Developing Non-Intrusive Diagnostics for the Characterization of Direct-Fired sCO_2 Flows

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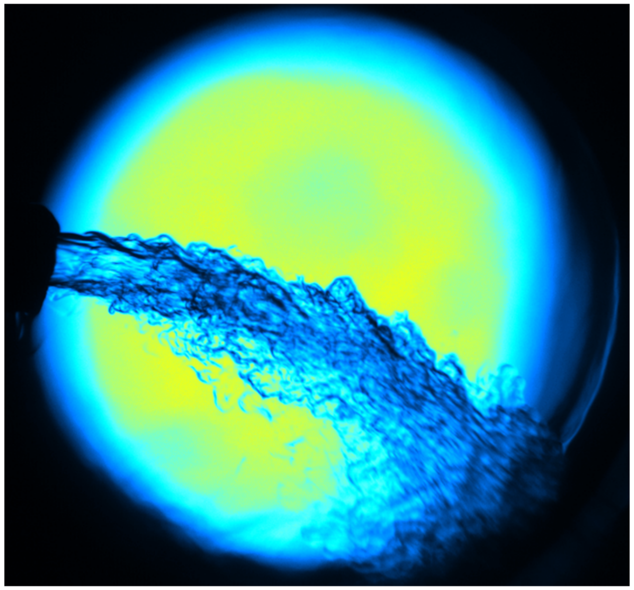
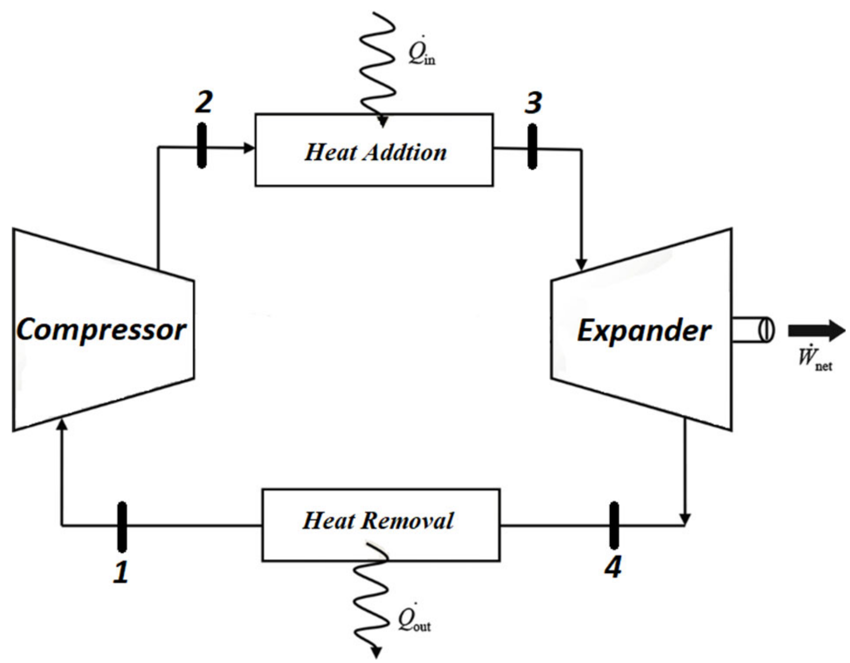


Funded by UTSA VPREDKE Connect program

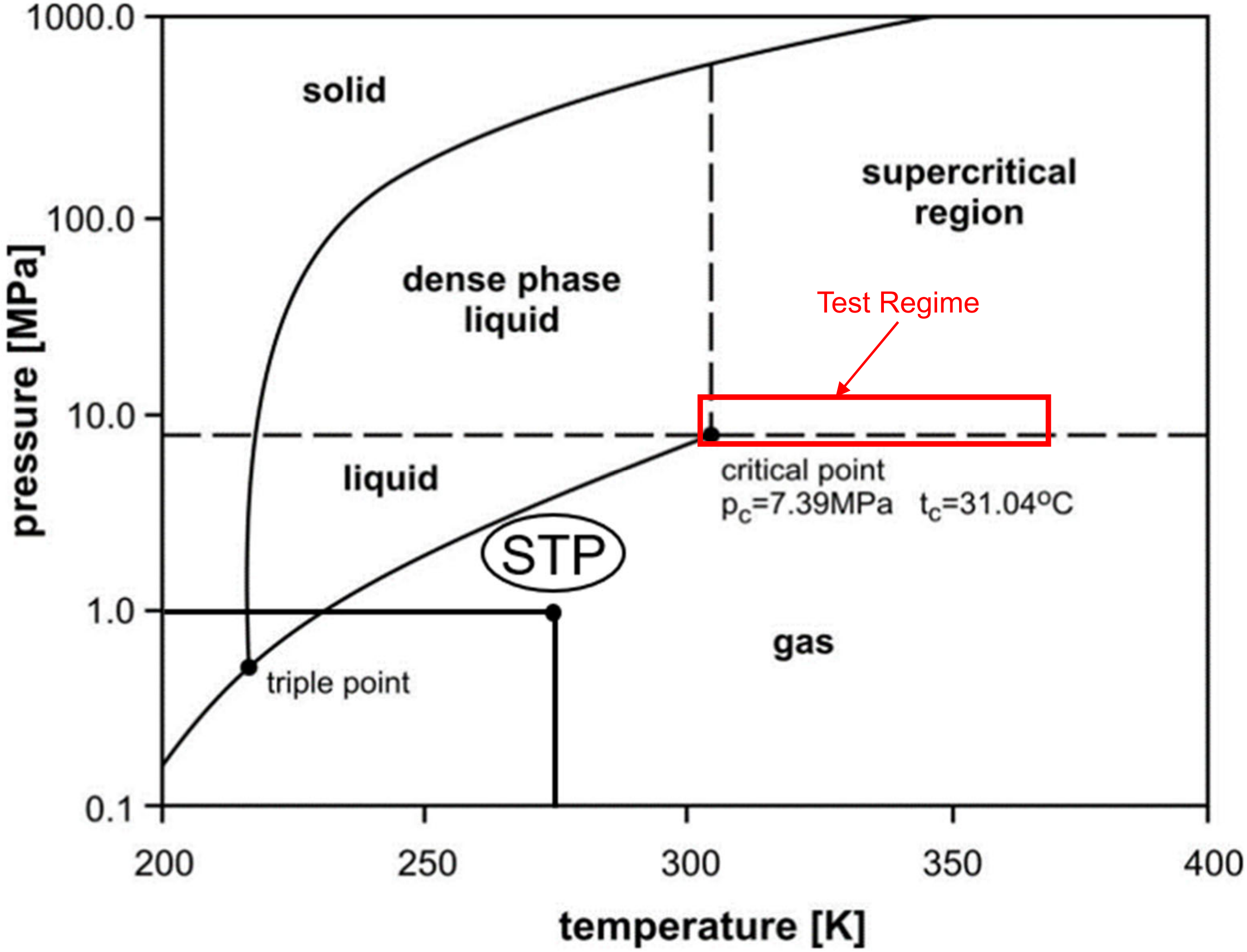
Motivation

- Assist in the development of efficient sCO_2 cycles
- Provide a means of obtaining validation data sets for computational models (CFD)



Closed Loop sCO_2 Brayton Cycle schematic – Patel et al. (2021)

