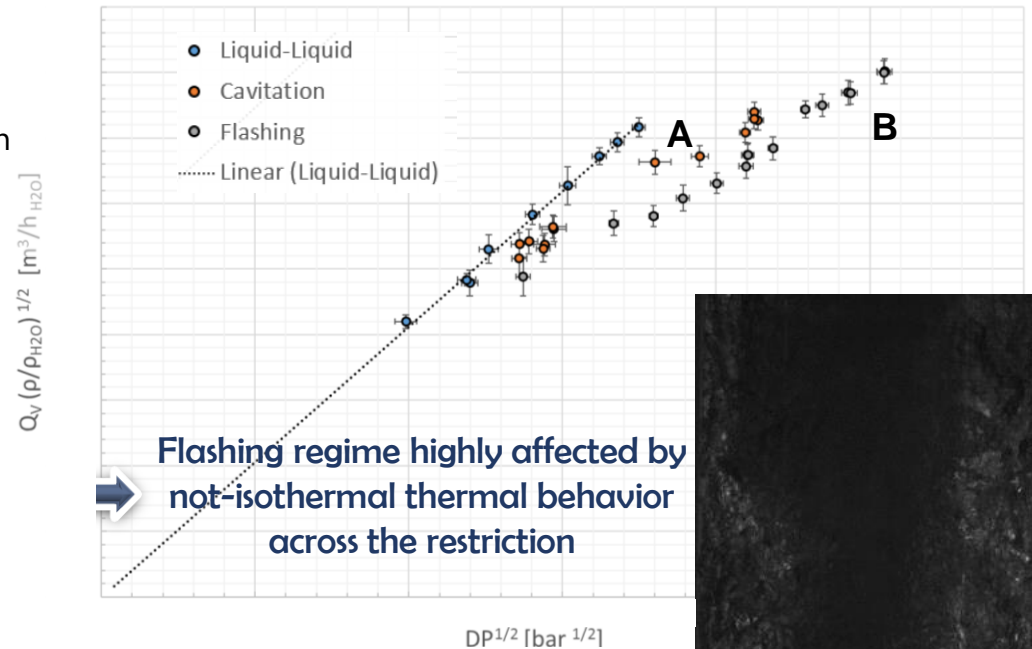
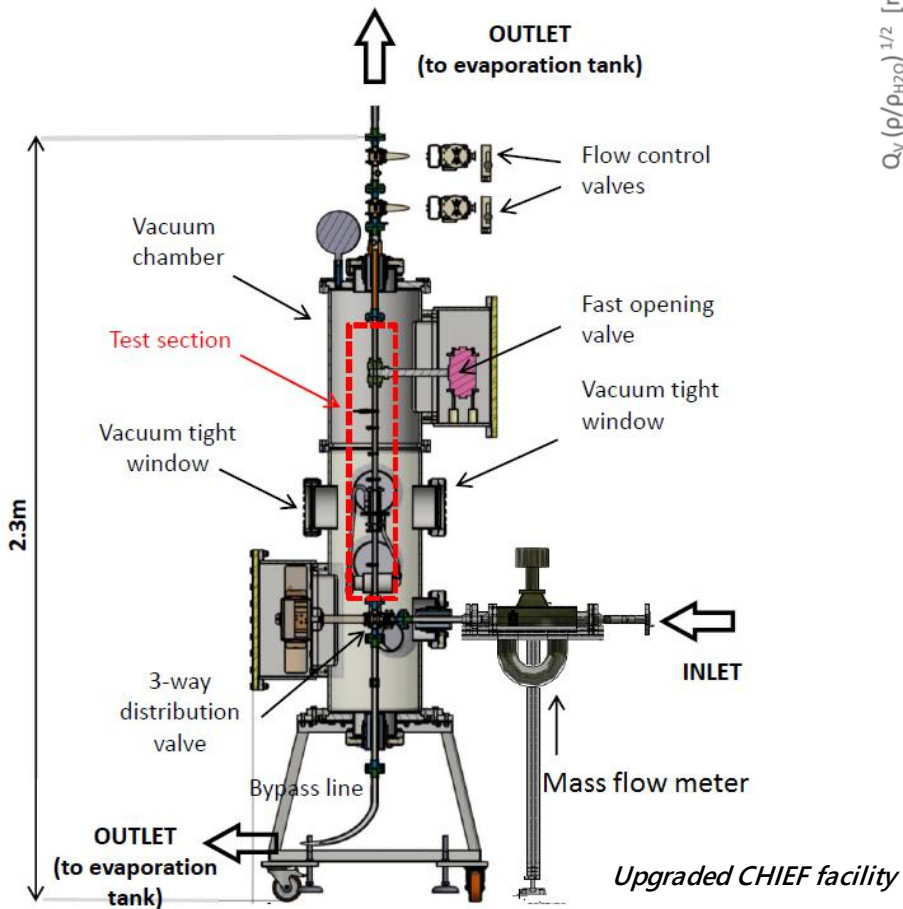
*Evolution of M_l becomes exponential when cavitation is developed
and small bubbles start appearing in the far-field too*

