Tomographic Background-Oriented Schlieren for Visualizing Supersonic Nozzle Flows

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Outline

- Motivation
- Theoretical Background
- Proof-of-concept using hot water
- Experimental Setup
- Results
- Discussion & Next Steps
- Conclusion

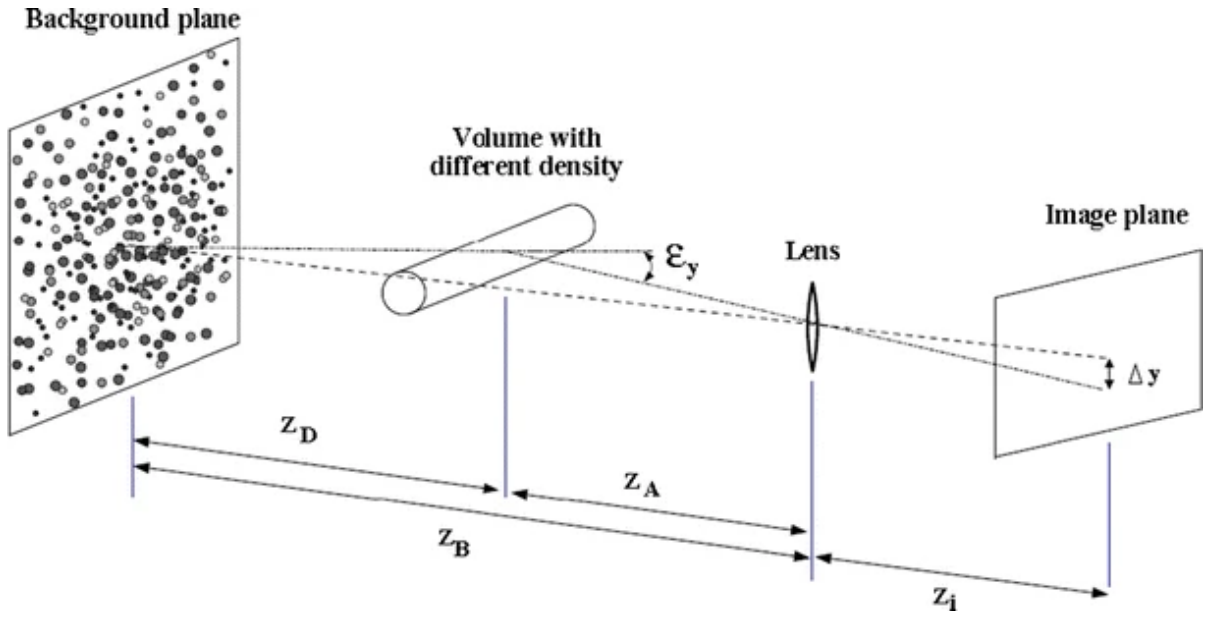
Introduction & Motivation

- Difficult to visualize large flows with current techniques
- Current nozzles over-designed for critical loads

Imaging Supersonic Aircraft in Flight using BOS [Heineck et al. (2020)]

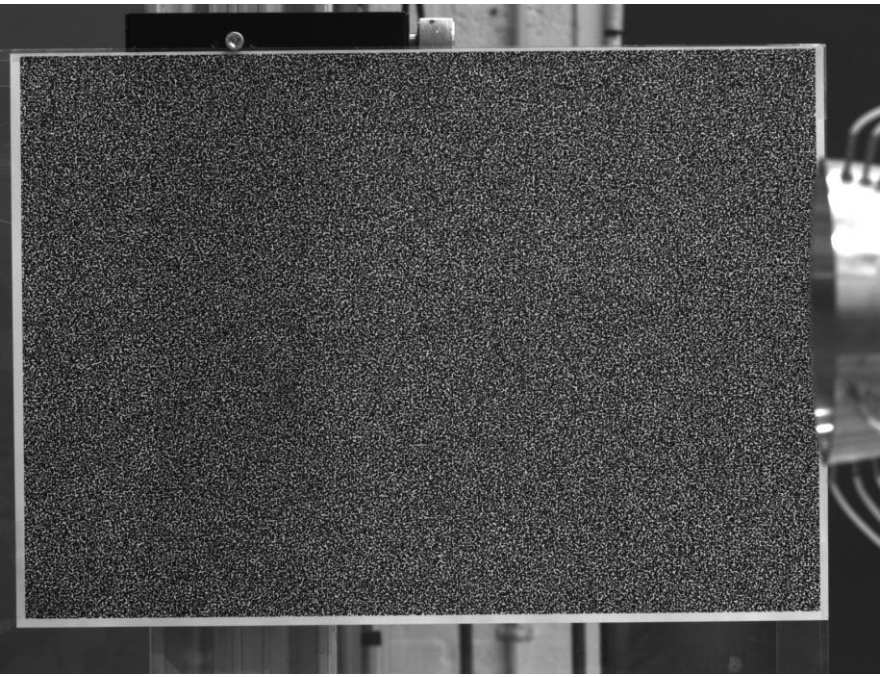
Theoretical background: BOS

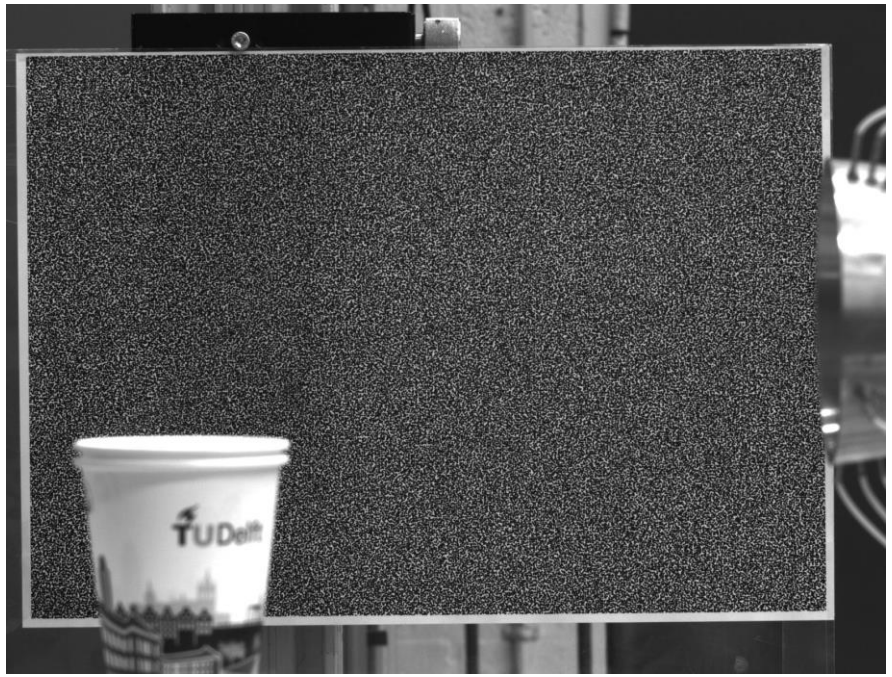
- Background-Oriented Schlieren (BOS) imaging
- Density gradients in transparent media refract light
- Image cross-correlation to extract pixel deflections