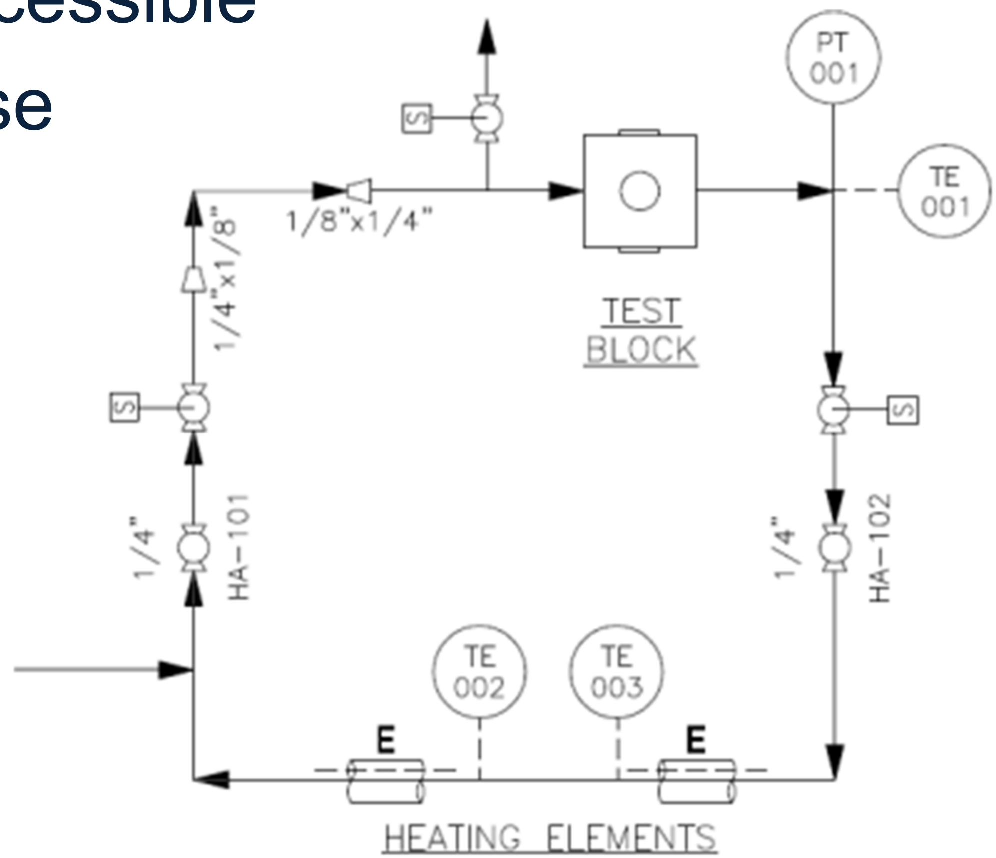
Test Regime



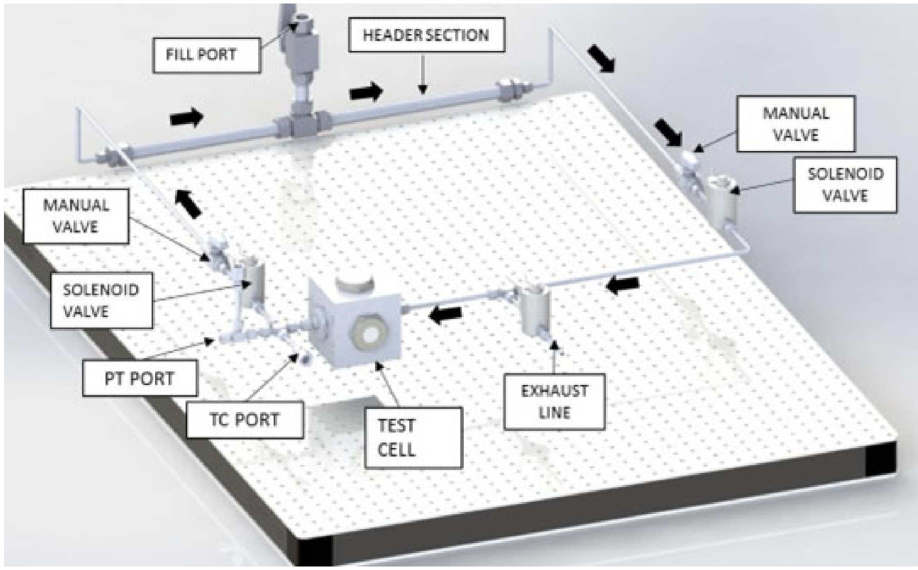
1000.0
100.0
10.0
1.0
0.1
pressure [MPa]
solid
supercritical region
dense phase liquid
Test Regime
liquid
critical point
pc=7.39MPa tc=31.04ºC
STP
gas
triple point
200
250
300
350
400
temperature [K]

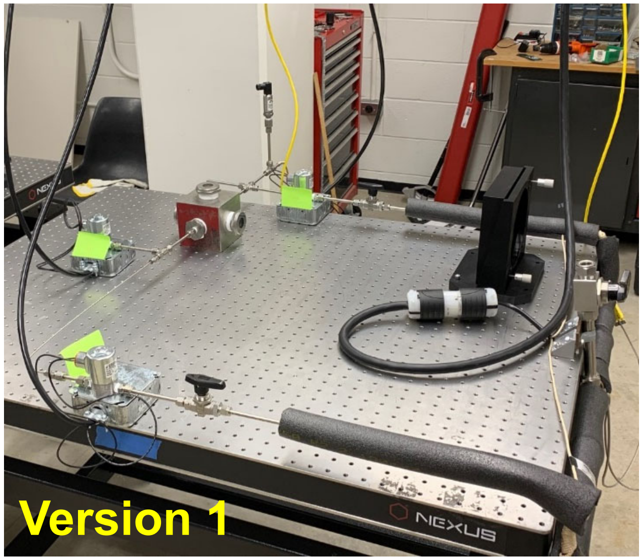
System Design Requirements

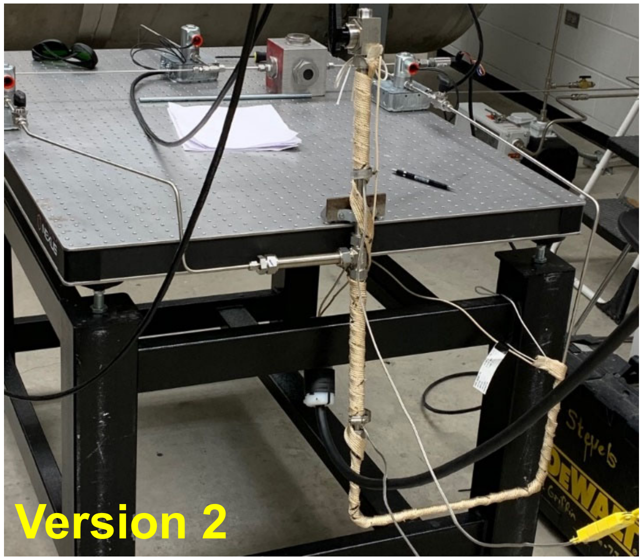
- Handle CO_2 @ conditions up to
  - P = 17.2 MPa (2500 psia) T = 373 K (212 F)
- Optically accessible
- Simple to use