Cavitating Flows

orifice representative of space valve: thermo-hydraulic characterization

LN2, fundamental & applied research

- T, DP vs. Q measurements
- 3 pressure sensors method for void fraction detection
- High-speed flow high quality visualizations
- EcosimPro/ESPSS validations



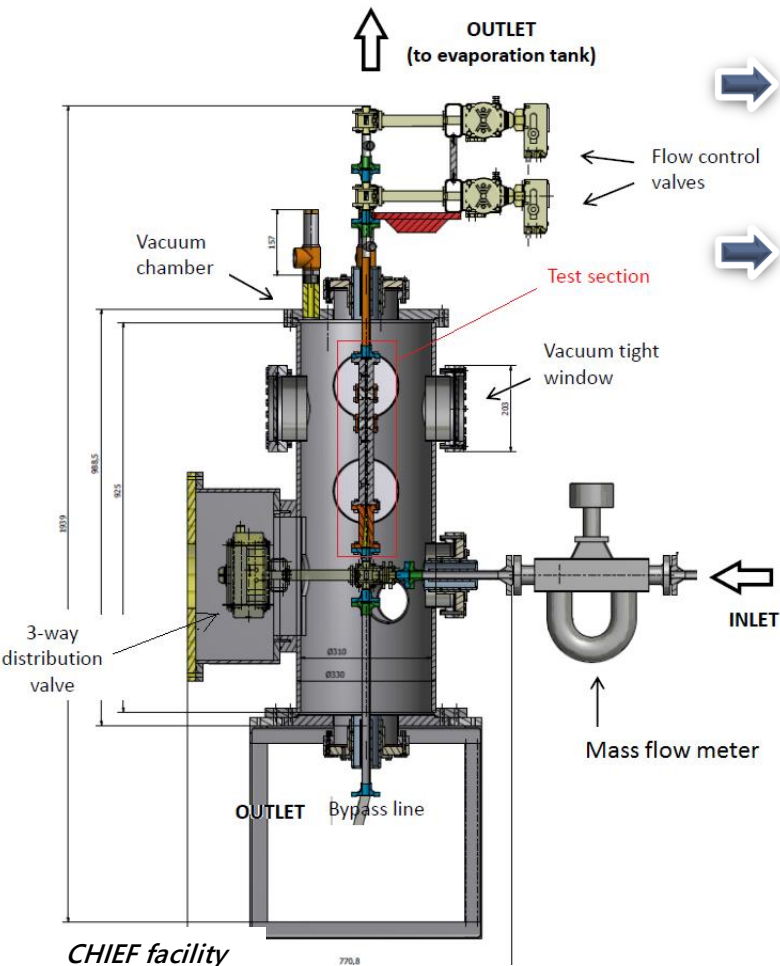
A
B
Orifice hydraulic curve and flow regimes

Flow Boiling

chilldown in space engine cooling channel

LN2, applied research

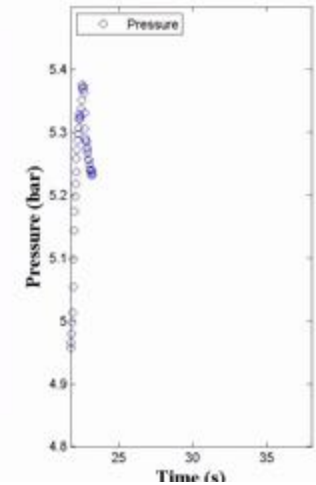
- P, T, Q and *void fraction* measurements (WASEDA univ. collaboration)
- High speed flow topology visualizations
- Development of a non-equilibrium 2-fluid model in EcosimPro/ESPSS