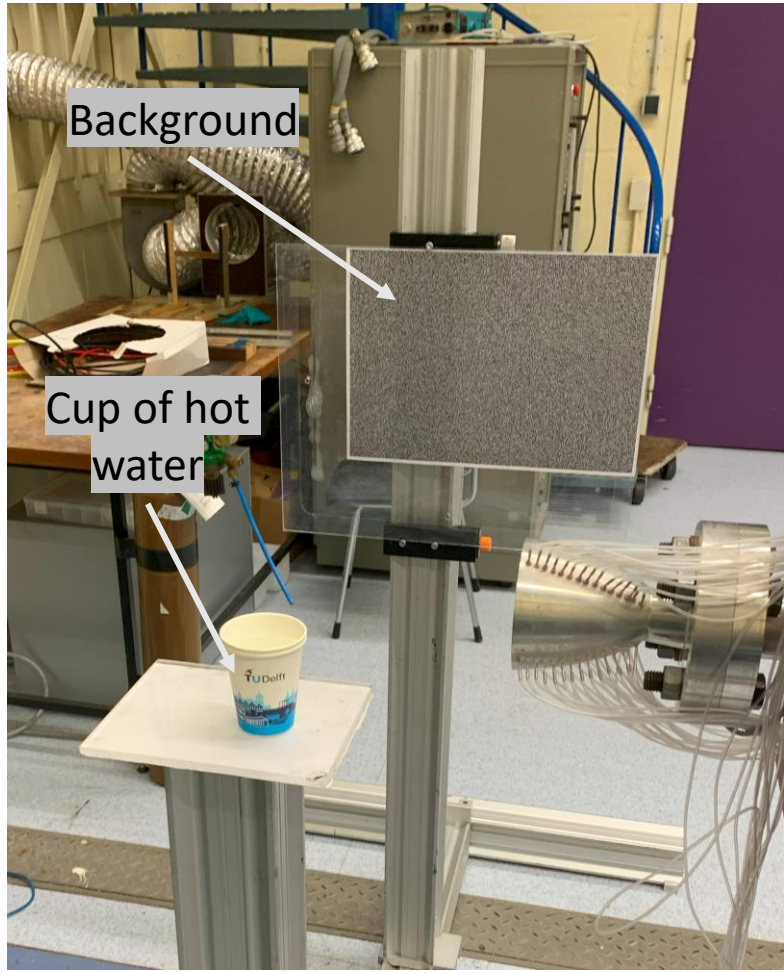


BOS Imaging [Settles (2015)]

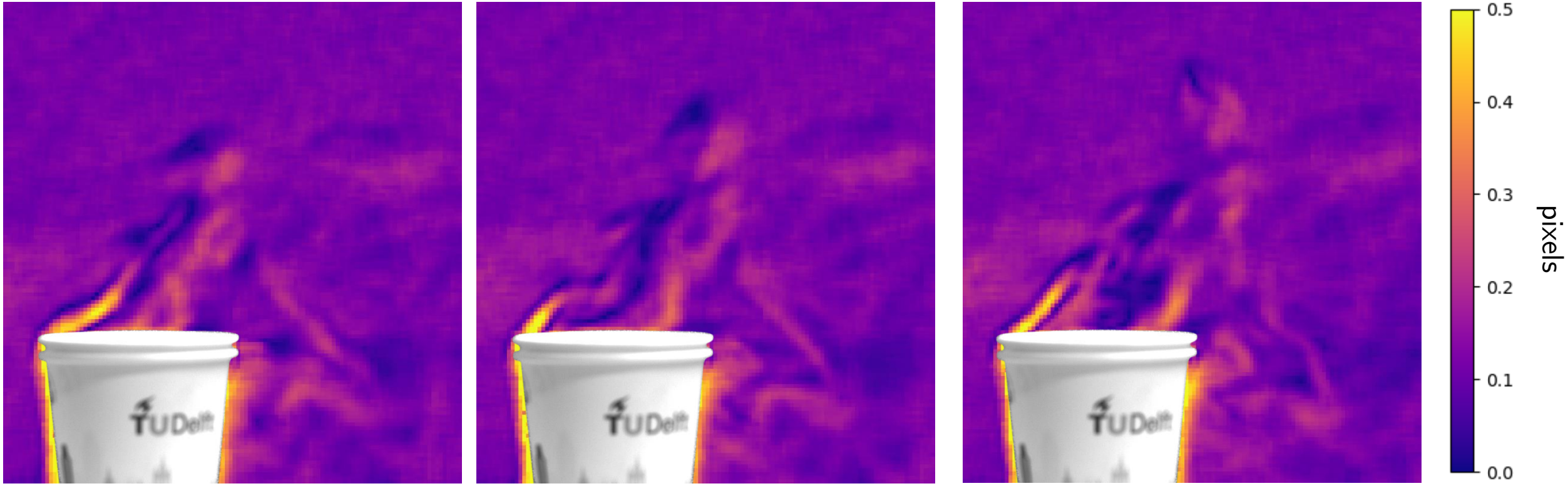
Proof-of-concept: Hot Water







Proof-of-concept: Hot Water



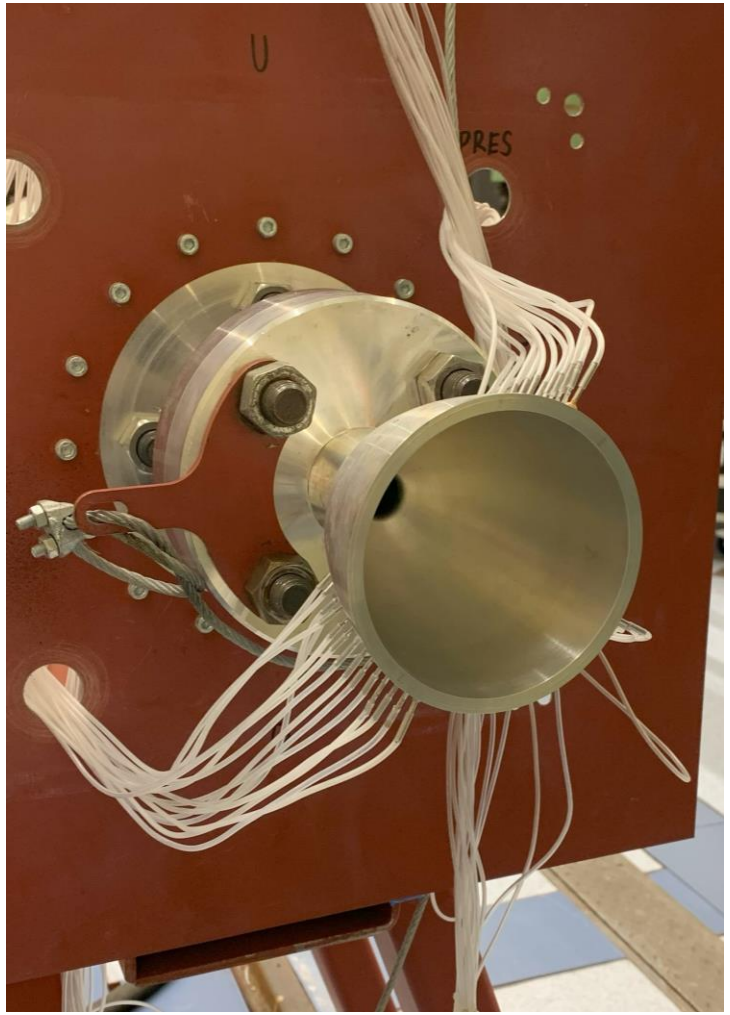
$t = t_0$ $t = t_0 + \Delta t$ $t = t_0 + 2\Delta t$