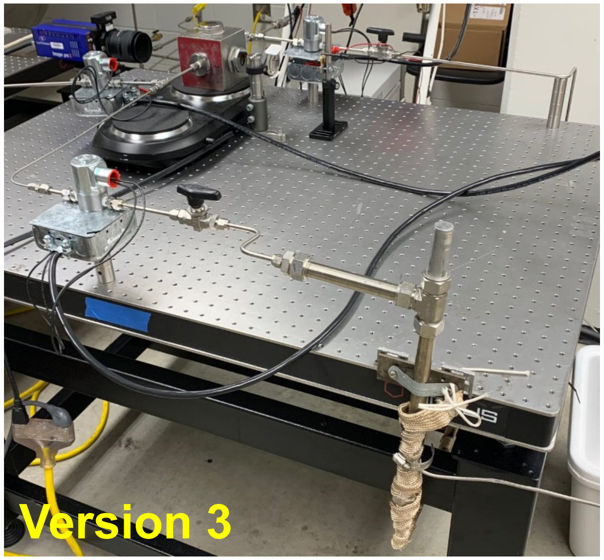


Completed System

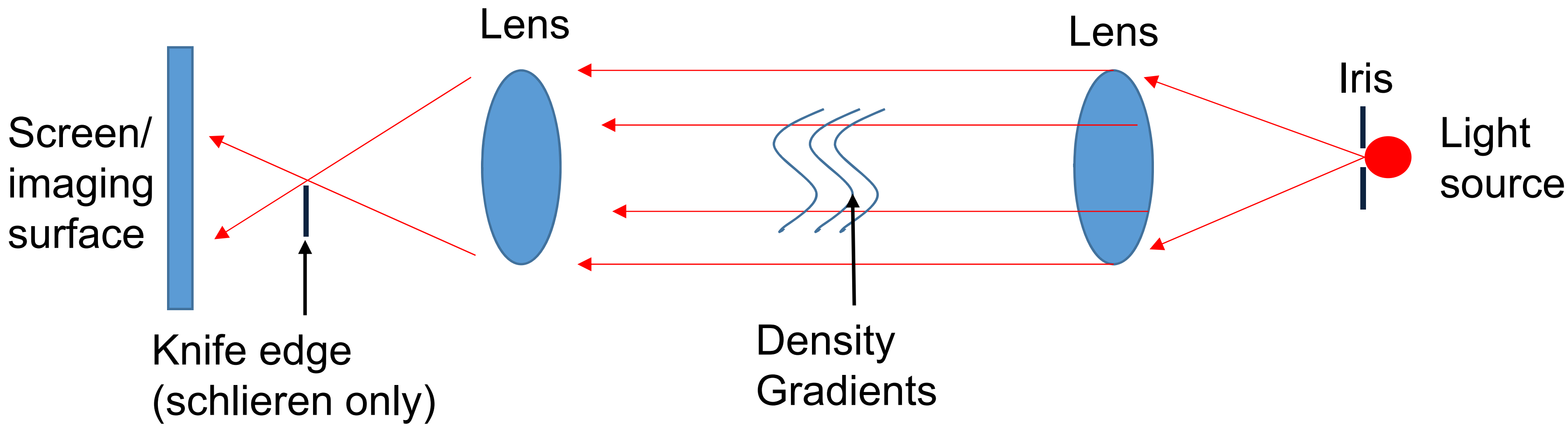




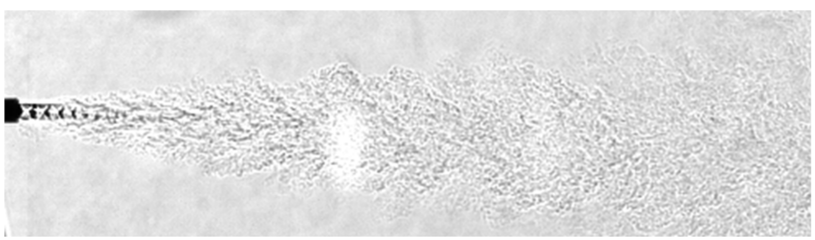




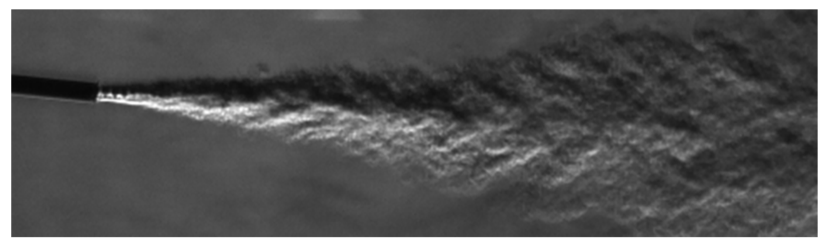
Shadowgraphy / Schlieren



Ray Tracing Diagram of Shadowgraphy Setup



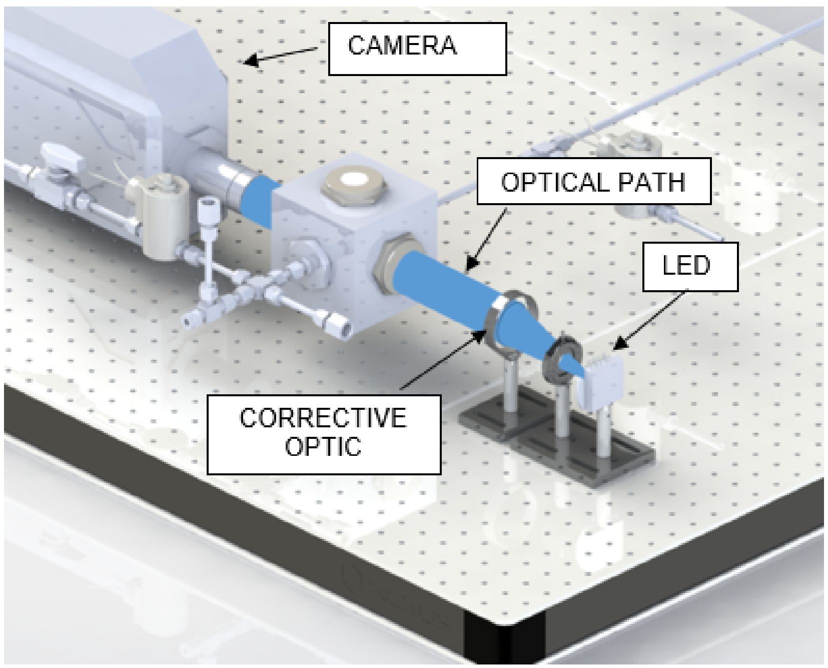
Shadowgraphy Jet visualization



Schlieren Jet visualization

Shadowgraphy setup in System

Property	Lavision Imager ProX	Photron FastCam Saz
Acquisition Rate (Hz)	20	2000
Resolution	1600p ×1200p	1024p × 1024p



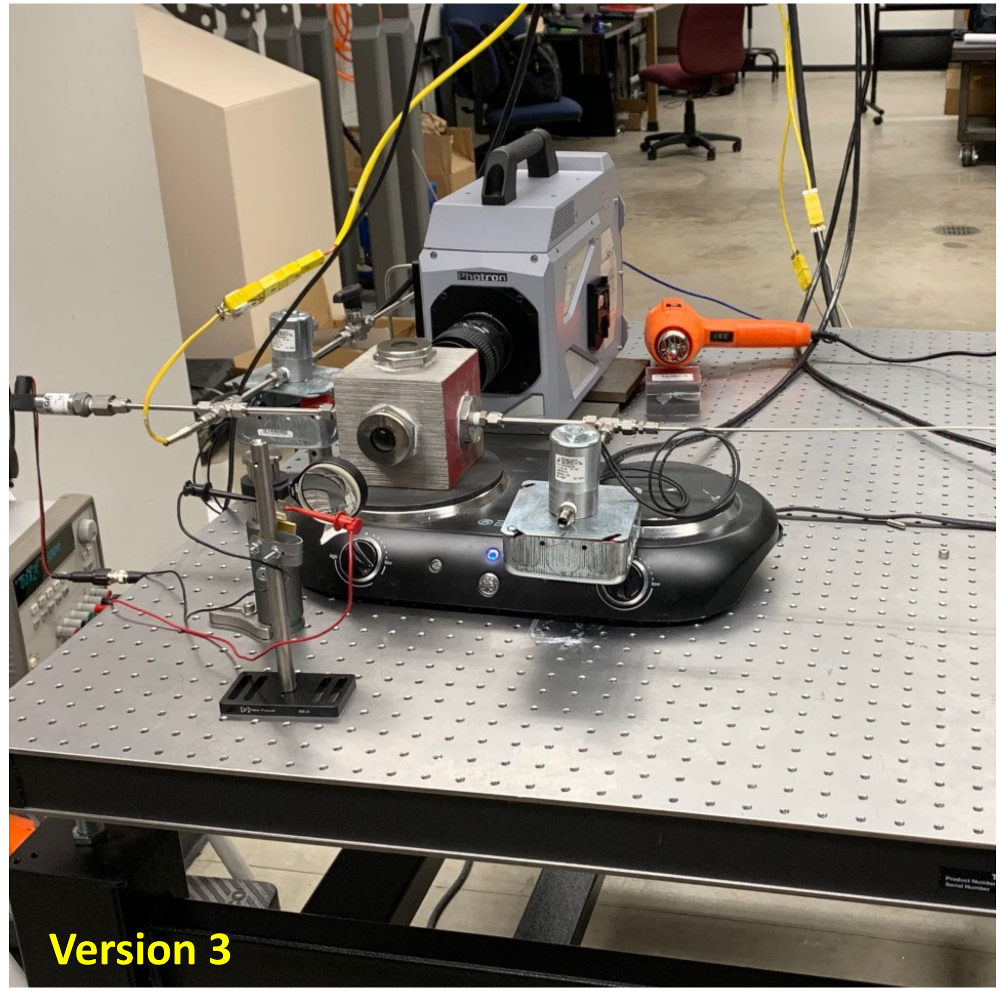
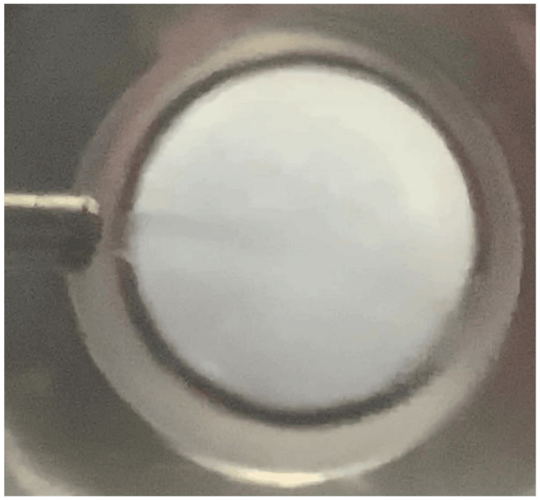
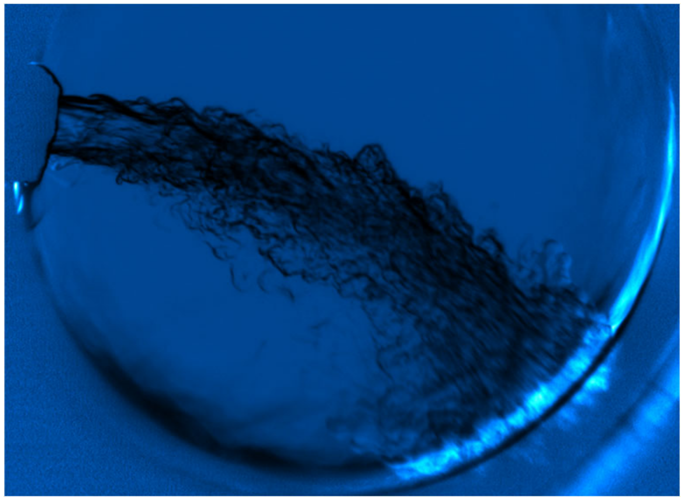


