Experimental Investigation of Cryogenic Two-Phase-Flow
Space Engineering and Technology Final Presentation Days, ESTEC, 23.05.2017
Sebastian Soller, Airbus Safran Launchers
Johan Steelant, ESTEC
Introduction: Two-Phase Flow

Example: Phase Diagram Methane

- Supercritical Fluid
- Solid
- Liquid
- Gas
- Condensation
- Boiling/Film Cooling
- Cavitation
Two Phase Flow in Rocket Thrust Chambers: Cavitation

**Application:** Orifices to tap off fuel from the TCA regenerative coolant circuit for dump cooling of nozzle extension.

Depending on operating conditions \((p, T)\), amount of gaseous fluid may vary and impact discharge coefficient of orifice and hence coolant dump mass flow rates → inherent risk if evolution of discharge coefficient cannot be assessed properly during transients or in off-design load points.
**Application:** Prediction of chill-down behaviour of regenerative cooling circuit before ignition

In the past, HM7 engine featured HF pressure oscillation after a prolonged engine-chill-down. Apart from ensuring the safe operation of the engine, predicting the chill-down process with higher accuracy allows optimising the chill-down routine, save propellants and increase payload.
• **Airbus Safran Launchers (ASL), Taufkirchen:** Application requirements, engineering models for cavitation & two-phase-flow

• **Energie Technologie (ET), Brunnthal:** Expertise in handling and test facilities using LH2

• **NUMECA Int., Brussels:** Development of CFD solver FINE/Open with OpenLabs, used in aerospace, turbomachinery and multiphysics application

• **TUM Chair of Aerodynamics and Fluid Mechanics, München:** International acknowledged competence in modelling of two-phase flow phenomena (e.g. fuel injection systems, ship propellers)

• **Von-Karman-Institute (VKI), Rhode-Saint-Génése:** LN2 cryo-lab, expertise in optical diagnostics
Characterisation of LH2 orifice flow in sub- and transcritical conditions

**ASL:** Definition of orifice, selection of operating conditions, 1D simulation

**ET:** Design, manufacturing and execution of experiment

**VKI:** Consulting with expertise on visualisation

**NUMECA & TUM:** 3D-CFD simulations with real fluid modeling of cryogenic LH2

Investigation of chill-down phenomena in cooling channel setup:

**ASL:** Definition of geometry and operating conditions, 1D transient modelling

**ET:** Design, manufacturing and execution of experiment using LH2

**VKI:** Design, manufacturing and execution of experiment using LN2

**TUM:** TUM: 3D-CFD simulations with real fluid modeling of cryogenic LH2
Cavitation – Operating Conditions and Experimental Setup

Pressure: 25 – 50 bar
Temperature: 25 – 35 K
Mass flow rate: up to 11 g/s

Test vessel filled with LH2
Test chamber
Flowmeter
Main valve
Optical system for imaging
Constant pressure adjusted in range 20 – 50 bar
Lighting system
Orifice flow
Orifice
Cavitation – Comparison of Test Data with 1D-Steady-State Simulation

- In general, 1D model assuming real gas isentropic expansion predicts mass flow correctly and consistently with CATUM and Fluent 3D CFD simulations
- Significant deviation between experiment and simulation detected for 50 bar inlet pressure below 32 K inlet temperature
Test data recorded in GSTP provided important input for HM7 justification in upgraded Ariane 5 mission in 2016 (cf. HM7-PRE-005-2016 “OTN Investigation of increased dump mass flow need on HM7 NE “)

Numeca: Investigation of potential effect of heat transfer from GH2
# Coolant Circuit Chilldown – Operating Conditions and Experimental Setup @ VKI

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Geometry [mm]</th>
<th>Represent. conditions [bar], [K] Range and/or Represent. value</th>
<th>$Q_e$ [Kg/s] Range and/or Represent. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real Engine</td>
<td>LH2</td>
<td>9.3 x 3.5</td>
<td>[1.5 – 3.2] bar, [22 - 25] K 2.65 bar 23 K</td>
</tr>
<tr>
<td>VKI</td>
<td>LN2</td>
<td>10 x 3.8</td>
<td>[2 - 6] bar, [80 - 96] K 5 bar 94 K</td>
</tr>
<tr>
<td>ET</td>
<td>LH2</td>
<td>10 x 3.8</td>
<td>[1.5 - 3.2] bar, [22 - 25] K 2.65 bar 23 K</td>
</tr>
</tbody>
</table>

Key parameters: $We$, $Nu$, $Ja$, $Bo_{ef}$
Tests from VKI using LN₂ provide benchmark data and lessons learned for upcoming experiments with LH₂ @ ET.

Visualisation results correlate well with pressure measurement.
For 10 g/s LN2, pressure fluctuation can be reproduced reasonably well with regard to frequency and amplitude - for higher mass flow rates, significant deviations have been observed. Detailed investigations are ongoing.
Motivation: Hydrocarbon fuels offer cost advantages in operation + are a green option for in-space propulsion

Limitation: Subcritical pressure can occur

• in throttling operation of landers or reusable launch systems
• in low-cost pressure fed thrust chambers of micro-launchers or In-space propulsion systems

At ASL, there’s considerable experience in operating hydrocarbon-fuelled engines – but limited experience with two-phase flow

→ Continuation of scientific cooperation with focus on transient two phase flow in TCA cooling channels, driven by hot-gas heat flux
The TRP / GSTP on Cryogenic Two-Phase-Flow is a good example of transnational cooperation:

- **Belgian-German** cooperation of academia and industry
- Team combines expert know-how on experiments and simulation
- Industry ensures orientation towards “real-life” need and supports swift transfer of results to application
- Capitalise on established network and know-how for additional topics relevant for launcher and in-space propulsion

Thank you for your attention!

sebastian.soller@airbusafran-launchers.com