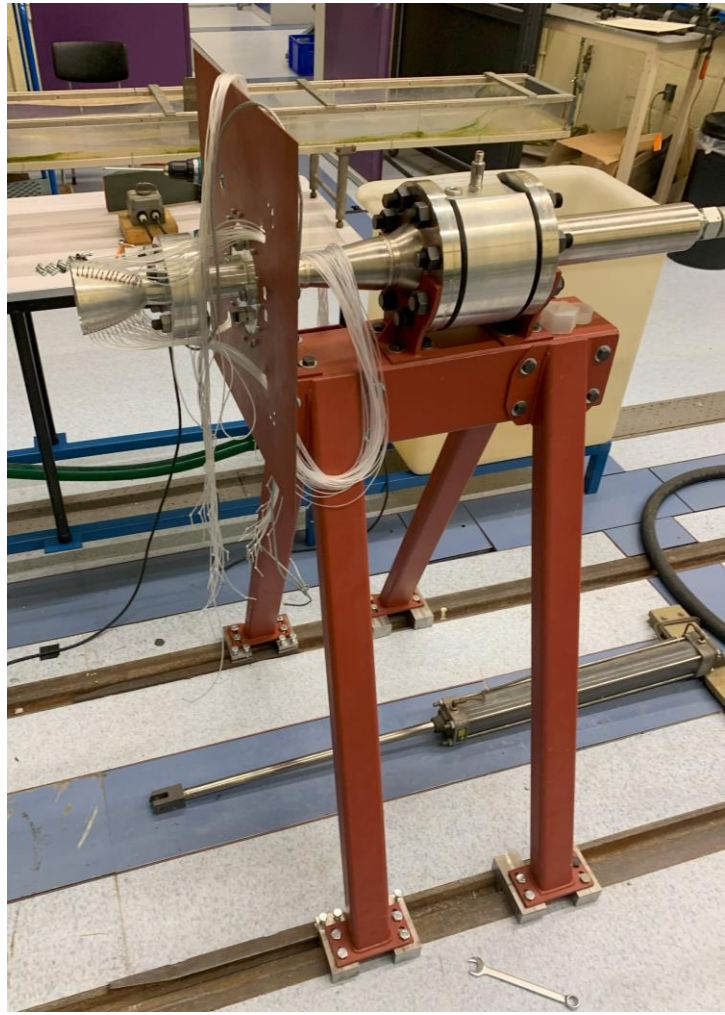
Proof-of-concept: Hot Water

Experimental Setup

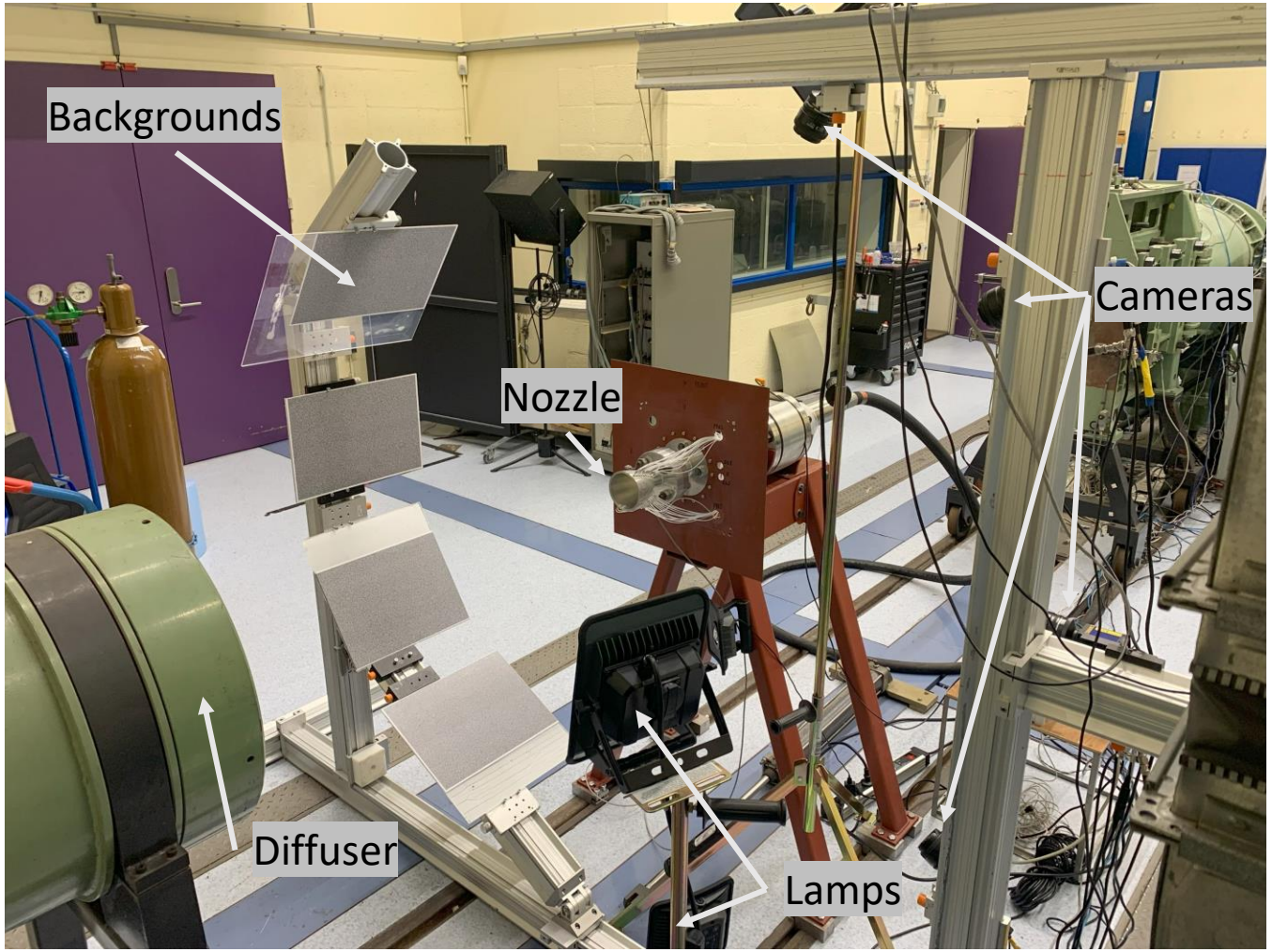
Experimental Setup

- ASCENT test rig in ST15
- 3-week test campaign
- Measurements at NPR = 12, 22, and 26 using 4 cameras
- 350 GB of image data