Image Results

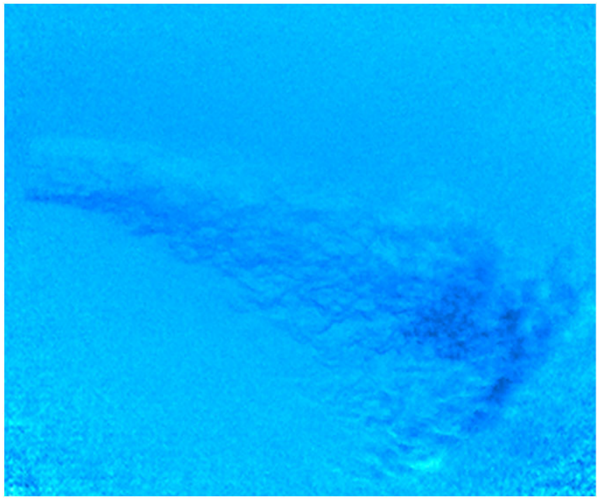
- Sample images acquired



Standard camera footage



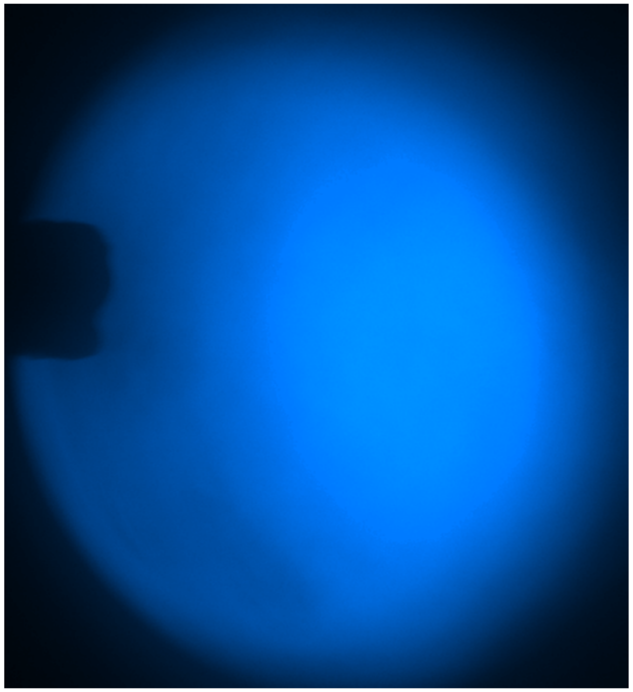
High resolution shadowgraphy images from Lavision Imager Pro-X



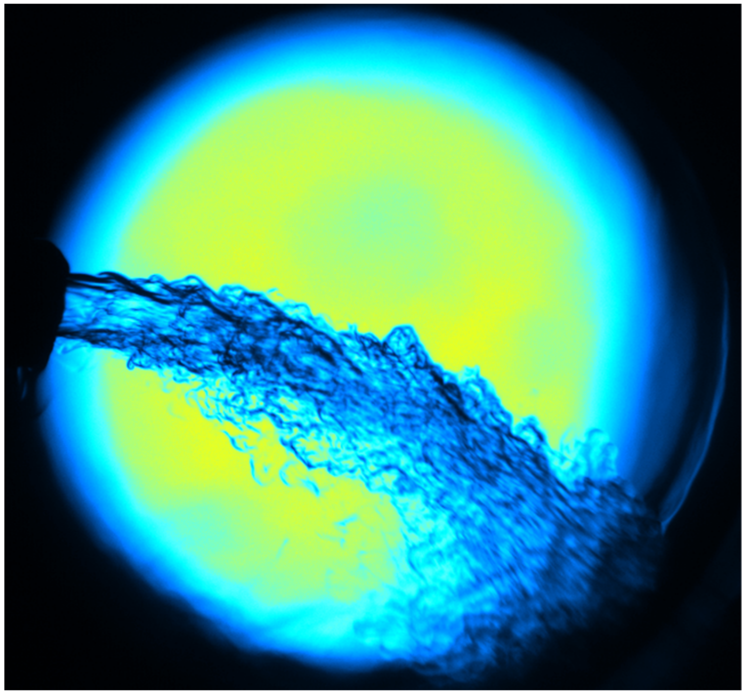
Time-resolved shadowgraphy images from Photron SA-Z