Film boiling regime behavior highly depend on mass flow rate entity

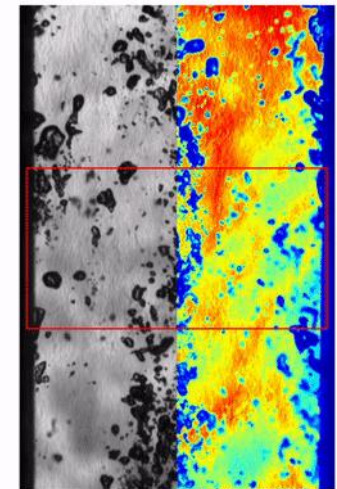
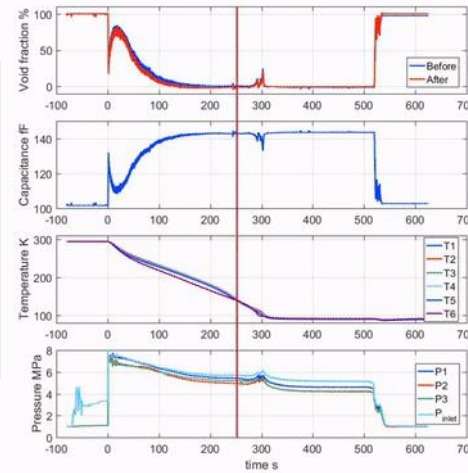
C-sensor encouraging performances

Low mass flow rate



Simultaneous time-resolved pressure measurements and flow visualization (pumping effect in film boiling region)

High mass flow rate



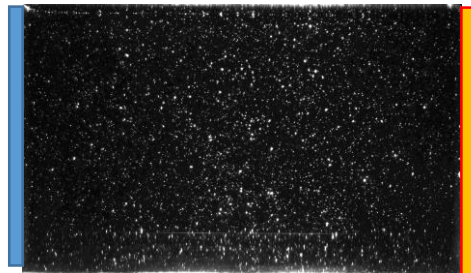
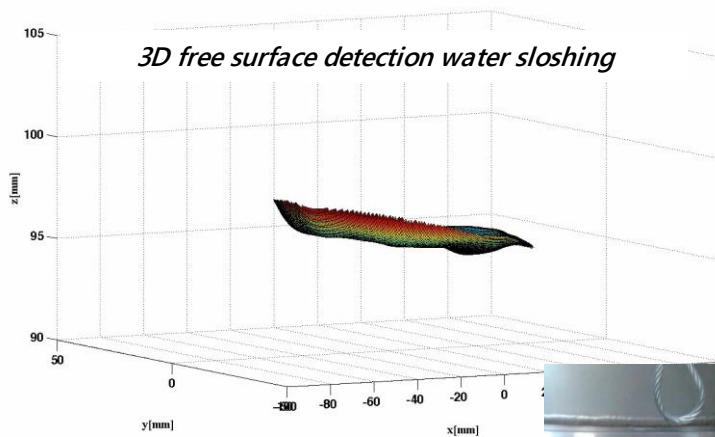
void fraction, capacitance, temperature, pressure evolution

Propellant Management in Tanks

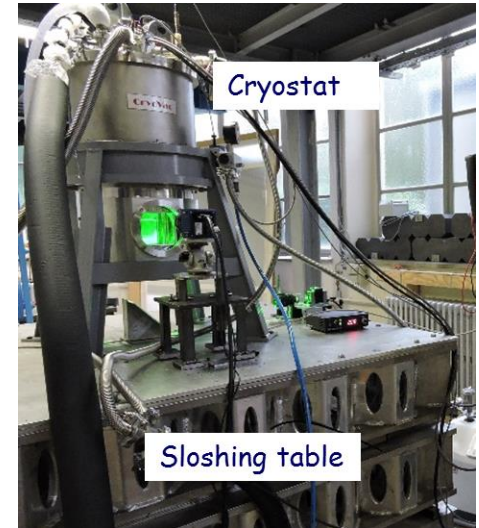
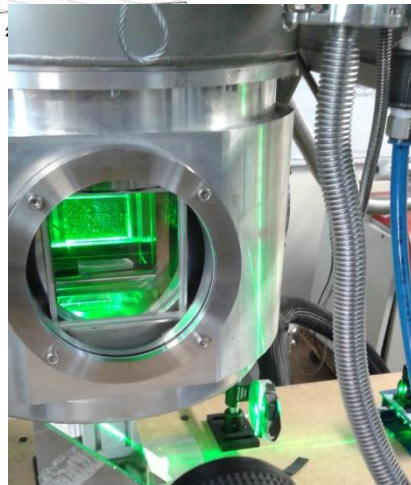
space propellant handling and storage in 1g environment:
sloshing, contact angle, pool boiling, natural convection