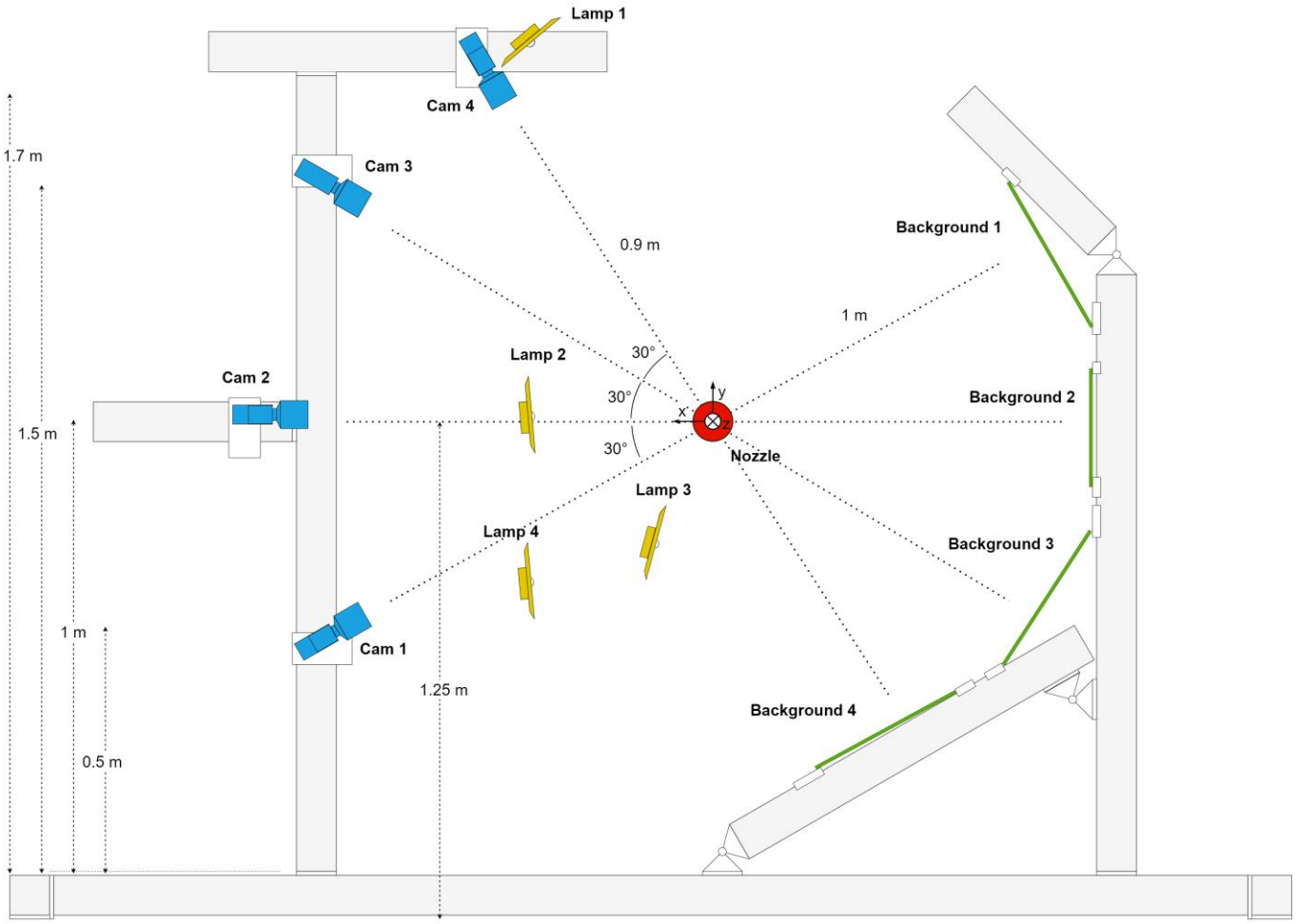


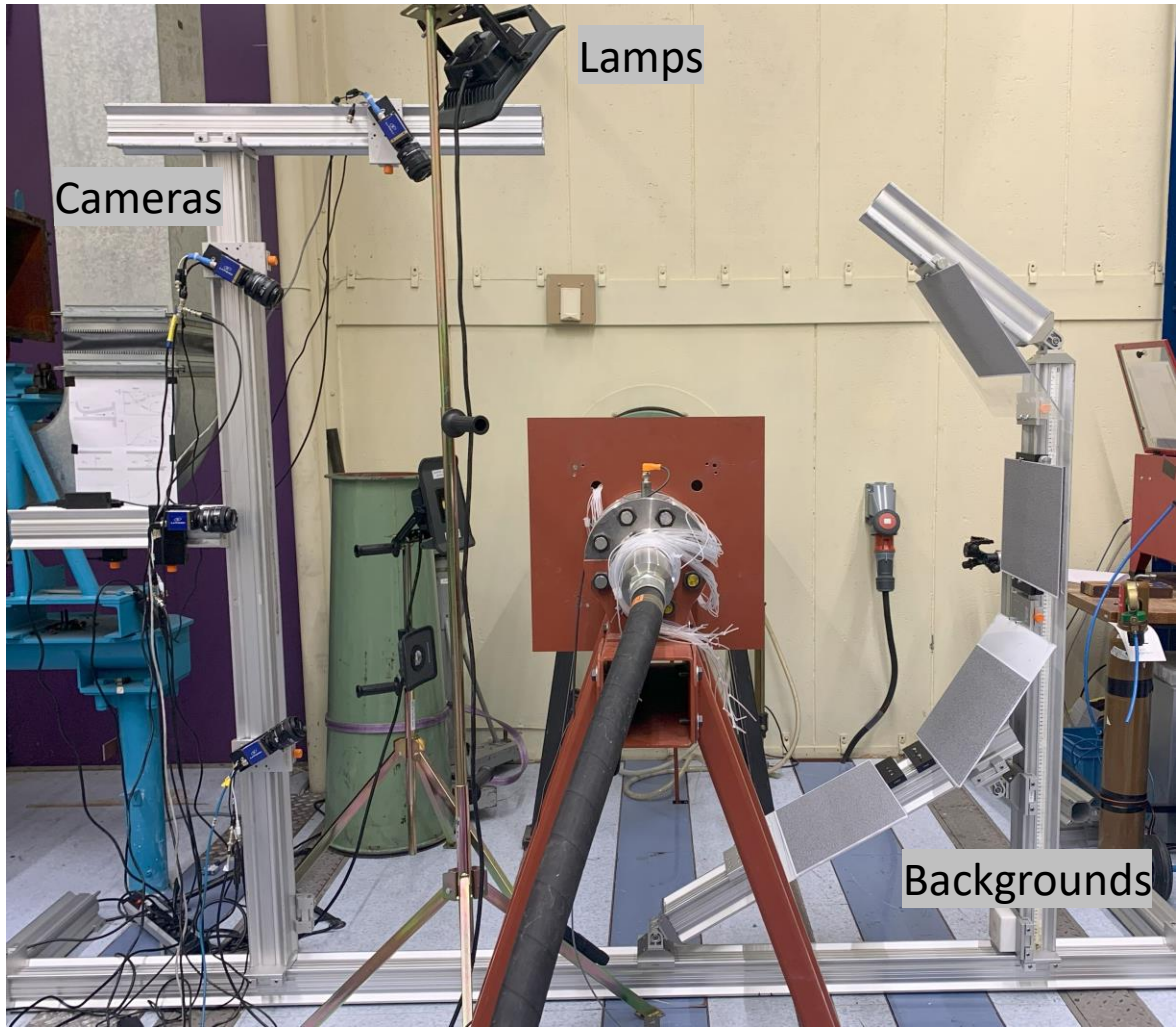


Experimental Setup



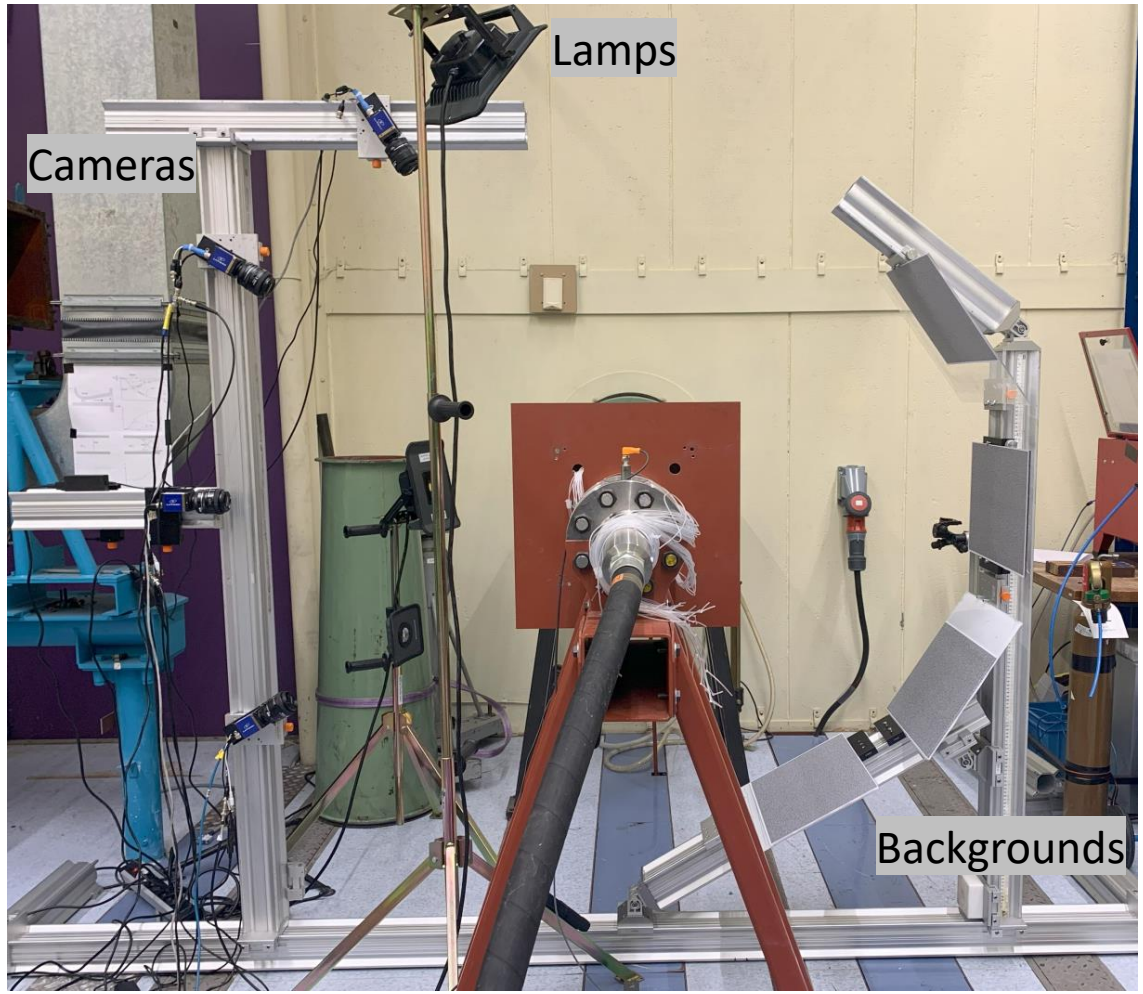
Experimental Setup





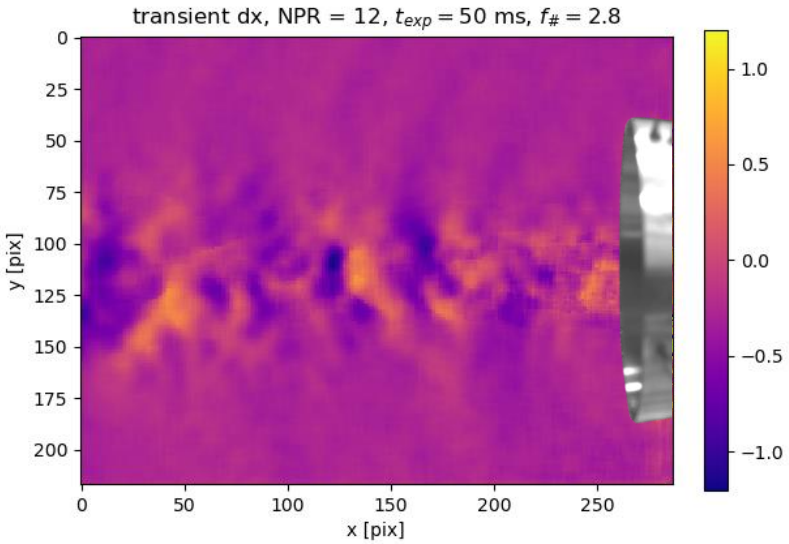
