

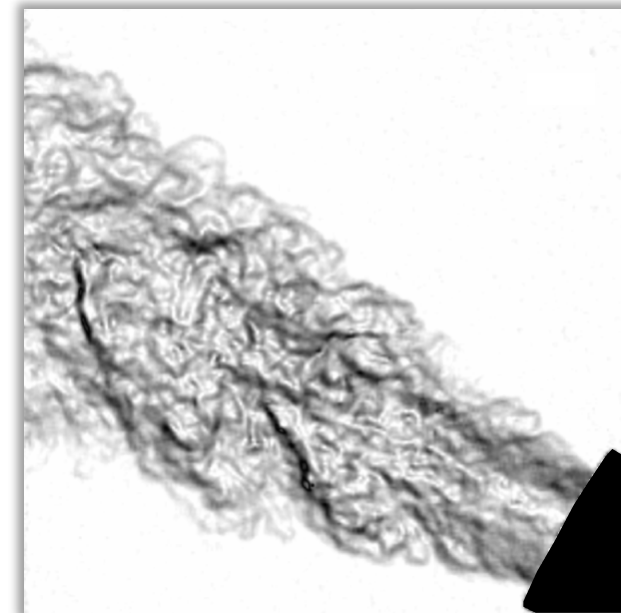
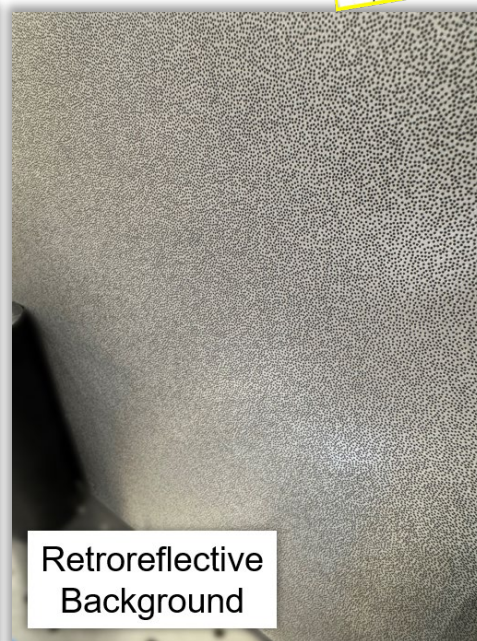
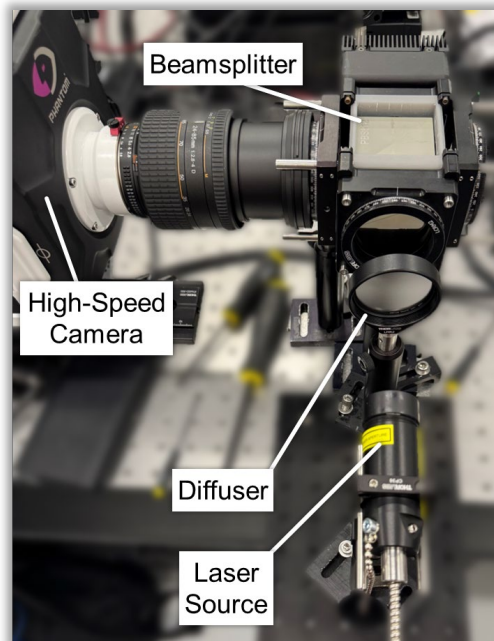
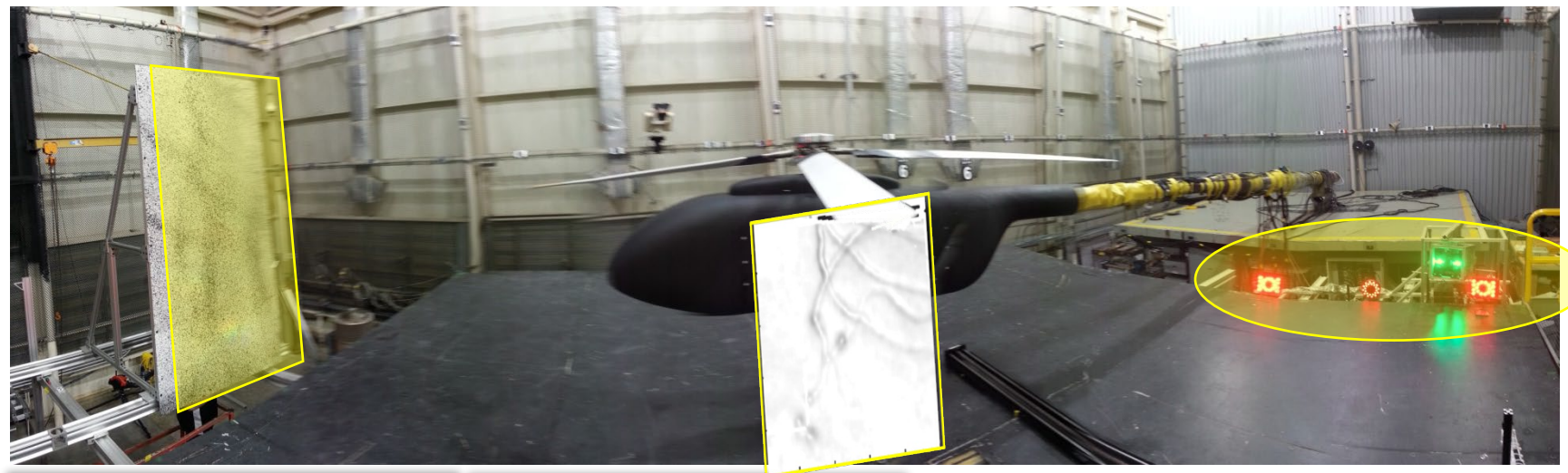
Considerations for High-Speed Background-Oriented Schlieren Visualization Capability for Ground Test Facilities

Brett Bathel

*Advanced Measurements and Data Systems Branch
NASA Langley Research Center, Hampton, Virginia*

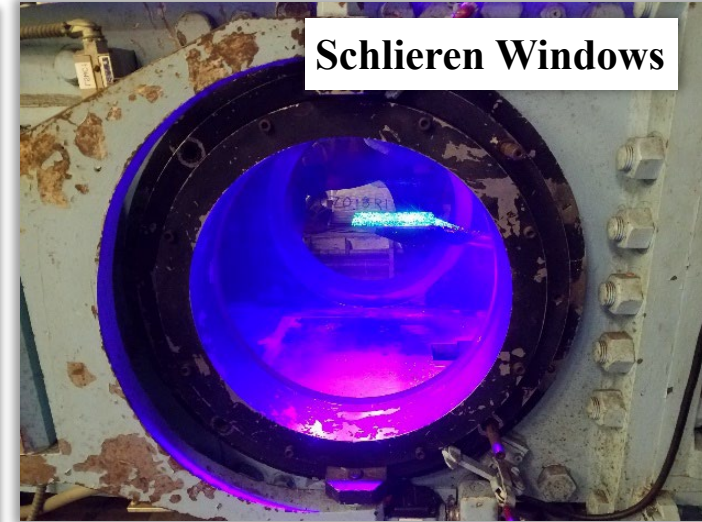
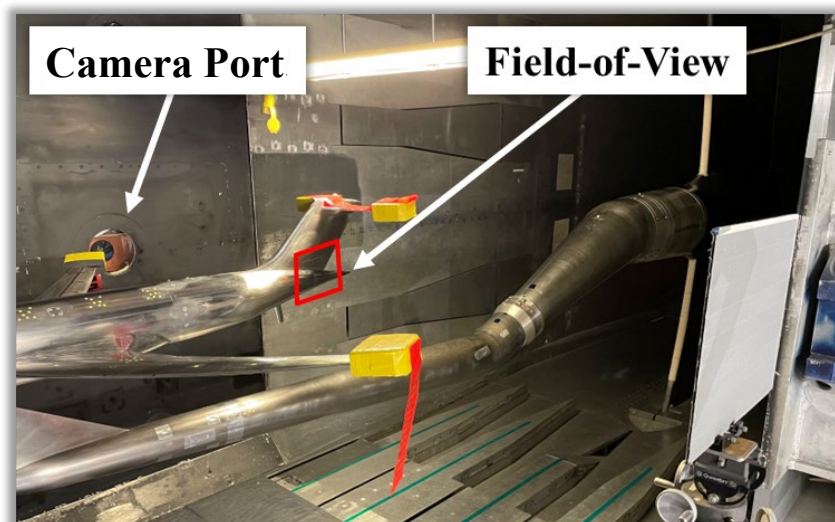
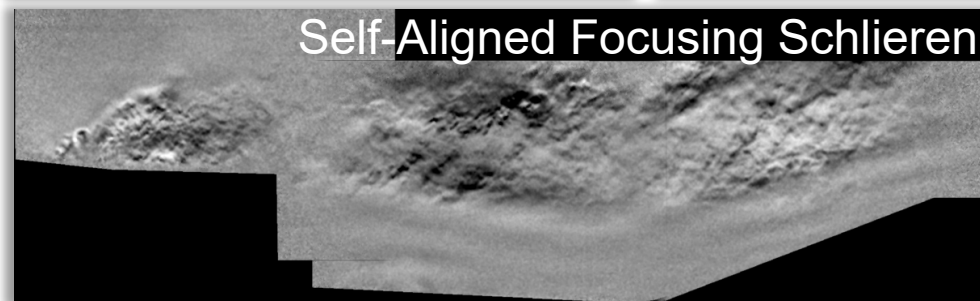
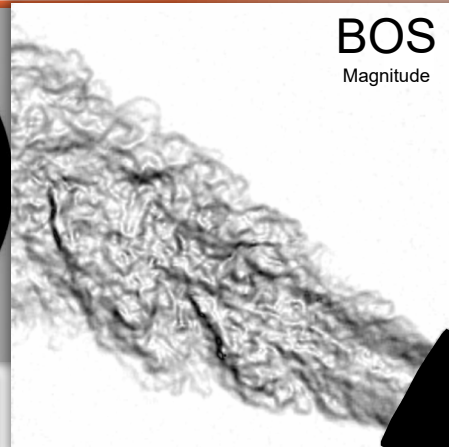
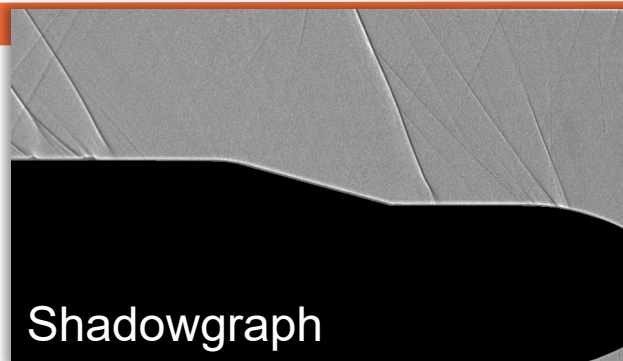
Why Background-Oriented Schlieren?

