The Morphology of Flash Boiling LN2 Sprays in High-Altitude Liquid Rocket Engines

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6th Cavitation and Multi-Phase Flows Workshop IICR, Chania, 2019
Superheat & Flash boiling (I)

- Re-ignitable upper stage engines
- New engine & propellant systems for RCS engines
  → cryogenic oxygen (LOX), other green propellants
- LOX injection into vacuum (superheated condition)
  → Flash evaporation
- Characteristics of spray important for ignition process
  → ignition?
  → combustion stability?
Superheat & Flash boiling (II)

- Degree of superheat: \[ \Delta T^* = \frac{\Delta T}{\Delta T_{sat}} = \frac{T_{inj} - T_{sat}(p_c)}{T_{sat}(p_{inj}) - T_{sat}(p_c)} \] or \[ R_p = \frac{p_{sat}(T_{inj})}{p_c} \]
Test bench M3.3

- Cryogenic temperature adjustment and injection system: LN2 pressure tank, LN2 run tank and injector unit
- Vacuum system
- Chill-down of the test bench
Optical Setup

- **Backlight Shadowgraphy**
  - Fastcam SA-X
  - Xe light source
  - Translucent milk glass screen
  - 10.000 fps
  - 1024x1024
Shadowgraphy Camp. LN2 (I)

- $T_{\text{inj}} = 82.5 \text{ K (±0.6 K)}$
- $D_{\text{inj}} = 1 \text{ mm}$
- $p_c = 36-600 \text{ mbar}$
- $p_{\text{inj}} = 4 \text{ (±0.2) bar}$
- $p_{\text{inj}} = 8 \text{ (±0.3) bar}$

*start injection + 120ms*
Shadowgraphy Camp. LN2 (II)

- $T_{inj} = 82.5 \text{ K (±0.6 K)}$
- $p_{inj} = 4 \& 8 \text{ (±0.3) bar}$
- $D_{inj} = 1 \text{ mm}$
- $p_c = 36\text{-}600 \text{ mbar}$

\[
\begin{align*}
\text{We} &= \frac{\rho_g u^2 d}{\sigma} \\
\text{Ja} &= \frac{\rho_l c_p \Delta T}{\rho_g h_{\text{vap}}} \\
\Phi &= 1 - e^{-2300 \ast \left(\frac{\rho_g}{\rho_l}\right)}
\end{align*}
\]

Blue and red lines by Cleary et al. [2]
Conclusions and Outlook

- Test bench with cryogenic injection system provides reproducible, constant and homogeneous injection conditions.
- Evolution of LN2 sprays with increasing $R_p \rightarrow$ fully flashing sprays.
- Variation of $p_{inj}$: different spray patterns despite $R_p = \text{const.} \rightarrow$ other definition for degree of superheat.
- Flashing LN2 sprays fit into transition correlations for storable fluids.

- Determination of spray angles, droplet size and velocity distributions.

$\rightarrow$ Detailed data base of flash boiling LN2 sprays for numerical modelling and validation.
Literature