Experimental Setup: measurements

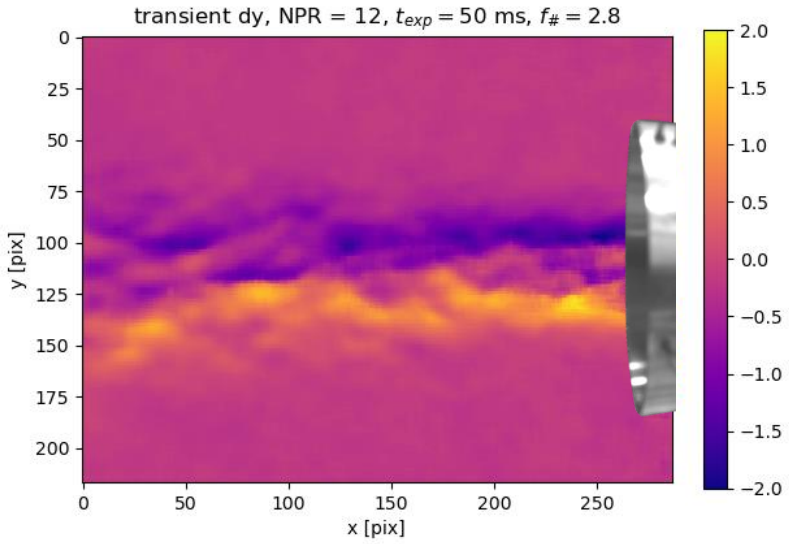
- 4 cameras started simultaneously
- Take flow-off image
- Flow-on image recording started
  - NPR ramped up
  - NPR kept at steady
  - NPR ramped down

