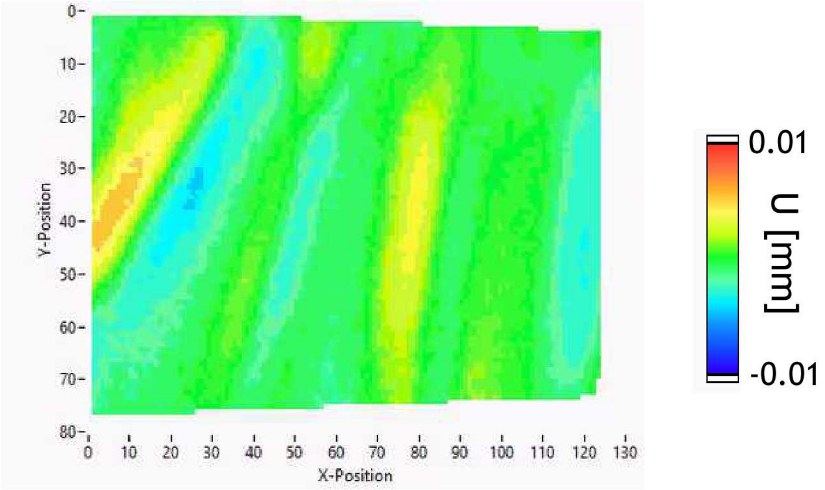
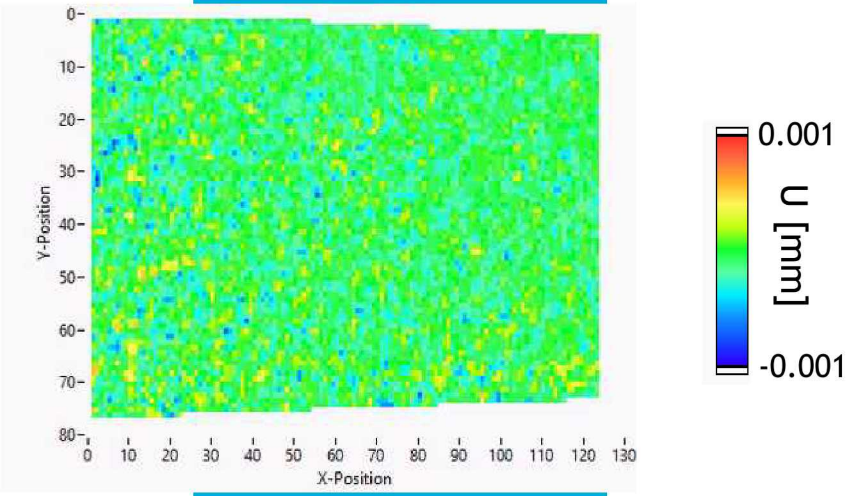
SAND2018-5848C

Eliminating air refraction issues in DIC by conducting experiments in vacuum





PRESENTED BY

Phillip Reu and Elizabeth Jones

Sandia National Laboratory

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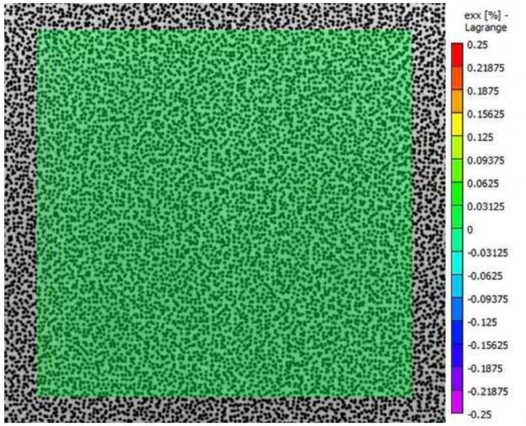
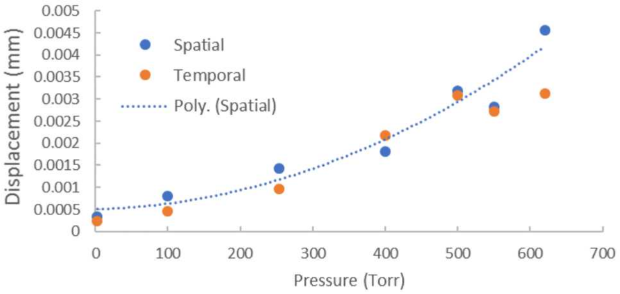
One of the largest remaining DIC error sources is air refraction. Can this be fixed?

Review of the problem



Experimental Setup
Large Vacuum chamber

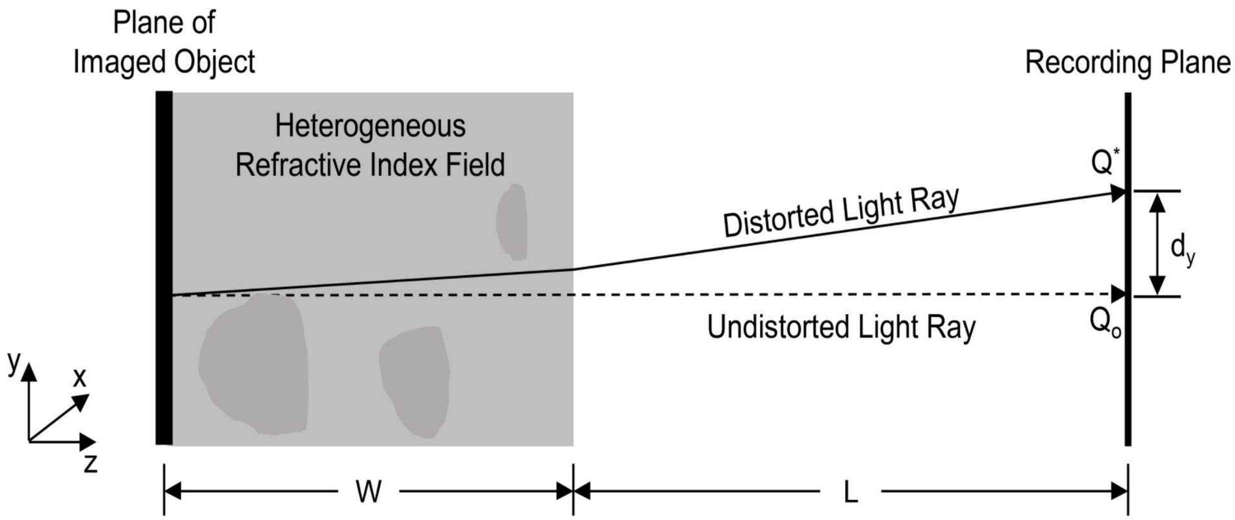
Reduced spatial and temporal errors

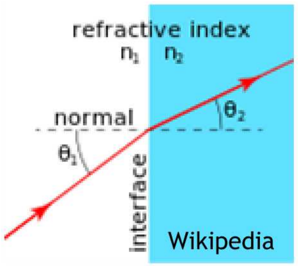


Top 3 Stereo-DIC Errors (Barcelona Panel Discussion)