Image Results

- Footage of sCO_2 at various states



Optical Opacity witnessed during transition across critical point



Above critical point

UTSA

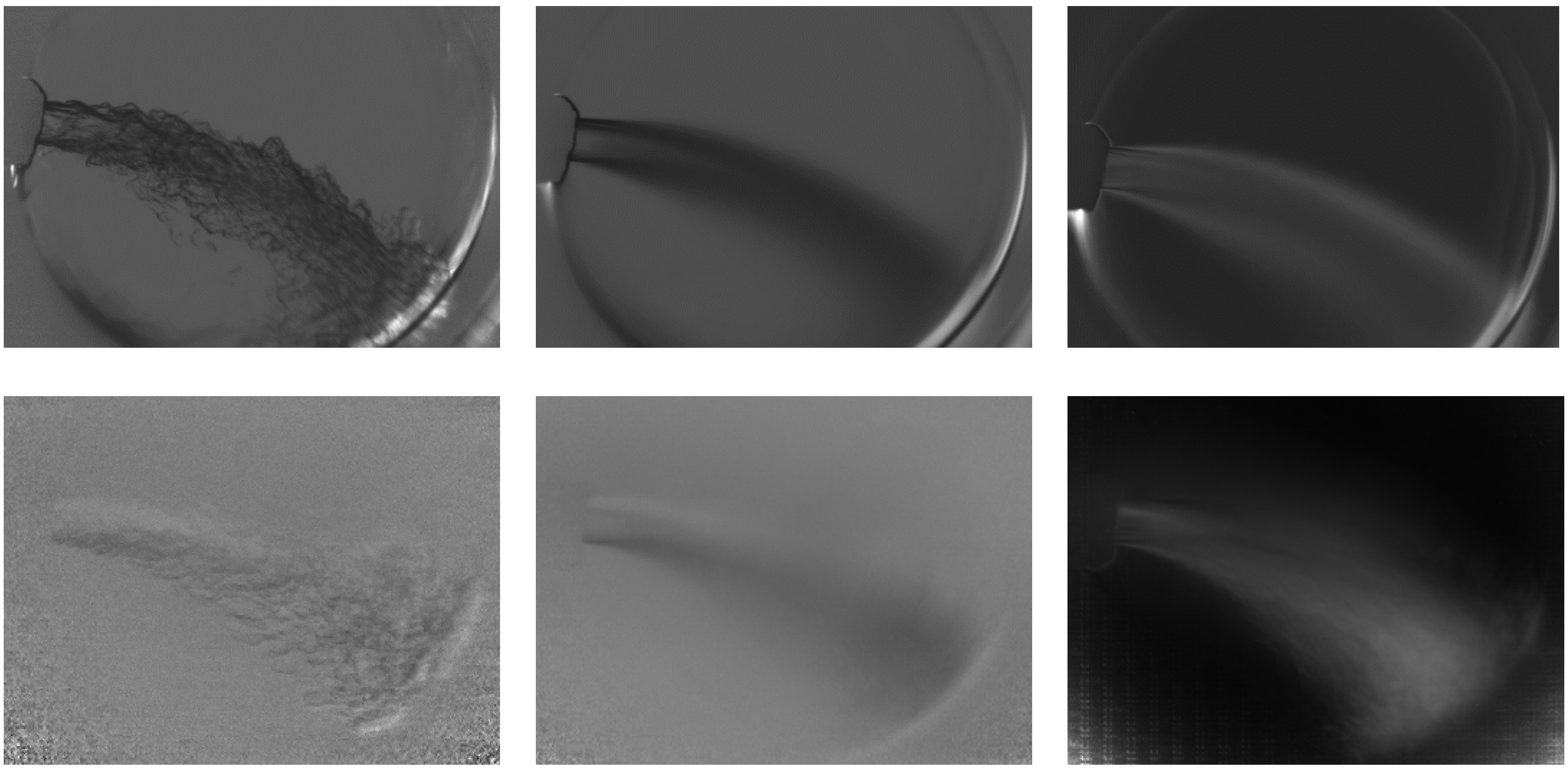
Results

- Descriptive Statistics
  - Image count: 2000

Instantaneous Image | Average Image | Standard Deviation Image

Lavision Imager Pro X 20 Hz

Photron Fastcam 2000 Hz



Proper Orthogonal Decomposition (POD)

- Snapshot POD (Spatially orthogonal modes)

- Steps
  1. Create data matrix
  2. Obtain mean of data set
  3. Create mean matrix
  4. Obtain fluctuating properties matrix
  5. Calculate correlation matrix
  6. Perform eigenvalue decomposition
  7. POD modes

$$X = \begin{bmatrix} X_1 & X_2 & X_3 \cdots & X_n \end{bmatrix} \text{ (1)} \rightarrow \bar{x} \text{ (2)} \rightarrow \bar{X} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \bar{x} \text{ (3)}$$

$$A = X - \bar{X} \text{ (4)}$$

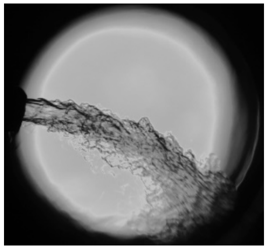
$$B = A^T A \text{ (5)}$$

$$BV = CV \text{ (6)}$$

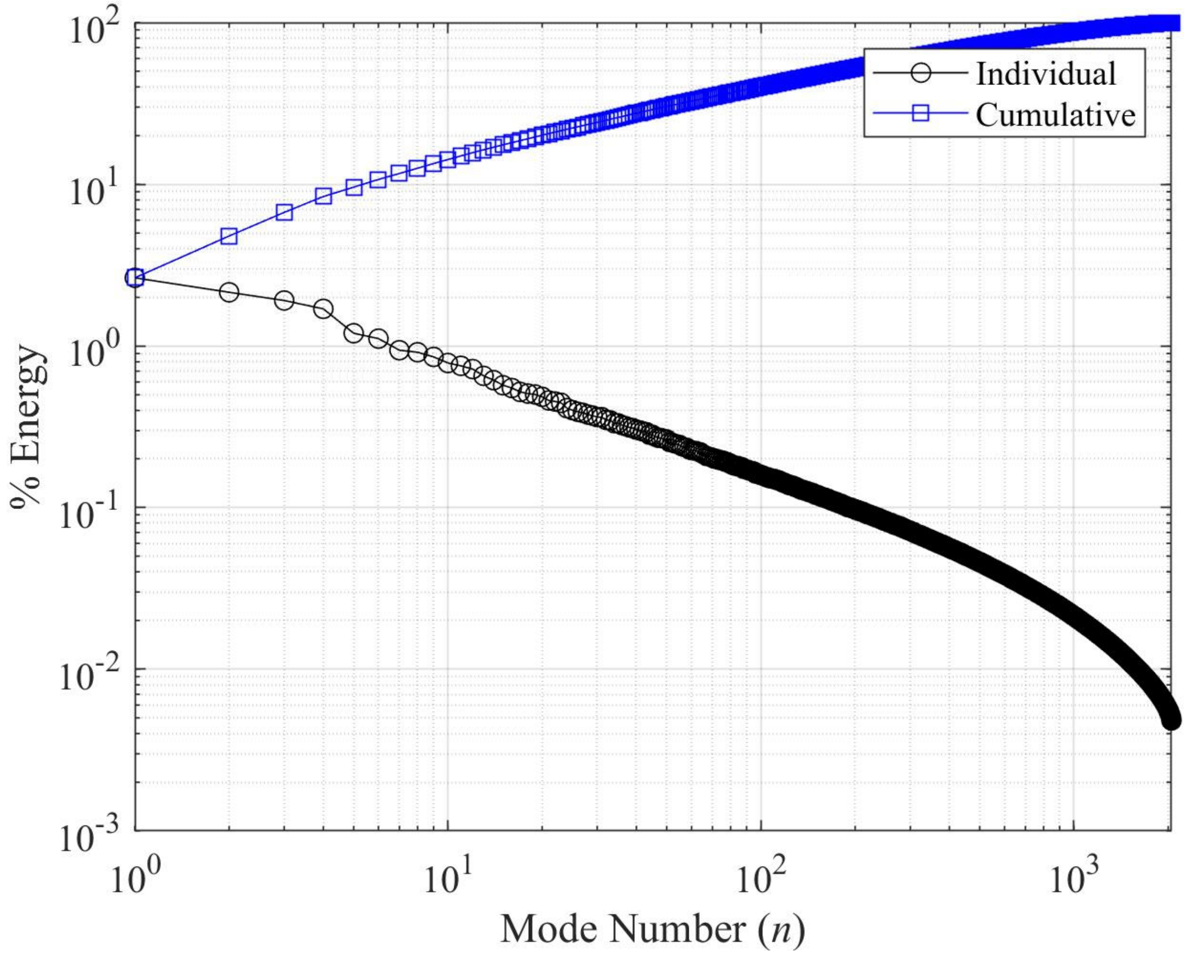
$$Z = AV \text{ (7)}$$

A = Fluctuating properties matrix
B = Temporal correlation matrix
C = Eigen values
X = Original data
V = Eigen vectors
Z = POD modes