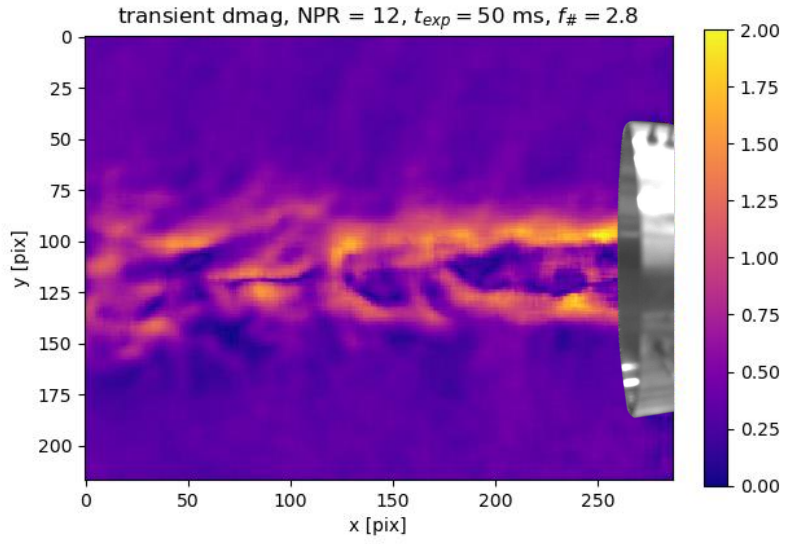


Results

Transient NPR = 12





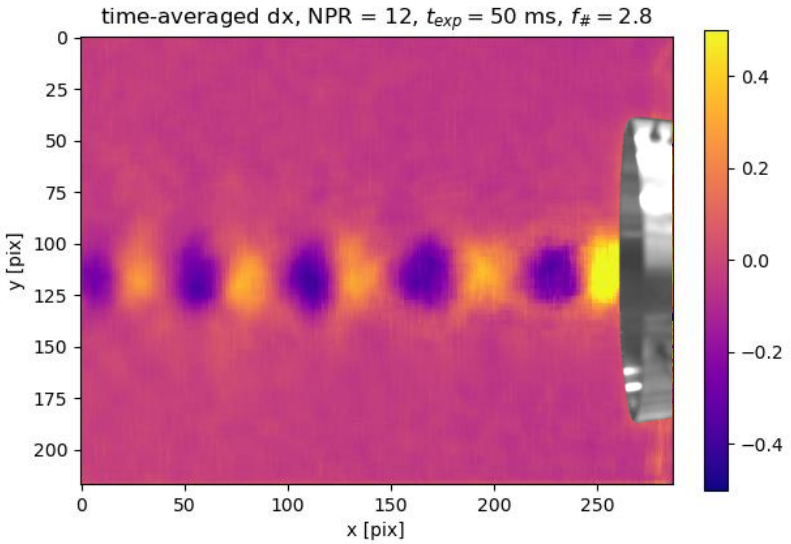


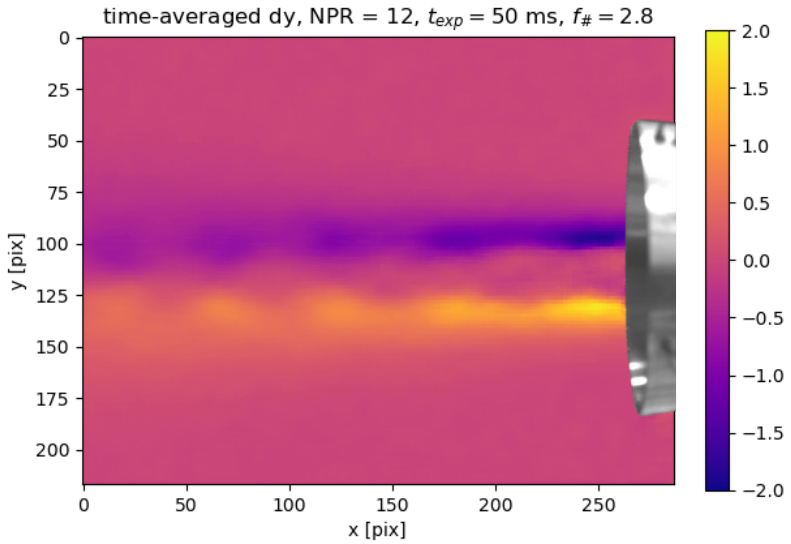
Results

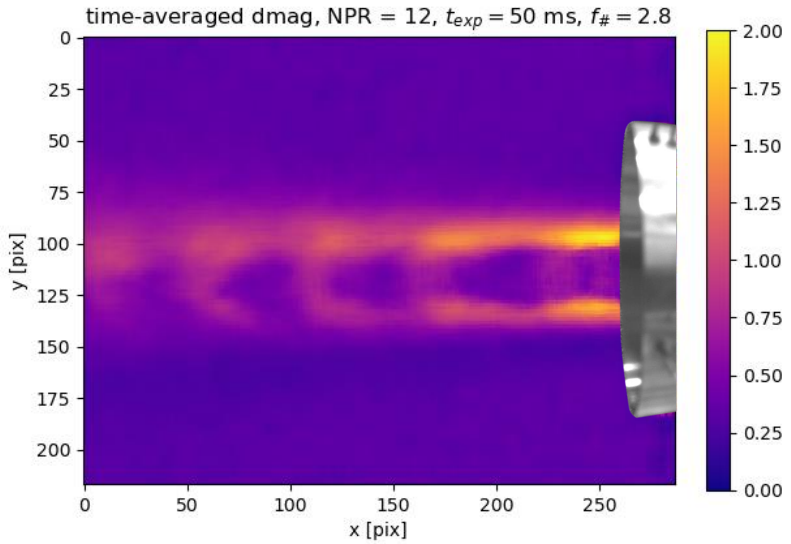
- NPR = 12 (steady)
- Sound waves visible