1. Air-refraction
2. Aliased speckle content
3. DIC users

Index of refraction changes between the sample and camera will distort the image



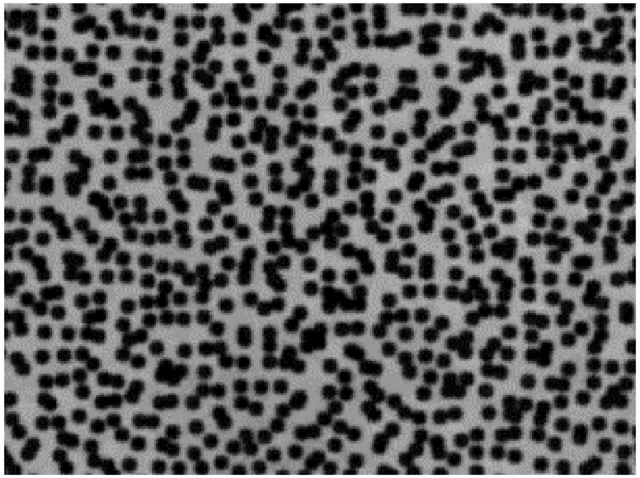


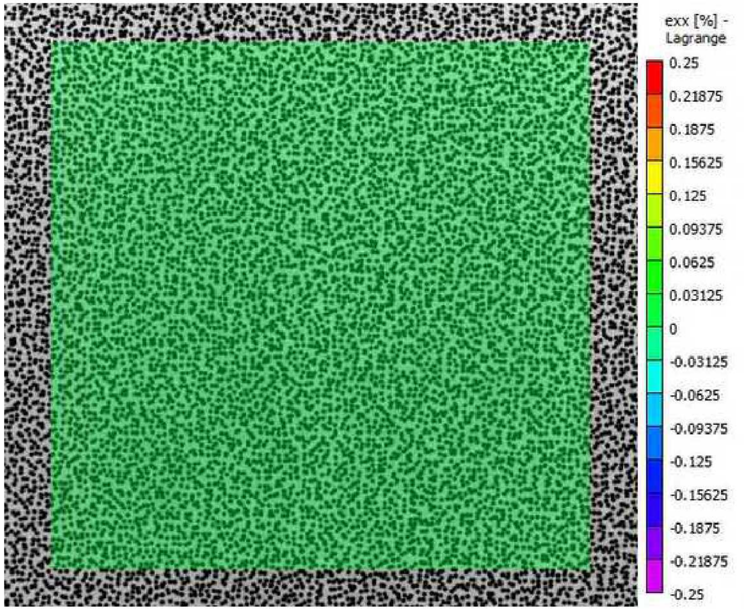
I am using the phrase “air turbulence” loosely to mean, a volume of air that has both spatial and temporal index of refraction variation.

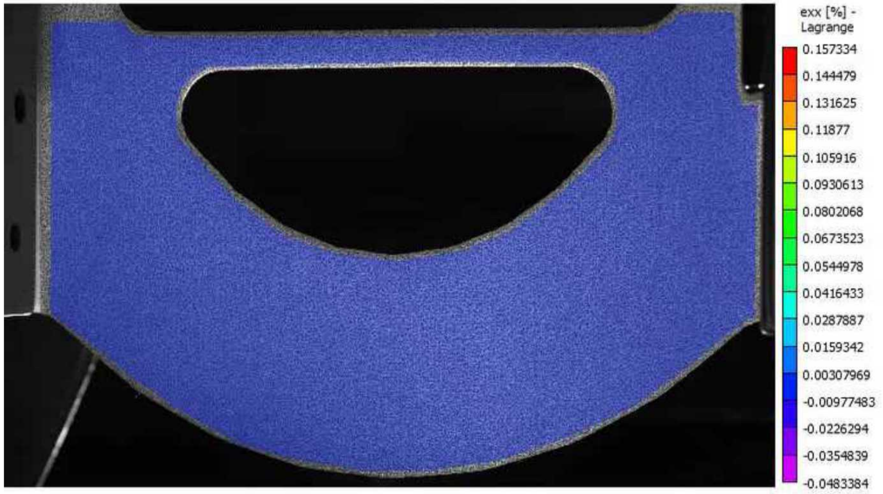
Causes of index of refraction changes in air

- Shock waves (explosive or wakes)
- Heated air
- Species of molecule
- Foundation of BOS/Schlieren

Index of refraction changes can only sometimes be seen with the naked eye.

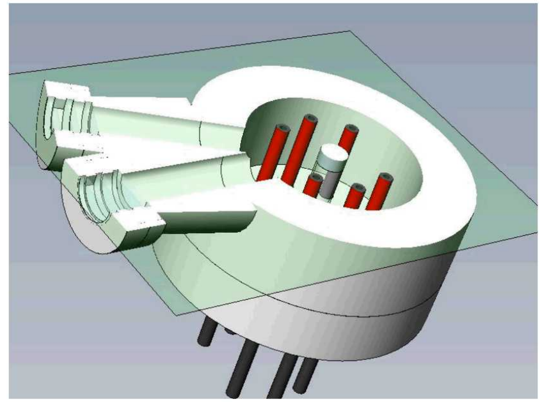


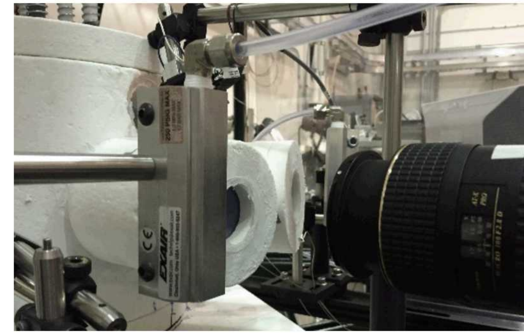


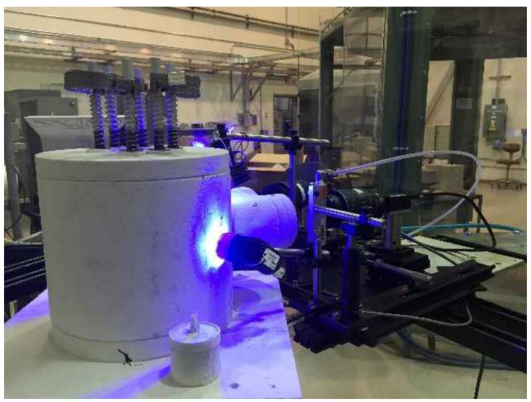


But often seen in the DIC results!

First approach is to attempt to eliminate heat waves experimentally. Sort of fixes the problem.

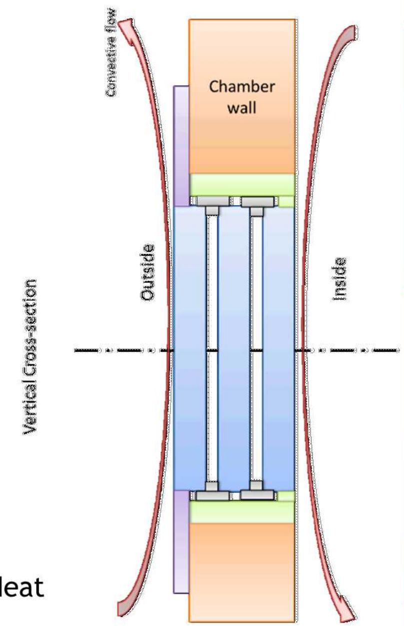






Mitigation Strategies

- Fans/Air knives
- Minimizing temperature gradients
- Block red/IR wavelengths



For a complete overview of the problem see:

Jones, E. M. C. and P. L. Reu (2017). "Distortion of Digital Image Correlation (DIC) Displacements and Strains from Heat Waves." Experimental Mechanics.