LN2, HFE and **water**, applied research

- Non intrusive measurement techniques
- CFD validation and development (OpenFoam)



2D Particle Image Velocimetry natural convection test



2D Particle Image Velocimetry sloshing test



Preliminary flow visualization in LN2 pool boiling test

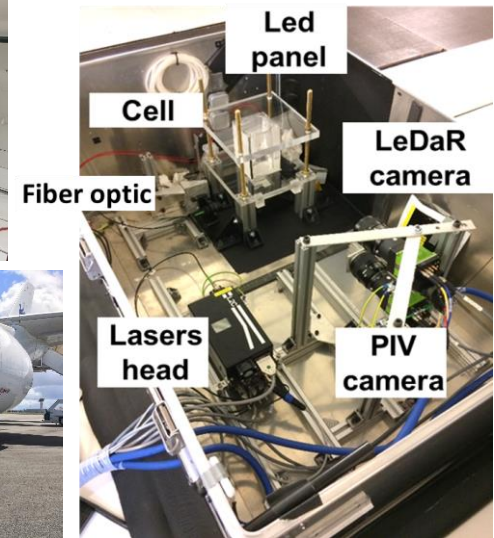
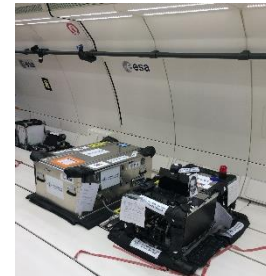
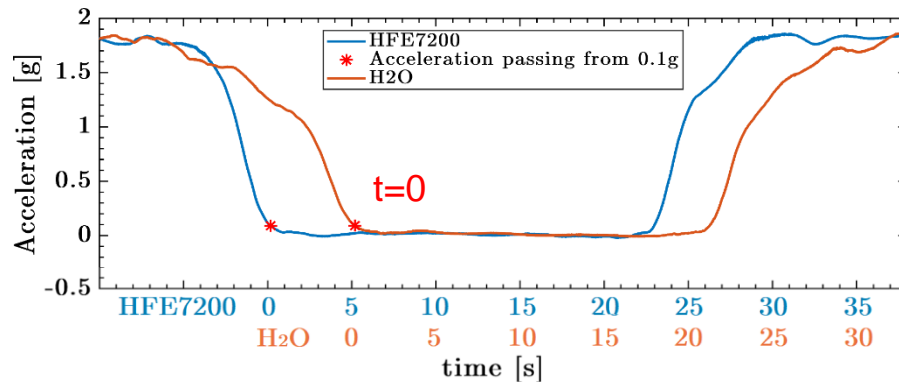
Propellant Management in Tanks

space propellant handling and storage in 0g environment

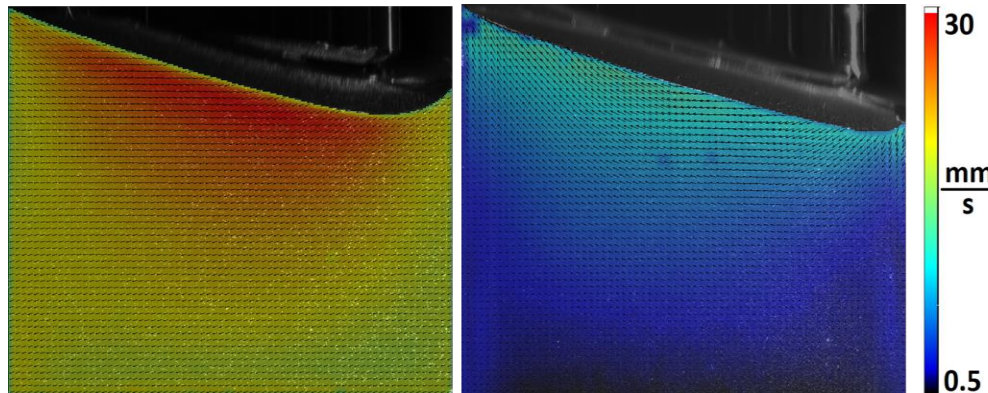
sloshing

HFE and **water**, applied research

- Non intrusive measurement techniques
- CFD validation and development (OpenFoam)