POD Results

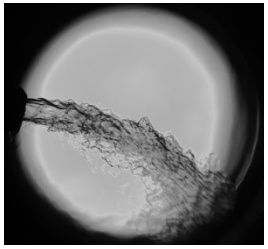


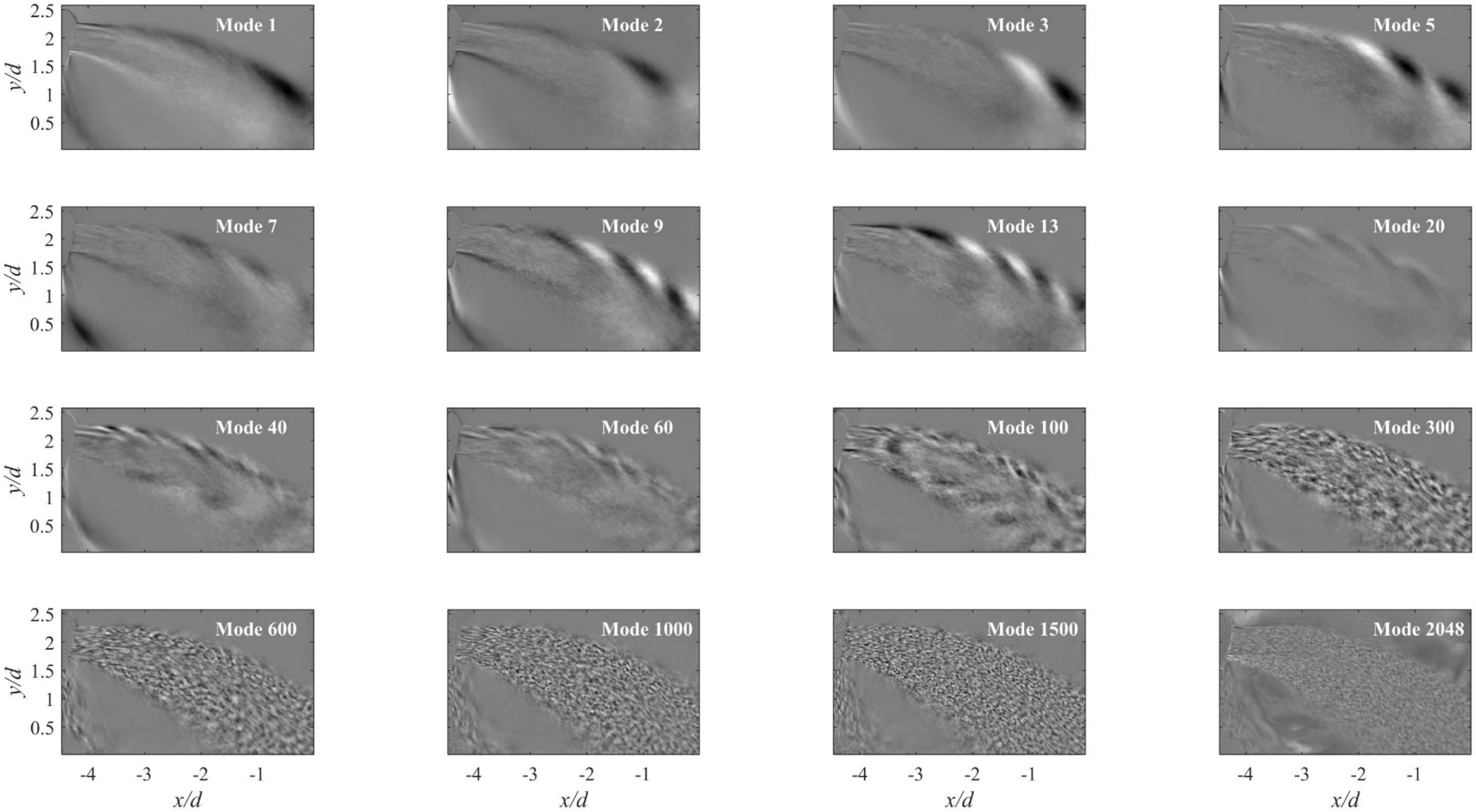
- Individual and Cumulative Energy Distribution