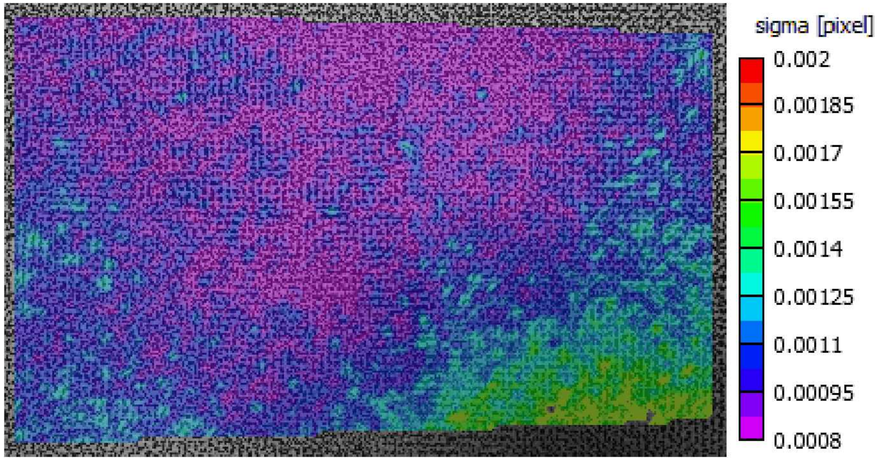
Selected References:

1. Berke, R.B. and J. Lambros, *Review of Scientific Instruments*, 2014. ***85(4)***: *p. 045121*.
2. Novak, M.D. and F.W. Zok, *Review of scientific instruments*, 2011. **82(11)**: p. 115101.
3. Lyons, J., J. Liu, and M. Sutton, *Experimental Mechanics*, 1996. **36(1)**: p. 64-70.
4. Pan, B., et al., *Measurement Science & Technology*, 2011. **22(1)**.
5. De Strycker, M., et al., *Optics and Lasers in Engineering*, 2010. **48(10)**: p. 978-986.

Experimental setup used a large walk-in vacuum chamber to remove the air effects.

Experimental Details

- Vacuum chamber capable of about 2 Torr (i.e. “medium vacuum”)
- Two FLIR cameras. Either 2.3 Megapixel or 5 Megapixel depending.
- Slow image rate: 5 fps for 180 s
- Fast image rate: 140 fps for 14 s (2048 frames)
- Cameras experienced no problems with the vacuum.
- Rigidly mounted cameras on same optical plate as speckle pattern.
- Rubber stamp speckle pattern.
- Thermocouples monitored temperature of cameras, hot plate and ambient.

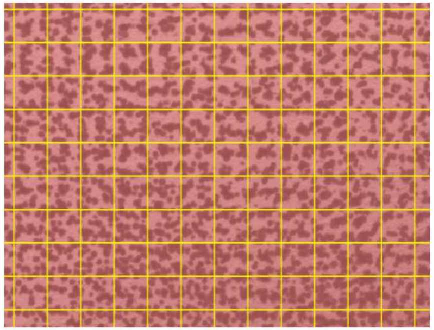


DIC Software Settings

SS=35, ST=15, SW = 15 (Lagrange)

For High Rate ST = 30 to have less points.

8-Tap, ZNSSD, Low pass filter image

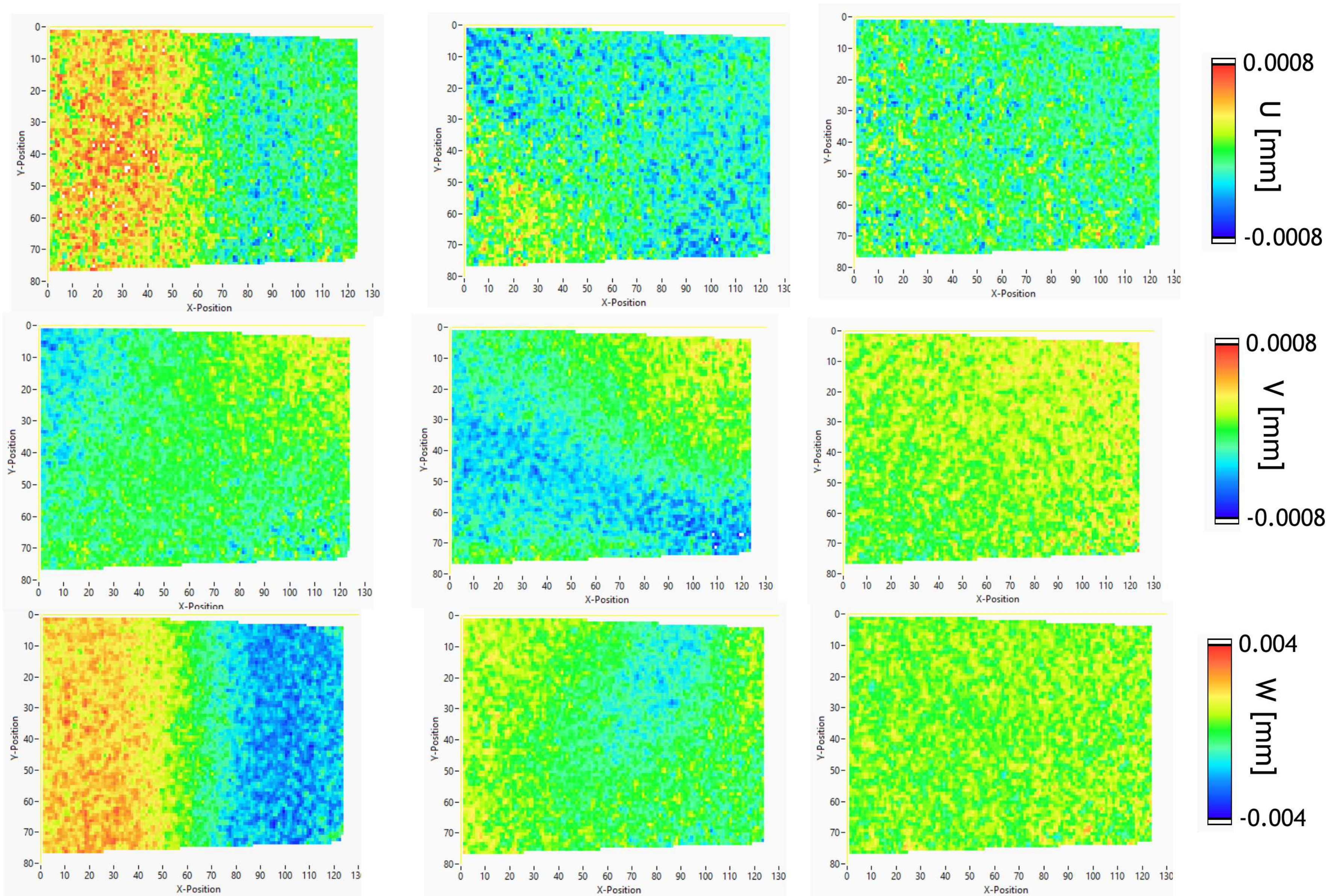


The quality of the displacement noise is different at low vacuums. I.e. index changes are removed.