Results

Time-averaged NPR = 12

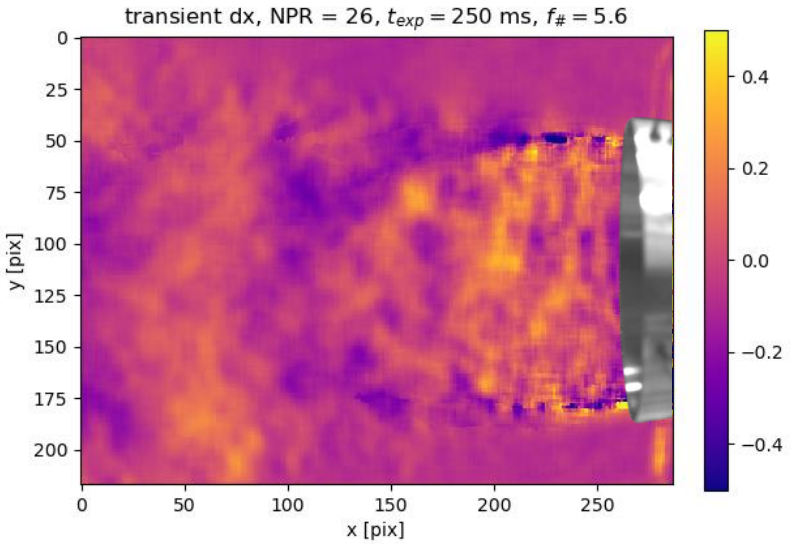


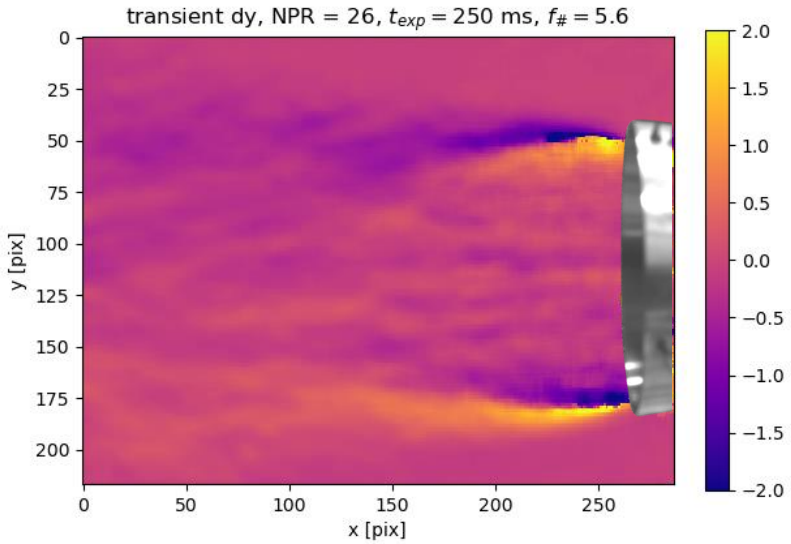


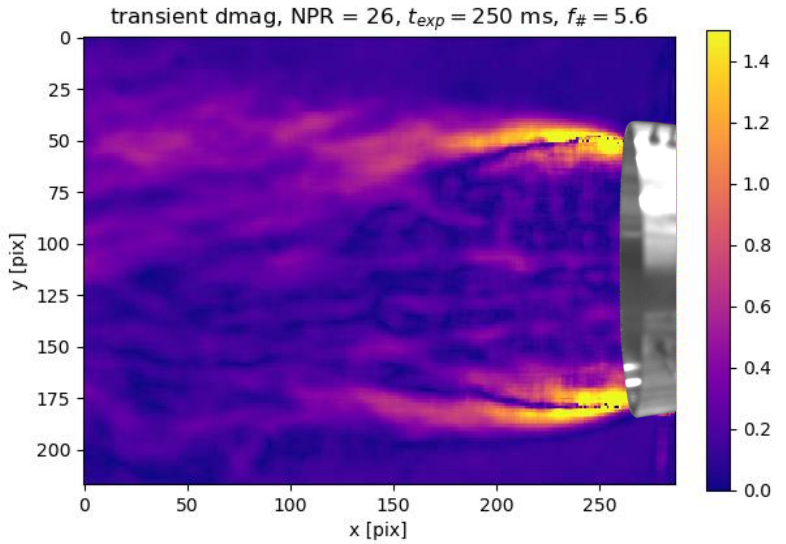


Results

Transient NPR = 26

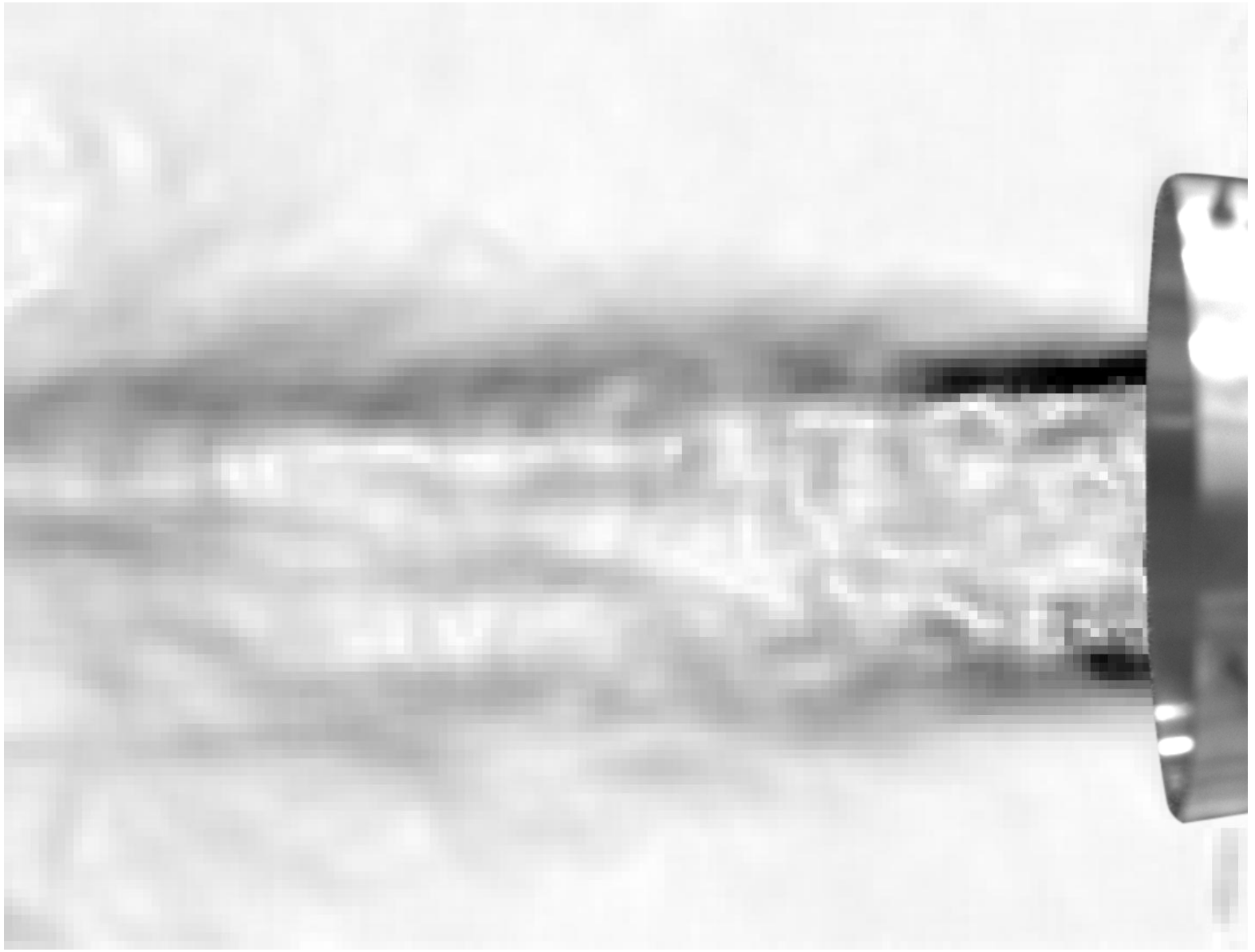






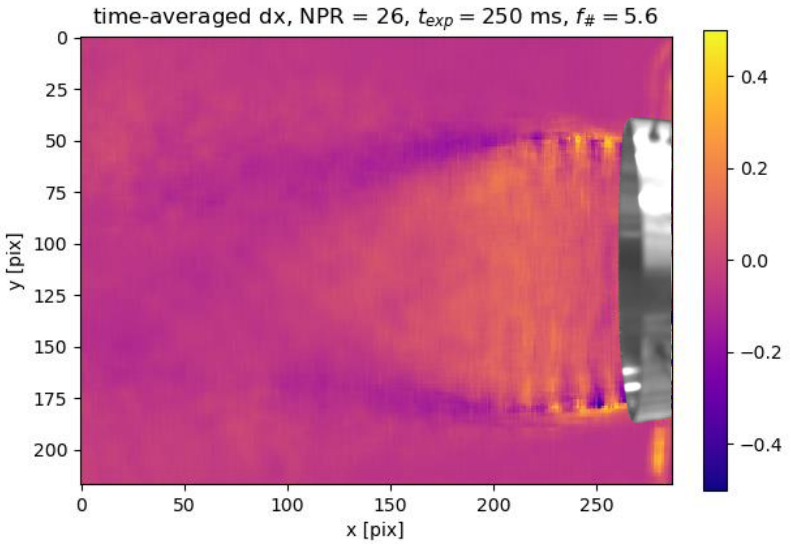
Results

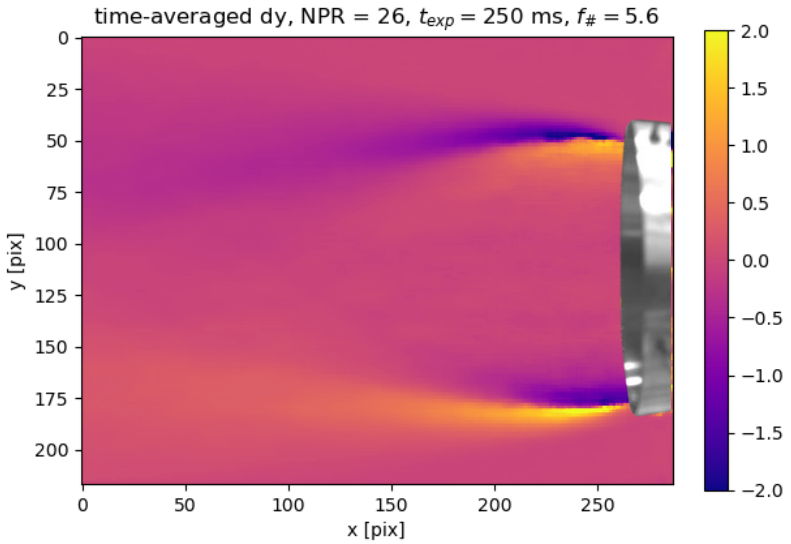
- NPR = ramp up to 26
- Flow structure changes