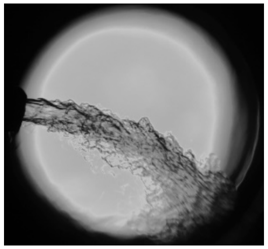
POD Results

- Individual modes

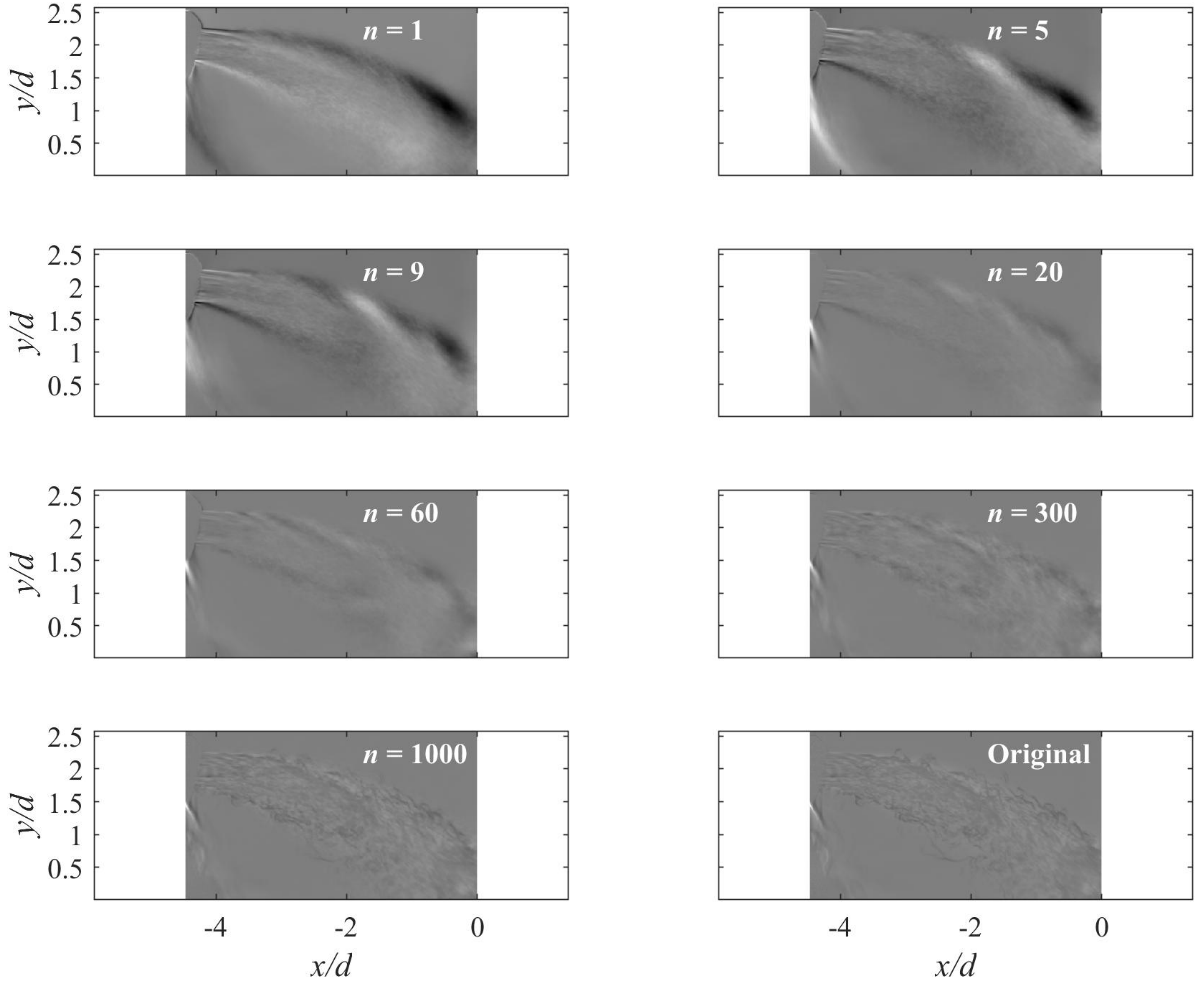




POD Results

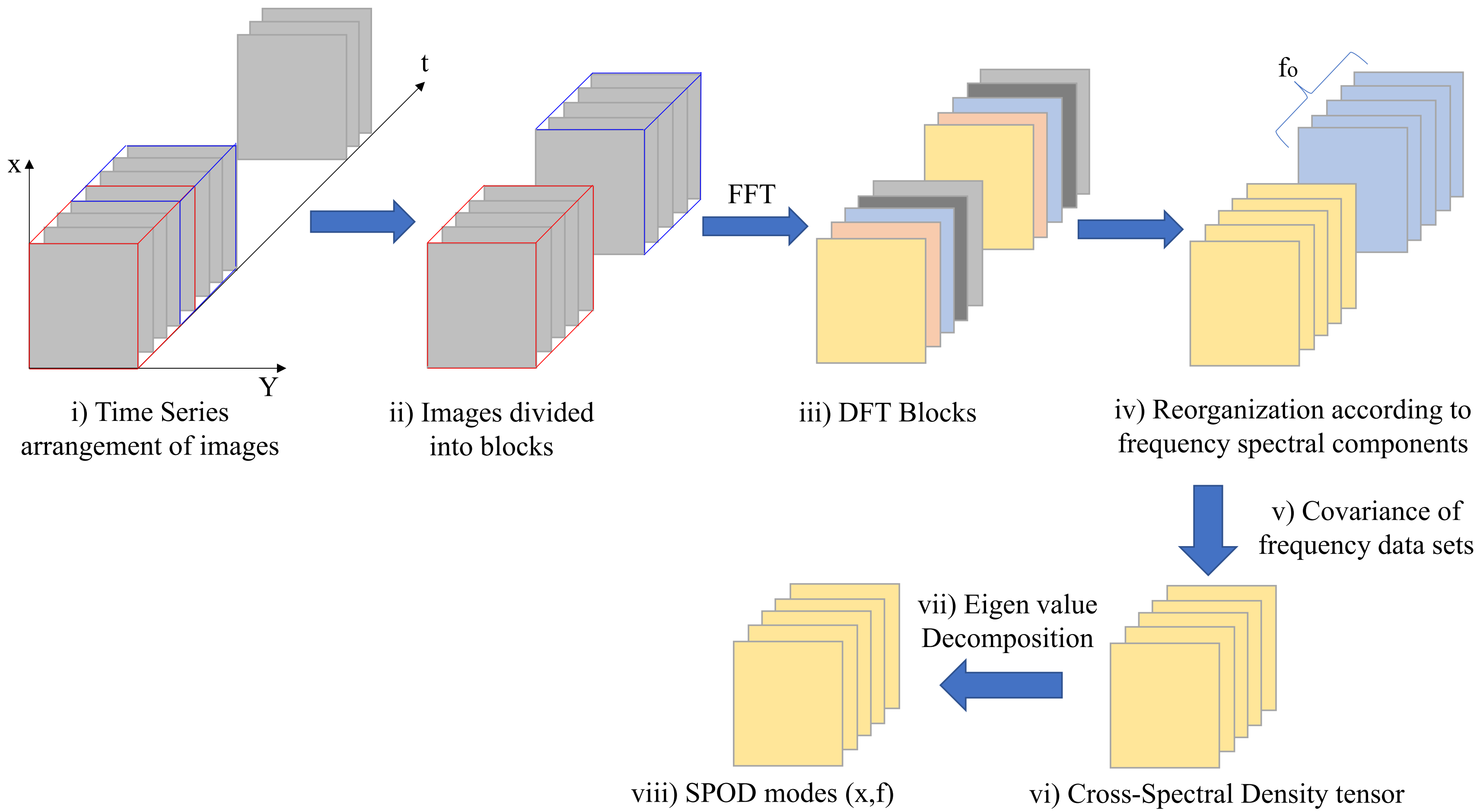


- Cumulation/ Summation of modes

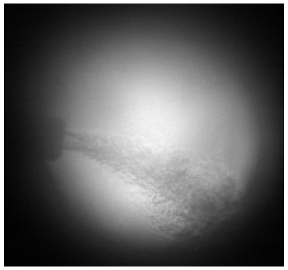


Spectral Proper Orthogonal Decomposition (SPOD)

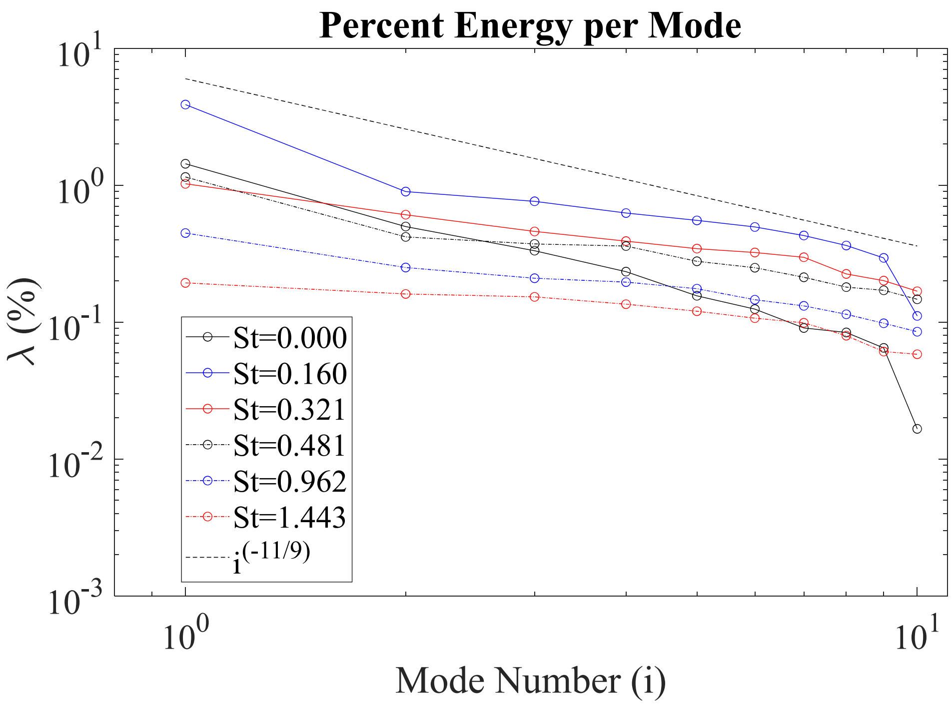
- Spatially and temporally orthogonal modes