Vacuum 620 Torr (ATM)
Clear heat waves

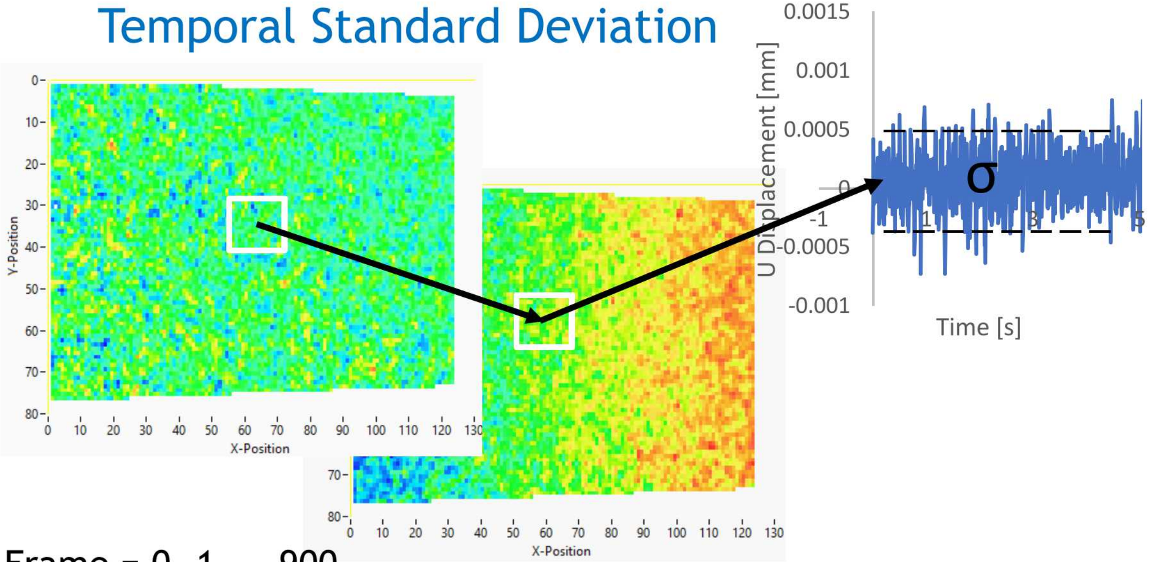
Vacuum 250 Torr
First heat waves

Medium Vacuum 25 Torr
and below



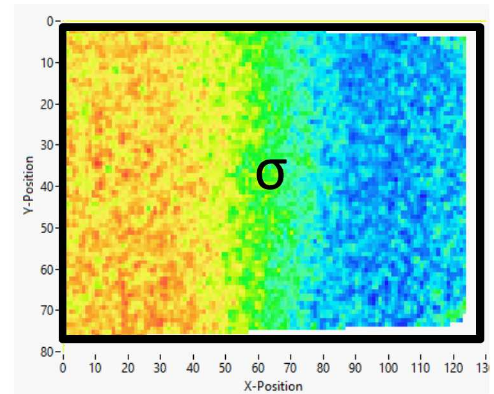
Unfortunately the statistics have a more confusing representation of the data.

