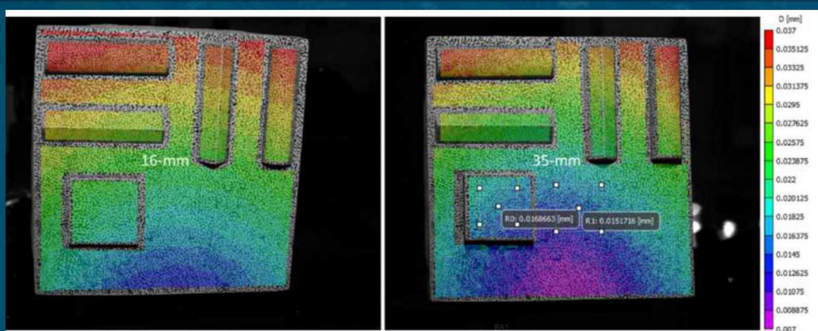
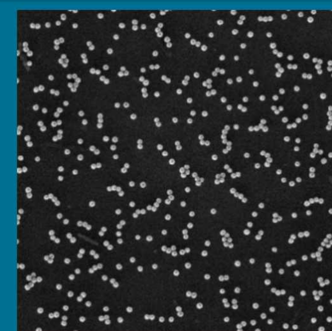
https://sem.org/

SAND2018-11394C

Digital Image Correlation DIC – Challenge Meeting





PRESENTED BY

Phillip Reu

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DIC Challenge Charter

The DIC Challenge seeks to:

- Provide sample images for code verification and development.
- Benchmarked results for the sample images – published and peer-reviewed.
- A forum for the discussion and improvement of DIC.
- Provide image sets for all DIC modalities: Stereo-DIC (3D), Digital Volume Correlation (DVC), Scanning electron microscope (SEM-DIC)

The official charter is available at the website:
https://sem.org/dic-challenge

Current Board Members

Phillip Reu – Chairman (US – FFT Shifting)

Mark Iadicola (NIST) – co-chair

Will LePage (Univ. Mich.) – SEM challenge Lead

Helena Jin (Sandia) – DVC challenge Lead

Benoît Blaysat (University Clermont Auvergne, France) – 2D Challenge 2.0

Elizabeth Jones (Sandia) – Results analysis

Evelyne Toussaint (University Clermont Auvergne, France) – Results analysis

Hugh Bruck (University of Maryland) – Advisor at large

In memoriam – Laurent Robert

Looking for volunteers

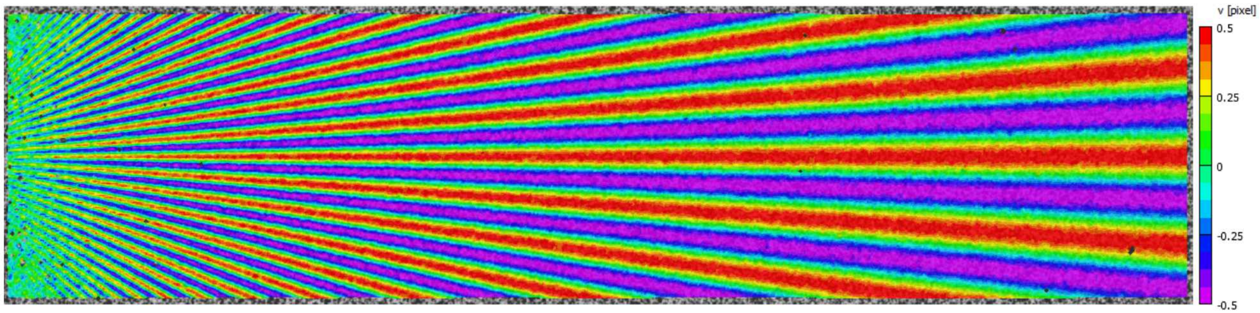
The DIC challenge is important because it is an independent organization

- No ties to any commercial or university codes
- Open and free to participate
- Code developers will run their own code ensuring "optimum" parameter selection
- Validated image sets will be available tested by many groups for testing software
- Benchmark results will be presented for all participants

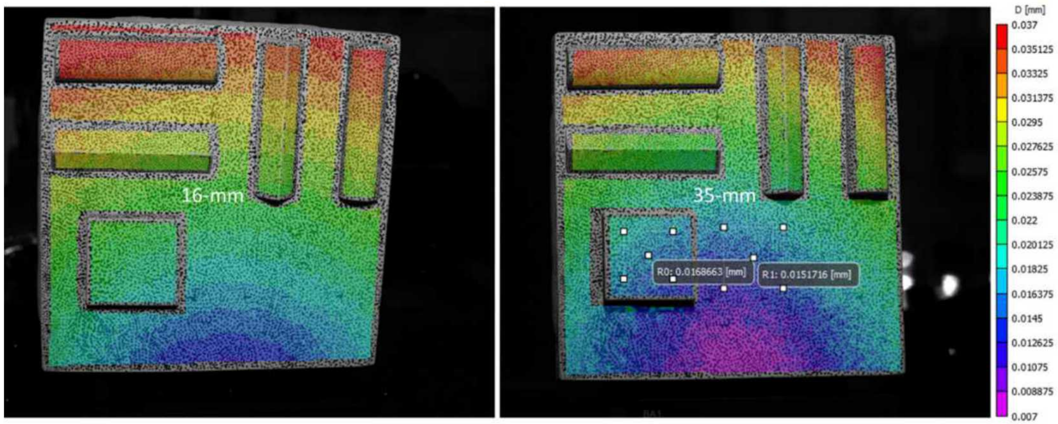
We have moved to Google Drive for better global access (sorry China).

Current state of the challenge

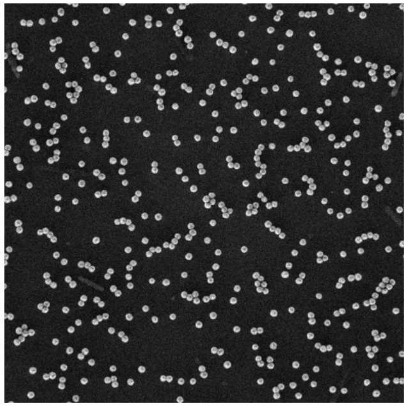
2D Challenge 2.0



Stereo-DIC Image Set Description



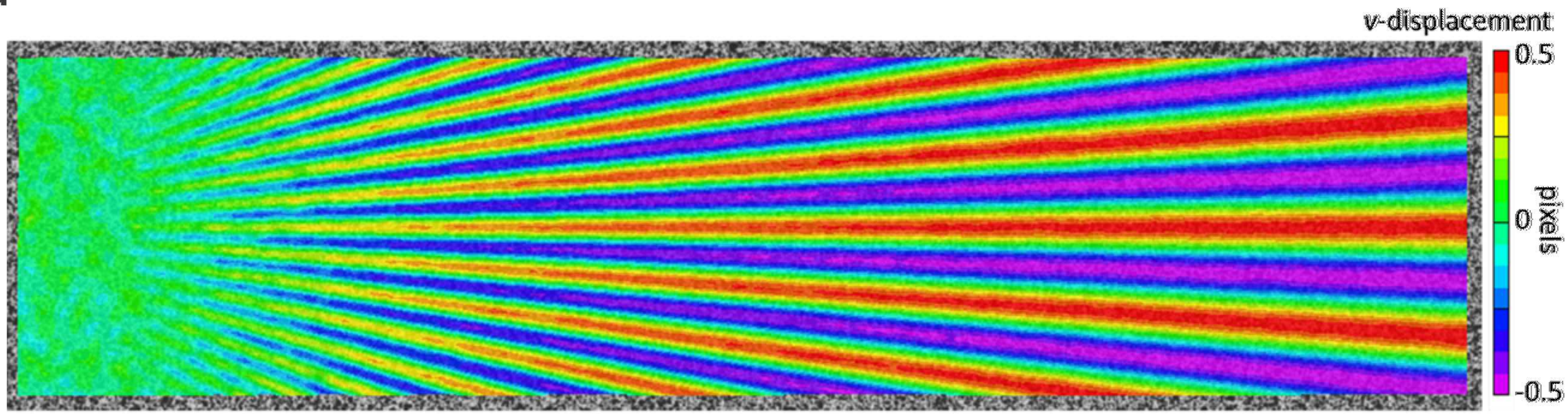
SEM-DIC Challenge



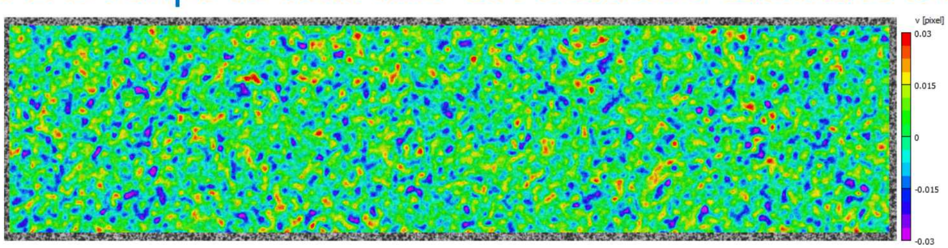
DVC-DIC Challenge

We have moved to Google Drive for better global access (sorry China).

2D Challenge 2.0 – New images for better spatial resolution studies

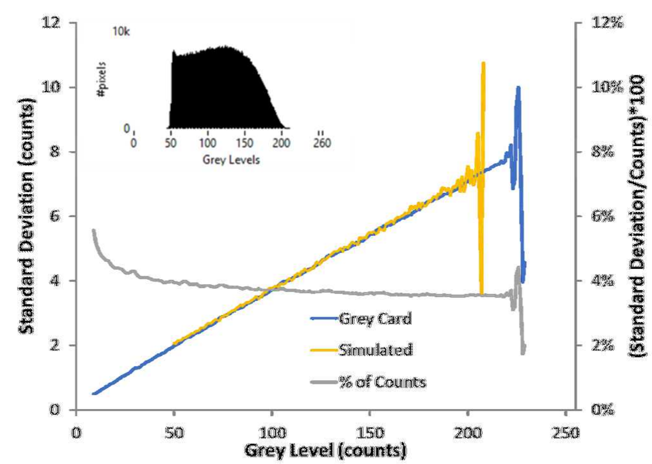


- Constant amplitude (±0.5 pixels) with varying period (10 to 150 pixels)
- Noise profile of Flir 5 Megapixel camera (heteroscedastic)
- Undeformed noise image for calculating noise floor.
- Line cut through the middle quickly visualizes the data.
- MATLAB script to take line cut data and calculate a spatial resolution



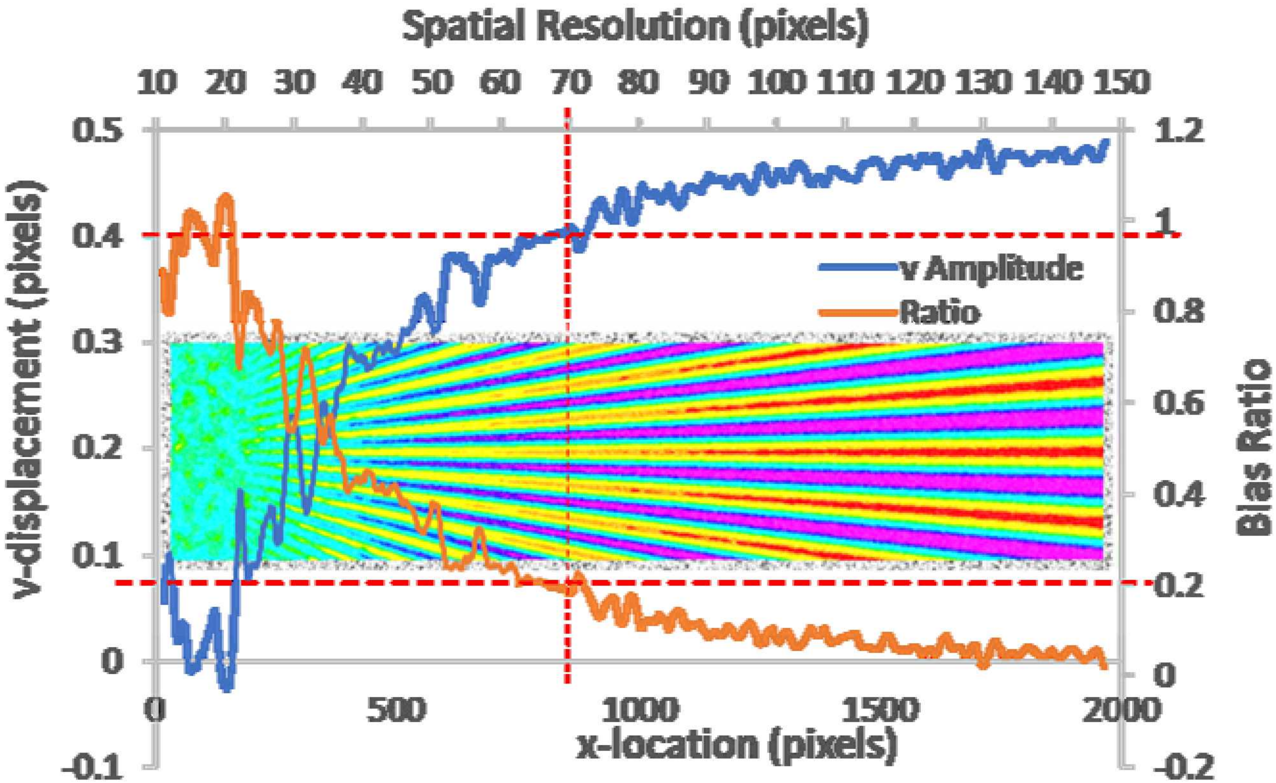
Based on References

1. Sur, F., B. Blaysat, and M. Grédiac, *Rendering Deformed Speckle Images with a Boolean Model.* Journal of Mathematical Imaging and Vision, 2017.
2. Grediac, M., B. Blaysat, and F. Sur, *A Critical Comparison of Some Metrological Parameters Characterizing Local Digital Image Correlation and Grid Method.* Experimental Mechanics, 2017. **57**(6): p. 871-903.



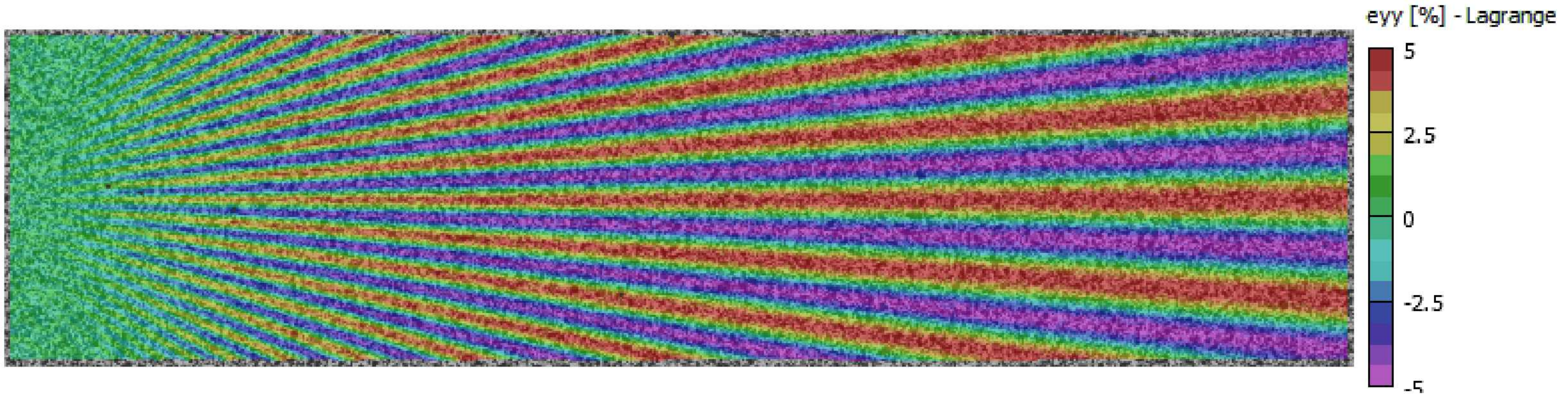
Images at:
https://drive.google.com/drive/folders/1ELWo0GMxxRBjG9KSQ8PIyMk1CL__GtLB?usp=sharing

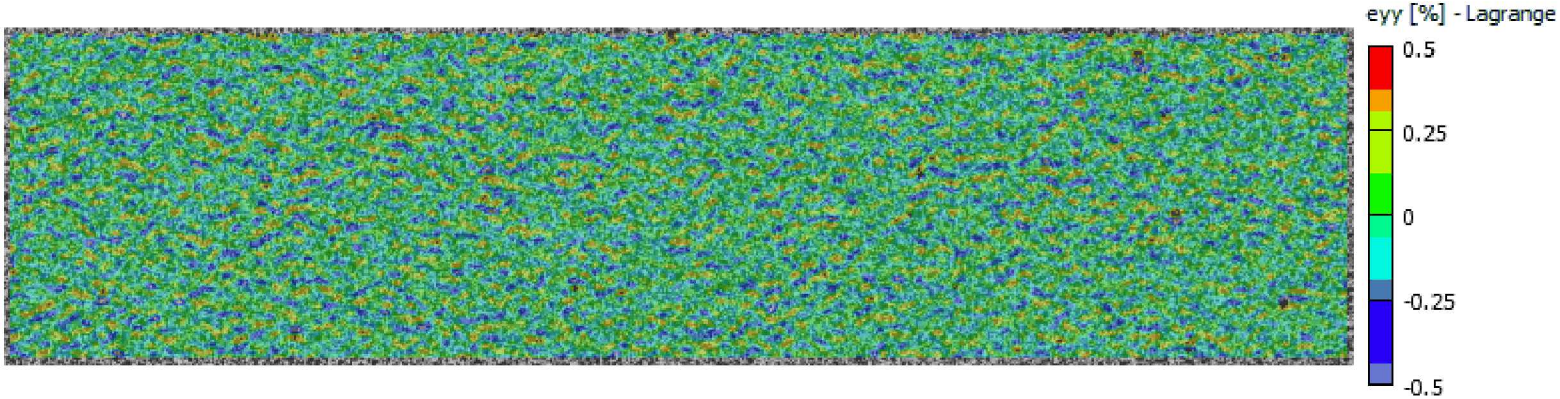
One line-cut tells the entire story. A cutoff ratio needs to be chosen.