- Low barrier to entry
- Relatively easy setup
- Versatile
 - High-speed imaging
 - Facility challenges
- BOS is quantitative
 - Tomography
 - Potential of advanced algorithms



Why Background-Oriented Schlieren?

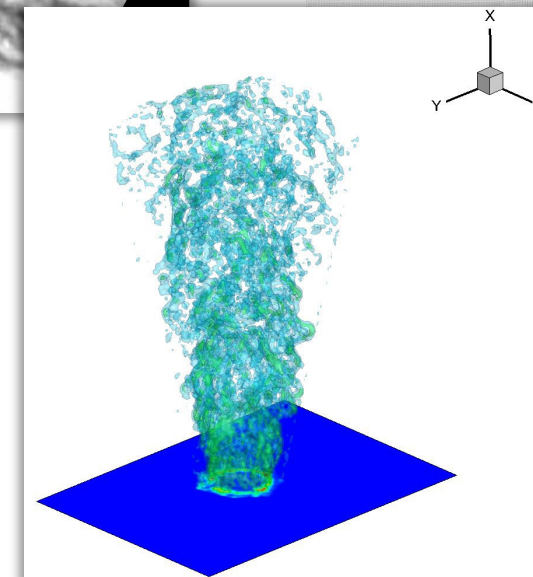
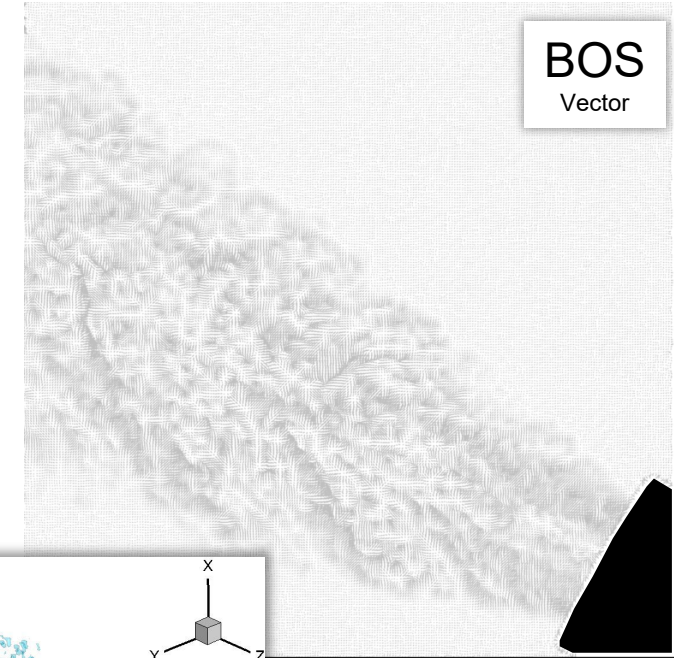
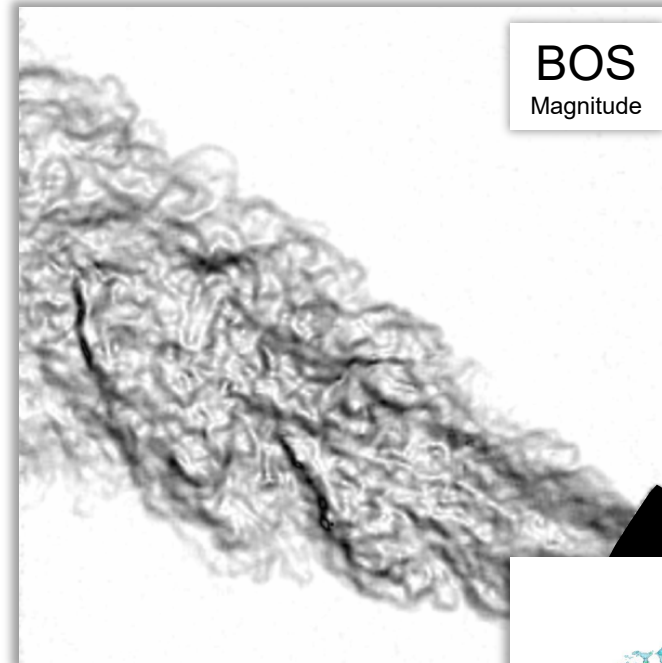
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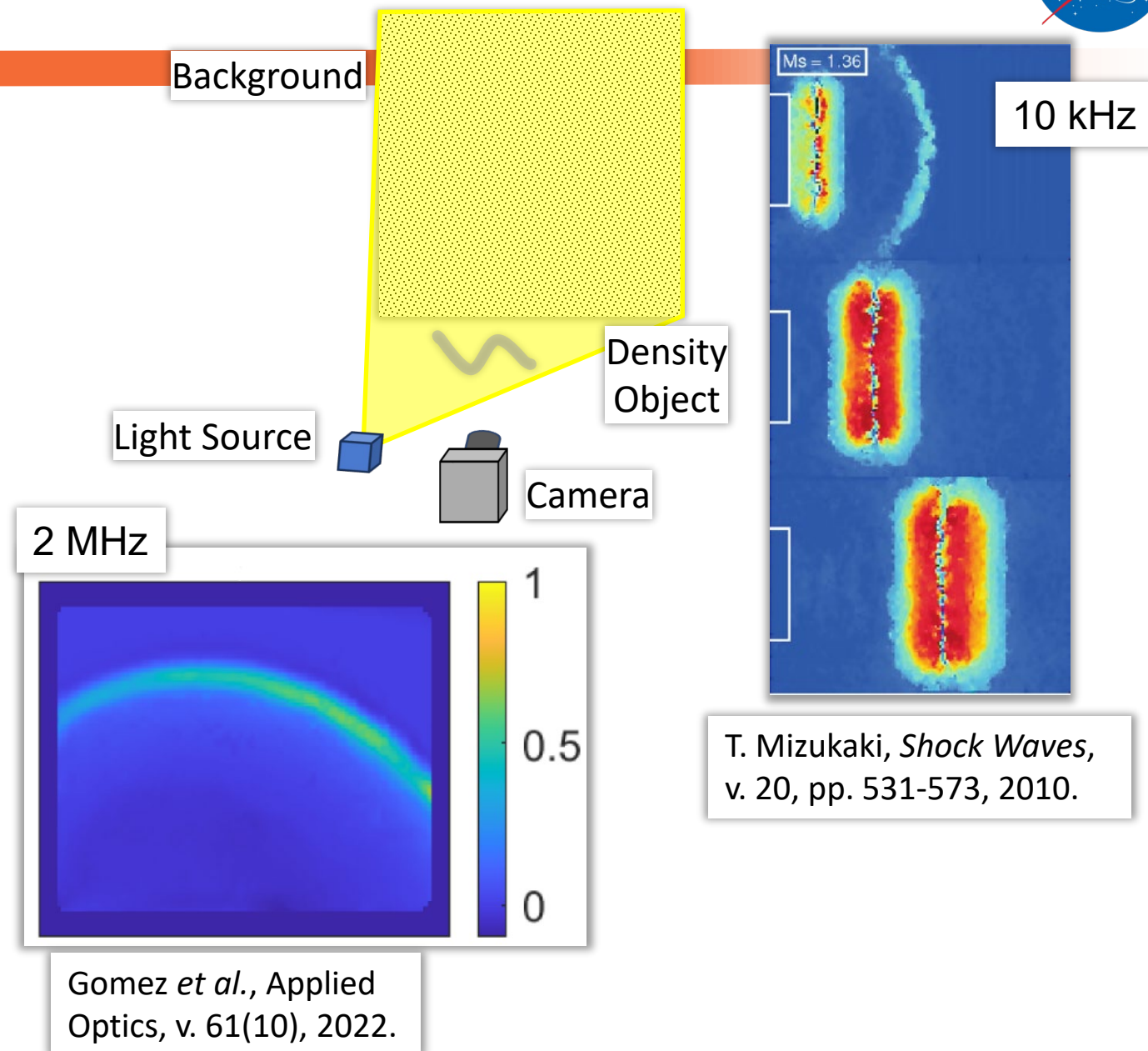


Why Background-Oriented Schlieren?