Temporal Standard Deviation

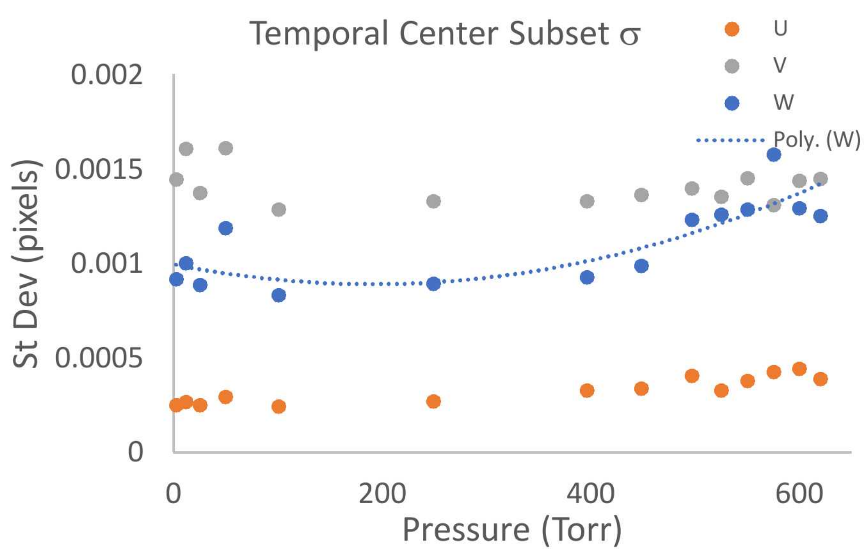


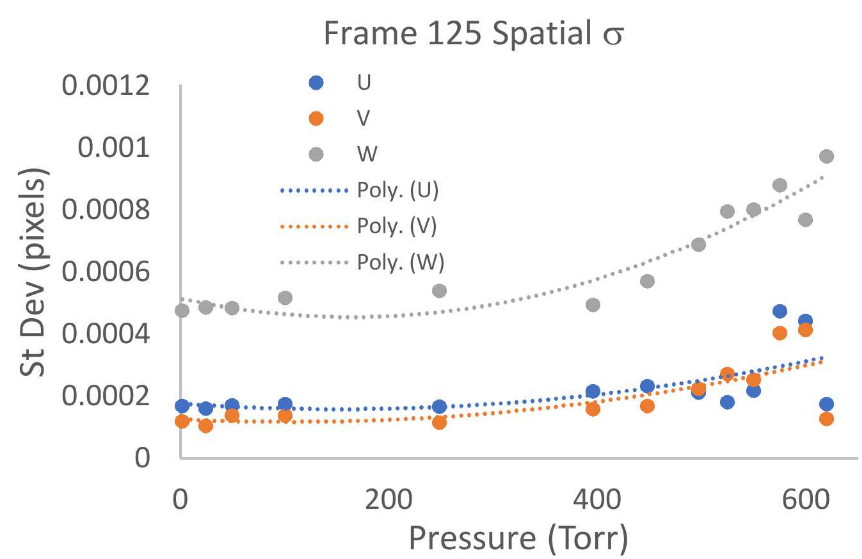
Frame = 0, 1, … 900

Spatial Standard Deviation

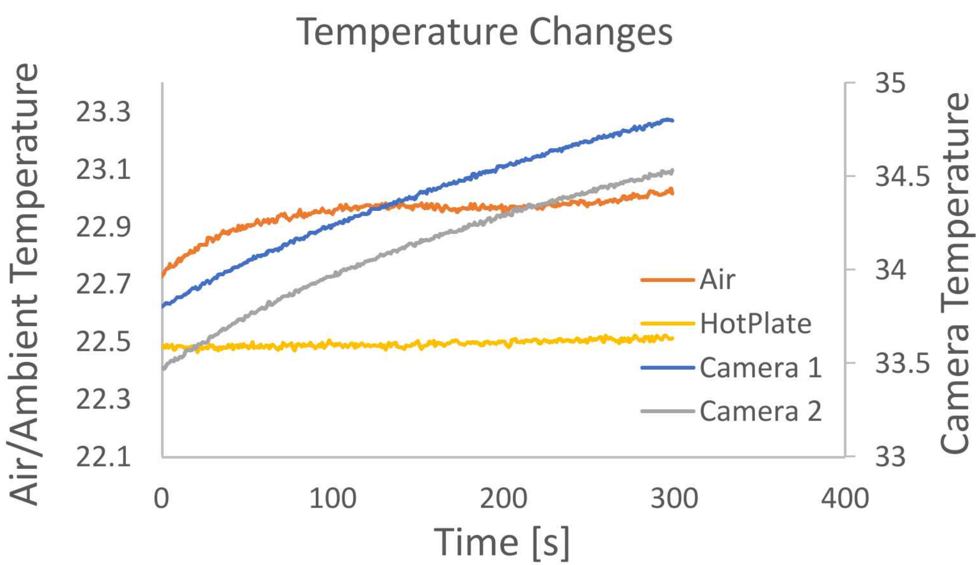


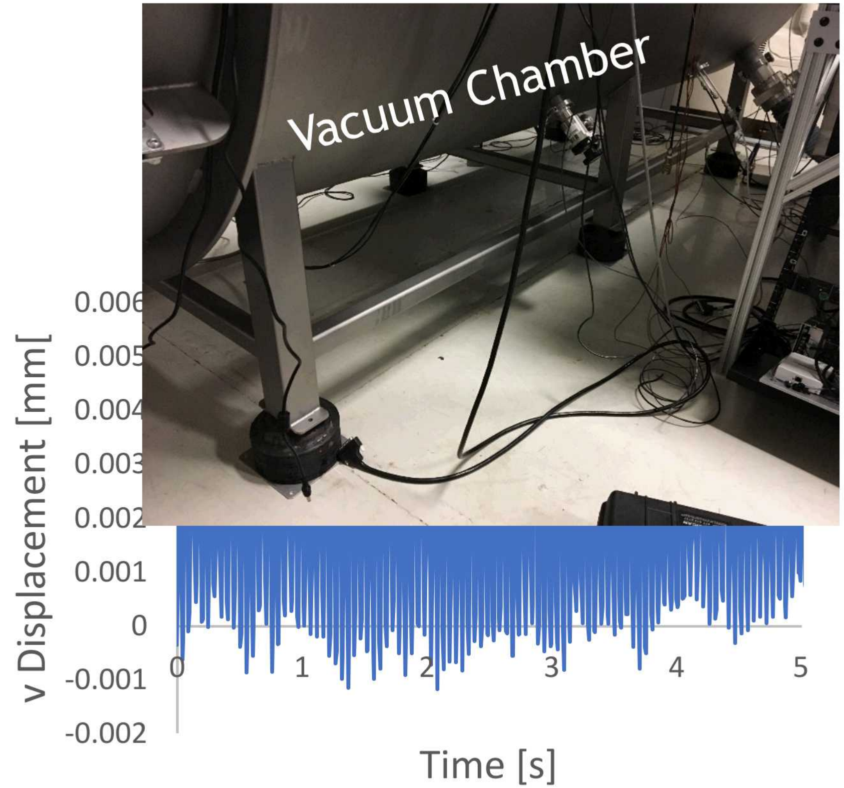
Frame = 125



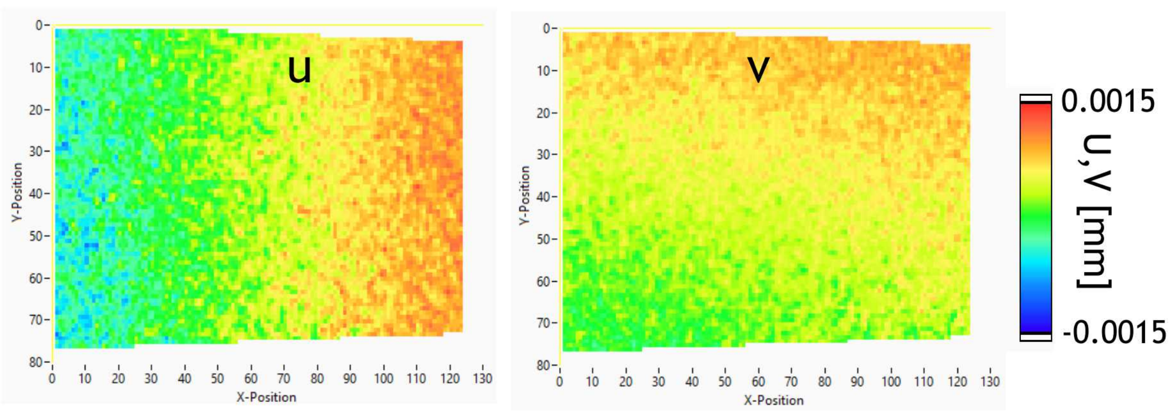


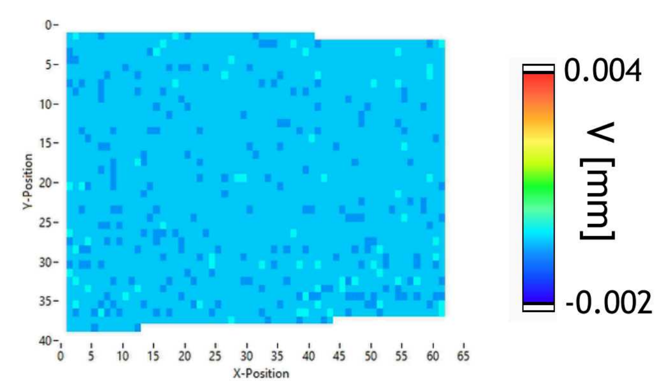
Data was corrupted by vibration and thermal expansion.