- 90% for displacement, i.e. 10% signal loss.
- 90% for strain, i.e. 10% signal loss
- This may be a little too high for the strain! I.e. most VSG sizes don't meet this criterion.

We have a constant strain amplitude image as well.





- Avoids the Sample 14 problem of having increasing strain gradients for constant displacement images.
- We have now added Strain Window as a new parameter to vary!
- User will choose subset size and step size. The only thing defined is the VSG!

$$VSG = [(SW - 1) \cdot ST] + SS$$

Submission guidelines must be followed. Comma separated file is to be used.

For Displacement:

- 1-pixel step from 1 to 2000 pixel location (in x)
- Subset size is defined in spreadsheet.
- Global codes should use the “smallest” practical subset to one that filters heavily.

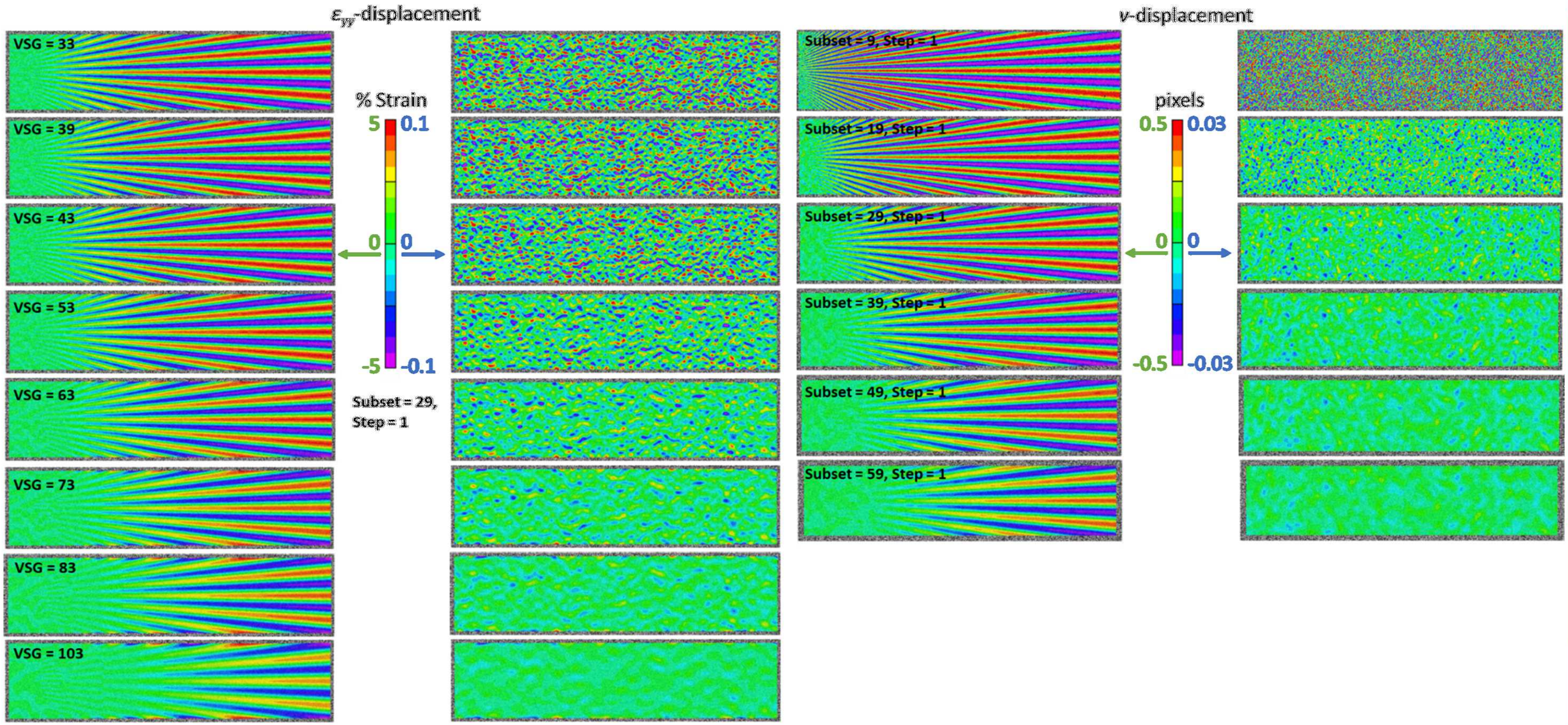
Row 250	Subset 9	Subset 9	Subset 19	Subset 19	Subset 29	Subset 29	Subset 39	Subset 39	Subset 49	Subset 49	Subset 59	Subset 59
Pixel	v-Noise	v-deforme	v-Noise	v-deforme	v-Noise	v-deforme	v-Noise	v-deforme	v-Noise	v-deforme	v-Noise	v-deformed
1	NaN	NaN										
2	NaN	NaN										
...												
25	0.0015	0.055482	etc.									
26	-0.0025	0.064797										
...												
2000	NaN	NaN										

For Strain:

- 1-pixel step from 1 to 2000 pixel location (in x)
- VSG is undefined.
- Go from smallest possible VSG up to one with lower noise profile.

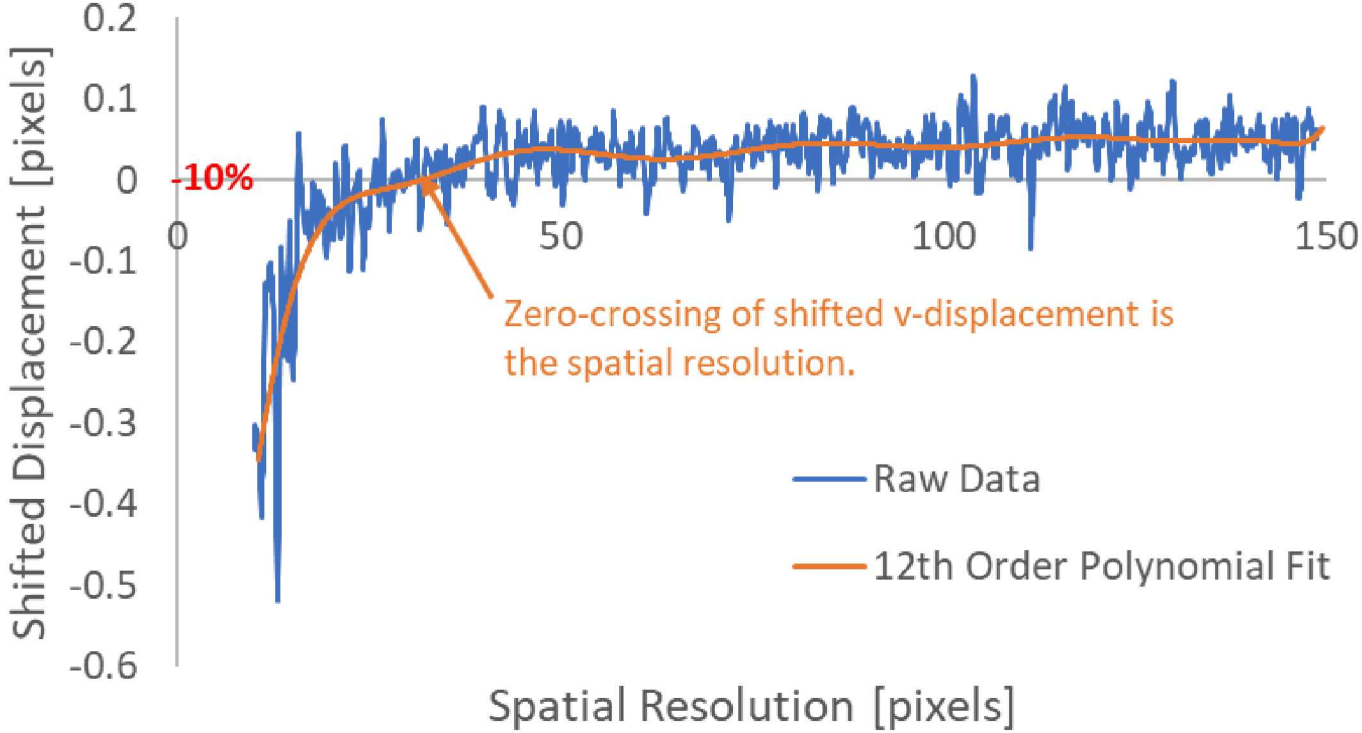
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Row 250														
2	Interpolant	8-Tap													
3	Type	Local	(Or similar description)												
4	Step	1													
5	Subset	9													
6	Strain Window	5													
7	VSG = [(SW - 1)*ST]+SS	Smallest Possible					Lowest noise but OK		Smallest Possible					Lowest noise but OK SR	
8	Pixel	v-Noise	v-Noise	v-Noise	v-Noise	v-Noise	v-Noise		v-deforme	v-deforme	v-deforme	v-deforme	v-deforme	v-deformed	
9	1	NaN							NaN						
10	2	NaN							NaN						
11	Etc.								Etc.						
12	25	0.0015	etc.						0.055482						
13	26	-0.0025							0.064797						
14	Etc.								Etc.						
15	2000	NaN							NaN						

Preliminary results will need both the text values and a screen shot with the scales set as shown here.



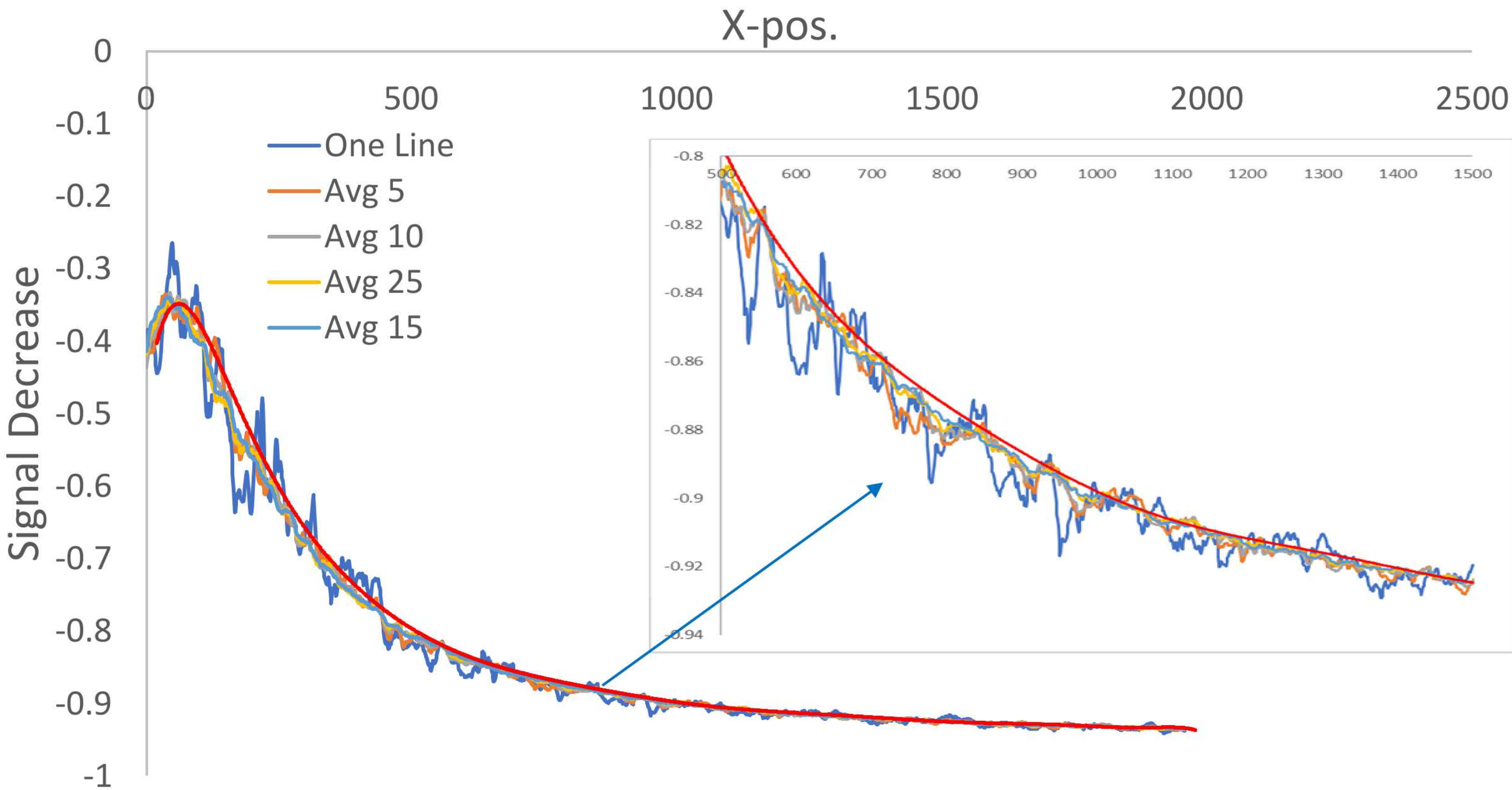
- Full-field results allow the nature of the noise to be more quickly perceived.
- Plots of each code will be created to show the same trends.
- Full-field data may be required for the paper to ensure similar plotting of the results!

Analysis will be done by fitting a 12^{th} Order polynomial to the line cuts and finding the cut-off crossing value.



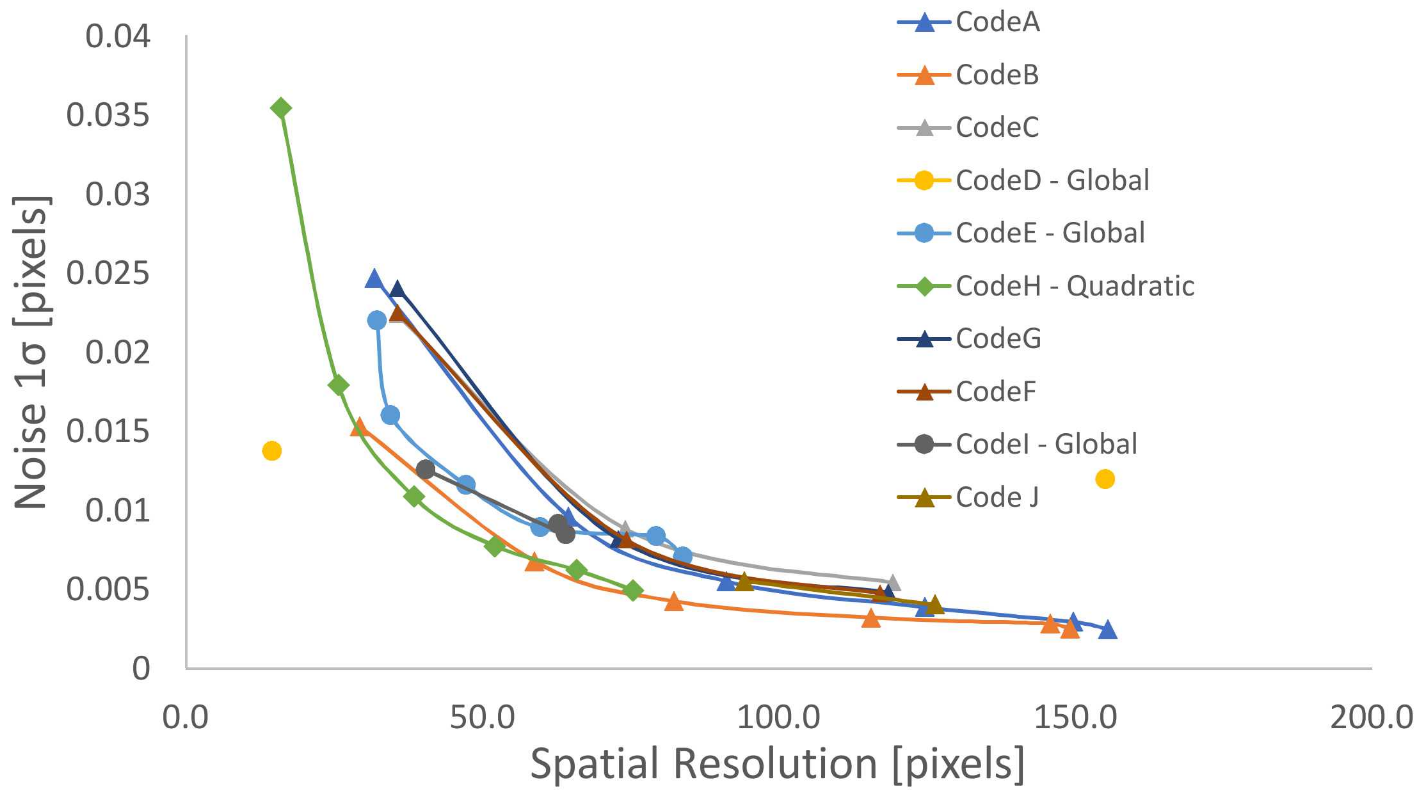
- 12^{th} Order was chosen after studying the response of a number of codes. It is a good compromise between fitting and matching the curve.
- "Good Compromise" is completely subjective.
- The same approach will be used for all codes.
- Strain analysis will follow the same approach.

A “new” DIC error term: Speckle-induced bias (SIB) was explored and can be removed by averaging.



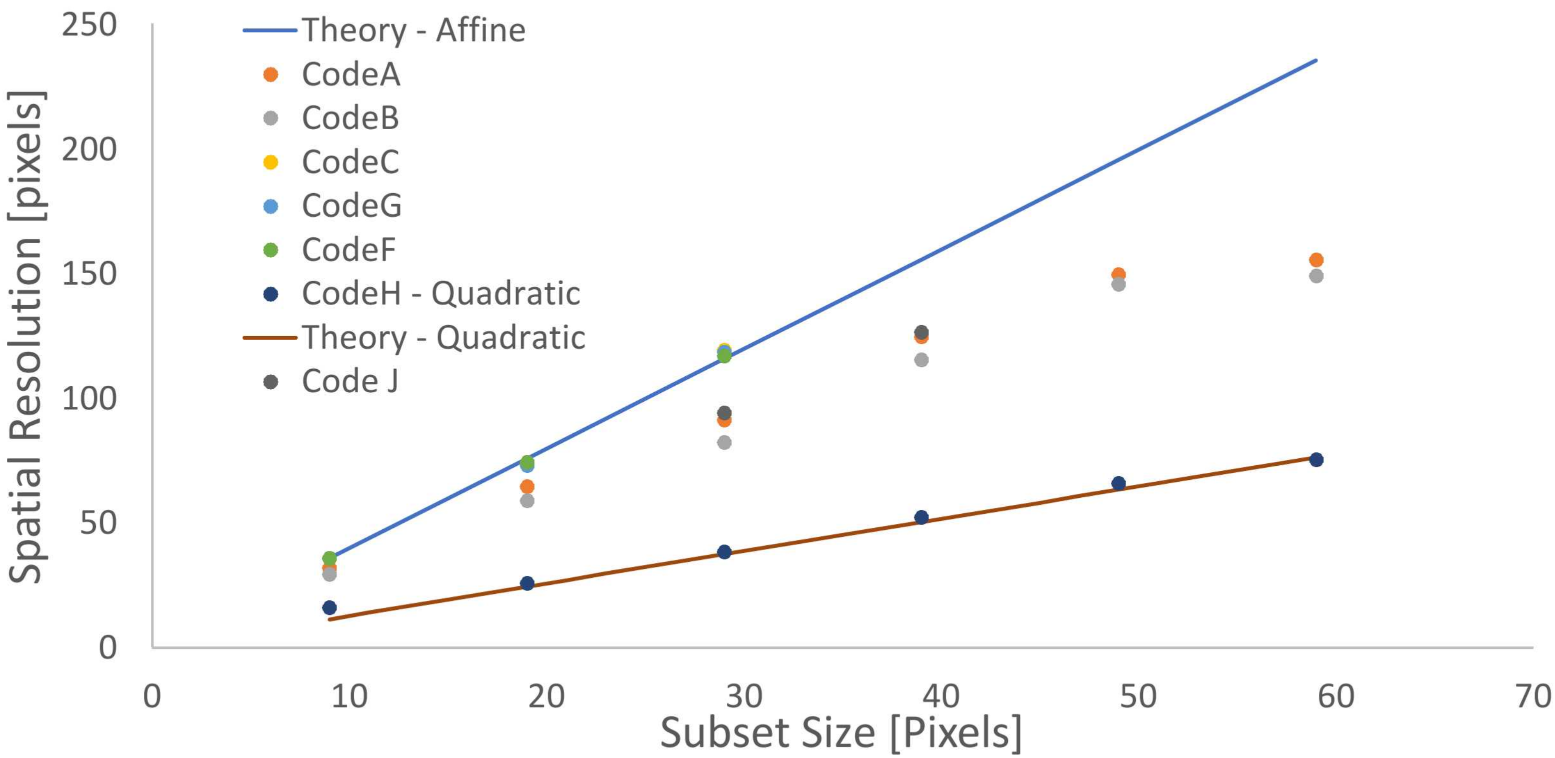
- Averaging the **same** image with different noise does not remove the error.
- Different speckle patterns are required for every set of images.
- 12^{th} Order fit follows this curve pretty well.

Preliminary results show similar trends between all of the codes.



- 10 Codes have submitted results so far. Don’t be left out!
- A good mix of local and global codes.
- A few “unique” implementations: Including adaptive and PIV based

Results match the theory pretty well.



- Good match to theory†
- Theory assumed a uniform window in the subset.
- Analysis is still preliminary.

†Grediac, M., B. Blaysat, and F. Sur, *A Critical Comparison of Some Metrological Parameters Characterizing Local Digital Image Correlation and Grid Method.* Experimental Mechanics, 2017. **57**(6): p. 871-903.

Stereo-DIC Challenge are available on Google Drive.

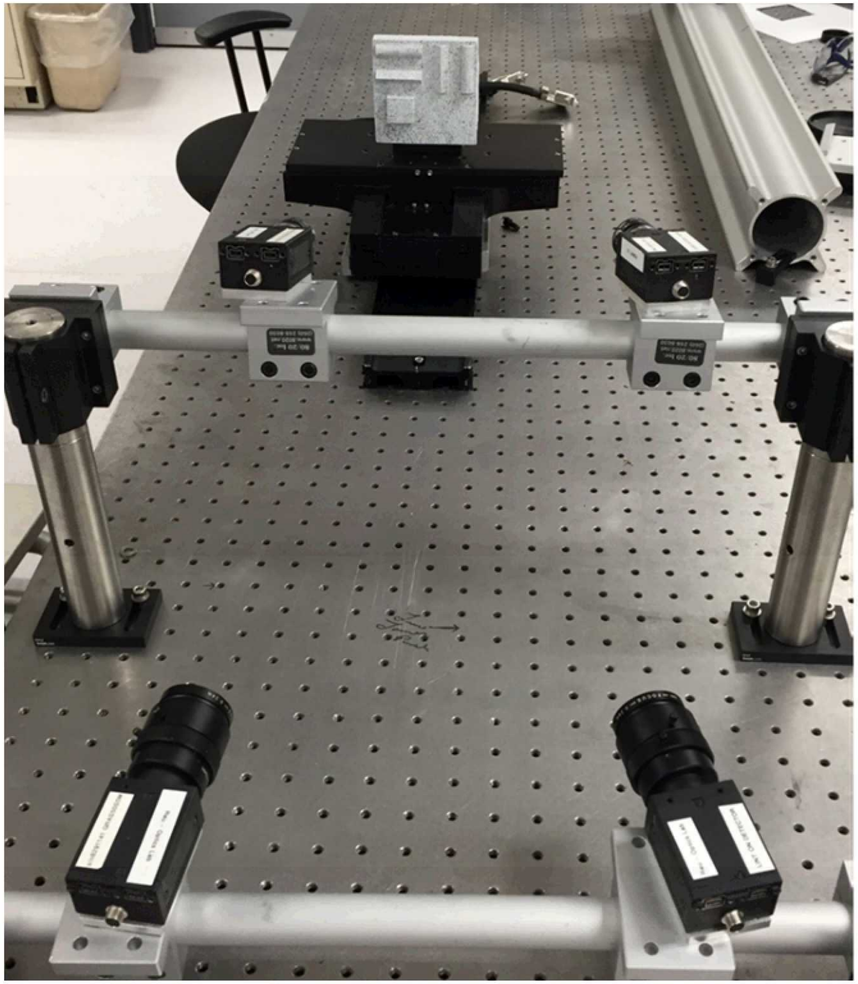
Challenge Set Name	Description	Method of Creation
StereoSample1 - Experiment StereoSample1&2 - Sim Cal	Translation of sample with known dimension. Includes calibration and translation images for a 16-mm and 35-mm stereo-system. Calibration 14×10-10mm	Experimental
StereoSample2 - Simulated StereoSample1&2 - Sim Cal	Simulated translation of plate with known dimensions. Includes calibration and translation images for a 16-mm and 35-mm stereo-system.	Balcaen Simulator
StereoSample3 - Experiment StereoSample3&4 - Sim Cal	D-Specimen tensile test. Calibration 14x10-7mm	Experimental
StereoSample4 - Simulated StereoSample3&4 - Sim Cal	D-Specimen simulated from FE displacement field	Balcaen Simulator
StereoSample5 - Experiment	Tensile specimen with "dummy" region. Calibration 12×9-3.5mm	Experimental
TelecentricSample6 - Experiment	Tensile specimen with telecentric lens. Opposite side to StereoSample5 results.	Experimental

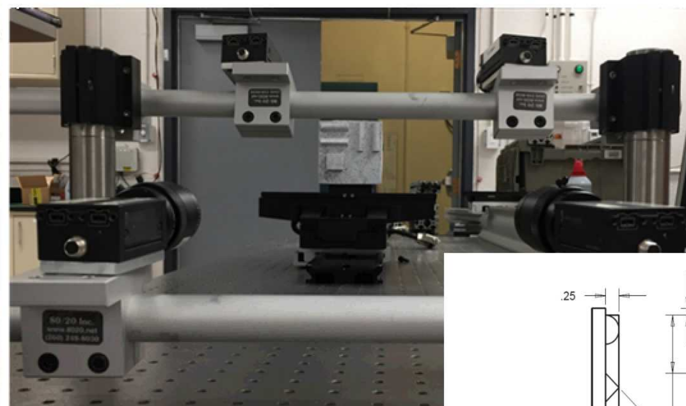
Balcaen R, Wittevrongel L, Reu PL, Lava P, Debruyne D (2017) Stereo-DIC Calibration and Speckle Image Generator Based on FE Formulations. Exp Mech 57 (5):703-718. doi:10.1007/s11340-017-0259-1

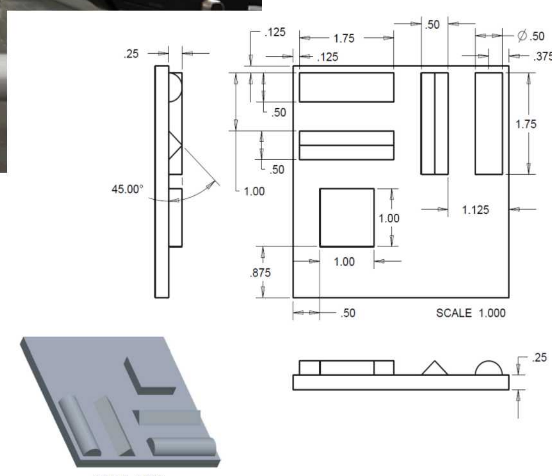
Images available at:

https://drive.google.com/open?id=1uLZdQscdt3pWVwNZU7HBaCxNlUx7ByJb

STEREO-Rigid body motion experimental setup.



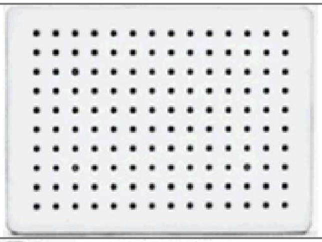
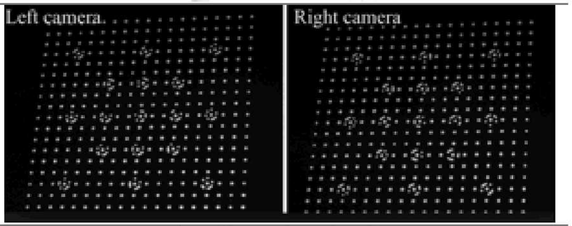
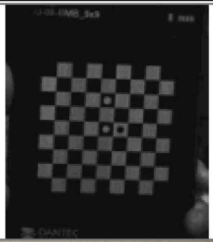
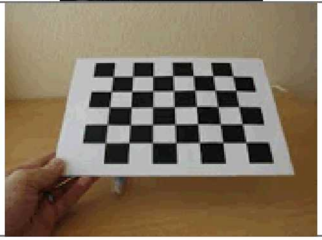




Part was measured via:
- CMM
- Laser scanner

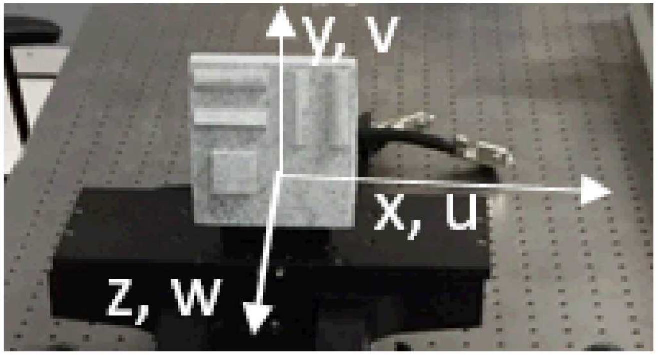
Calibration (with many extra images) were taken according to manufacturers directions.

- Generally followed each manufacturers procedures
- Extra images available if unhappy with some of the images.
- Hand-held all targets
- Everyone should be able to work with one of these image sets!

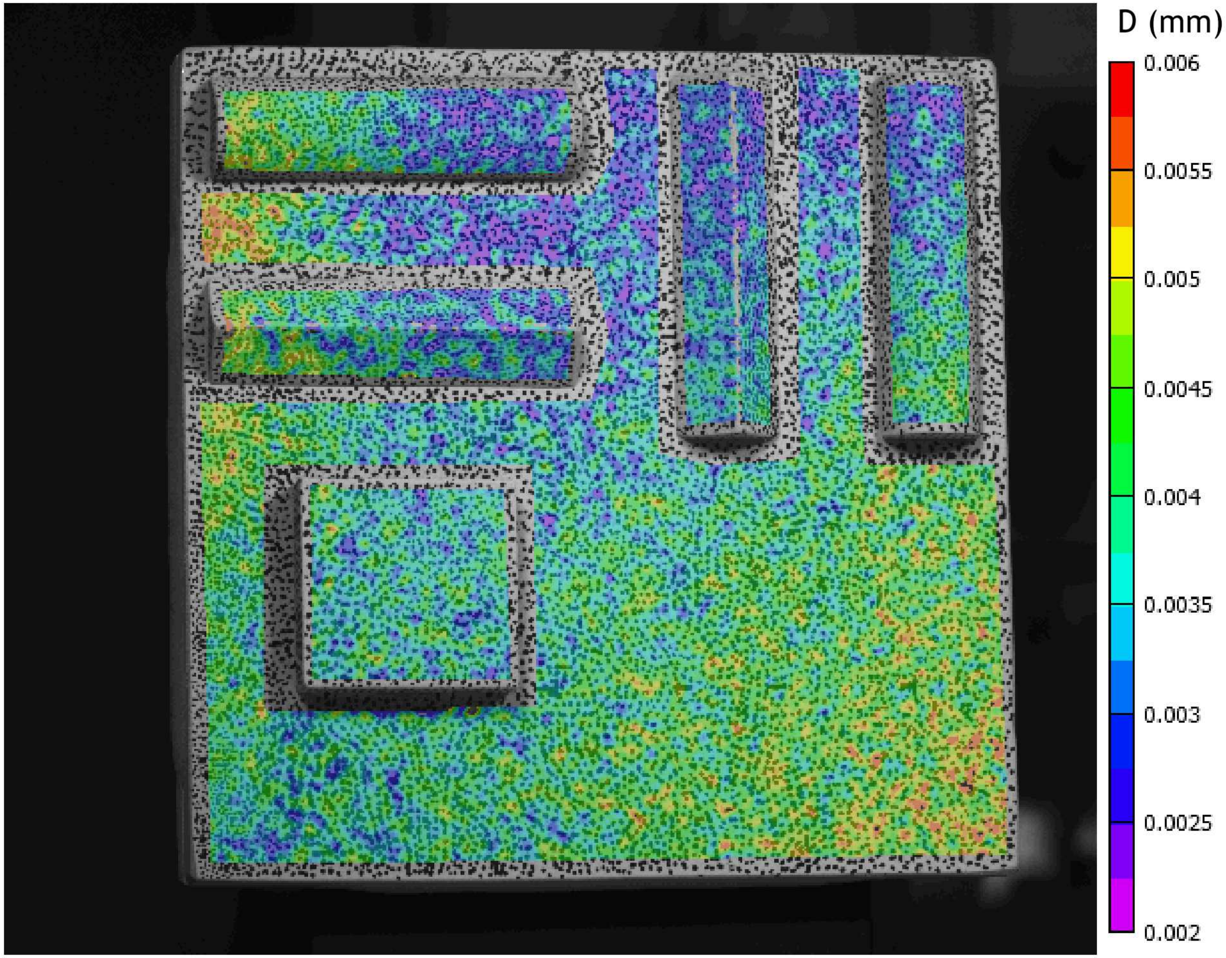
Vendor	Calibration Board
Basic Calibration target: 3 special dots Correlated Solutions, MatchID, and… Exp. images: DotGrid10-mm.zip Sim. images: SimDotCal-14x10-10mm.zip	
3D target with dots at 2 levels LaVision Exp. images: LaVision106-10.zip Simulated images: SimTwoLevelCal10mm2.2Dia2mmLevel.zip	
Coded calibration targets GOM/Trilion Exp. images: GOMCP20MV90x72.zip Sim. images: No simulated images.	
Grid Target Dantec Exp. images: DantecAl-08-BMB9x9-8mm.zip Sim. Images: No simulated images.	
Standard checkerboard pattern CorreliSTC Exp. images: Experimental not imaged. Sim. images: SimCheckerBoardCal.zip	

18-translated images with known displacements. In-Plane and out-of-plane.

Step	Filename 16-mm	Filename 35-mm	W Mean (mm)	StDev (nm)	U Mean (mm)	StDev (nm)
1	Step01 00,00-sys1-0000_0.tif	Step01 00,00-0000_0.tif	0	6.76	0	7.01
2	Step02 00,-10-sys1-0000_0.tif	Step02 00,-10-0000_0.tif	10	6.16	0	7.69
3	Step03 00,-20-sys1-0000_0.tif	Step03 00,-20-0000_0.tif	20	6.21	0	6.30
4	Step04 00,10-sys1-0000_0.tif	Step04 00,10-0000_0.tif	-10	6.12	0	7.67
5	Step05 00,20-sys1-0000_0.tif	Step05 00,20-0000_0.tif	-20	6.33	0	6.74
6	Step06 10,00-sys1-0000_0.tif	Step06 10,00-0000_0.tif	0	6.83	-10	4.91
7	Step07 20,00-sys1-0000_0.tif	Step07 20,00-0000_0.tif	0	7.27	-20	5.71
8	Step08 -10,00-sys1-0000_0.tif	Step08 -10,00-0000_0.tif	0	6.79	10	6.53
9	Step09 -20,00-sys1-0000_0.tif	Step09 -20,00-0000_0.tif	0	7.37	20	5.69
10	Step10 10,10-sys1-0000_0.tif	Step10 10,10-0000_0.tif	-10	4.57	-10	5.99
11	Step11 20,20-sys1-0000_0.tif	Step11 20,20-0000_0.tif	-20	25.19	-20	14.65
12	Step12 -10,-10-sys1-0000_0.tif	Step12 -10,-10-0000_0.tif	10	6.43	10	7.65
13	Step13 -20,-20-sys1-0000_0.tif	Step13 -20,-20-0000_0.tif	20	6.54	20	6.10
14	Step14 10,-10-sys1-0000_0.tif	Step14 10,-10-0000_0.tif	10	6.08	-10	5.70
15	Step15 20,-20-sys1-0000_0.tif	Step15 20,-20-0000_0.tif	20	6.45	-20	5.14
16	Step16 -10,10-sys1-0000_0.tif	Step16 -10,10-0000_0.tif	-10	5.01	10	6.29
17	Step17 -20,20-sys1-0000_0.tif	Step17 -20,20-0000_0.tif	-20	6.07	20	5.99
18	Step18 00,00-sys1-0000_0.tif	Step18 00,00-0000_0.tif	0	7.59	0	6.36



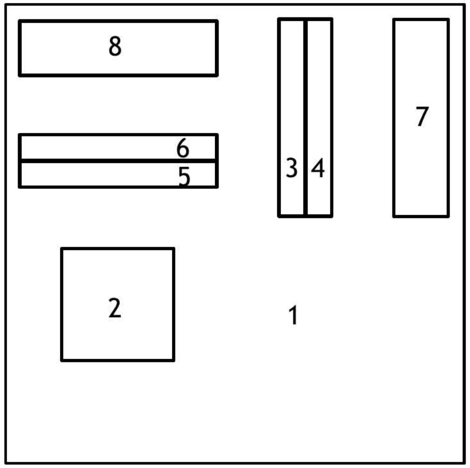
Return to home had very little offset from the start indicating a stable experiment.

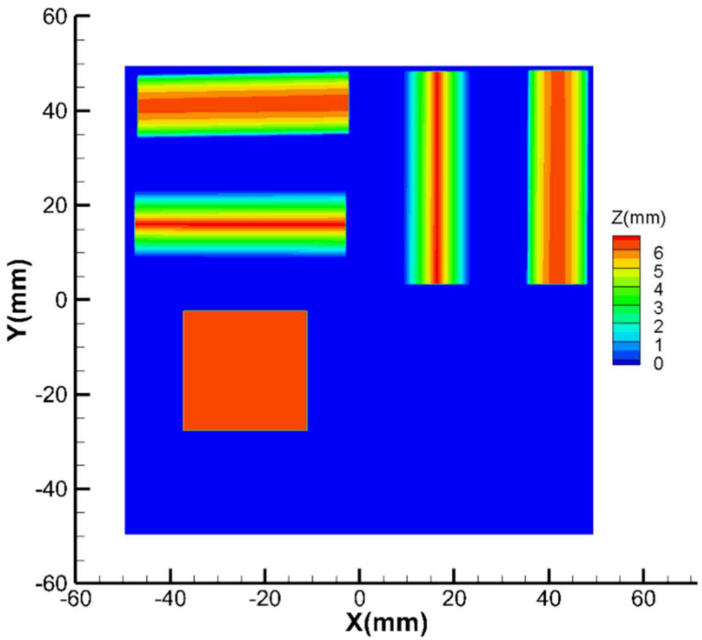


System 1 results (35-mm) Shown

Comparisons will be done after a "model" fit to the primitives of the object.

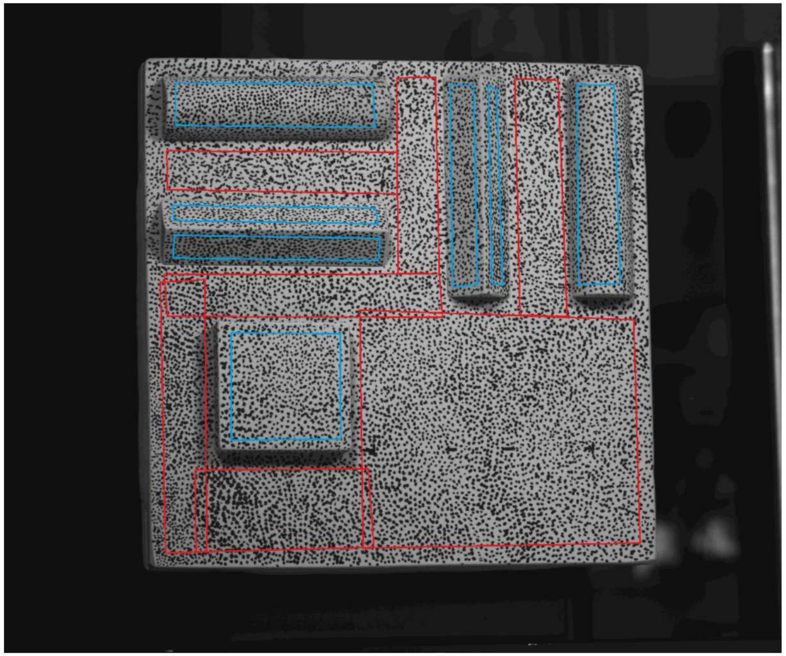
- The "model" is defined as the primitives as they are oriented on the as-built part fit from the laser scan data.

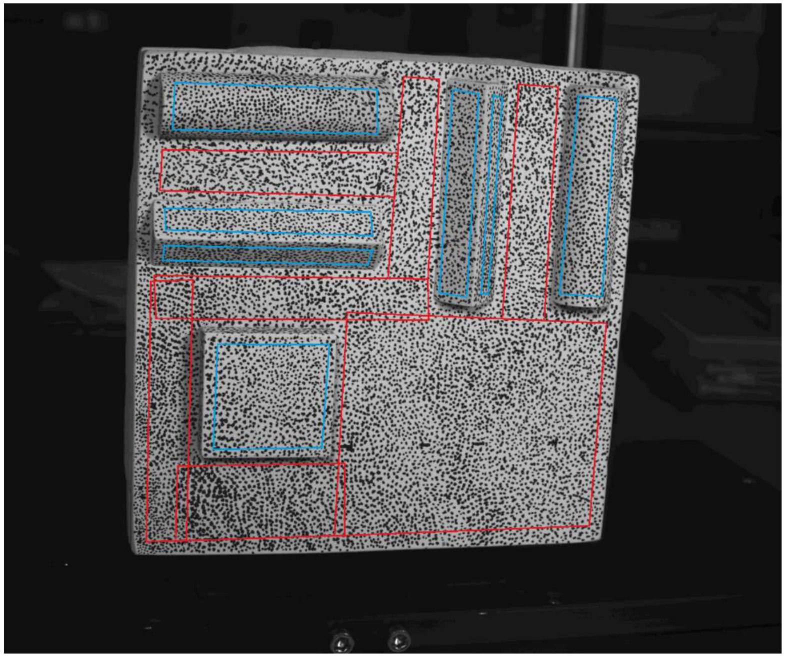




- After fit – data is in a common coordinate system in a best-fit sense.
- Rigid-body motion removal may be done by removing the large offset and then a final fit.
- Then data is interpolate to an x, y grid with a 0.02-mm spacing. Points with insufficient data density are omitted
- Pixel size is ~0.06 mm/pixel.

All data is used for comparisons, selected data used for the fit

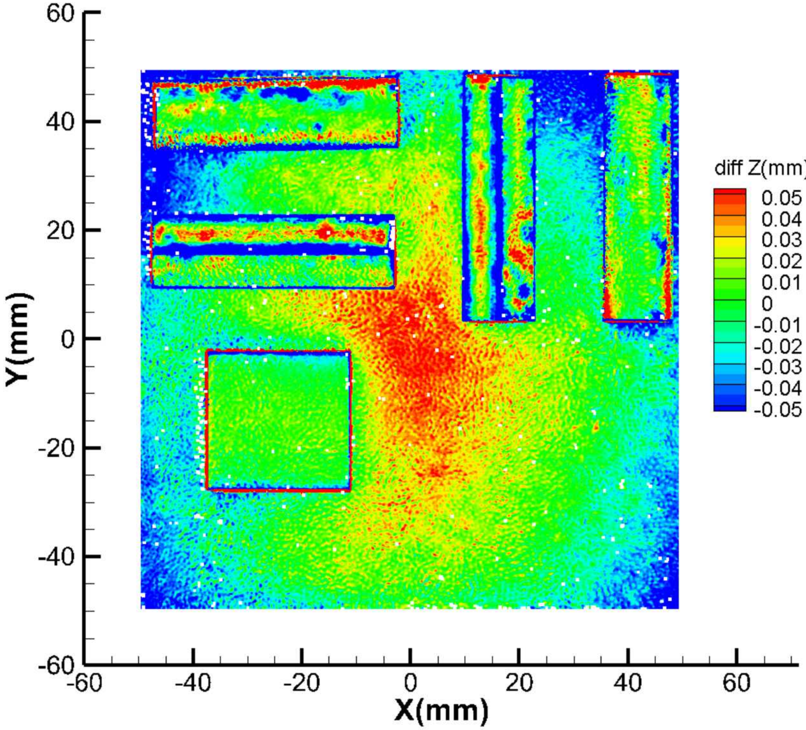




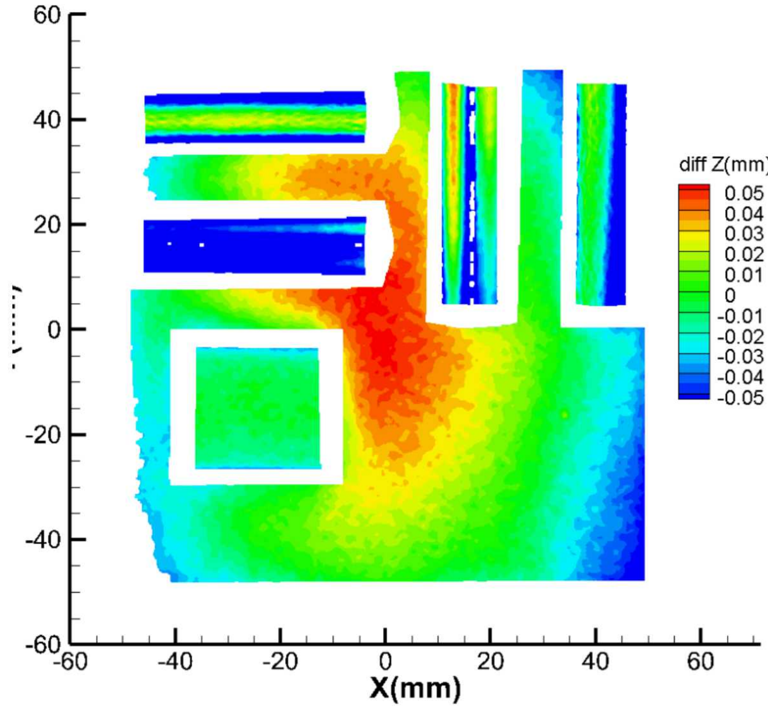
- The points used for the coordinate system fit are designated by their pixel locations in the step 1, camera 0 image of that system.
- Data used for the fit do not include discontinuous or transitional areas on the plate.
- Both systems use the same areas for the coordinate system fit.
- All data submitted for the plate will be used to develop the gridded data for the comparisons

Comparisons between the model and the data can now be made.

Laser scan to model

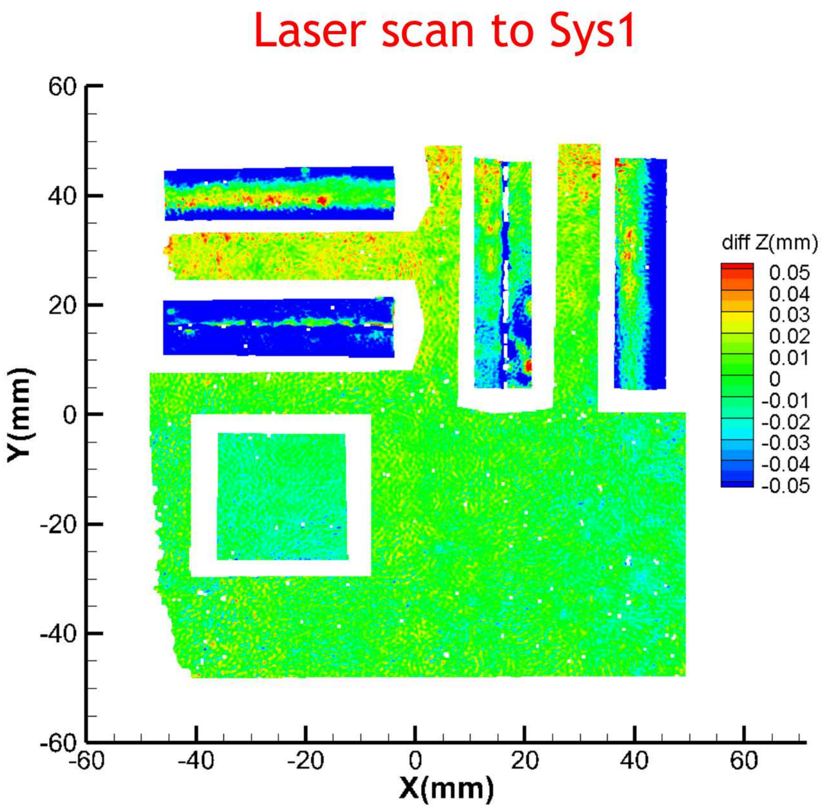


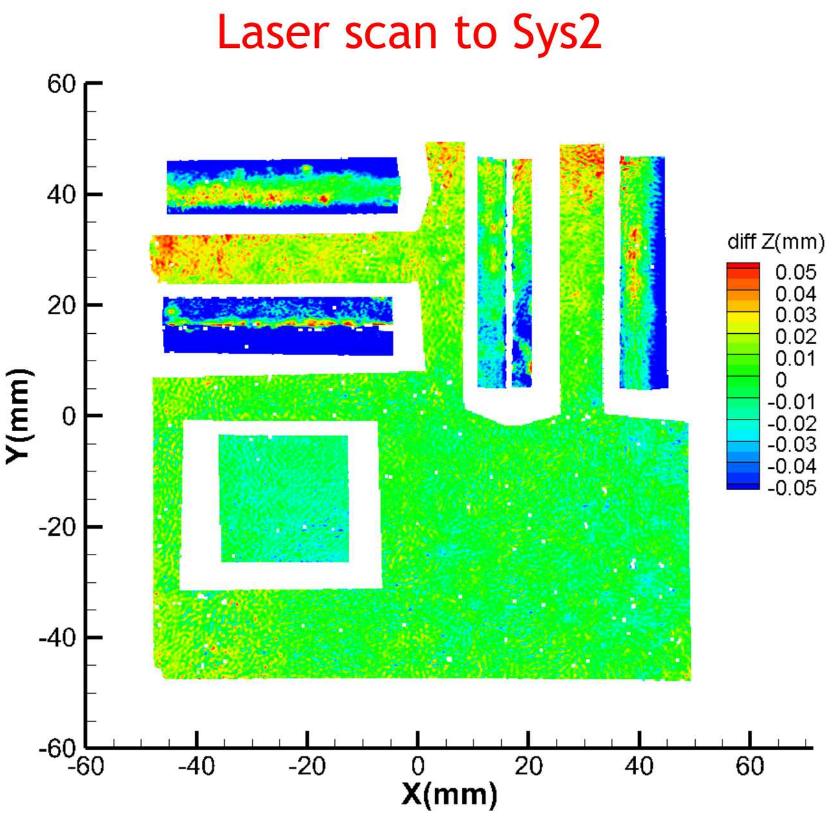
Sys1 to model



- Voids in the laser scan data are due to the lower data density of the scan
- Areas around the shapes in the sys1 data were not in the correlation

Comparisons between laser scan and DIC can now be made in a common coordinate system.

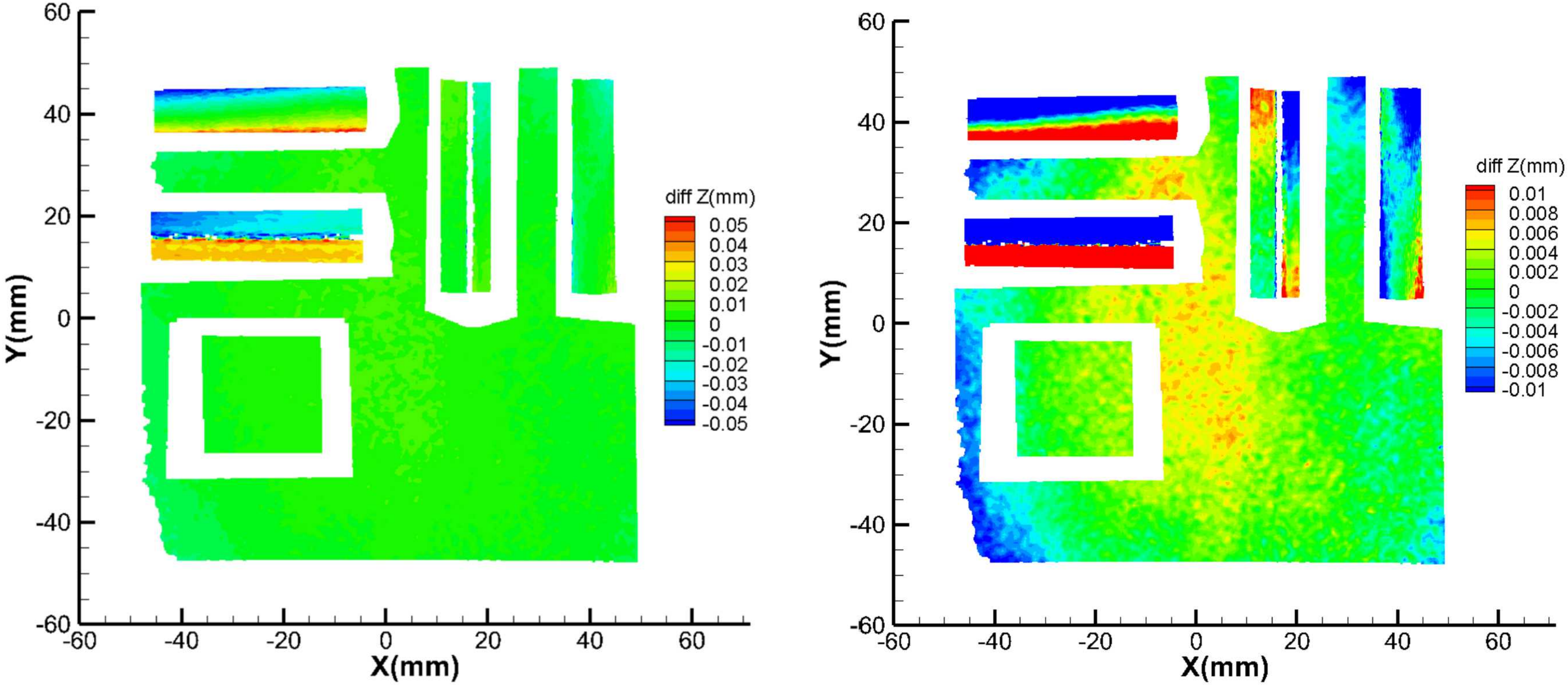




- Relevant comments will be put here.

Comparisons between DIC systems are also possible.

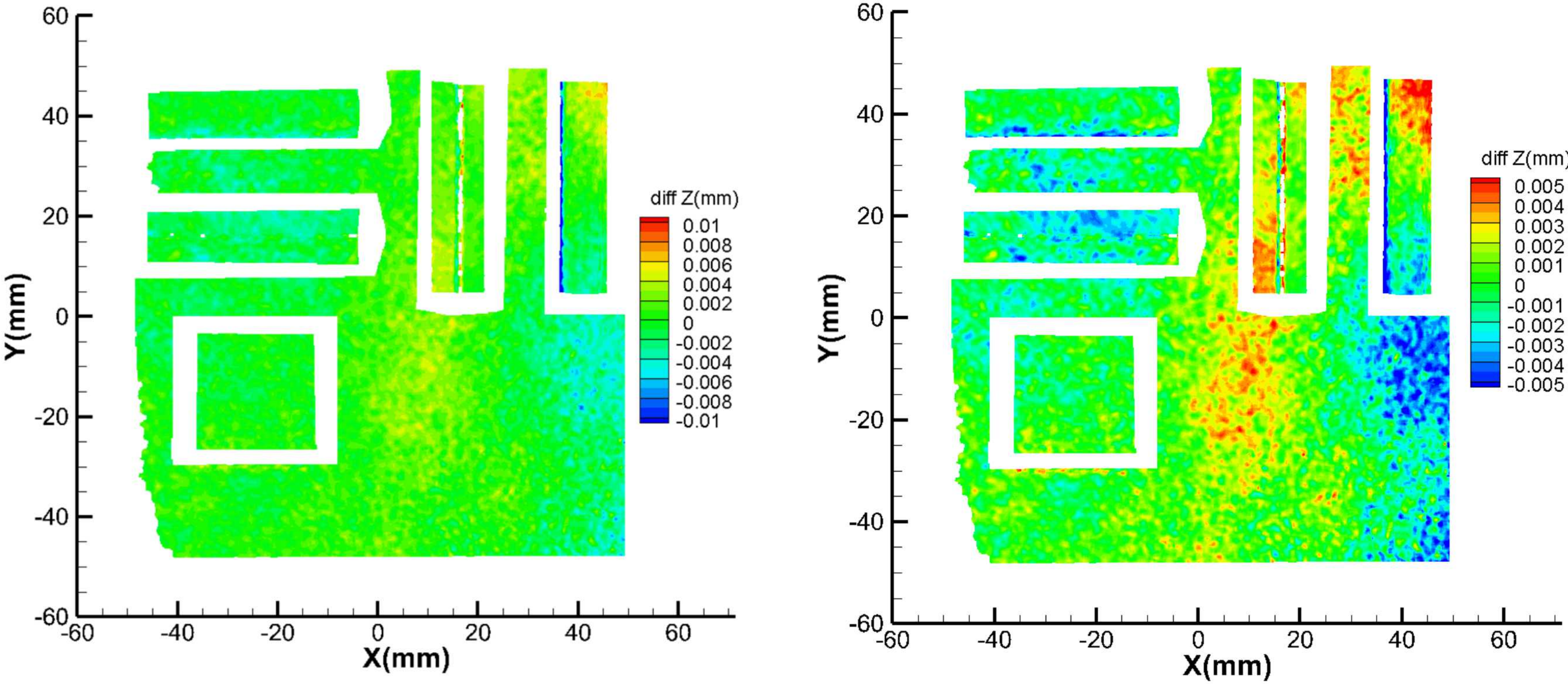
Sys1 to Sys2



- Sys1 to sys2 comparison for step 1.
- Second comparison between the profile from system 1 step 1 (X,Y,Z) and system 1 step 11 (X+U, Y+V, Z+W). Both oriented with the coordinate system fitting routine.

Comparisons between DIC systems are also possible.

Shifted Sys1 (20,20) to Sys1

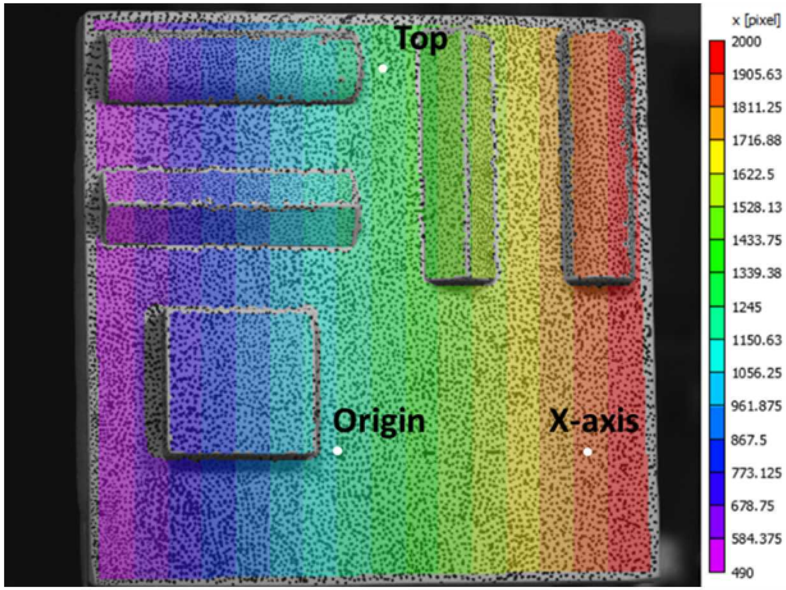


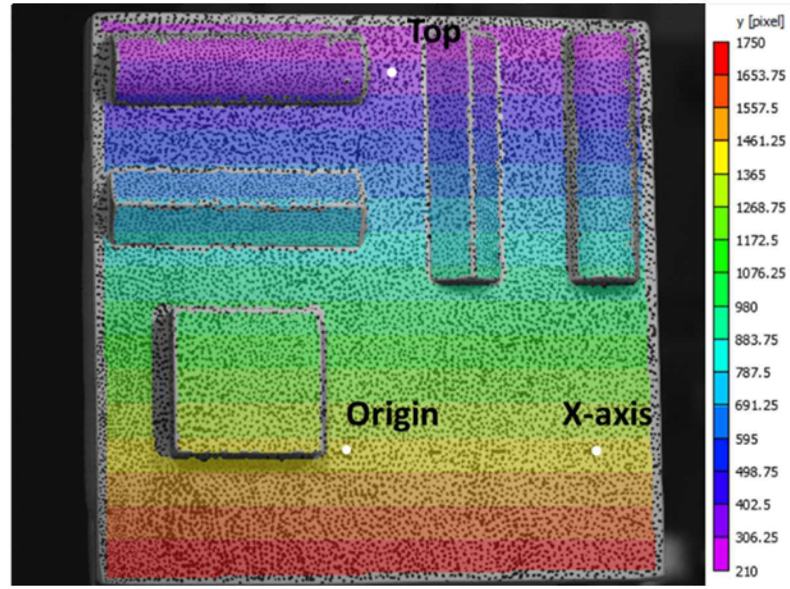
- Sys1 to sys2 comparison for step 1.
- Second comparison between the profile from system 1 step 1 (X,Y,Z) and system 1 step 11 (X+U, Y+V, Z+W). Both oriented with the coordinate system fitting routine.

Data submission requirements

- Data submitted in MatLab *.mat format
- Separate files for each position (step)
- Each file should contain a single [n,8] array with called DICData
- The columns of the data are [X_img, Y_img, X, Y, Z, U, V, W] where:
  - X_img, Y_img are image locations from the step 1 camera 0 image with 0,0 being the upper left corner of the image in pixels
  - X, Y, Z world coordinates of the surface profile in mm's
  - U, V, W displacements in space in mm's
- The data should be oriented so the Z axis is perpendicular to the base plate, the Y axis is oriented in the same direction as the vertical triangular prism, and 0,0,0 is on the plate surface approximately in the middle of the plate.
- Files must include points that the submitter considers valid. Bad points or areas that were not in the analysis should not be included in the file.
- A MatLab program that will read in the data, and create images based on the profile/displacement fields will be made available.

Common coordinate system is needed for comparison. We need to discuss this.





		System 1 35-mm				System 2 16-mm				Global Coordinates			System 1 Fit			System 2 Fit		
Point	Location	Xs1 [pix]	Ys1 [pix]	Xs2 [pix]	Ys2 [pix]	Xs1 [pix]	Ys1 [pix]	Xs2 [pix]	Ys2 [pix]	X [mm]	Y [mm]	Z [mm]	X [mm]	Y [mm]	Z [mm]	X [mm]	Y [mm]	Z [mm]
	Origin	1164	1409	1150.901	1392.114	1092.909	1395.507	1193.652	1354.671	0	0	0	0.168159	-0.03816	0	0.168764	-0.03765	0
	X	1855	1403	1843.909	1395.129	1738.654	1382.73	1859.497	1370.702	45	0	0	44.8353	-0.01943	-1.14E-13	44.8329	-0.0156	0
	Top	1306	312	1345.901	294.1977	1312.953	317.6764	1267.083	268.0739	11	70	0	10.9966	70.0576	-1.14E-13	10.9983	70.0532	0

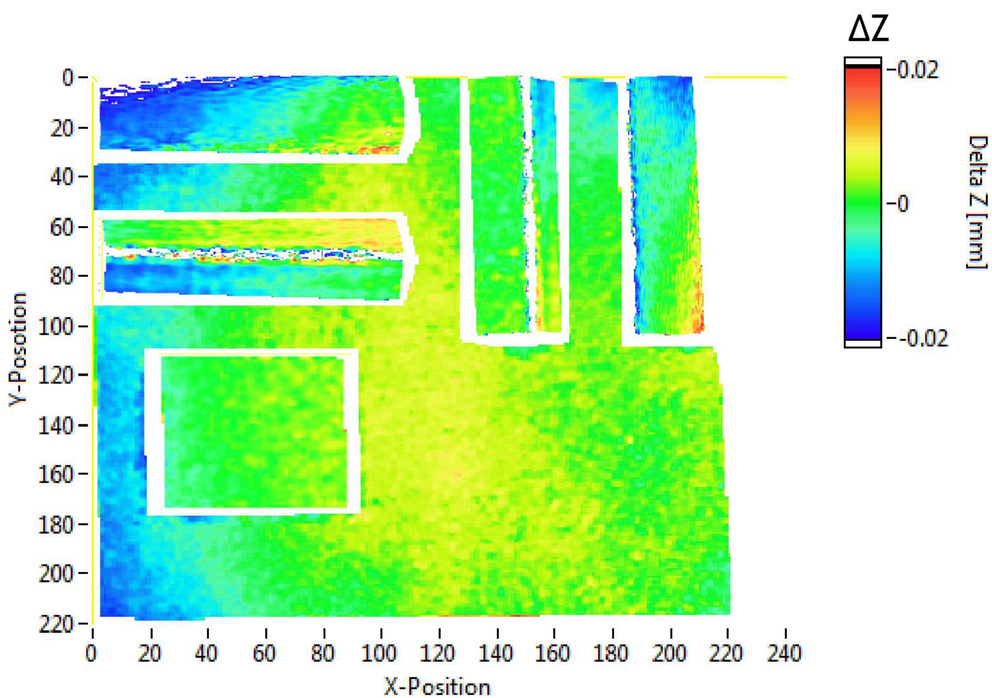
- System 1 reference image pixel coordinates image (x_{s1}, y_{s1}) will be provided for 3-points in System 1 (35-mm).
- Chosen at the integer pixel location nearest the integer Global coordinates.
- System 1 cross-correlation found via traditional methods.

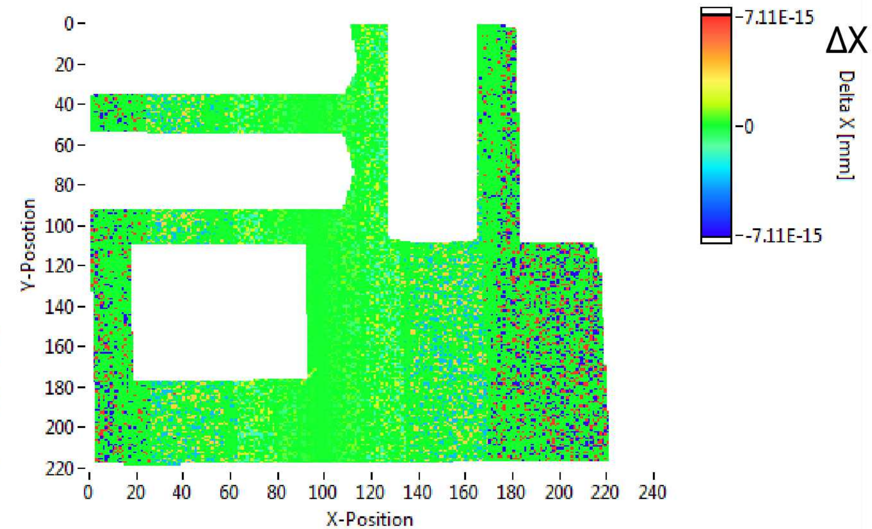
System 1 35-mm Transform				System 2 16-mm Transform			
0.99917	0.002924	0.040622	27.1137	0.998135	-0.00034	0.061037	18.4342
0.001878	0.99305	-0.11768	-49.0985	-0.01246	0.977778	0.209274	77.7759
-0.04068	0.117655	0.992221	614.207	-0.05975	-0.20965	0.97595	257.103
0	0	0	1	0	0	0	1

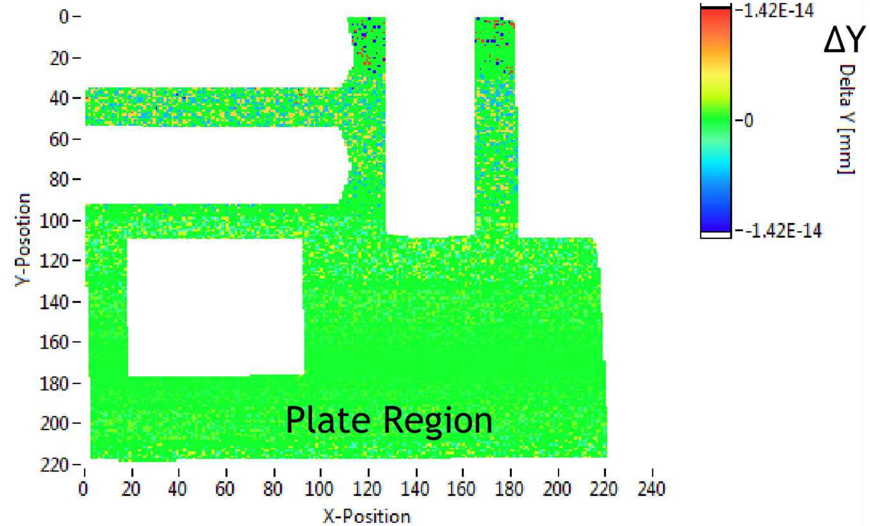
- Triangulate the 3 points and do a best fit to the global coordinates. Not a perfect fit. This transformation goes from any arbitrary coordinates to a single Global coordinate.
- Rigid-body-removal can also be handled by adding the u, v motions at other positions and then fitting.
- Or: This transformation will be used for all steps after to put into a single global coordinate system.
- System 2 pixel coordinates found by correlation with System 1 coordinates. This was done via multi-system in Vic at this point. Could be done with 2D correlation (lens distortion issues?). Find System 2 coordinate transform to Global Coordinates.

Comparison is done by interpolating onto the same data locations. (System 1 to System 2)

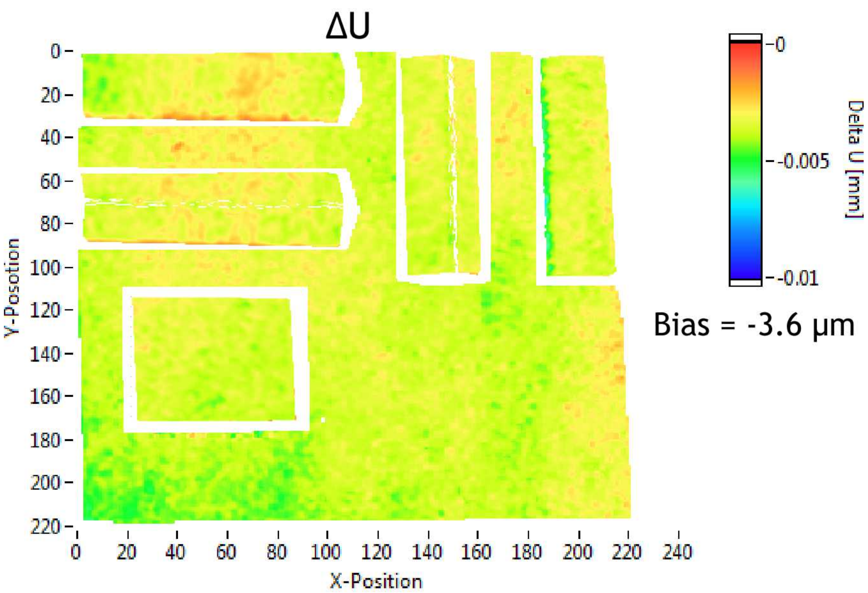
- We now have a 1 pixel spacing data for both Systems in a Global Coordinate system.
- We have a dense grid of X, Y and Z data (or U, V, W) that we need to align for comparison.
- System 1 used as a baseline and System 2 interpolated in X, Y and Z (Linear) to get aligned data points.
- For X and Y – Machine precision errors only.
- For Z only lens distortions remain.

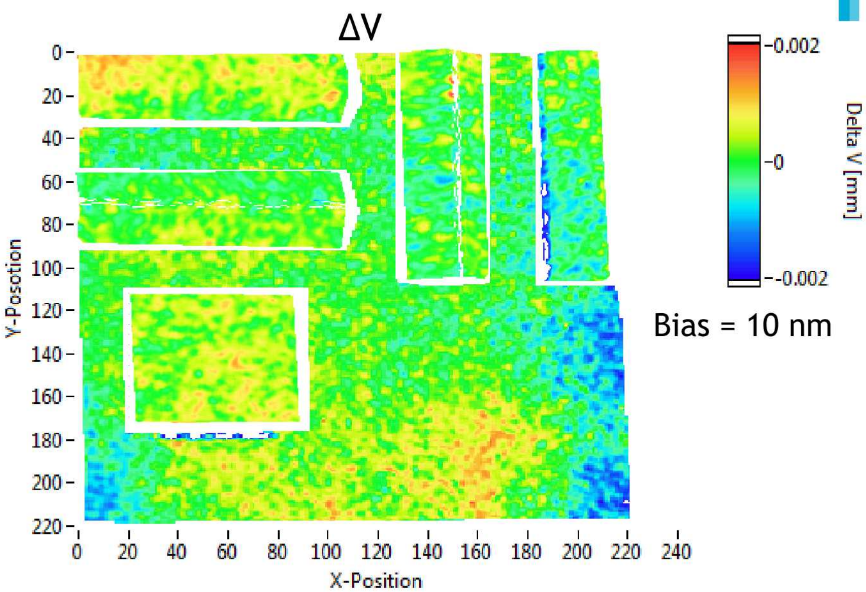




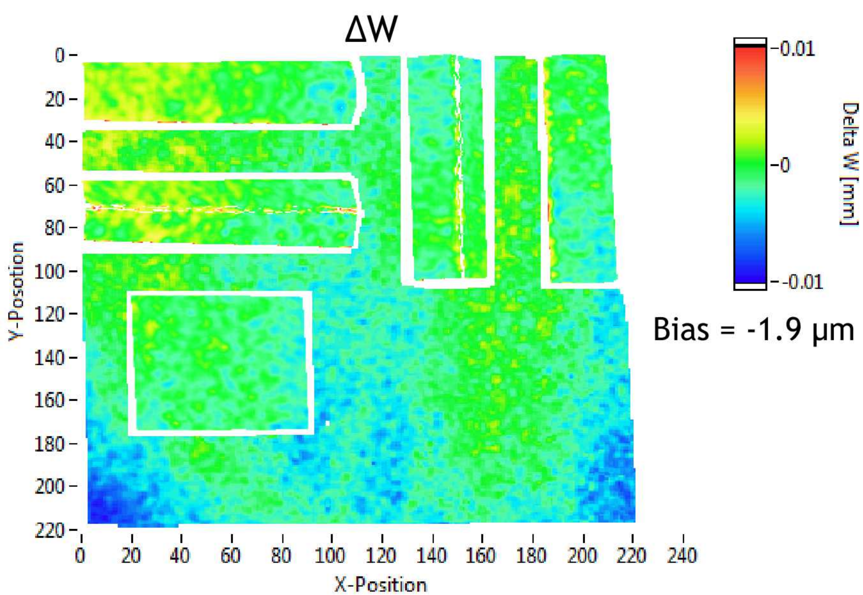


Step 4 Comparison: W = -10 mm, U = 0 mm

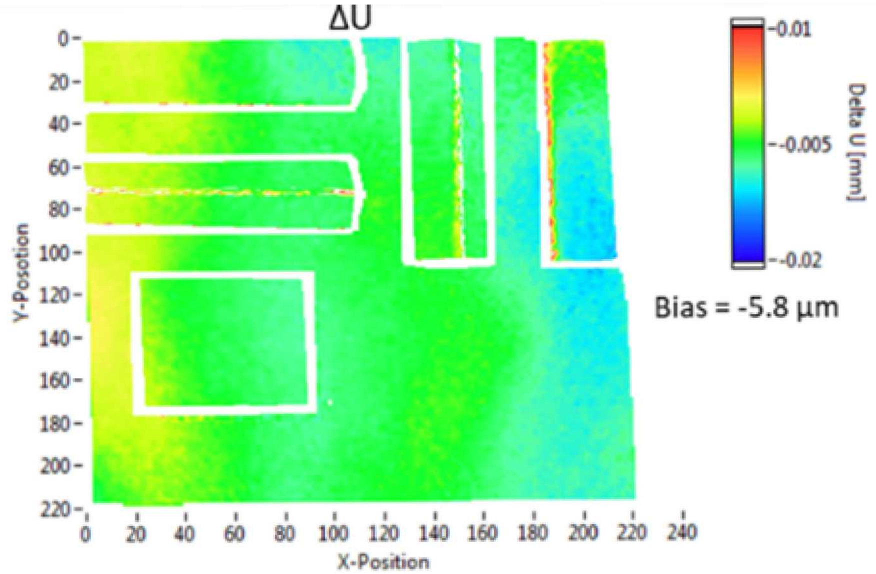


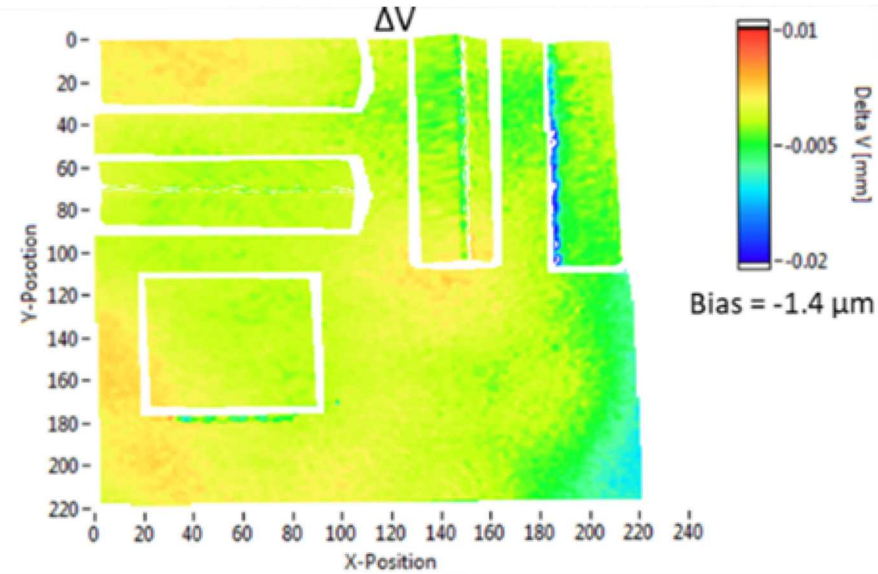


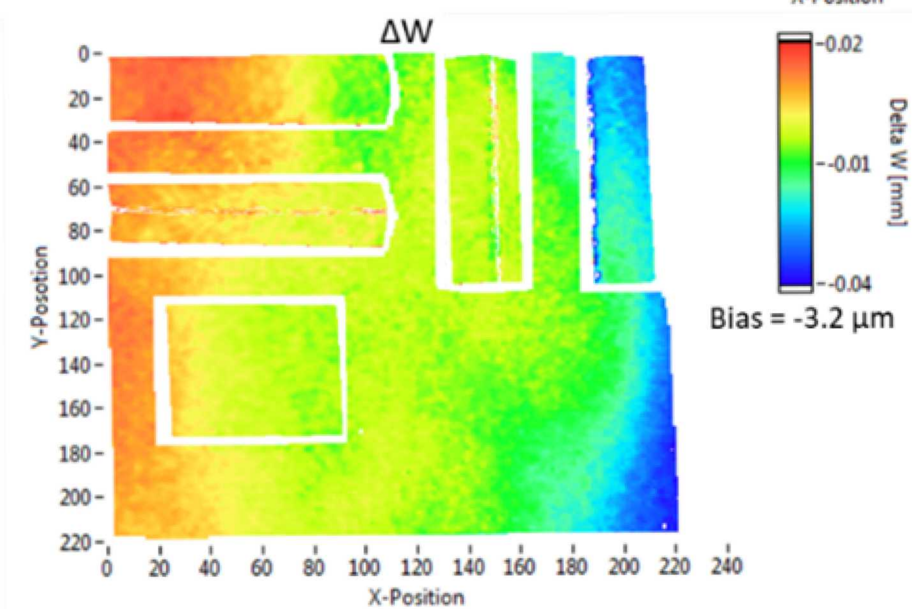
- Point by point comparison of System 1 to System 2 translation results.
- Bias indicates offset between the systems for the entire flat plate region.



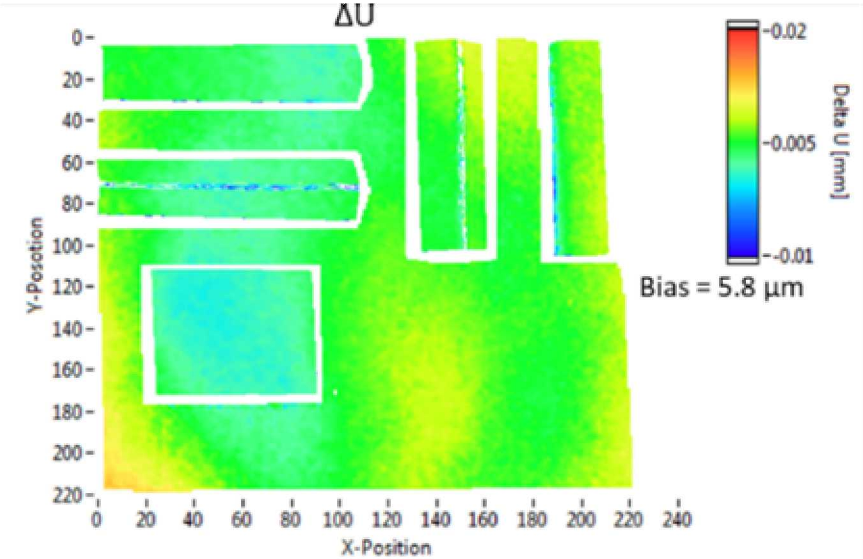
Step 11 Comparison: W = -20 mm, U = -20 mm

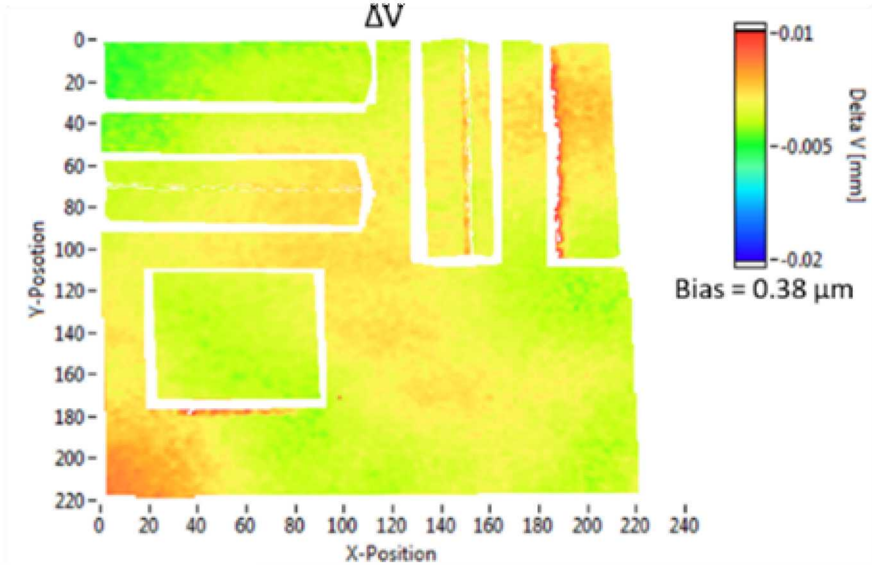


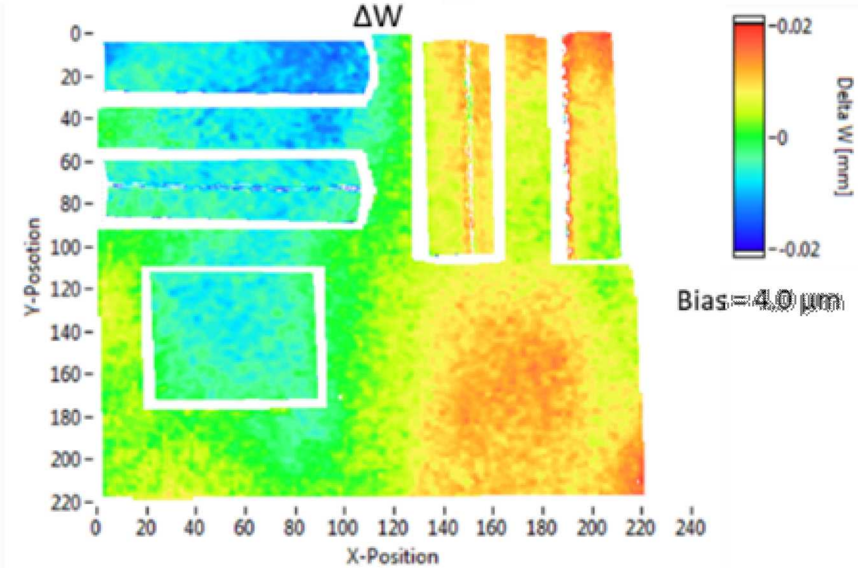




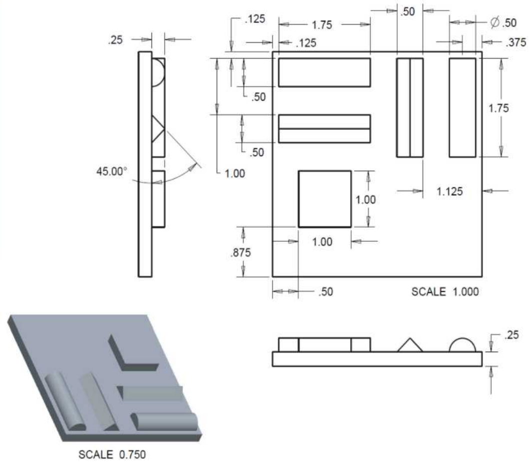
Step 13 Comparison: W = 20 mm, U = 20 mm

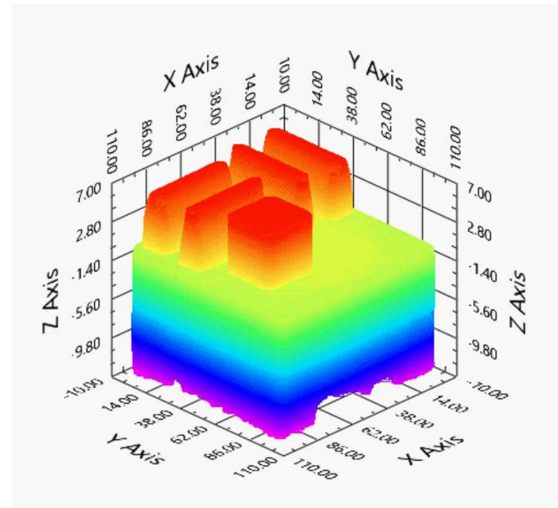






A laser scanner metrology system was used to measure the shape of the object.



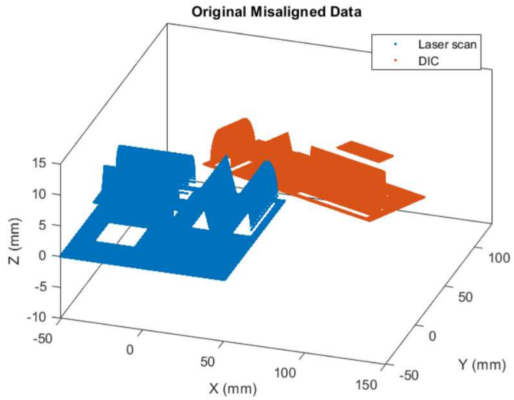


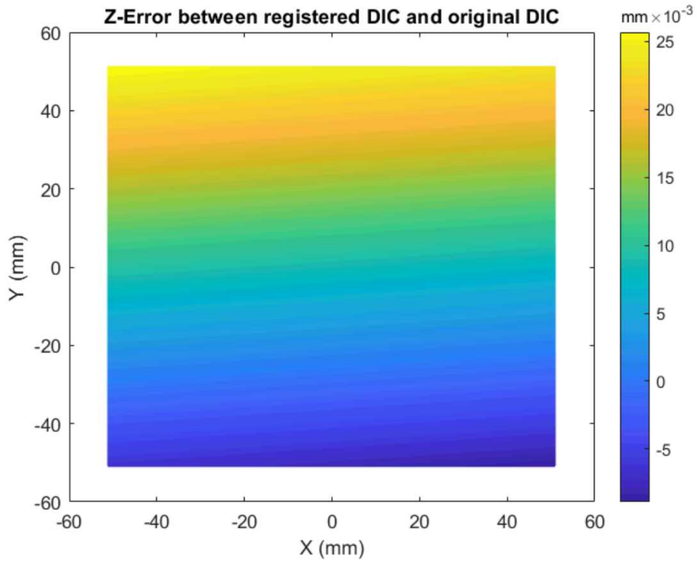
Faro Edge Laser Scan

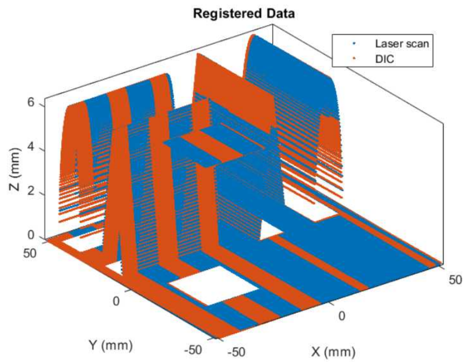
Laser Line Probe Specifications

Accuracy: ±25μm (±.001in)
Repeatability: 25μm, 2σ (.001in)
Stand-off: 115mm (4.5in)
Depth of Field: 115mm (4.5in)
Effective Scan width: Near Field 80mm (3.1in), Far Field 150mm (5.9in)
Points per line: 2,000 points/line
Minimum Point Spacing: 40μm (.0015in)
Scan Rate: 280 frames/second, 280fps x 2,000 points/line = 560,000 points/sec
Laser: Class 2M
Weight: 485g (1.1lb)

ICP algorithm didn't work very well for laser scan data.







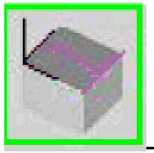
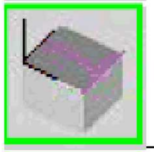
Original Transformation Matrix					Recovered Transformation Matrix			
-0.9981	-0.0261	0.0564	0		-0.9985	-0.0084	0.0549	0
0.031	-0.9955	0.0891	0		0.0133	-0.9959	0.0897	0
0.0539	0.0906	0.9944	0		0.0539	0.0903	0.9945	0
58.854	78.213	0.1	1		59.1656	78.5749	0.0418	1

A Coordinate Measurement Machine (CMM) was also used to get heights and angles.

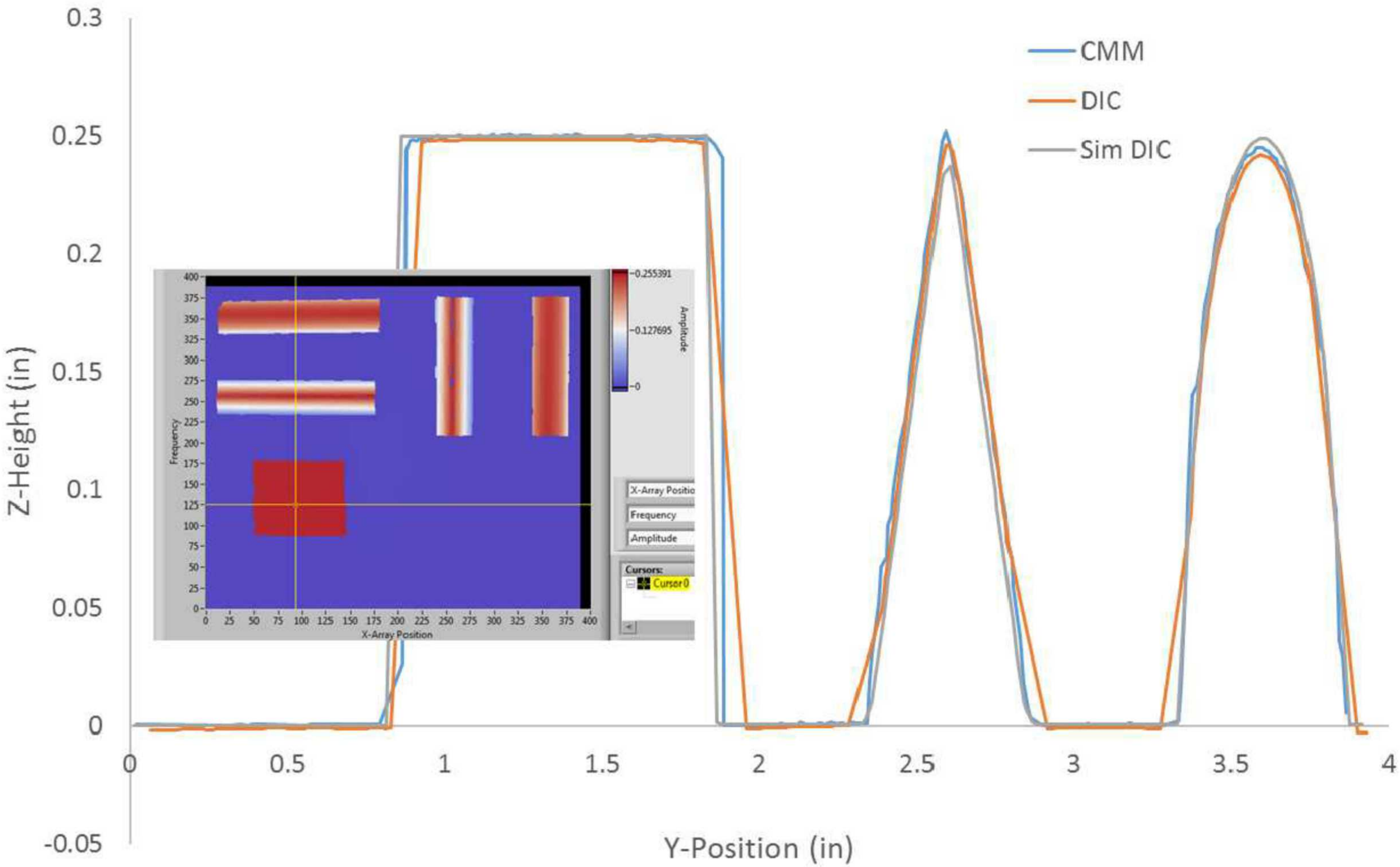
ZEISS Calypso

Measurement Plan Paul Farias - Test Plate	Date April 27, 2017	
Drawing No. * drawingno *	Time 8:03:04 am	Order
Operator Master	CMM Simulation	Incremental Part Number 2

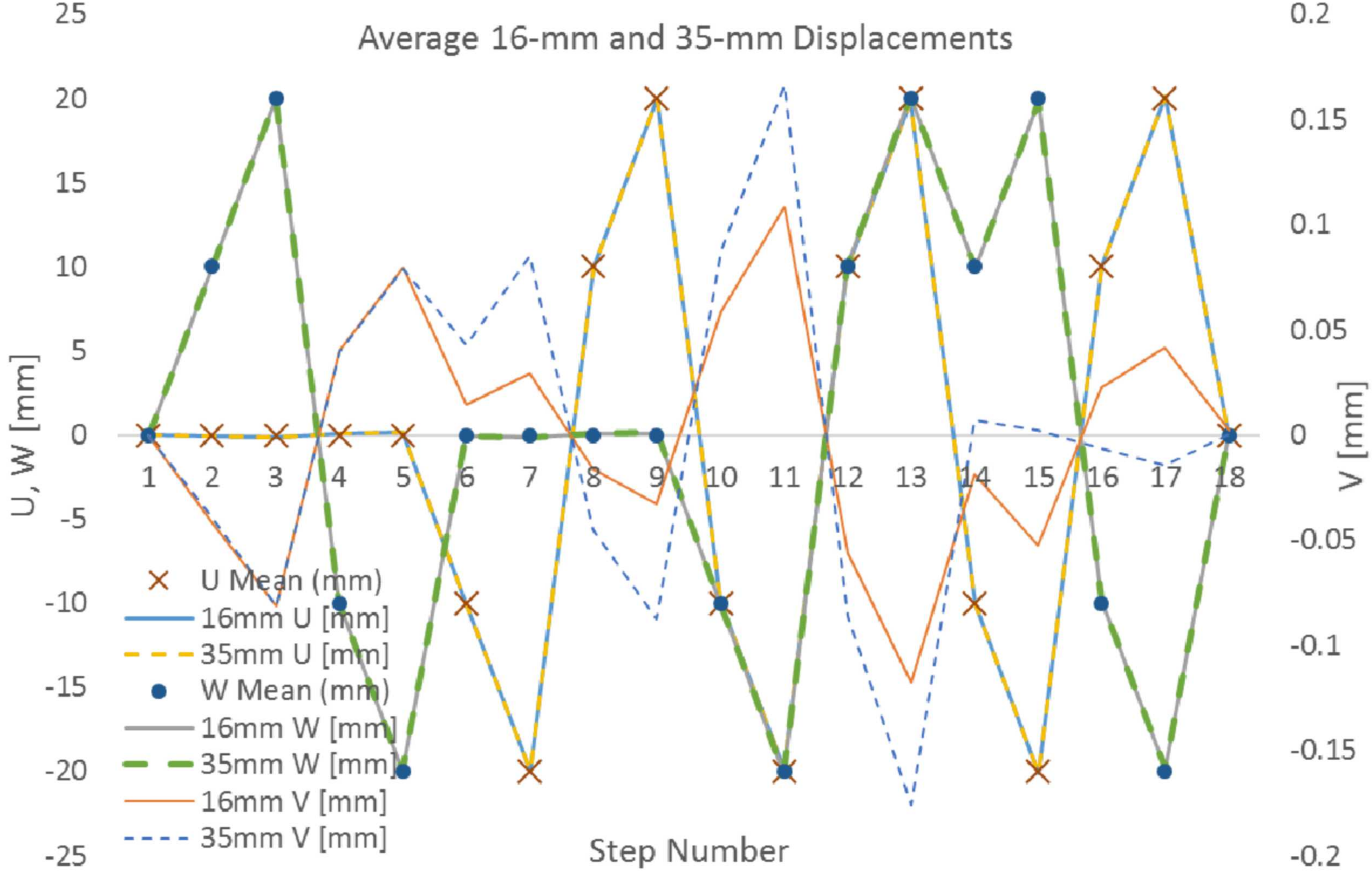
- Heights, angles and radius are measured.
- There are quite a few things we can compare to.

	Horizontal Triangle - Angle	90.1436	90.1426
	Horizontal Cylinder - Right	3.8917	3.8917
	Horizontal Cylinder - Left	2.1195	2.1195
	Horizontal Cylinder - Diameter	0.4959	0.4959

How do we compare to the laser scan data? Line cuts are one approach.

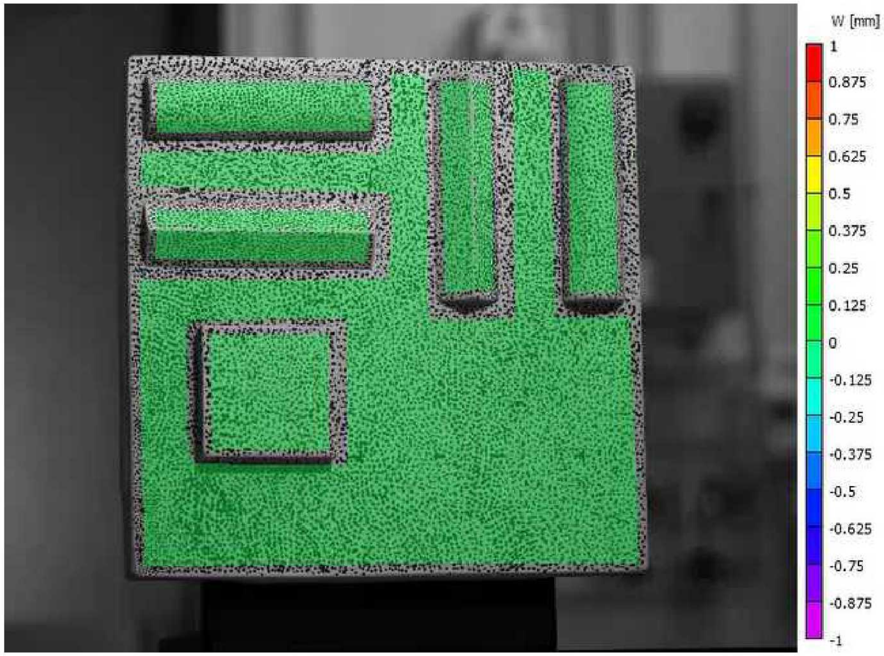


Sample 1 Translation results

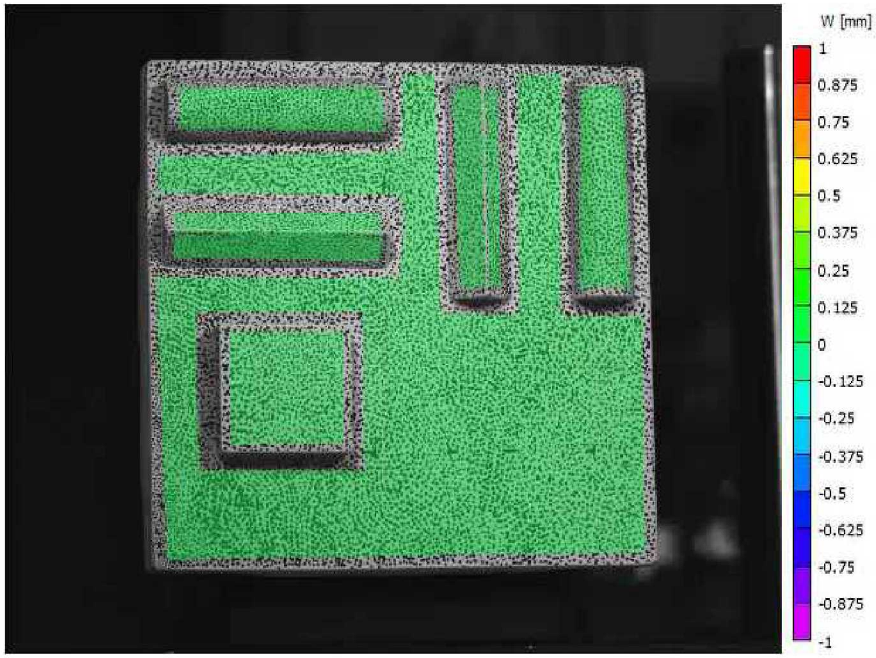


Issues with the first data sets

Old Image Set Firewire 5-MPixel



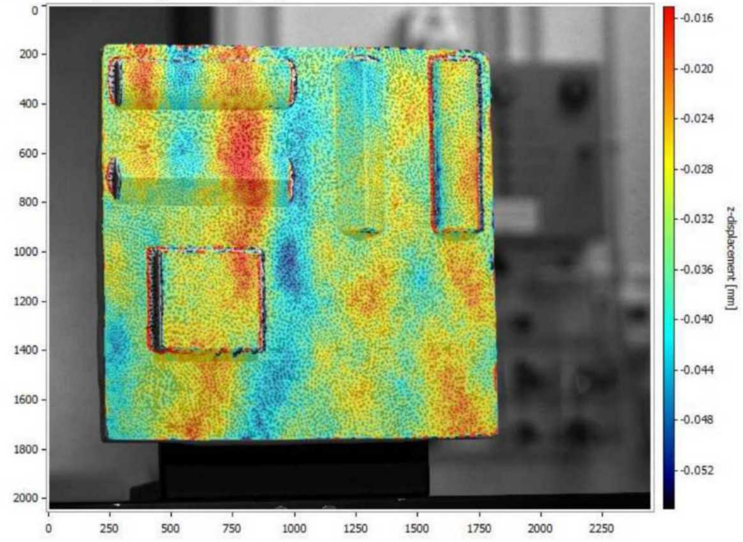
New Image Set Sony 5-MPixel

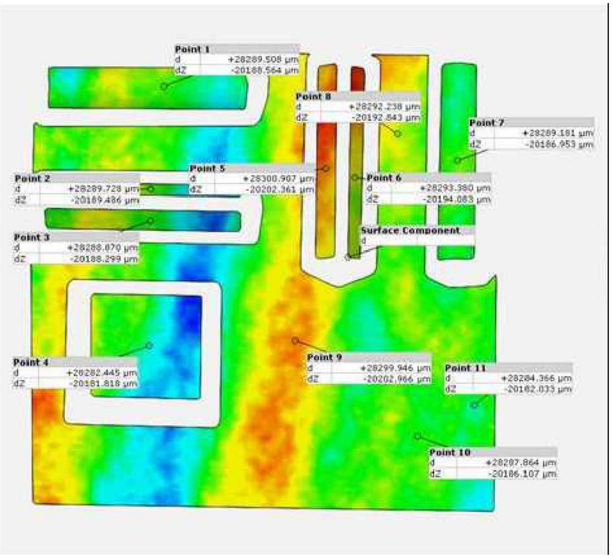


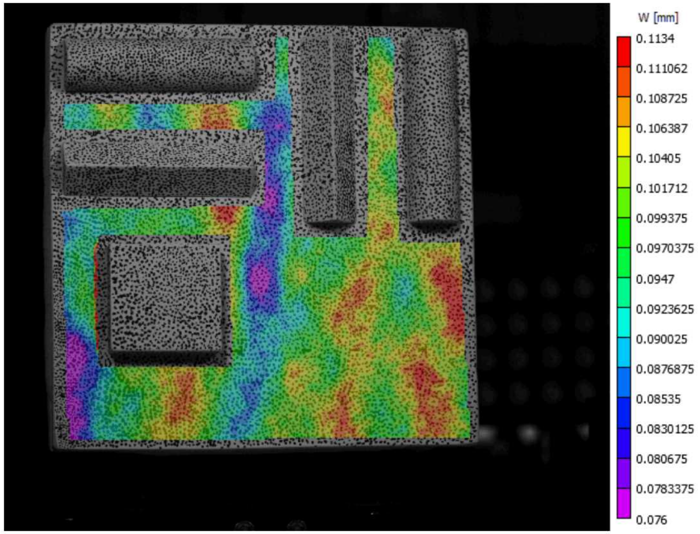
Relax and watch the moving plate…

Results from the codes

35mm – Step 8 z-displacement [mm]:

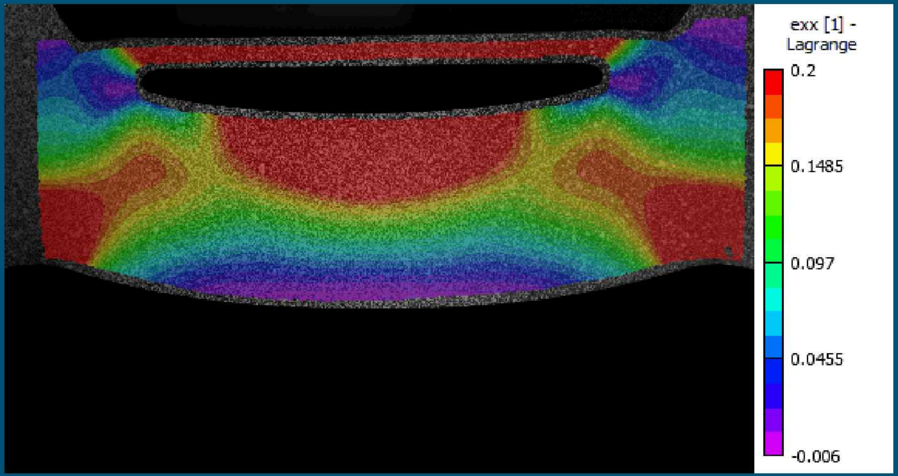


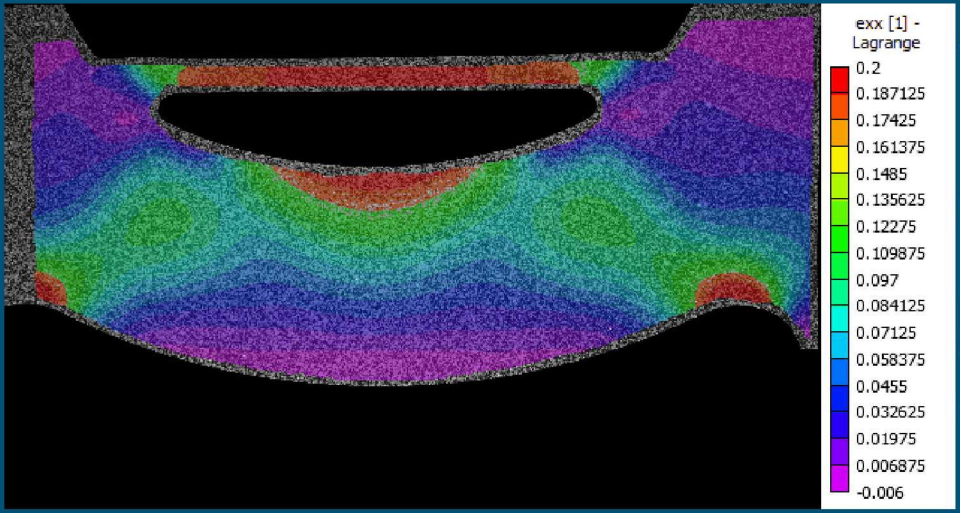




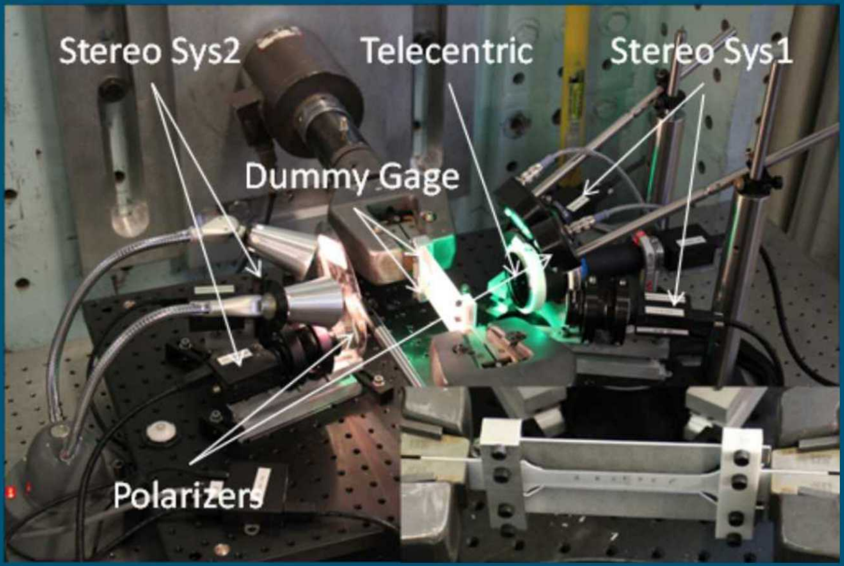
- Banding showed up in all codes and was stationary
- Is this a warped sensor? How would we prove that?

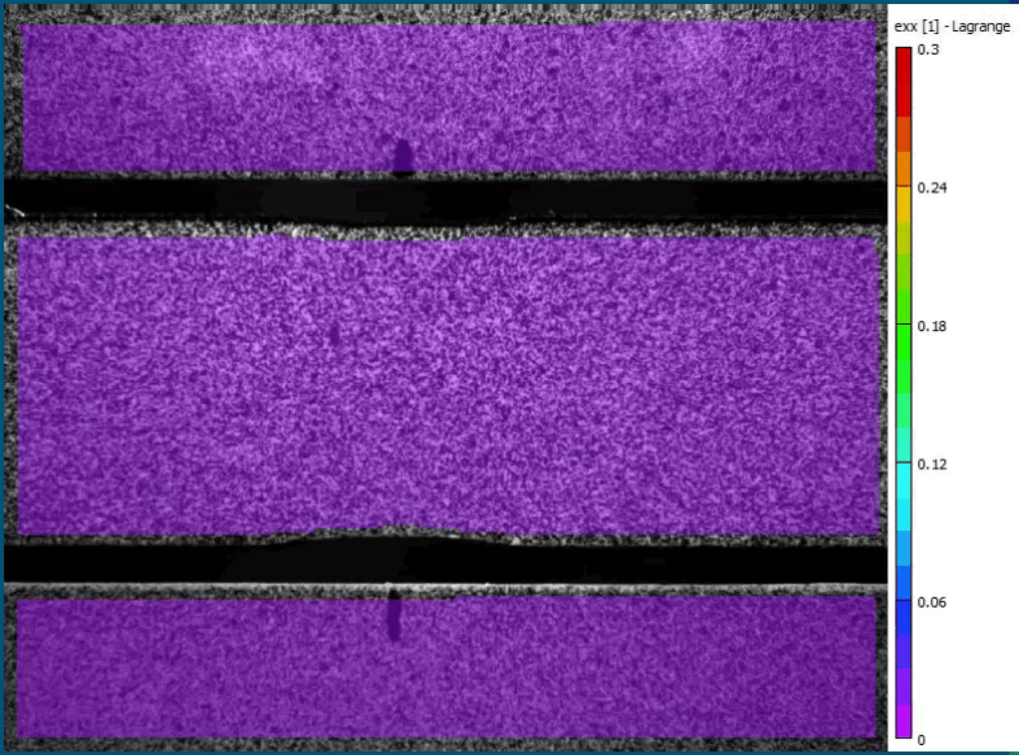
D-Specimen – Experimental and Simulation



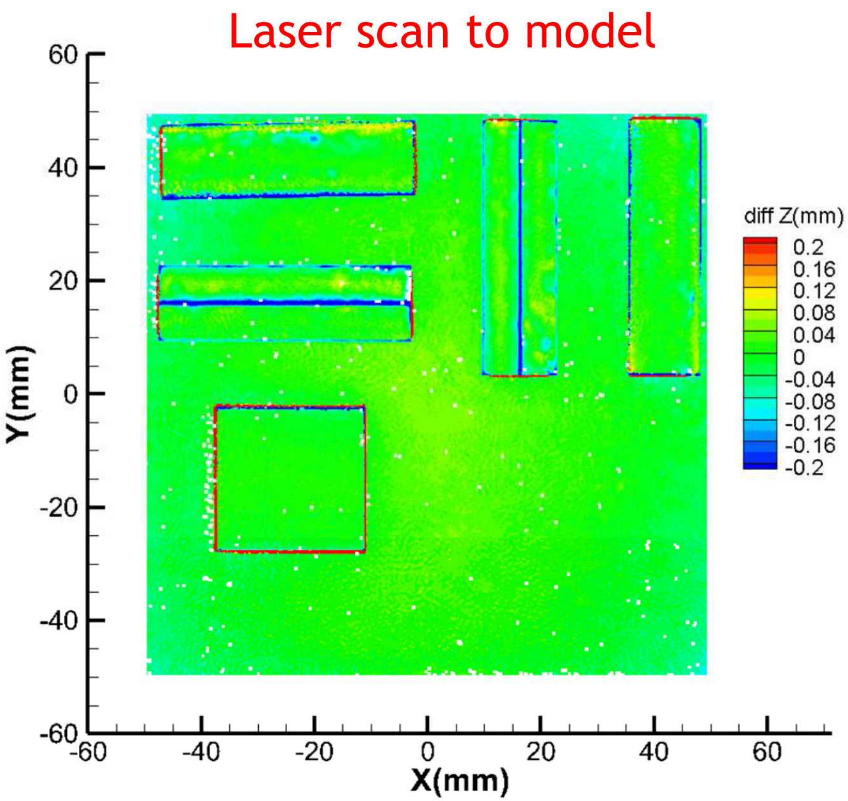


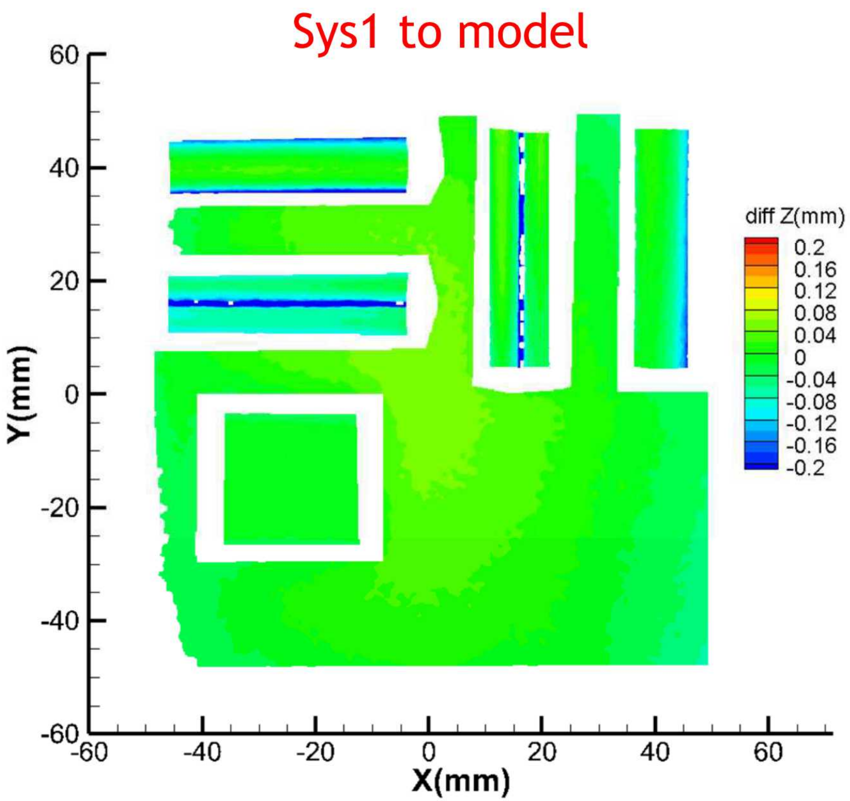
DIC experiment





Comparisons between the model and the data can now be made.

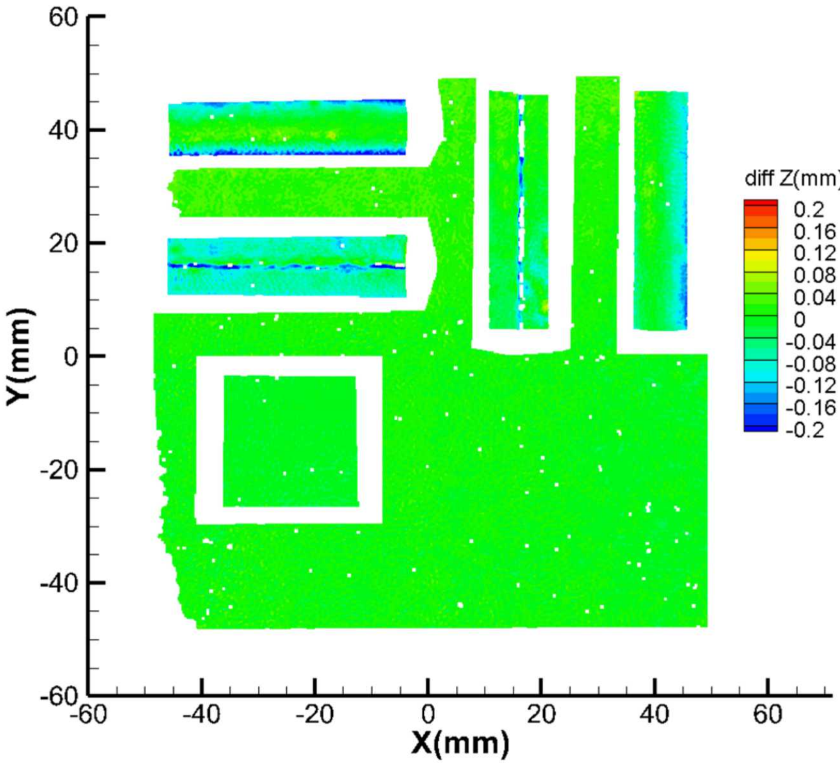




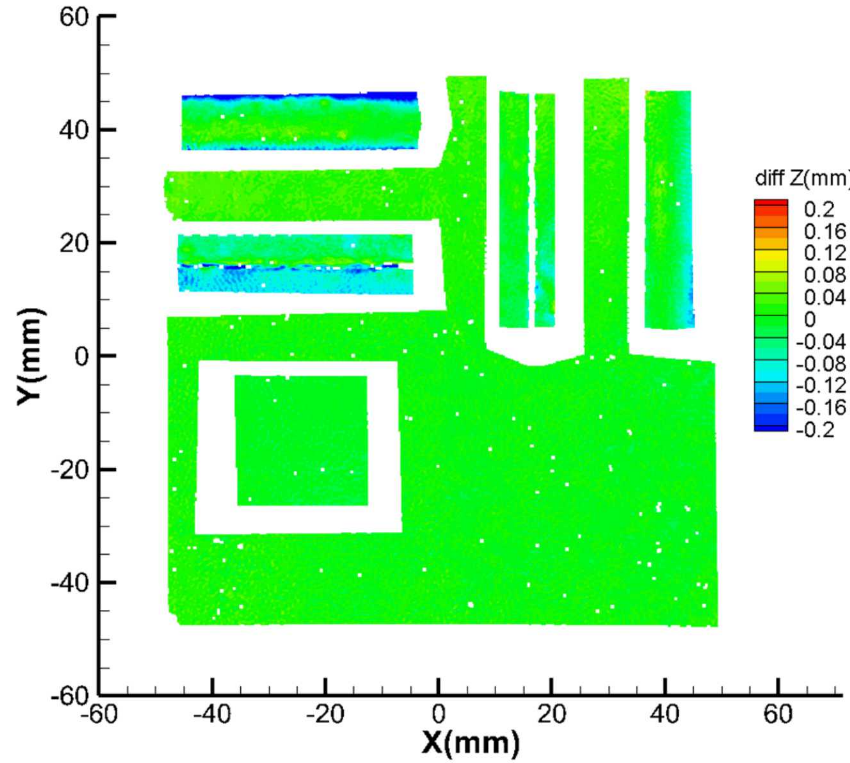
- Voids in the laser scan data are due to the lower data density of the scan
- Areas around the shapes in the sys1 data were not in the correlation

Comparisons between laser scan and DIC can now be made in a common coordinate system.

Laser scan to Sys1



Laser scan to Sys2



- Relevant comments will be put here.