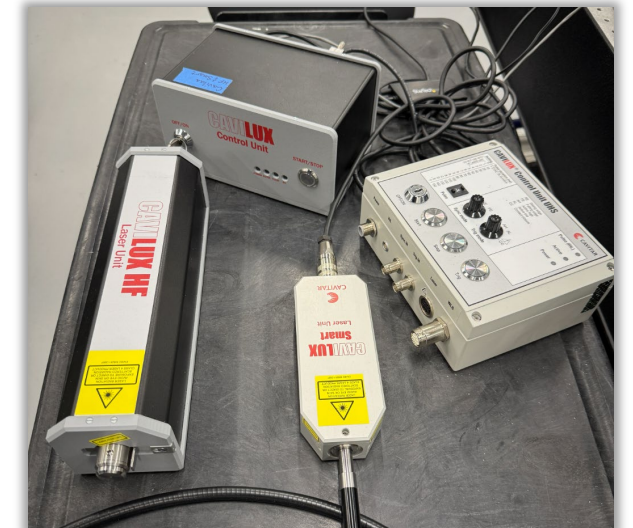
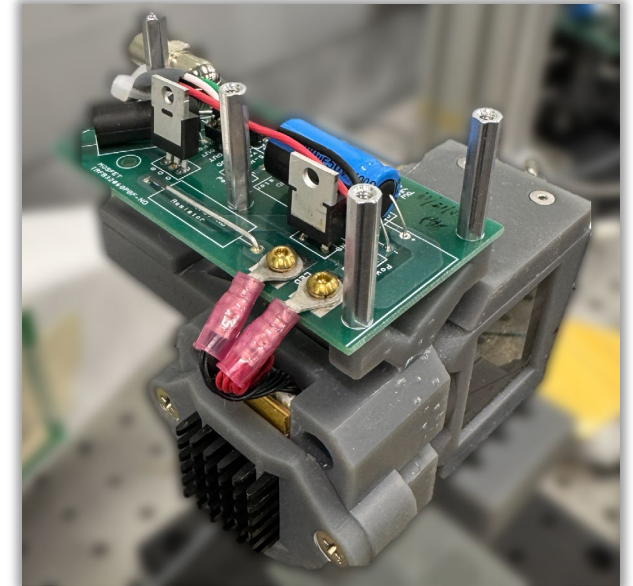
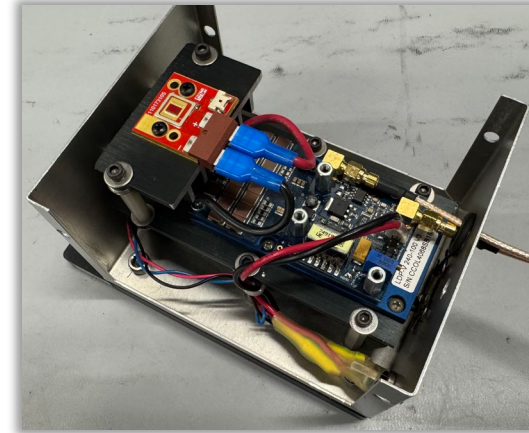
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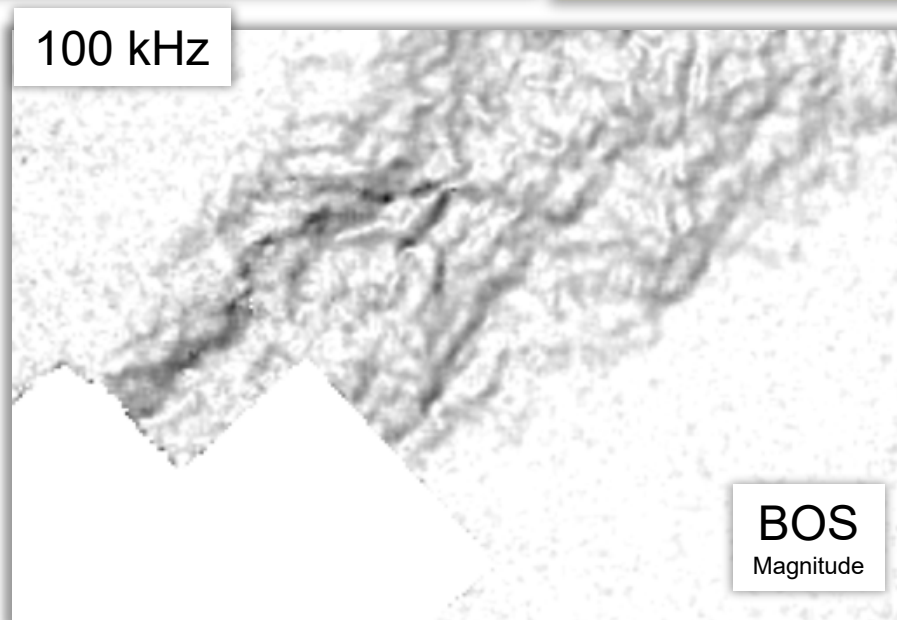
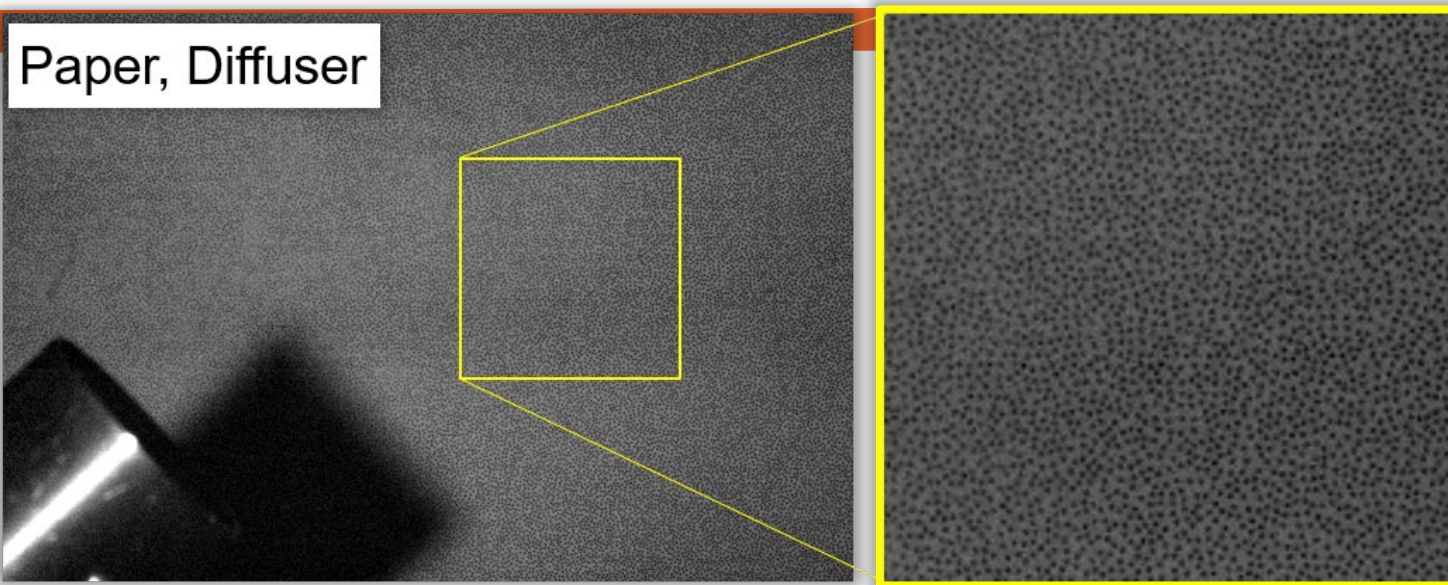
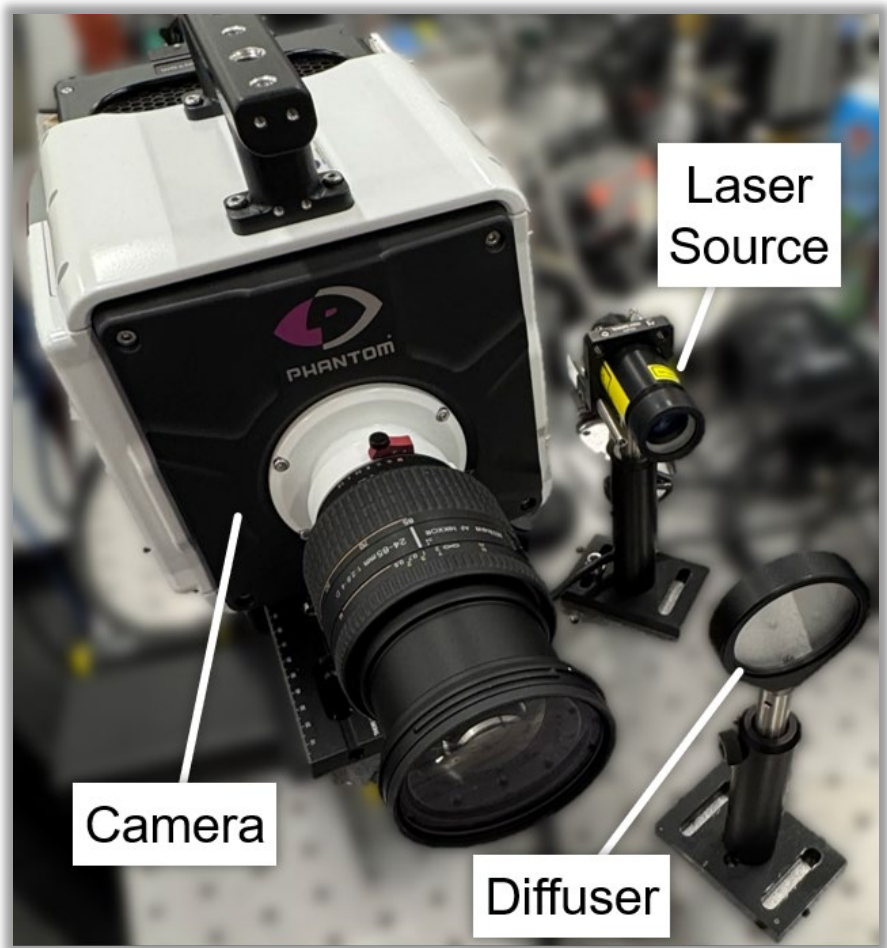