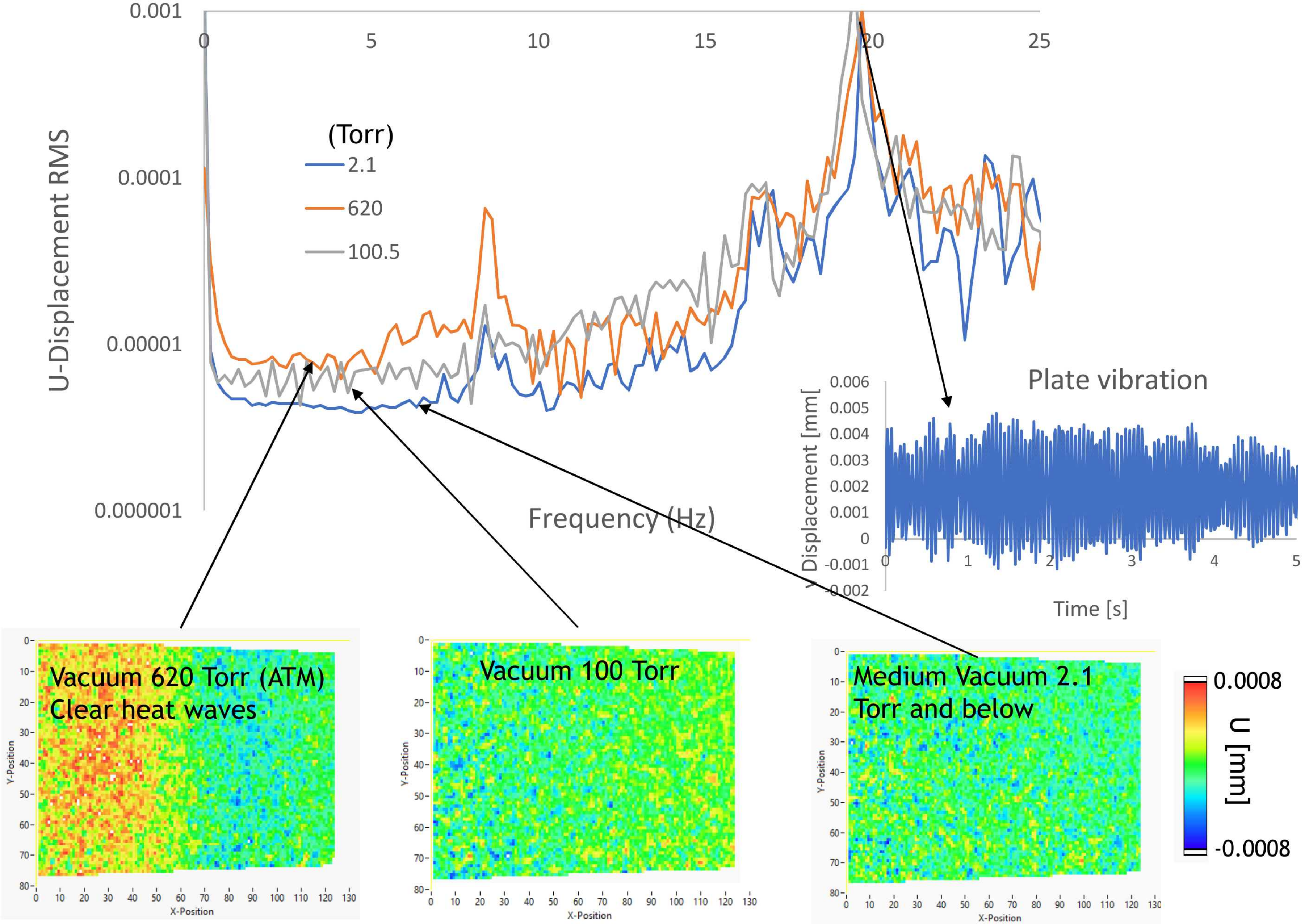


V

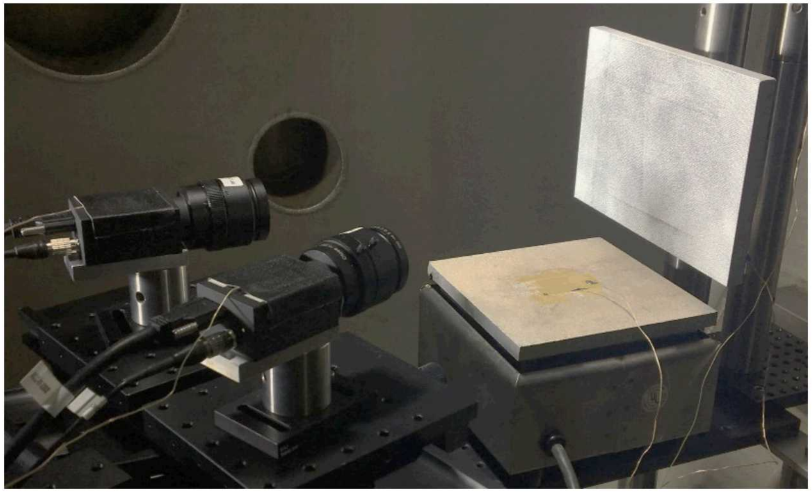


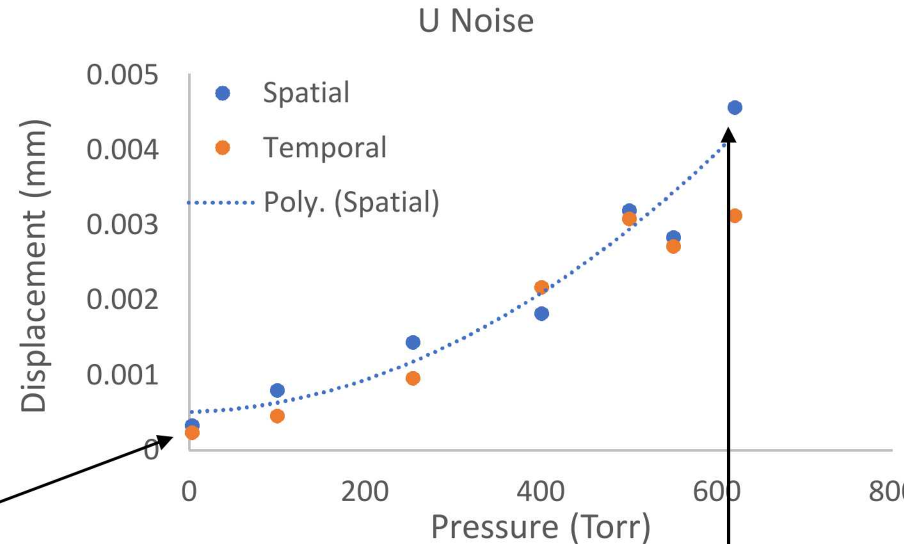


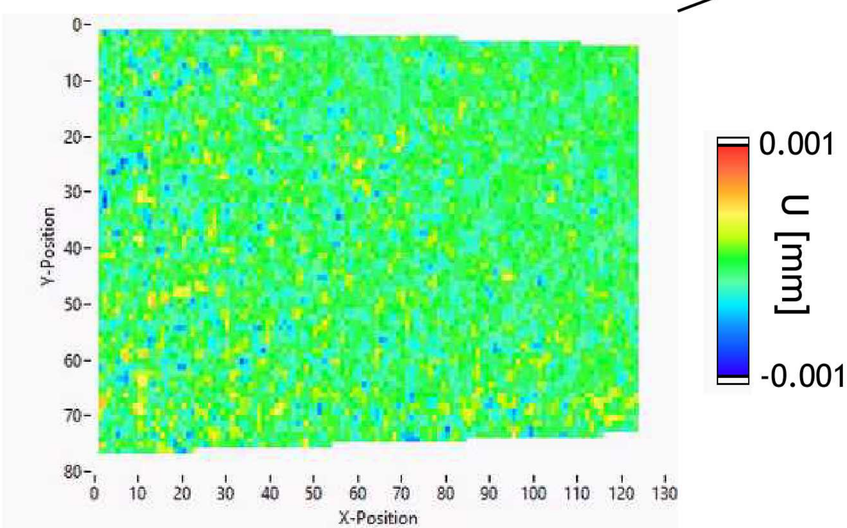
Frequency analysis shows a marked improvement in the low frequency noise.

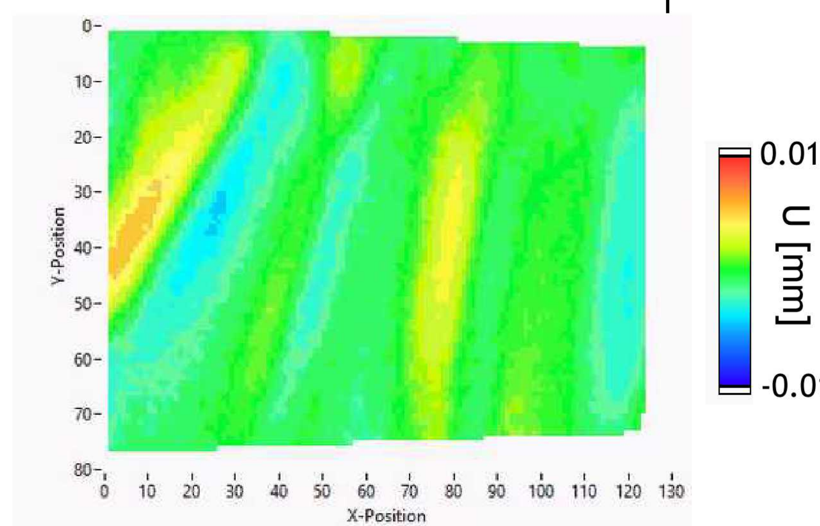


Hot plate in front of the cameras to amplify the problem.