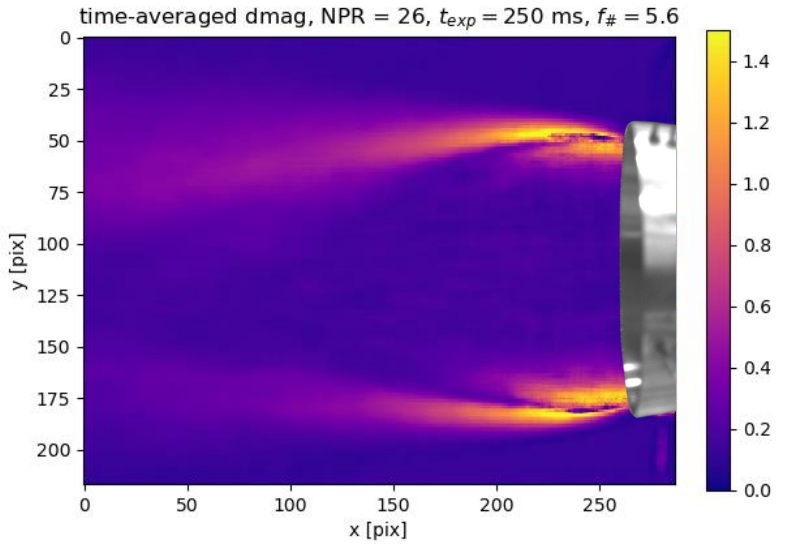


Results

Time-averaged NPR = 26





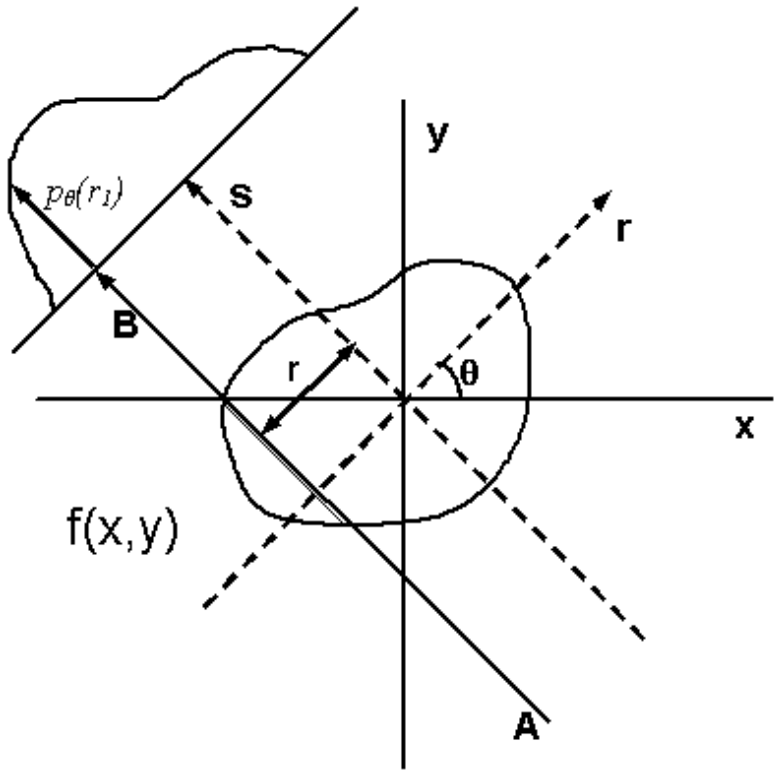


Discussion

- BOS works: most flow characteristics visible and sensitivity is good
- Limited spatial resolution
- Simple setup in theory

Next Steps: tomography

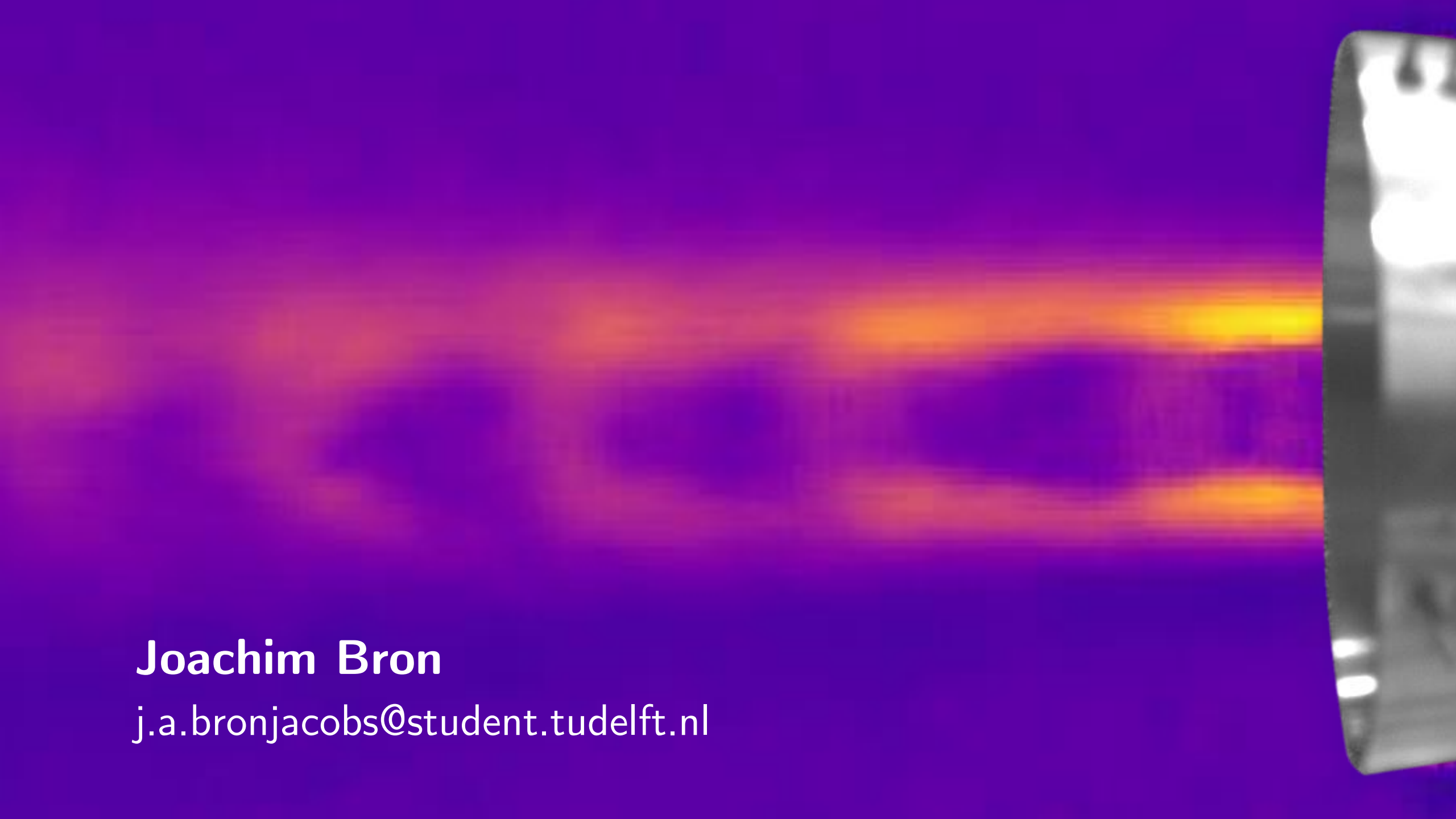
- Currently still more qualitative than quantitative
- Tomographically reconstruct density field
- Tomo-BOS leads to complex setup: calibration, time-synch, lots of data



[Wikipedia]

Conclusion

- BOS imaging is based on the refraction of light
- Tomo-BOS experimental setup developed
- BOS applied to hot water plume and overexpanded supersonic nozzle flow
- Next-step: tomographically reconstruct density field



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