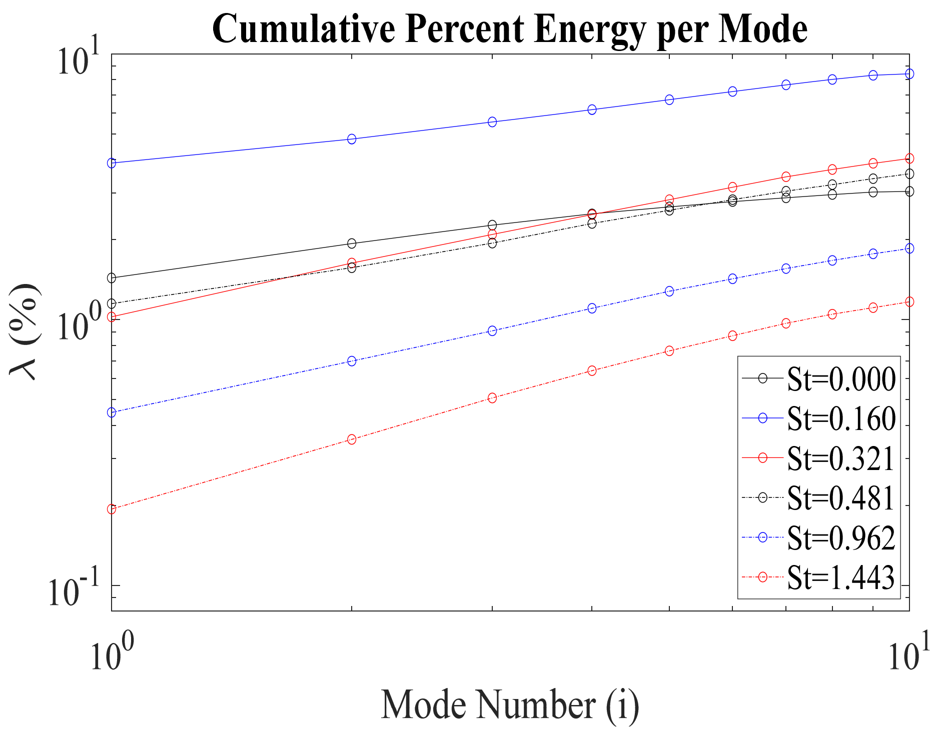


SPOD Results

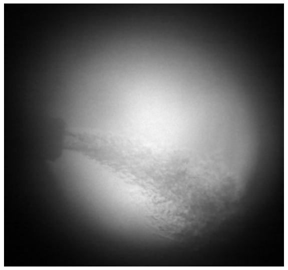


- Modal Energy Plots





SPOD Results



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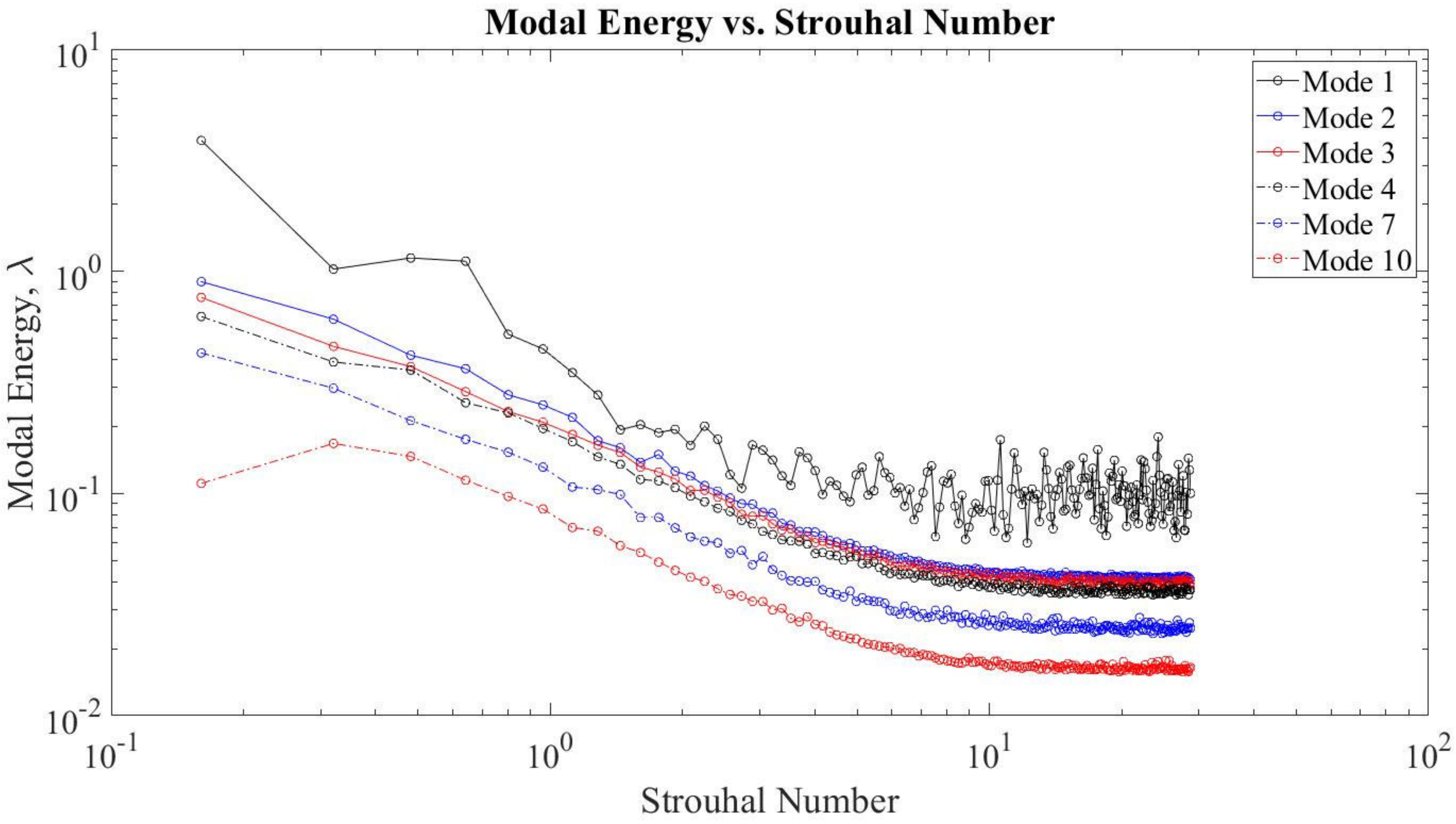
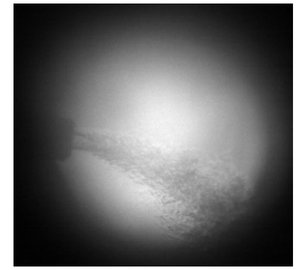
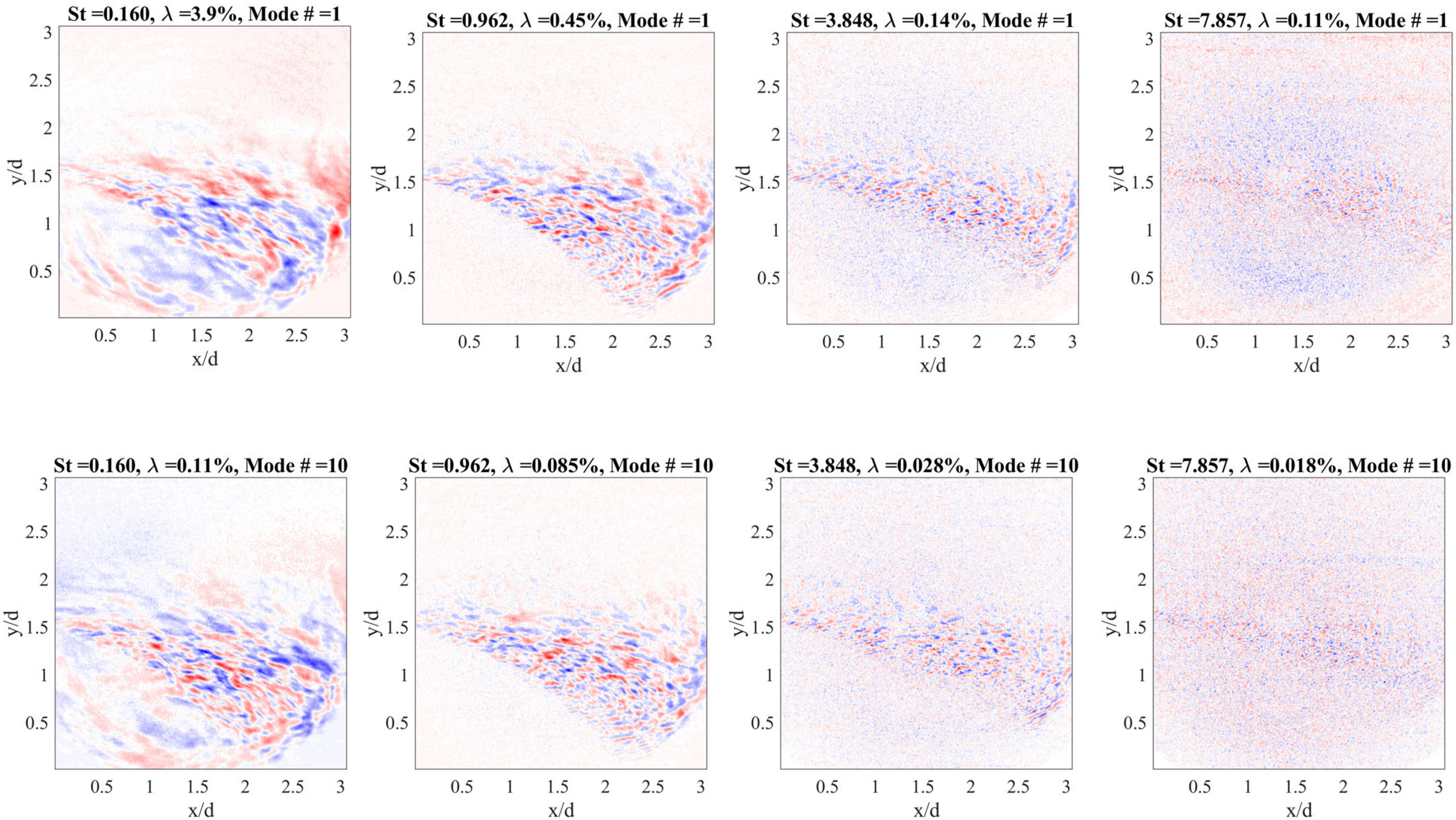


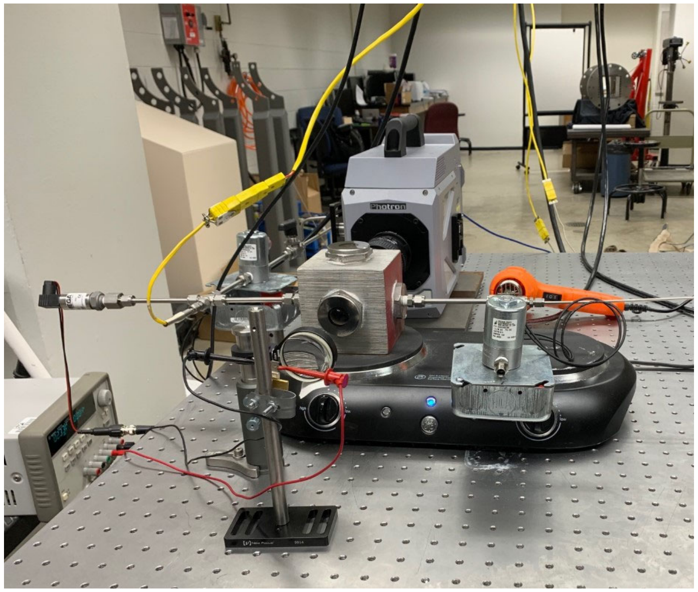
SPOD Results





Conclusion

- Constructed and tested a system for sCO_2 non-intrusive diagnostics
- Successfully employed shadowgraphy
- Successfully Applied modal analysis
- Challenges
  - Maintaining an optically accessible system



Thank you

Any Questions?

Contact (eugene.Hoffman@utsa.edu, Christopher.combs@utsa.edu)