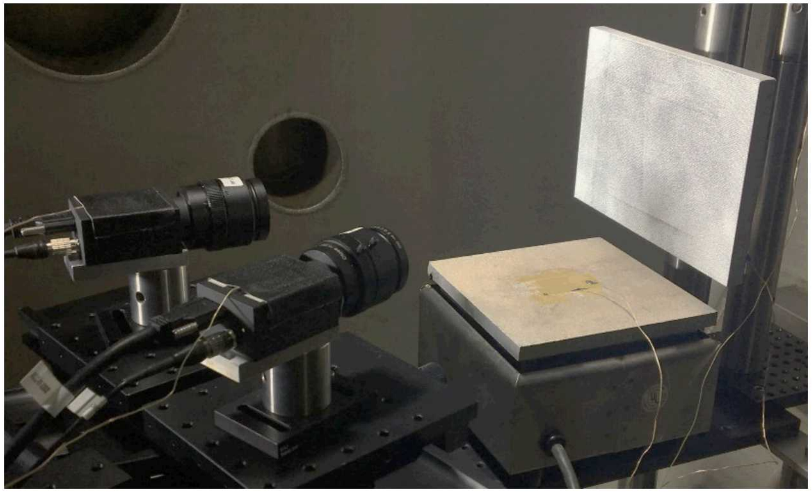


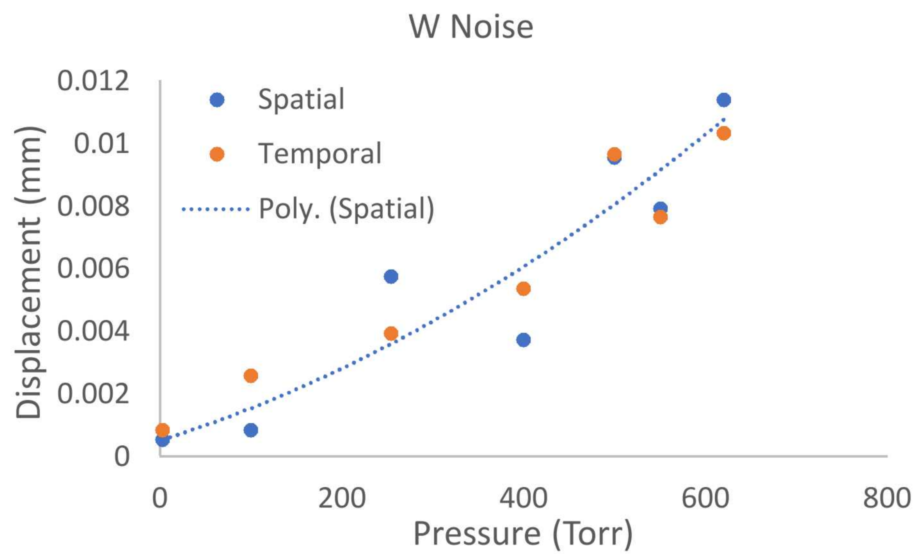




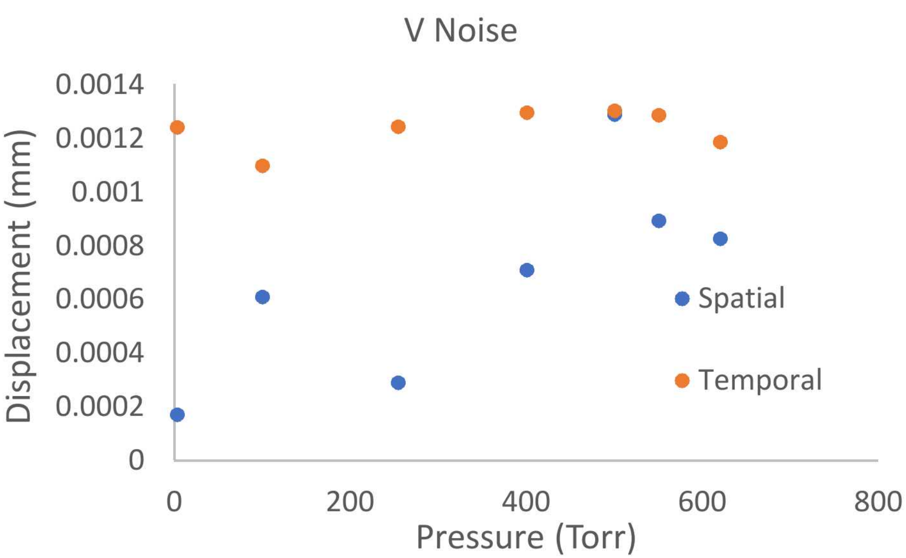
10× improvement under vacuum

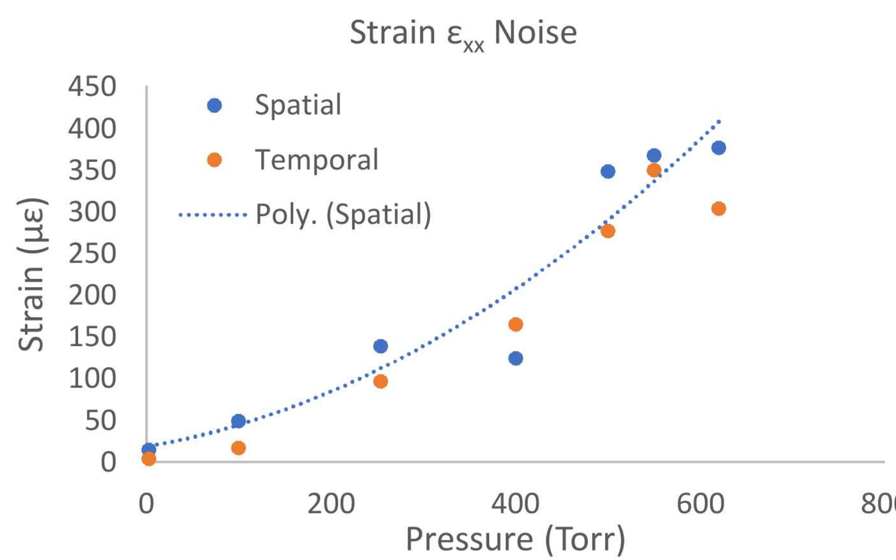
Hot plate in front of the cameras to amplify the problem.



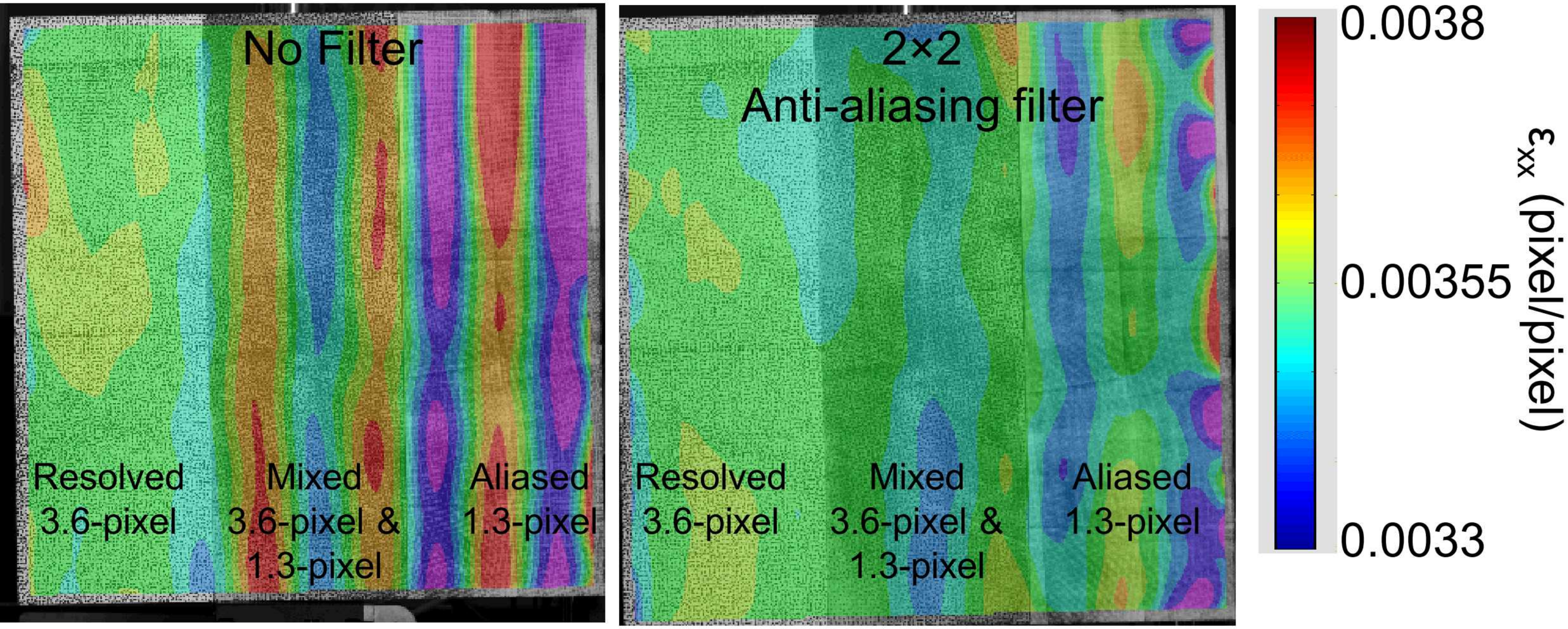


Corrupted by vibrations.



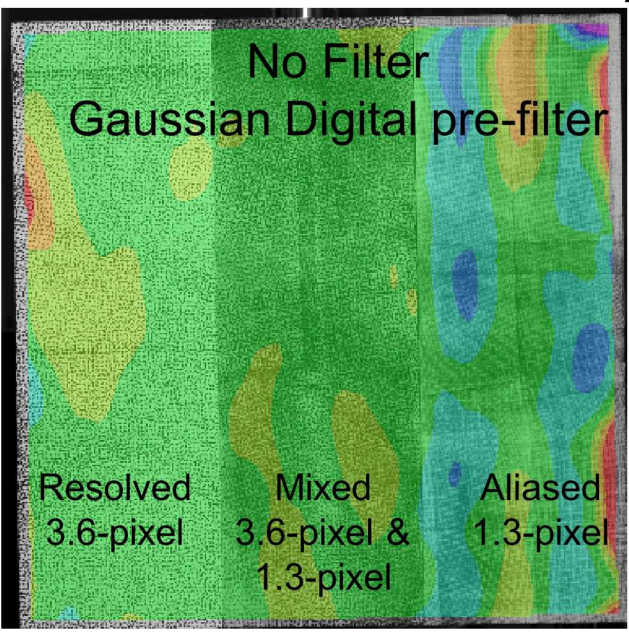


Air turbulence and speckle aliasing are two largest error sources. (Camera Motion?)



DIC Settings

- Subset 21×21
- Step = 5
- Strain Window = 41
- ZNSSD
- Interpolant: 4-Tap



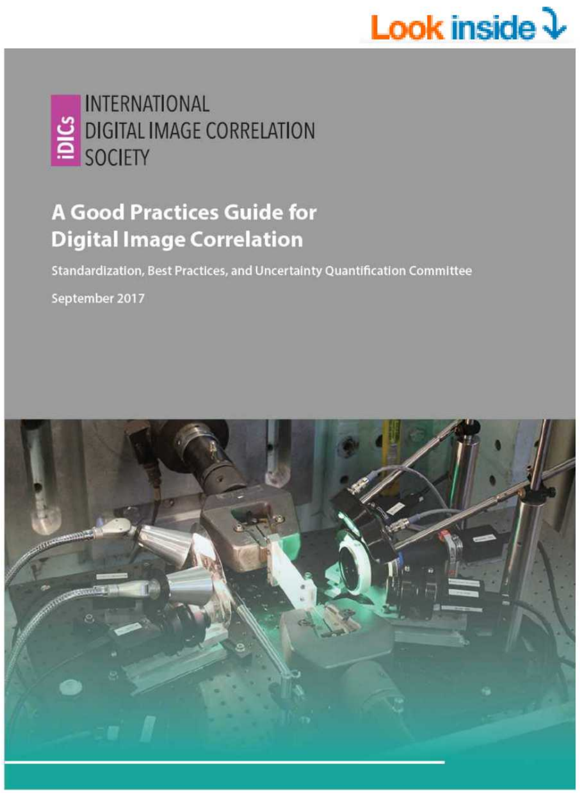
u-Displacement (1σ)

Filter	Good Speckle	Mixed Speckle	Aliased Speckle
None	0.0032	0.0088	0.0156
2×2	0.0036	0.0054	0.0127
Digital	0.0030	0.0038	0.0170

ε_1 ($\mu\varepsilon$)- 4-Tap Interpolant (1σ)

Filter	Good Speckle	Mixed Speckle	Aliased Speckle
None	44	94	139
2×2	40	67	117
Digital	41	31	88

DIC Good Practices Guide is under review. Release will be mid-2018.



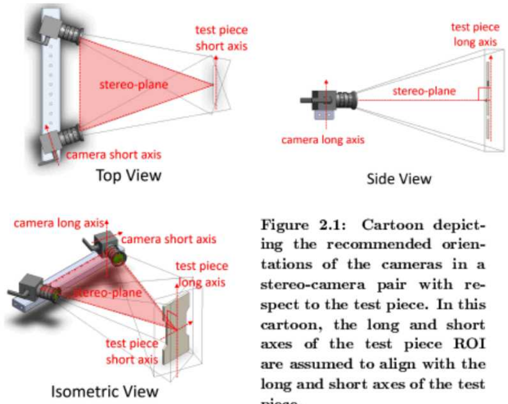


Figure 2.1: Cartoon depicting the recommended orientations of the cameras in a stereo-camera pair with respect to the test piece. In this cartoon, the long and short axes of the test piece ROI are assumed to align with the long and short axes of the test piece.

- For stereo-DIC, mount both cameras rigidly together to avoid relative camera motion.[3] See Sec. 2.2.2.2 for more information on common types of mounting systems.

Caution!

Any relative motion of one camera with respect to the second camera will induce errors in DIC measurements.[a] While these errors can be compensated for to some degree with post-processing calibration corrections,[b] avoiding relative camera motion is much more strongly preferred. Therefore, rigid mounting is critical!

[a] If both cameras move together rigidly with respect to the test piece, only rigid-body DIC displacements are affected. For most applications where rigid-body motion is not important (e.g. strains are the quantity-of-interest), this rigid-body displacement error is inconsequential.

[b] Rigid-body motion of the stereo-camera pair can be corrected for in post-processing if there is a fixed reference point somewhere in the field-of-view. However, correcting for relative motion of one camera with respect to the second camera requires adjusting the extrinsic parameters of the calibration (Sec. 3.2), but this type of correction is outside the scope of this edition of the guide.

6 | Reporting Requirements

With all the variables that must be selected in a mechanical test with DIC measurements, such as parameters of the physical system (e.g. camera, lens, patterning method, etc.) and parameters of the data analysis process (e.g. subset size, virtual strain gauge size, etc.), justification and documentation of the choices made is critical. The lists below present the minimum reporting requirements as well as suggested, detailed reporting recommendations. All documentation of DIC data — both internal reports and published journal articles — should contain this information.

Tip

Depending on the application of the DIC data, some of the reporting recommendations may not be necessary while others not listed here may be important. The key, though, is to document all relevant information!

6.1 Experimental Parameters

6.1.1 Required

- Camera Make and Model, and Image Resolution
- Lens Make, Model, Focal Length[1]
- Field-of-View
- Image Scale[2]
- Stereo-Angle[3]
- Stand-Off Distance
- Image Acquisition Rate
- Patterning Technique
- Approximate Speckle Size[4]

[1] If variable focal length, report both range and focal length used.
[2] For stereo-DIC, report the average image scale or the image scale in the center of the FOV.
[3] Applicable for stereo-DIC; not applicable for 2D-DIC
[4] Specify method used to determine speckle size. Note that both black and white regions are considered speckles.

Mark A. Iadicola and Elizabeth M. C. Jones
Co-chairs of the iDICs Standardization, Best Practice, and Uncertainty Quantification Committee

Important Dates

December 4, 2017: Deadline to email guide@idics.org to opt-in to vote and receive a copy of the draft version of the Guide.

January 15, 2018: Deadline to return your vote and comments by emailing the voting and comment form to guide@idics.org.

http://idics.org/guide/

iDICs – A society to provide training, certification, standardization and guidelines for DIC.

International DIC society (www.iDICs.org)

- 1st Annual conference: Philadelphia 203 attendees
- 2nd Annual Conference: Barcelona, Spain – 150 attendees
- 3rd Annual Conference: Hongzhou China – Oct. 2018
- Prof. Mike Sutton – President, Phillip Reu – Vice President

Committees

- Standards & Best Practices – Mark Iadicola
- Training & Certification – Tim Schmidt
- Applications – Dave Dawicke
- University Education – Mark Pankow
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Extending the Frontiers: Training the next Generation: Standardizing for Industry: Improving our