- High-speed
 - Framing rates ≥ 1 kHz
 - Sequential frames capture evolution of flow structures
- Forward illumination with diffuse background
 - Pattern printed on paper

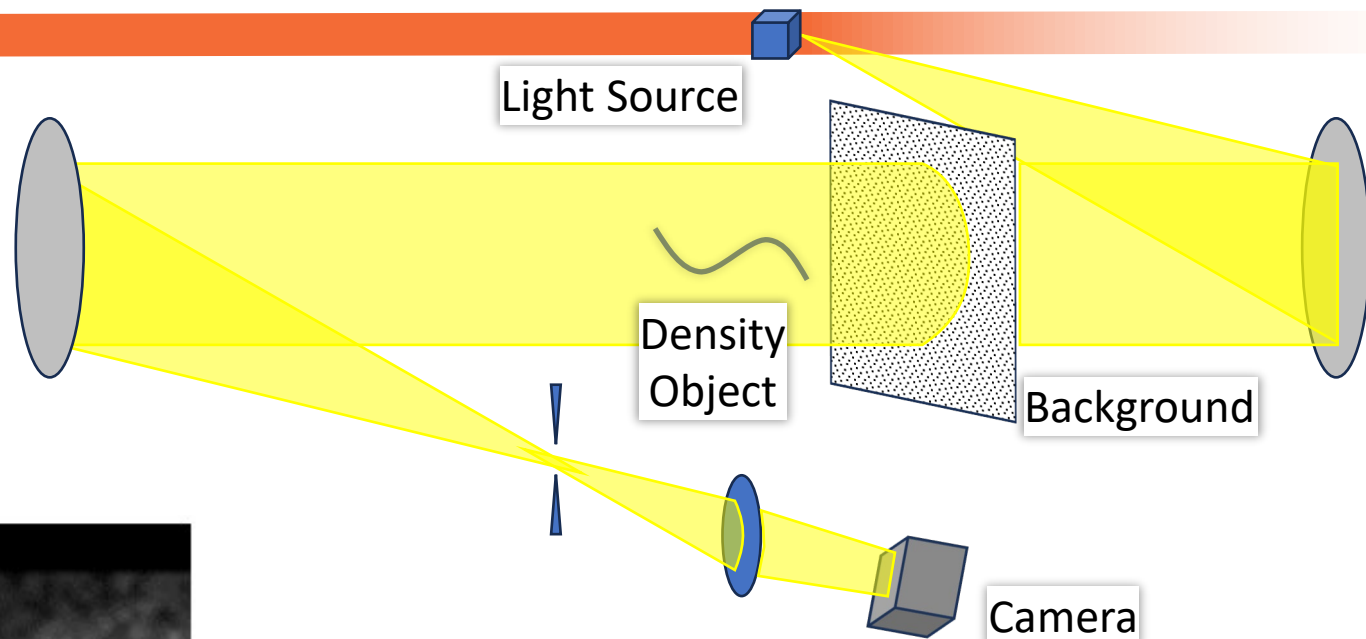


- Overdriven LEDS
 - Stasicki *et al.*, Technisches Messen, 51(6), 1984
 - Willert *et al.*, Exp. Fluids, 53(2), 2012
- Overdriven laser diodes
 - Parziale *et al.*, AIAA Paper 2015-530
 - Agrez *et al.*, Optics Letters, 45(6), 2020
- Commercial laser illumination systems with low coherence
 - Cavilux HF, Smart, and UHS
 - Specialised Imaging SI-LUX



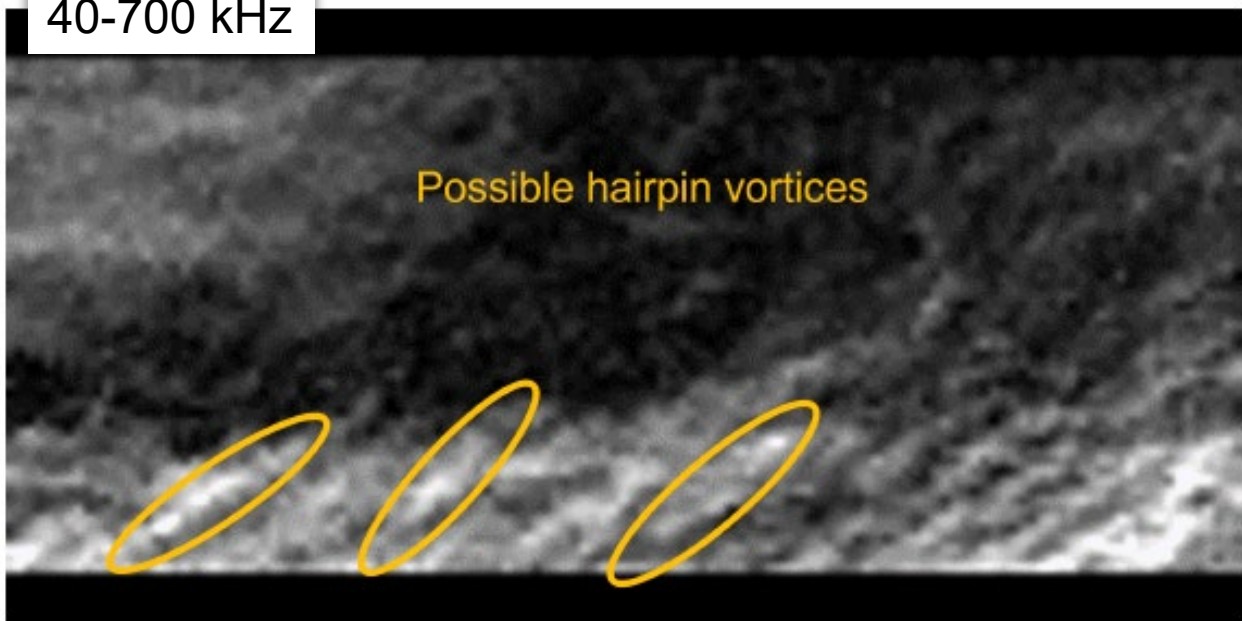


- Z-type schlieren system with telecentric imaging of transparent background



40-700 kHz

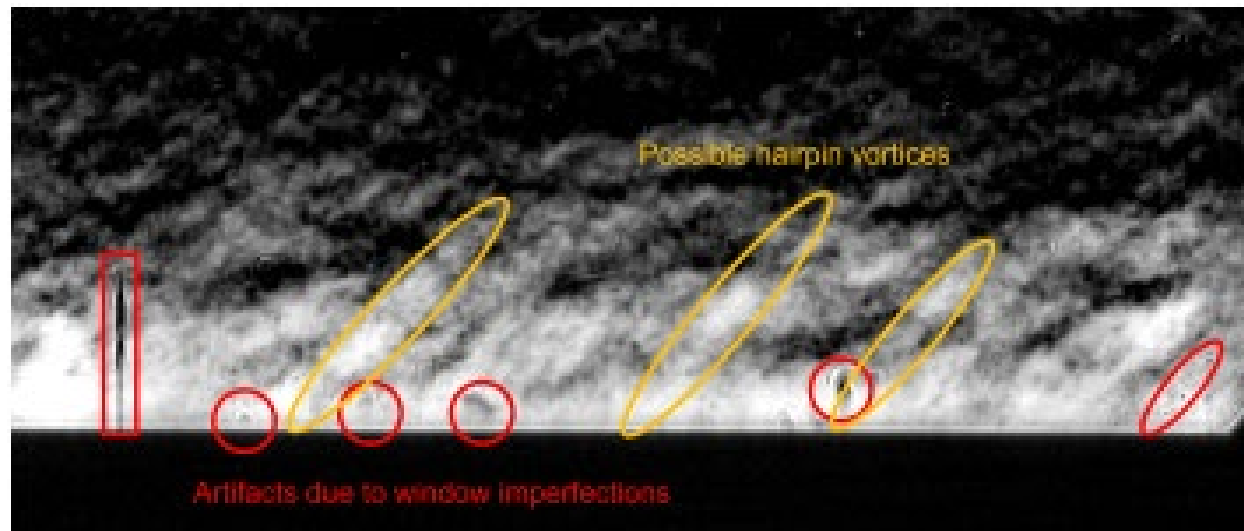
Possible hairpin vortices



T. Zhou *et al.*, 2024 AIAA SciTech Forum, Paper 2024-2126.

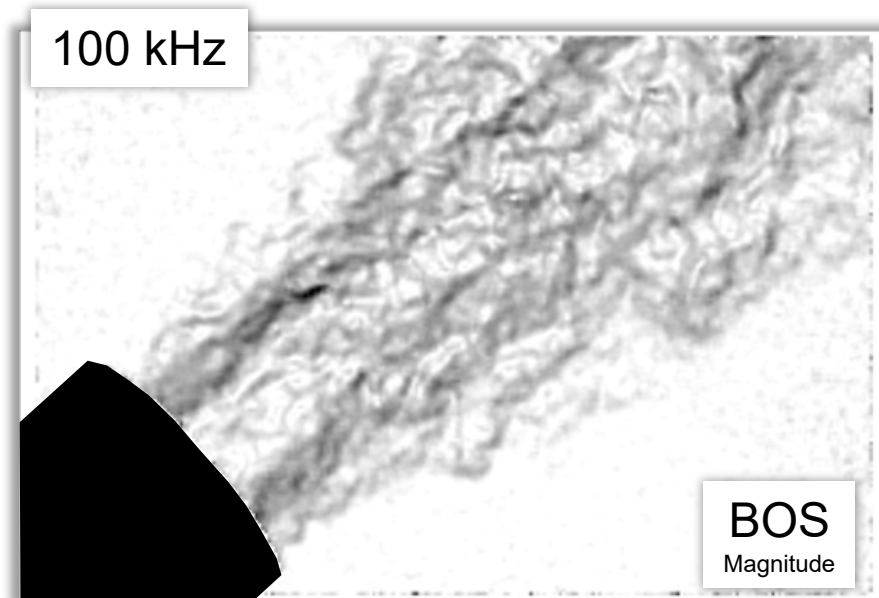
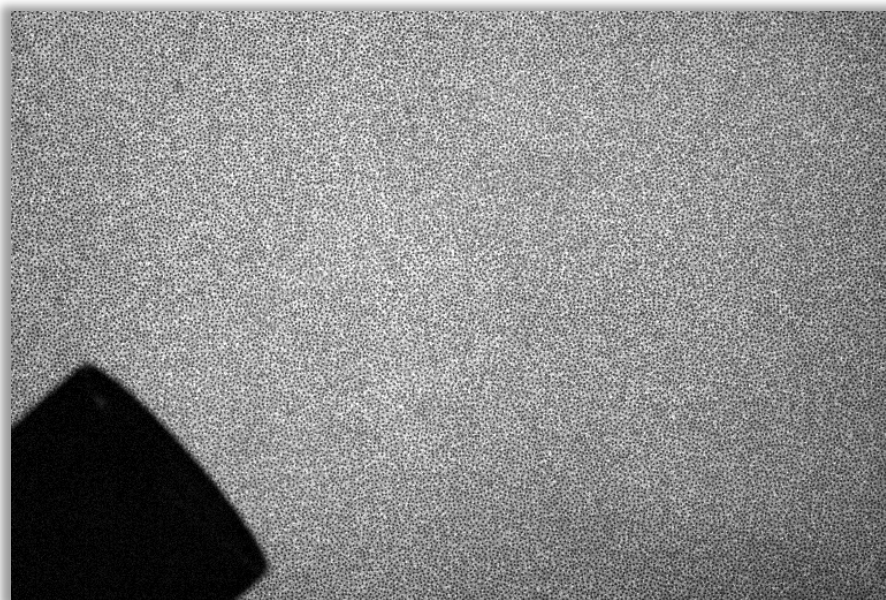
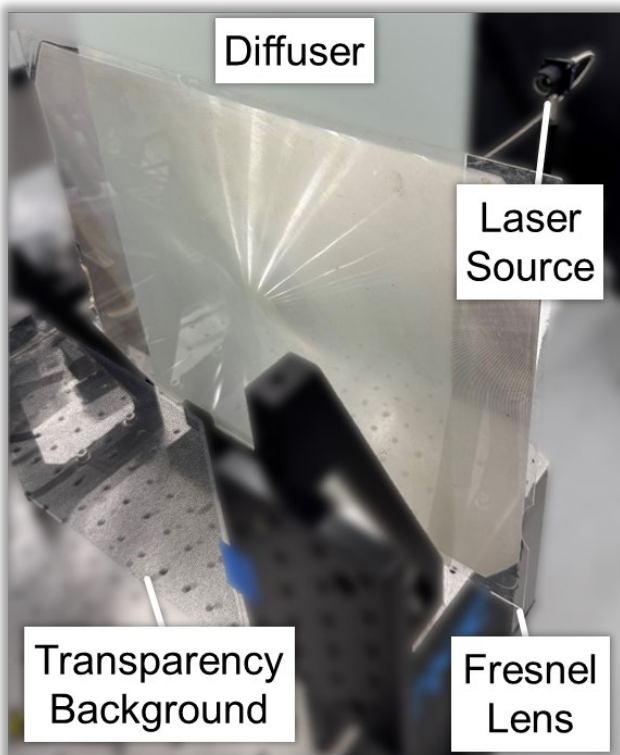
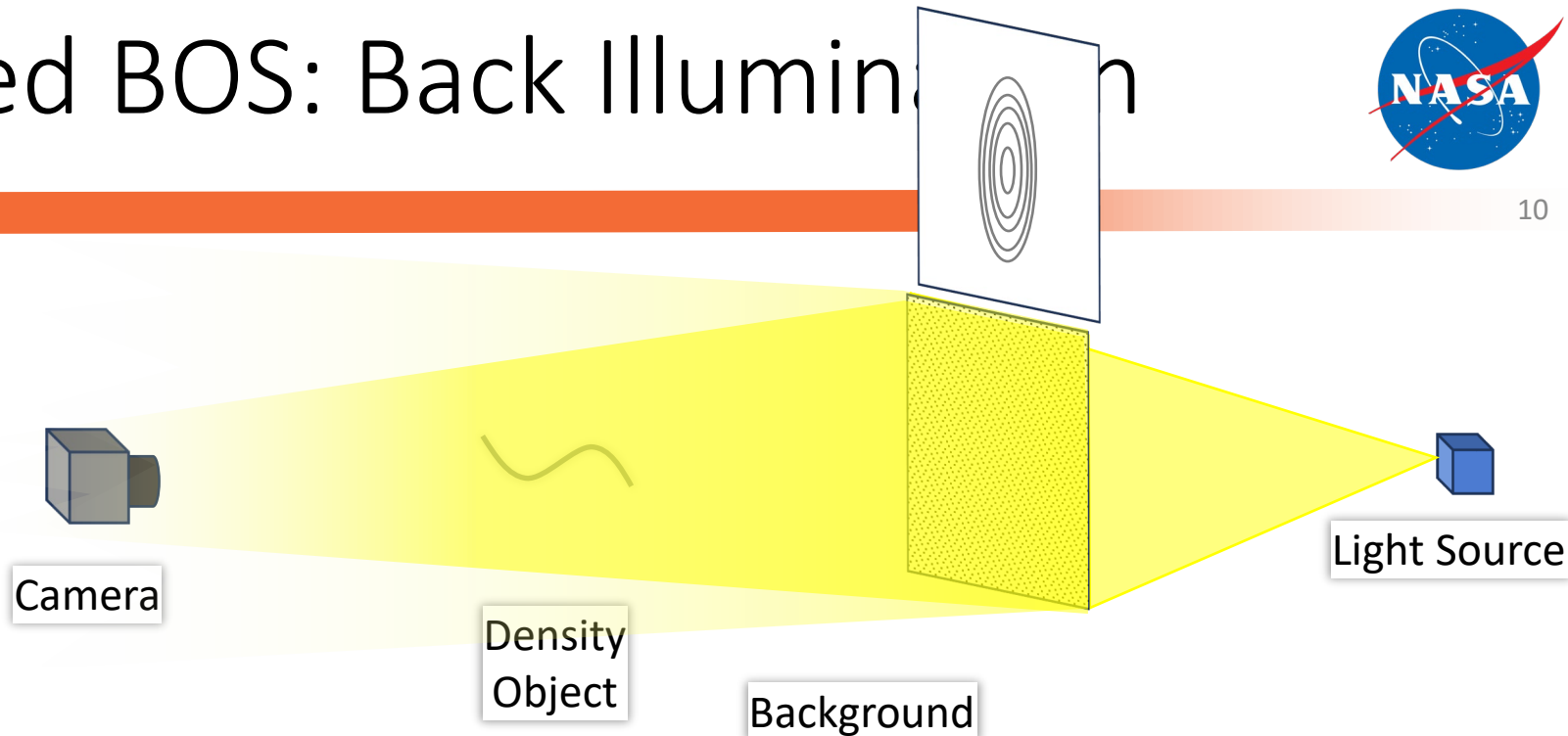
Possible hairpin vortices

Artifacts due to window imperfections

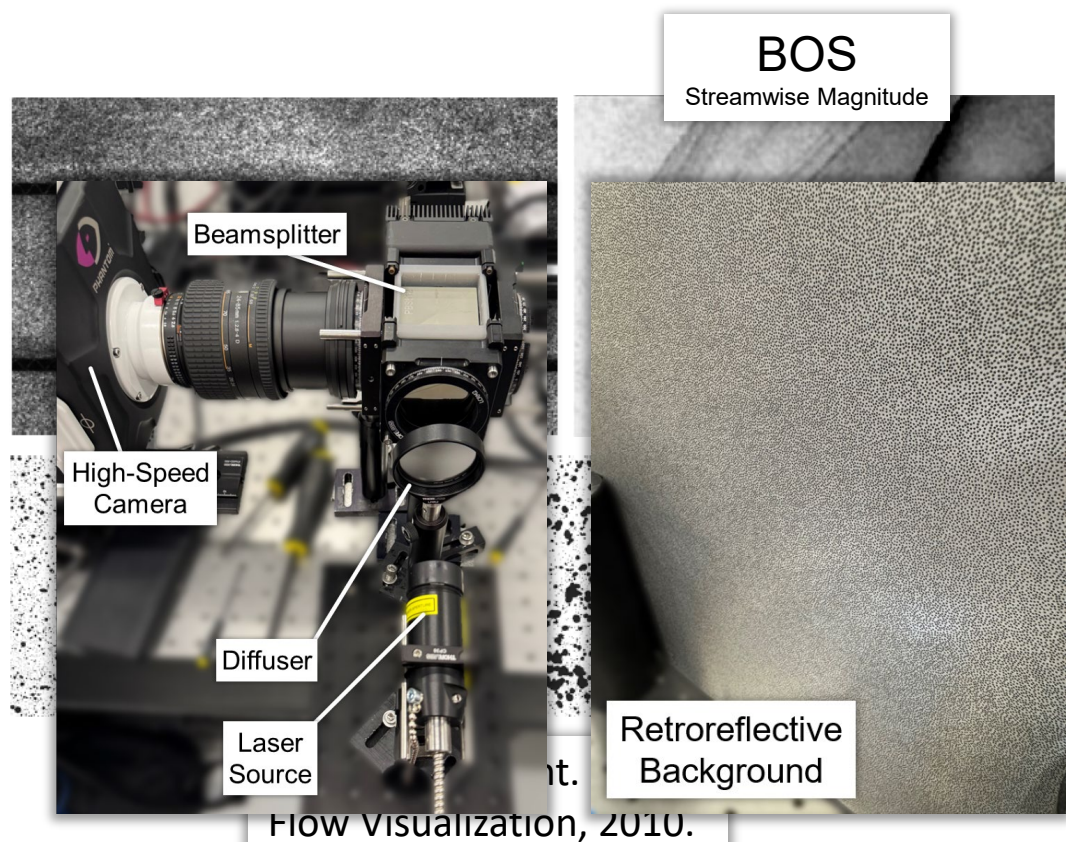




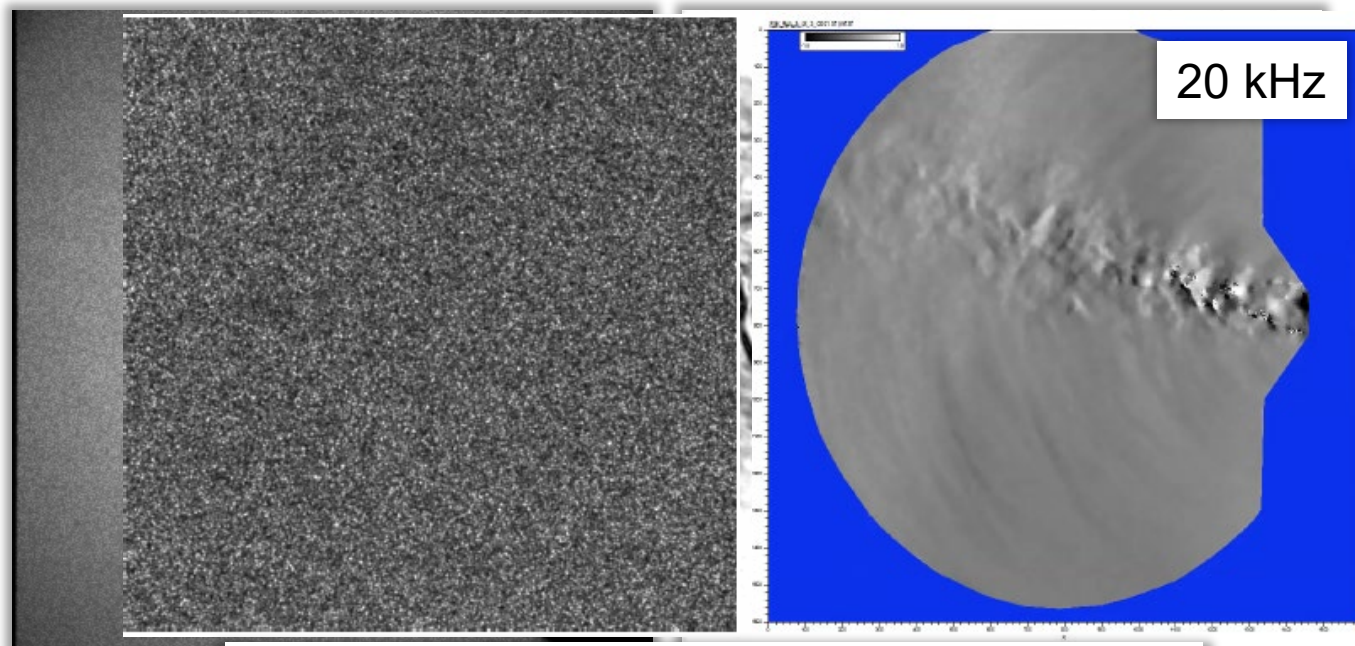
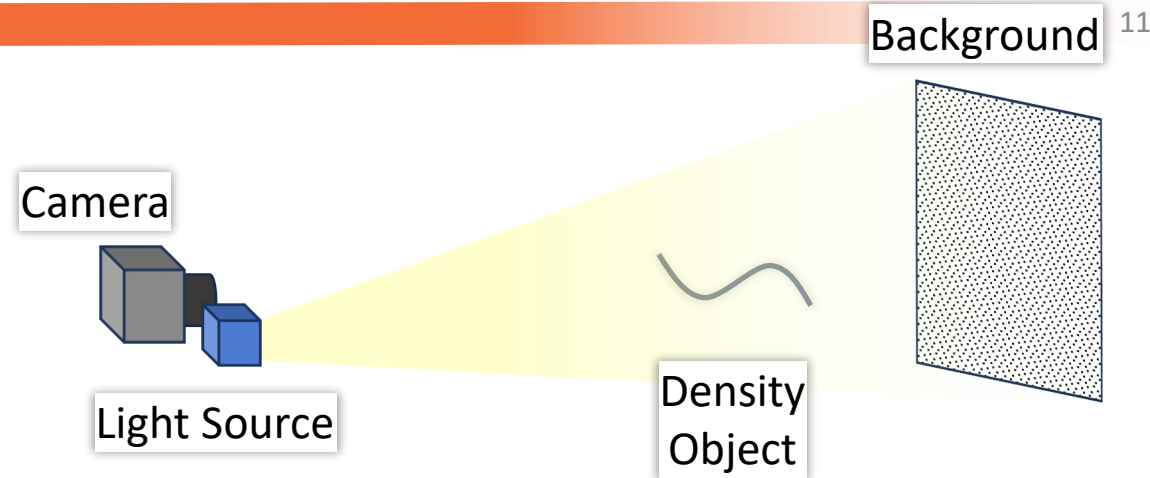
- Direct back-illumination of transparent pattern
 - Pattern printed on transparency



- Forward illumination of retroreflective background



Flow Visualization, 2010.



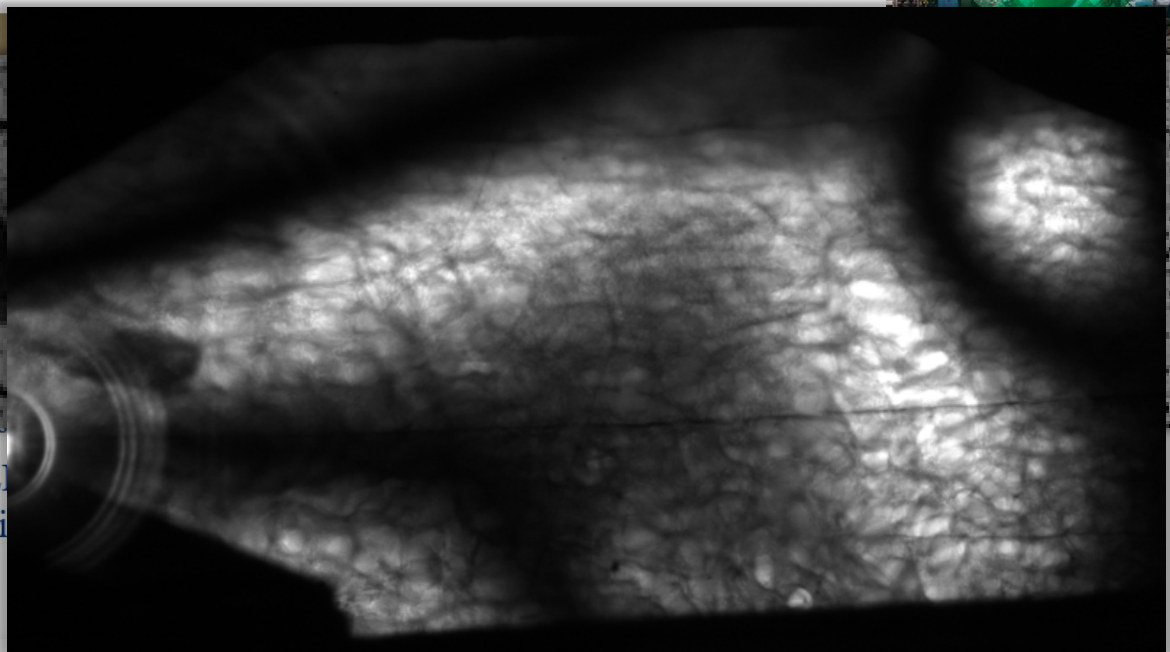
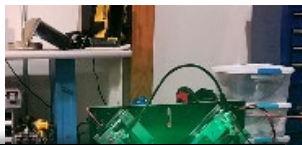
Kushner *et al.*, AIAA SciTech Forum, Paper 2015-1697.

After Burgess *et al.*, ISPRS J. Photogrammetry & Remote Sensing, v. 66, 2011.

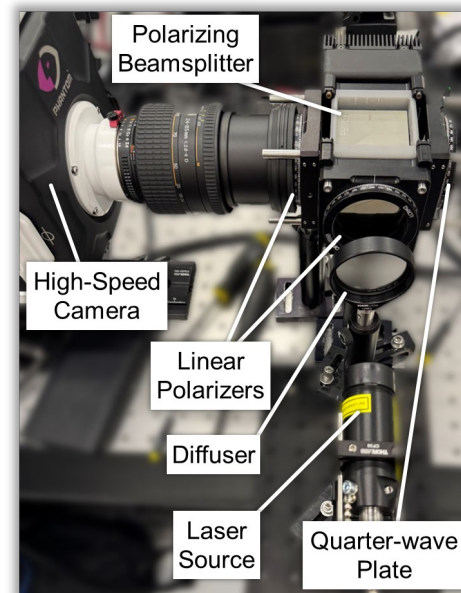
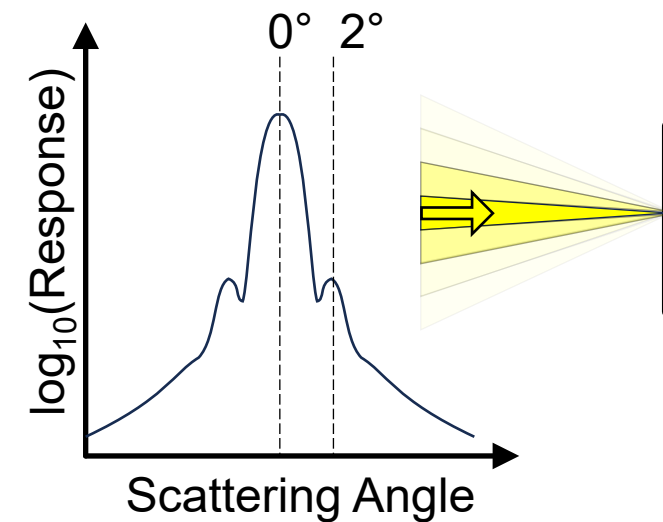
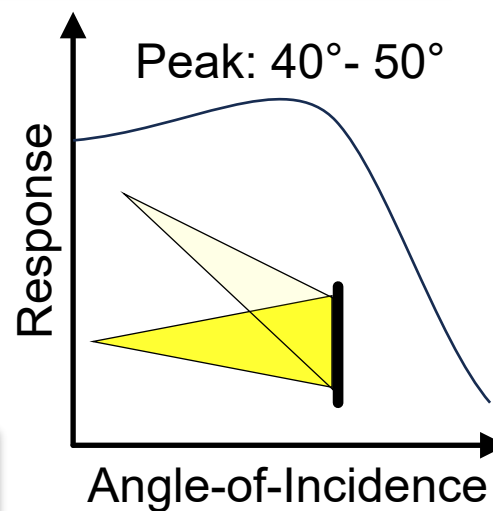
After Hericz *et al.*, Applied Optics, v. 56(14), 2017.

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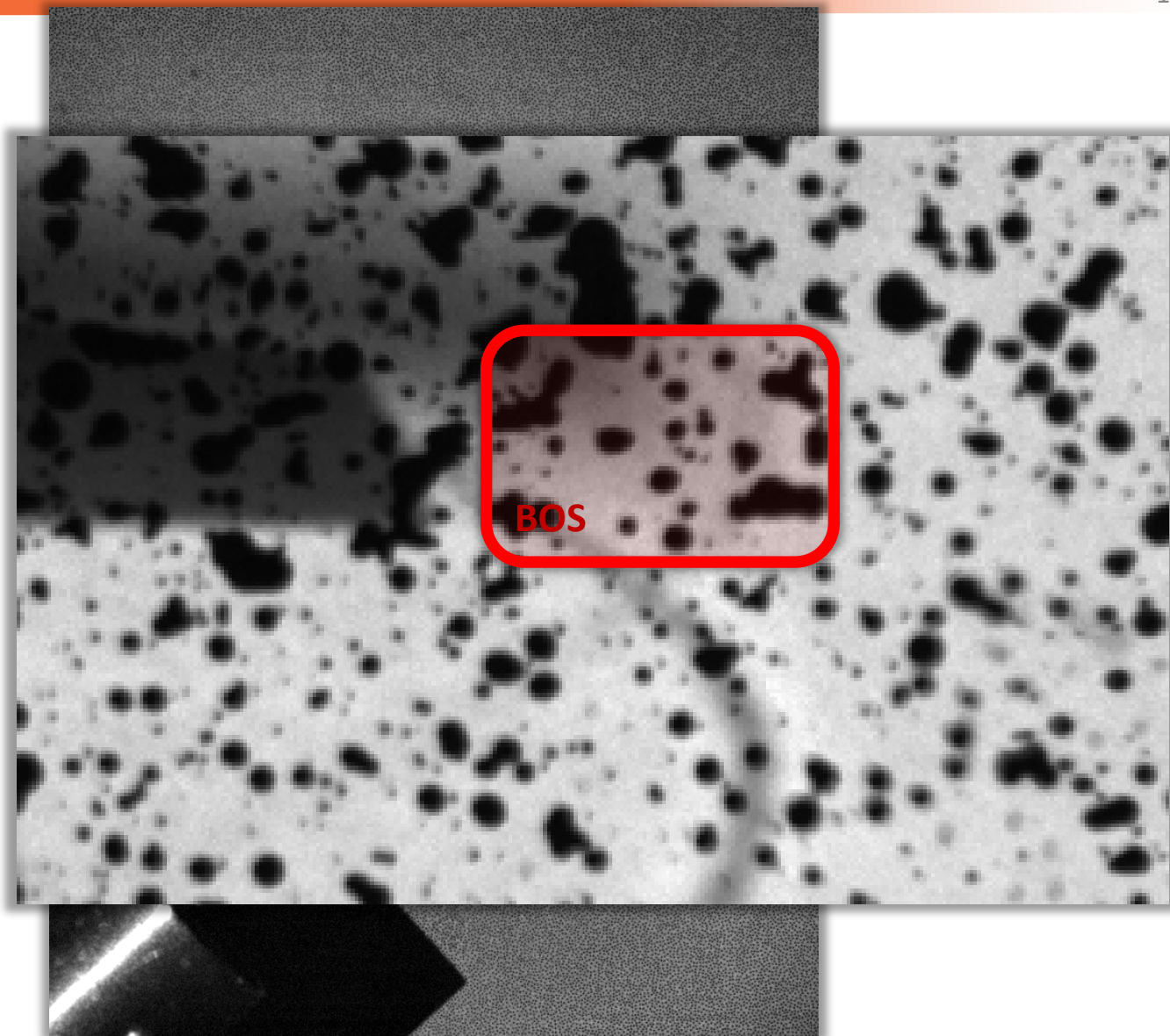
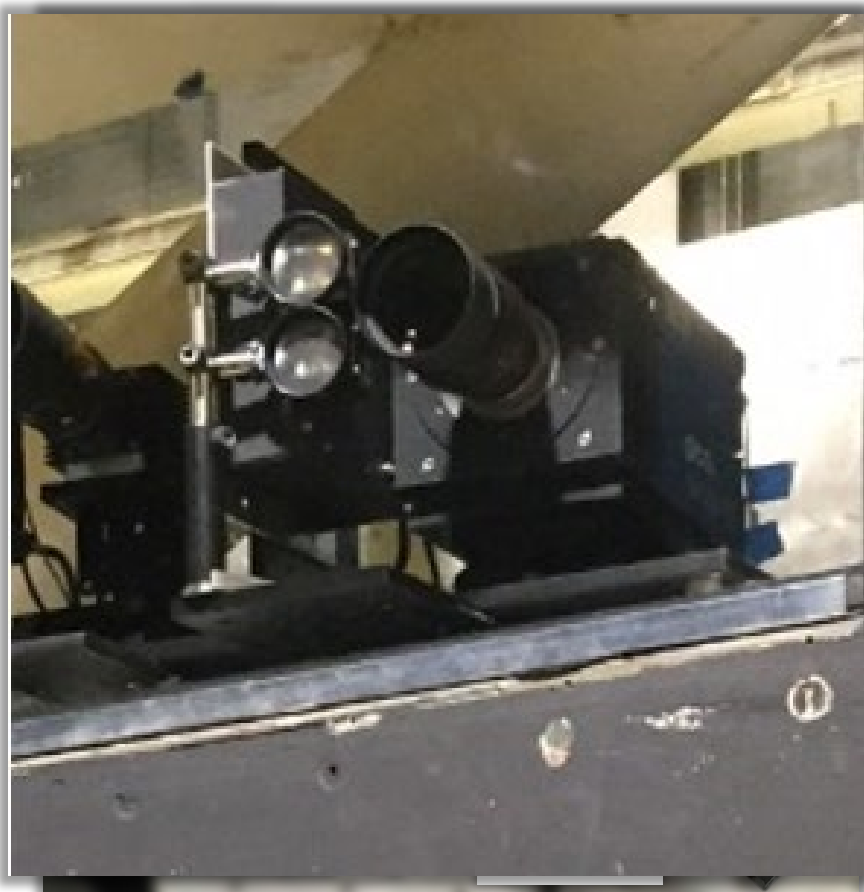
- Forward illumination of retroreflective backgrounds



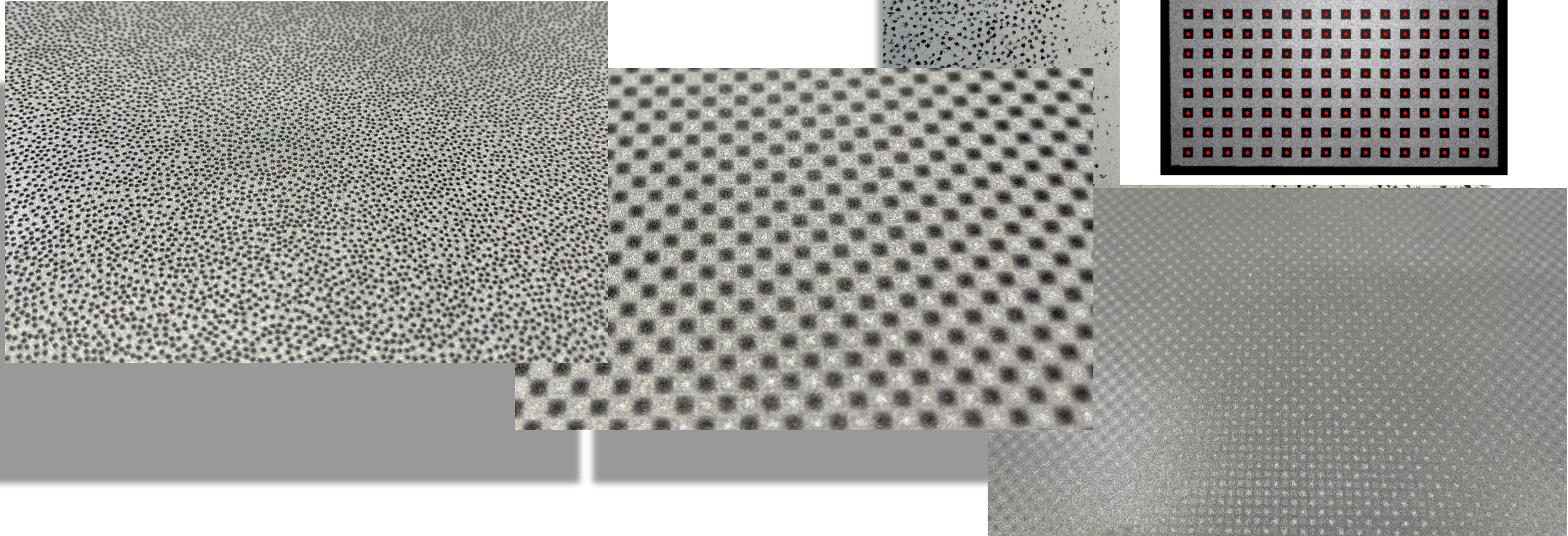
Weisberger *et al.*, AIAA SciTech Forum, Paper 2024-2500.

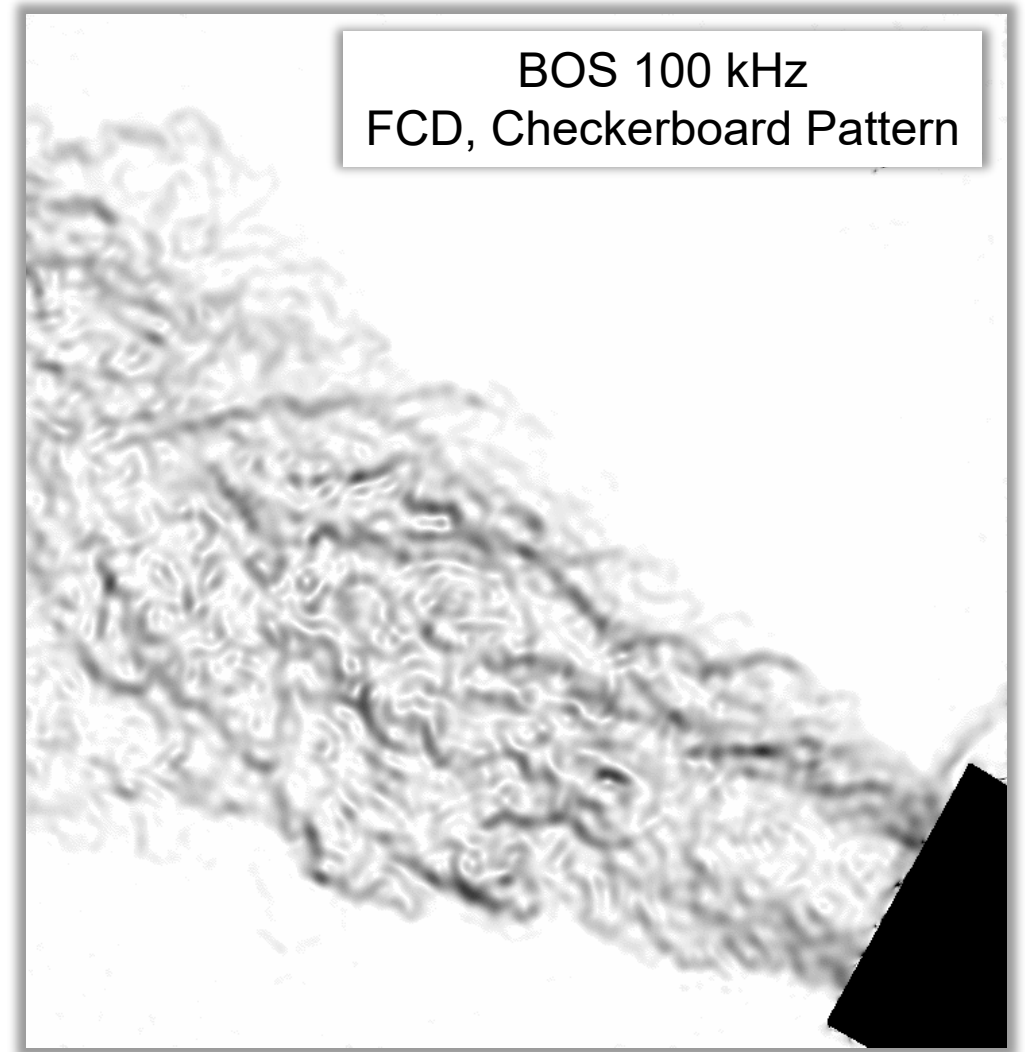
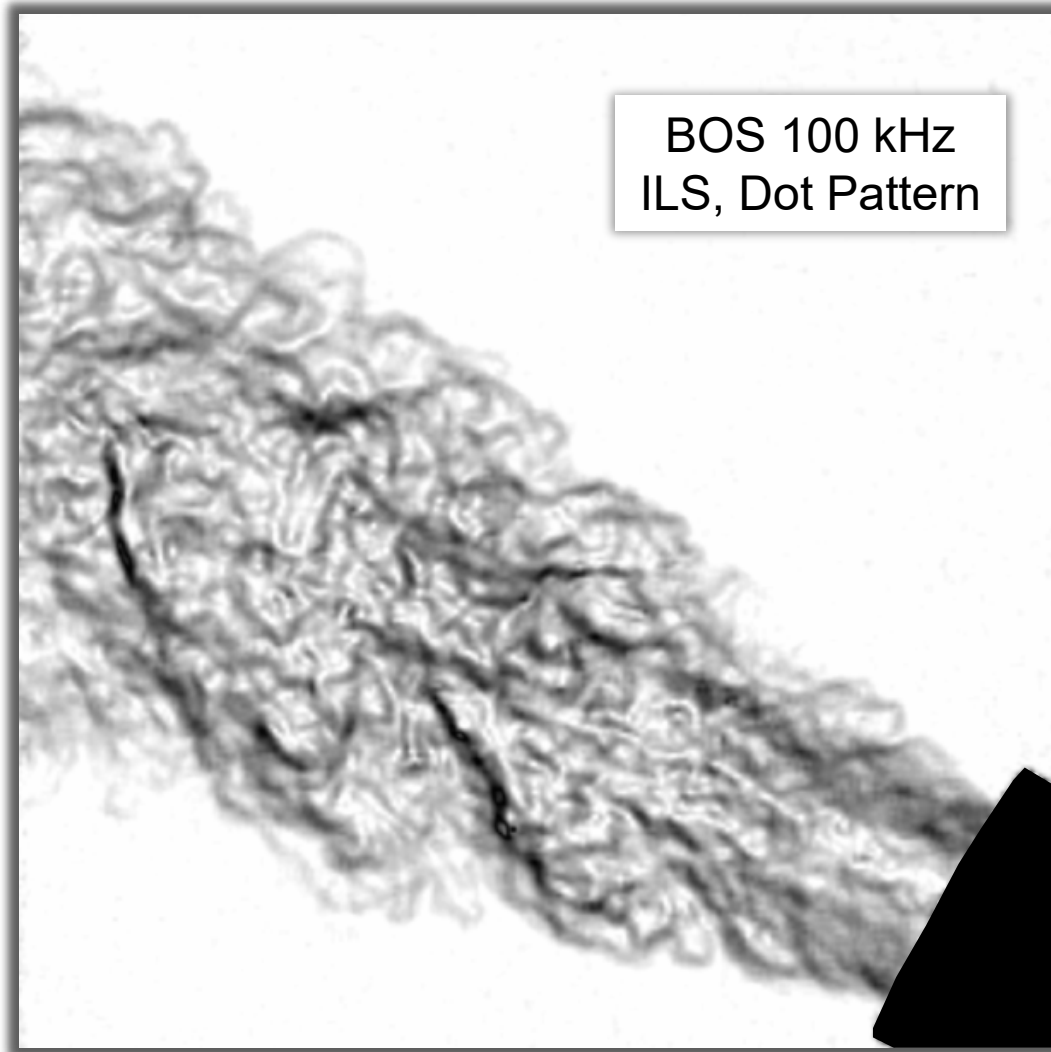


High-Speed BOS at NASA Langley



- Printing patterns on retroreflective materials





- Why BOS?
 - Low barrier to entry, easy setup, versatile, quantitative
- High-speed BOS examples
 - Forward illumination (diffuse background)
 - Back-illumination (transparent background)
 - Forward illumination (retroreflective background)
- Considerations in Application of High-Speed BOS in Large Ground Test Facilities
 - Performance characteristics of retroreflective sheeting
 - Use of colinear illumination and polarized light
 - Conditioning light sources to mitigate shadowgraph effects
 - Pattern application with advanced UV printing methods
- Acknowledgements:
 - Dr. Joshua Weisberger, Wayne Page, Steve Jones, Holt Ripley
 - Transformational Tools & Technologies (T³) Project, Aerosciences Evaluation & Test Capabilities (AETC) portfolio

- Invited Session on Background-Oriented Schlieren
- Speaking Order:
 - JT Heineck (NASA Ames)
 - In-flight BOS, processing methods for in-flight BOS
 - Sam Grauer (Penn State)
 - Tomographic BOS, use of neural networks for to estimate multiple parameters from BOS data, fundamental derivations
 - Mike Hargather (Los Alamos)
 - Outdoor BOS, BOS for ballistics and explosives
 - Former student of Gary Settles (literally wrote the book on schlieren-based imaging)
 - Bryan Schmidt (Case Western)
 - Markus Raffel (DLR)
 - Inventor of BOS, BOS applications, fundamentals of BOS
 - Brett Bathel (NASA Langley)
 - High-speed BOS, challenges for large-scale test facilities

Twenty-Five Years of Background-Oriented Schlieren: Advances and Novel Applications

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Invited Talk: Considerations for High-Speed Background-Oriented Schlieren Visualization Capability for Ground Test Facilities

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