66th parabolic flight campaign, SPARGE setup



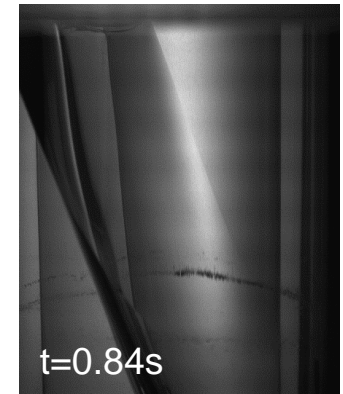
Distilled Water

HFE7200

Liquid sloshing (velocity field) due to gravity step reduction



Distilled Water



HFE7200

Liquid sloshing due to gravity step reduction

New Propellants

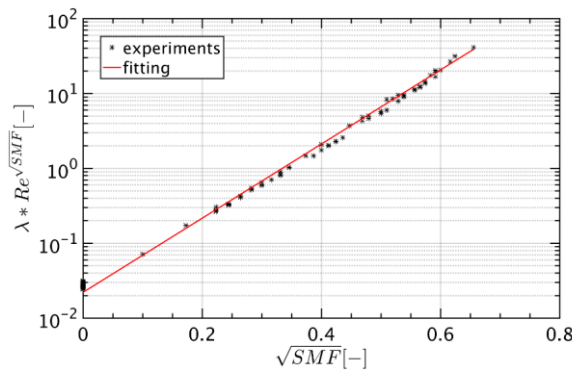
densification of liquid propellant: impact on launcher feedline

HFE and **water slurries**, fundamental and applied research

- Pressure losses, solid concentration, Q measurements
- High speed camera flow topology visualizations
- CFD validation and development (OpenFoam)



PREDICT facility test section



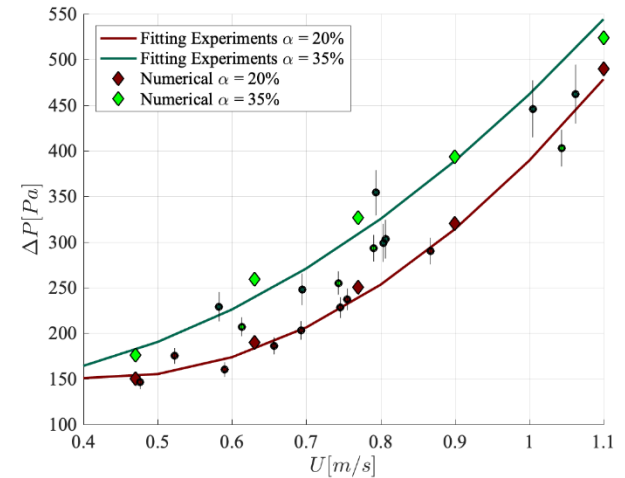
Pressure loss coefficient vs. SMF experimental correlation



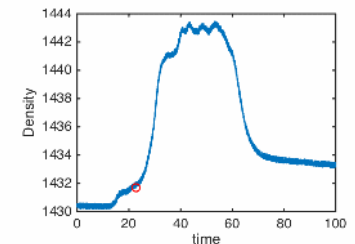
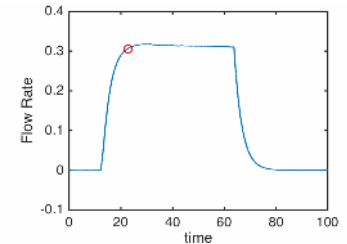
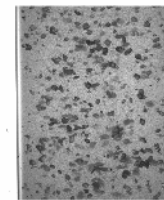
Design-oriented empirical correlation (implemented in 1D tool of DLR)



Validation of Euler-Euler RANS approach with Granular Kinetic Theory



Pressure drop in horizontal pipe CFD and experiments



Simultaneous time-resolved flow visualization, mass flow rate and density measurements

Thank you for your attention!

Acknowledgements:

