Improvements in High Speed, High Resolution Dynamic Digital Image Correlation for Experimental Evaluation of Composite Drive System Components

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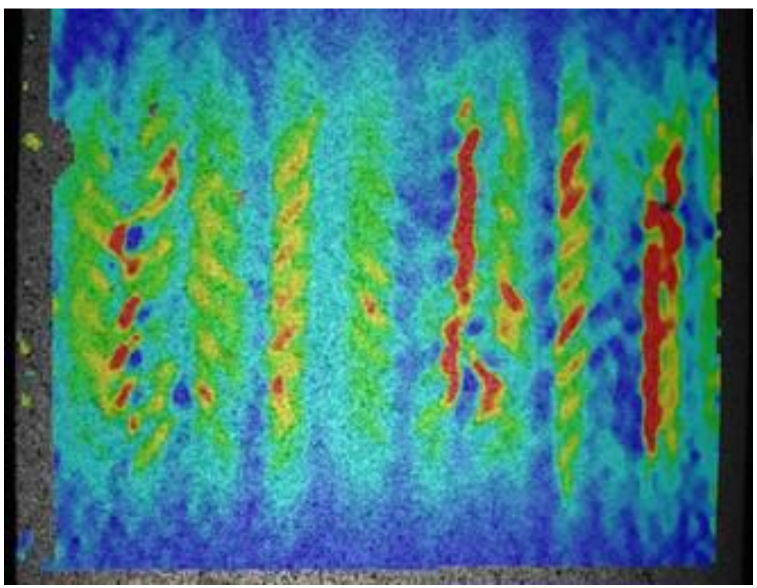
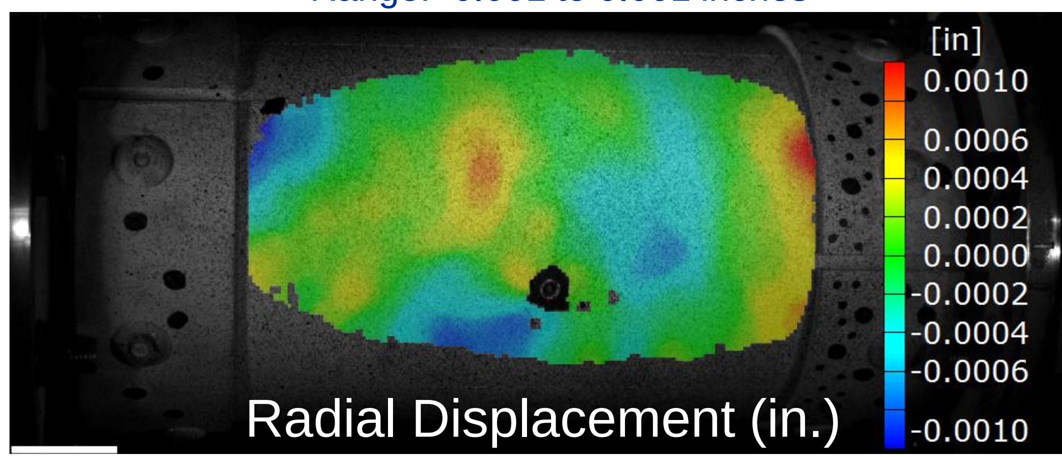
Motivation

- NASA Rotary Wing project is investigating multispeed drive system concepts. Weight reduction of components could be achieved through the use of composite materials.
- Fatigue failure of composite parts is related to local damage
- Local composite material failure can be resolved by static Digital Image Correlation (DIC).
- Need to achieve the same or better resolution as static tests in rotating tests.



Pressurized tube showing local damage

Range: -0.001 to 0.001 inches



Impact damage and dynamic torsion induced deformation (previous testing)

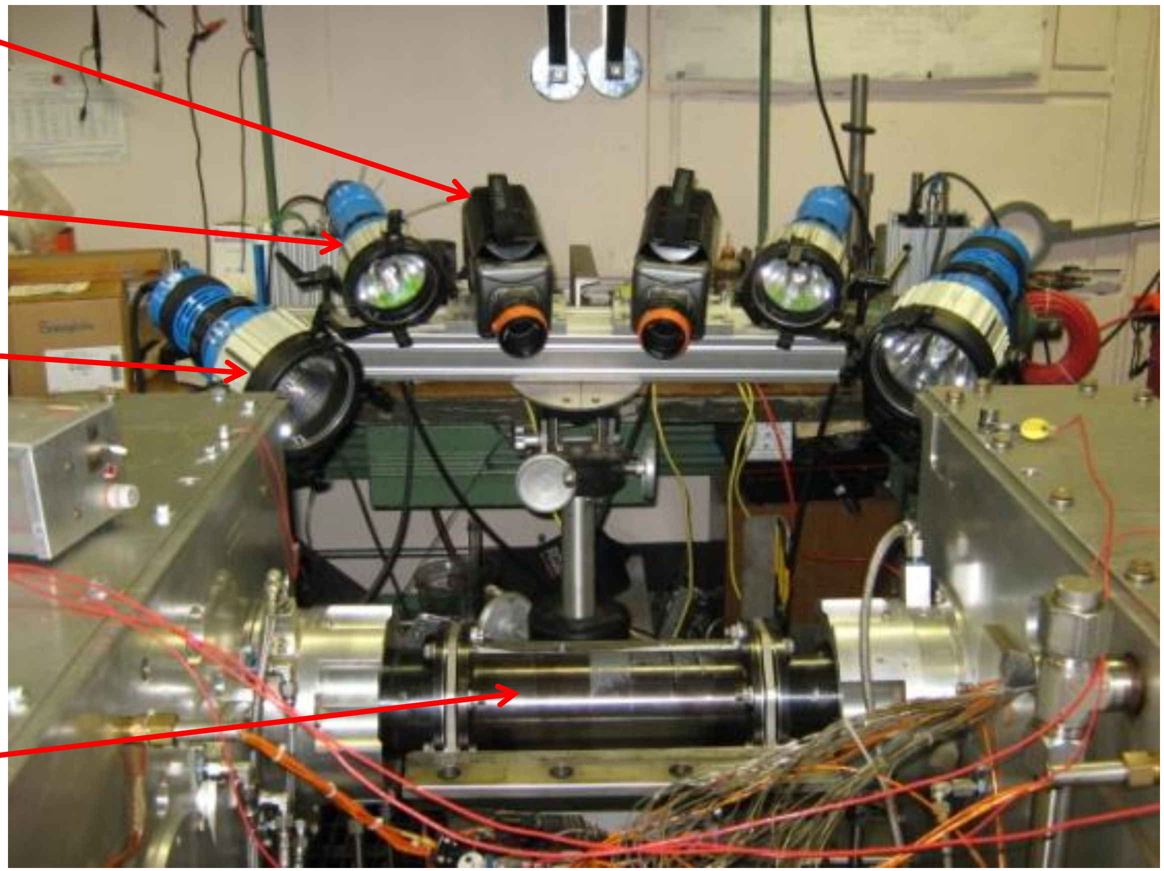
Previous High Speed Digital Image Correlation Setup

Phantom V10 Cameras

200 Watt HMI Lights

400 Watt HMI Lights

High Speed Shaft (original steel component)



Example DIC Pattern

Previous Conclusions (AHS 2012)

- The high speed DIC method was capable of resolving sufficient detail to indicate damage of the test article, though noise levels were high
- More light will reduce noise due to low camera signal and allow the exposure time to be shortened which will reduce error due to motion blur
- Pulsed lighting will be used to reduce heating of the test article
- A smaller field of view will be used to view local material damage
- Test articles with more complex geometry will be used in future tests

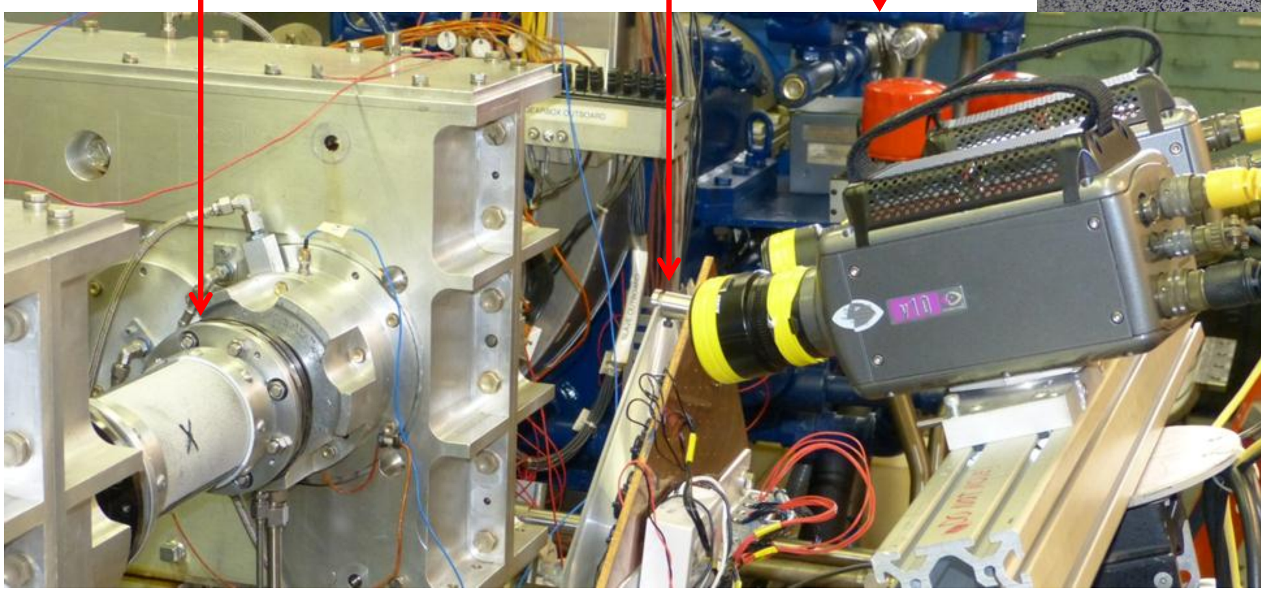
New High Speed Digital Image Correlation Setup

Example DIC Pattern

Phantom V10 Cameras

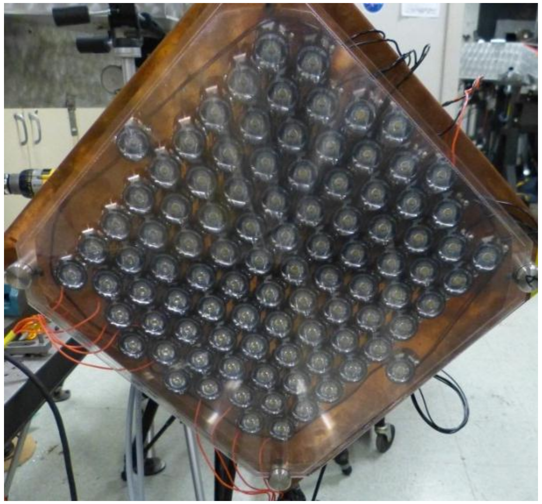
LED Array

High Speed Shaft (composite with "X" damage)

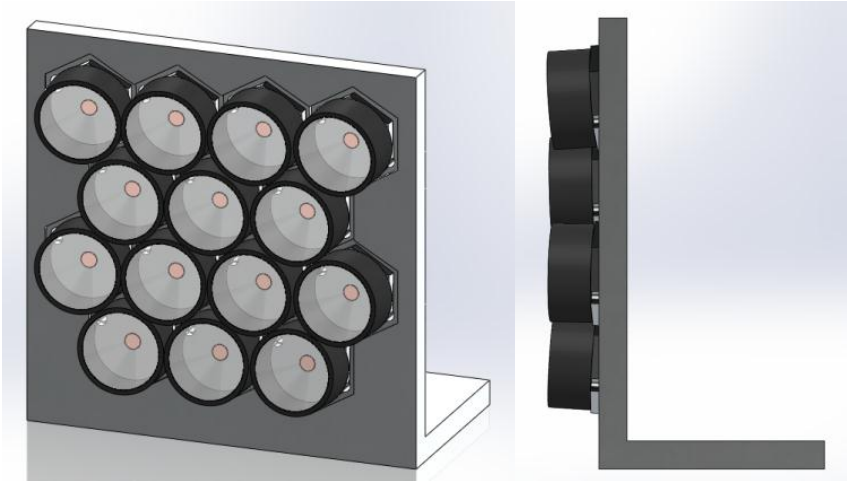


LED Lighting

1st Generation



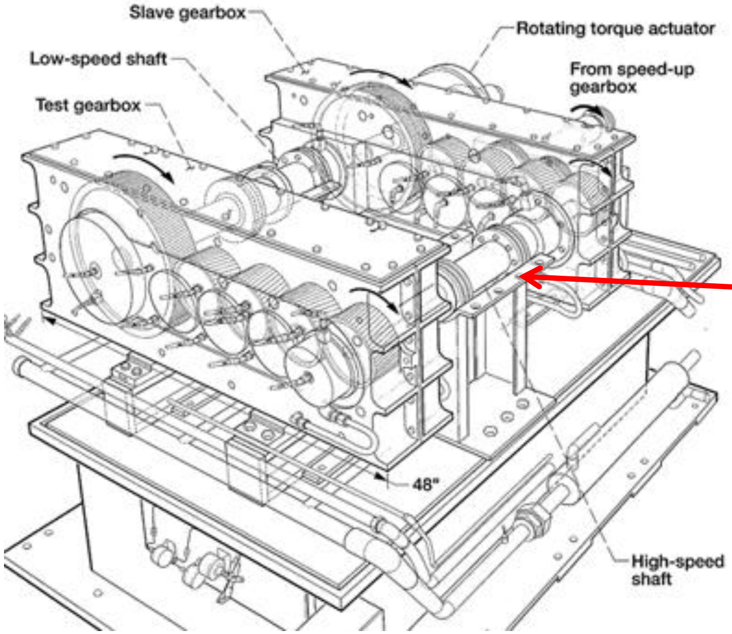
2nd Generation

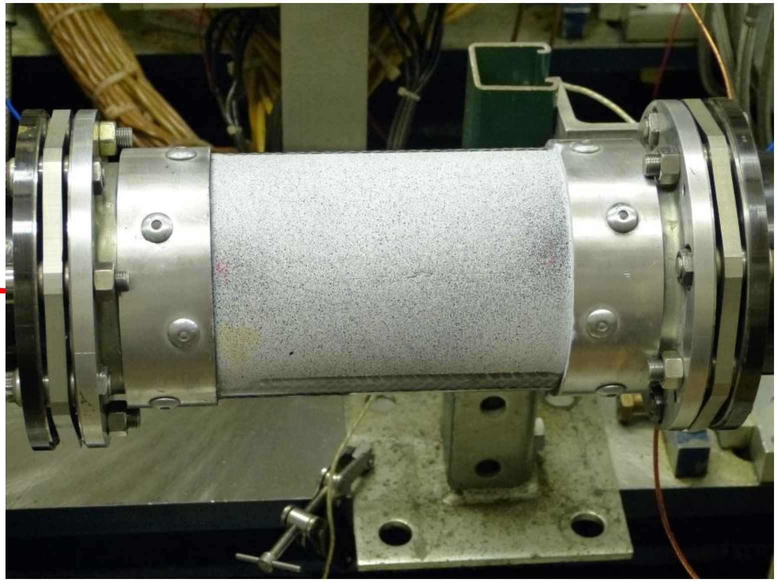


- 1st Generation
  - 90 LED's pulsed 10 amps (5 parallel strings of 9 per channel x2)
  - 3000 watt output for 2 microseconds
  - Discrete lenses and Fresnel focusing
- 2nd Generation
  - 56 LED's pulsed 25 amps (2 parallel 14 LED single string panels per channel x2)
  - >4500 watt output for 2 microseconds
  - Discrete lenses and tilted base focusing

Available Gear Test Rig: High Speed Shaft

- Normal maximum operating conditions
  - 15,000 rpm @ 2260 Nm (20,000 in-lbs) (4760 HP)
- Maximum allowable conditions with composite test article and high speed shaft shroud removed
  - 5,000 rpm @ 1130 Nm (10,000 in-lbs) (793 HP)
- Original shaft: length = 25.4 cm (10”), diameter = 8.9 cm (3.5”)





Composite shaft with DIC pattern

Composite Tube Test Plan

Dynamic Composite Tube

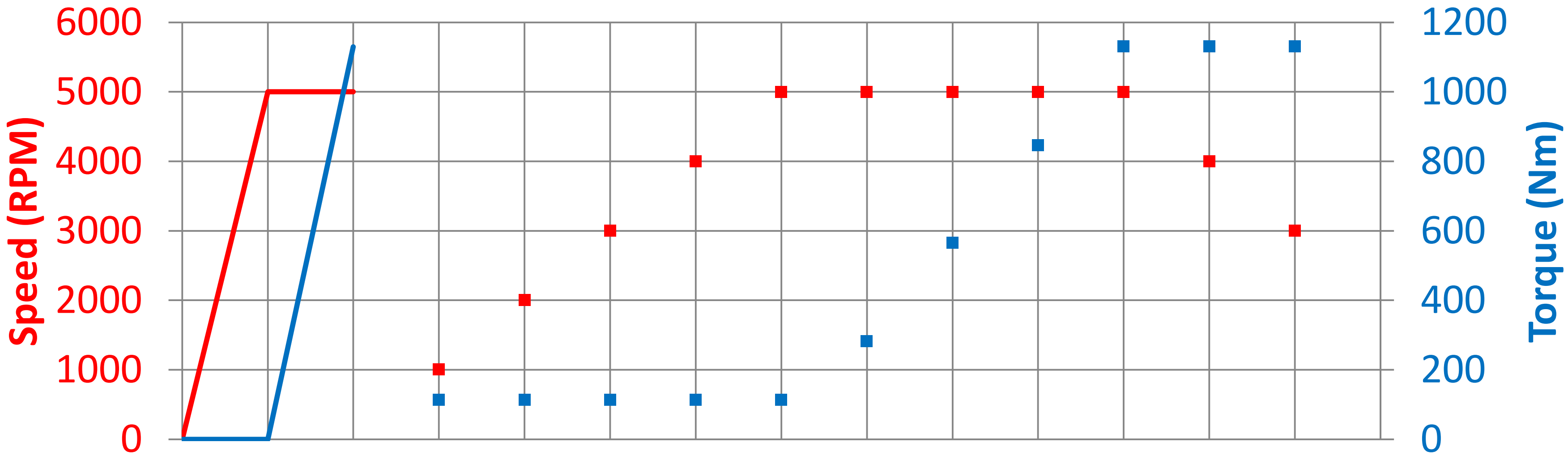
- Undamaged composite
- ¼” drilled hole composite damage
- “X” cut through ¼” hole

Dynamic Flexible Element

- Observation of local features on complex geometry

Tube Test Conditions

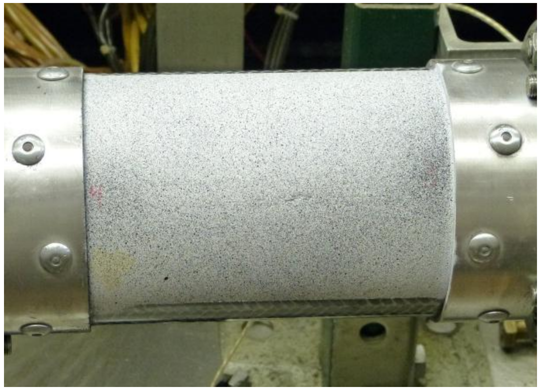
- Speed ramp to 5000 rpm, then torque ramp to 1130 Nm (10,000 in-lbs)
- Speed step increase (1000, 2000, 3000, 4000, 5000 rpm) with 113 Nm (1000 in-lbs) torque
- Torque step increase (113, 282, 565, 847, 1130 Nm) at 5000 rpm
- Speed step decrease (5000, 4000, 3000 rpm) at full torque (1130 Nm or 10,000 in-lbs)

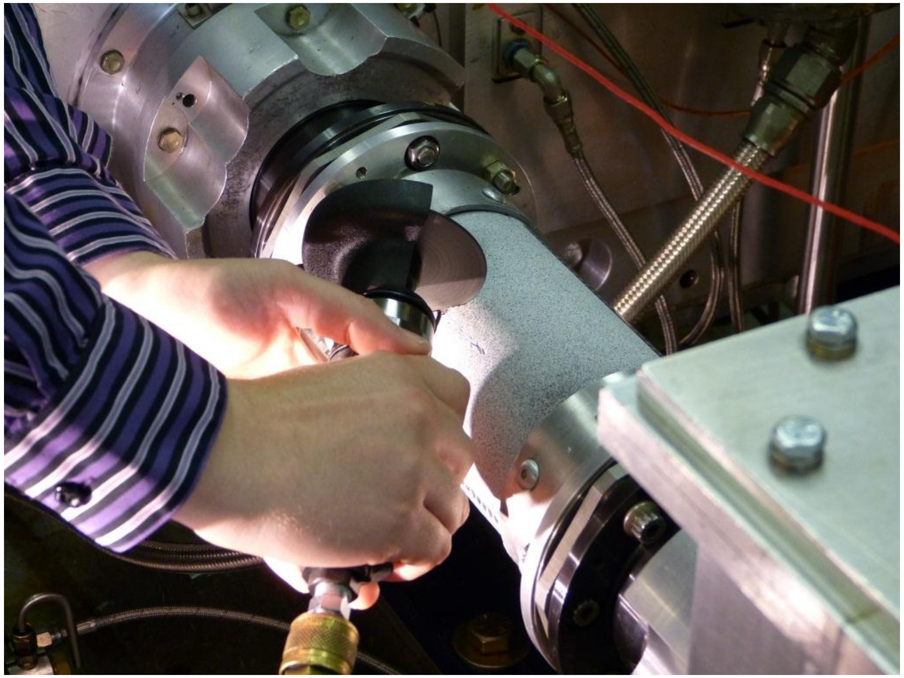


3 Conditions of the Composite Tube

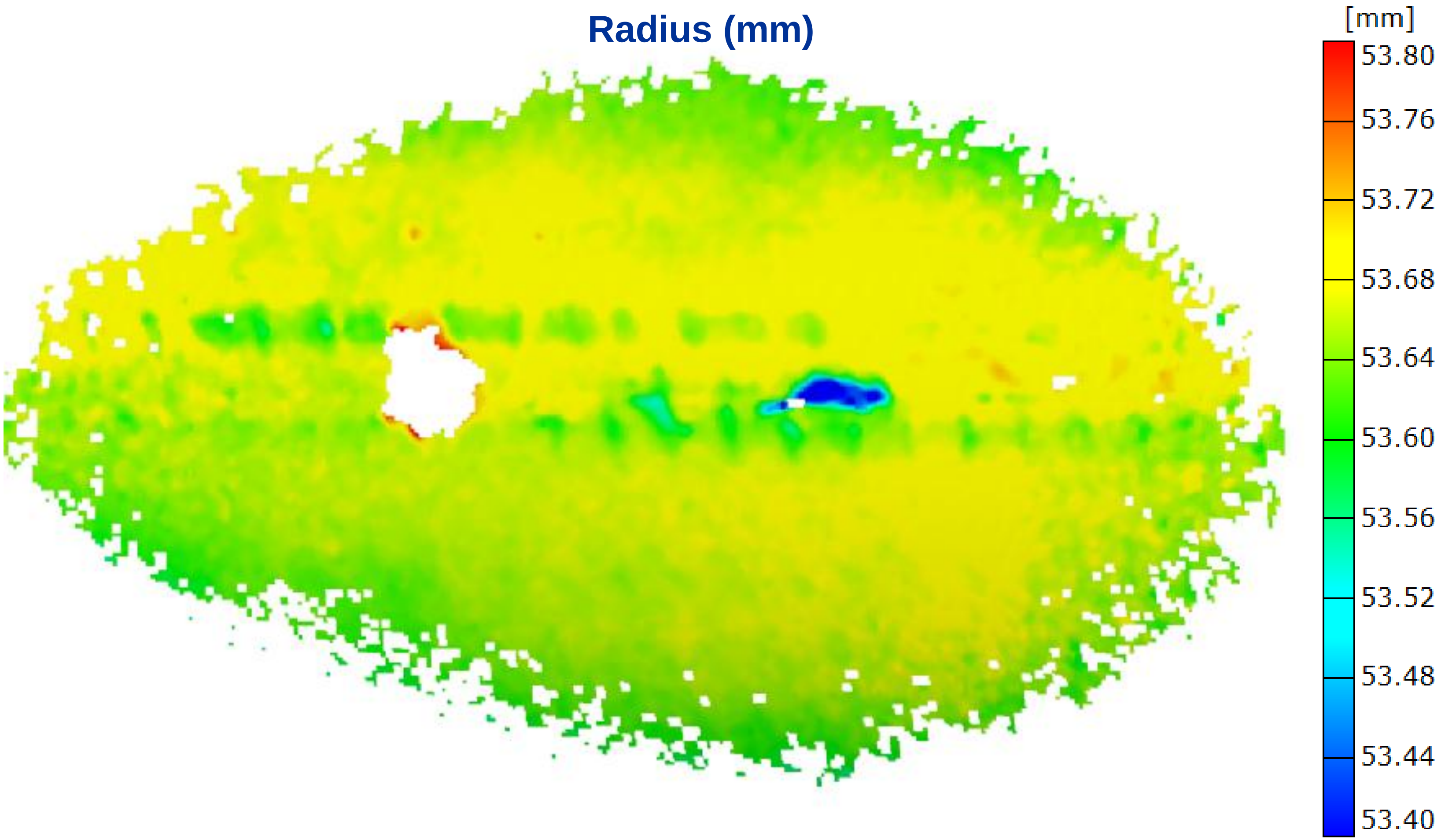
3 Test Conditions

- Undamaged
- ¼” hole drilled in line with defect
- “X” cut through hole





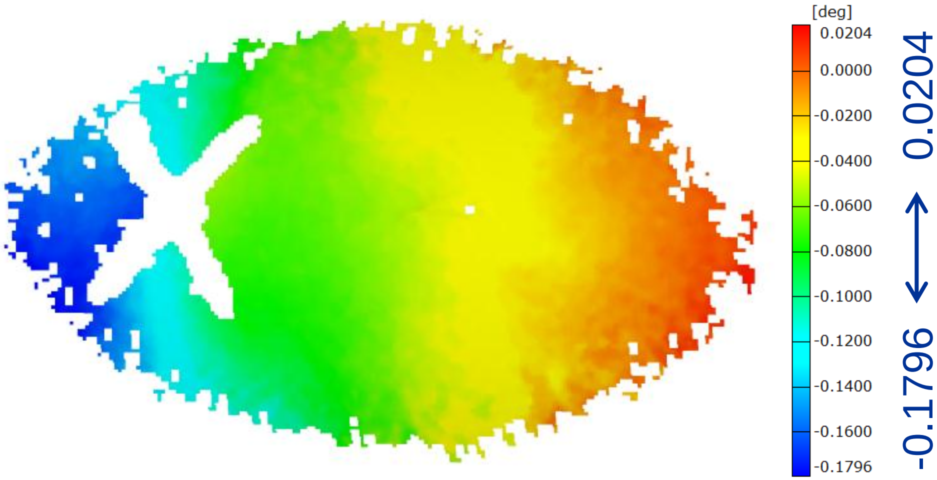
Dynamic Testing of Composite Tube: Drilled Hole Tube at 113 Nm, 5000 rpm



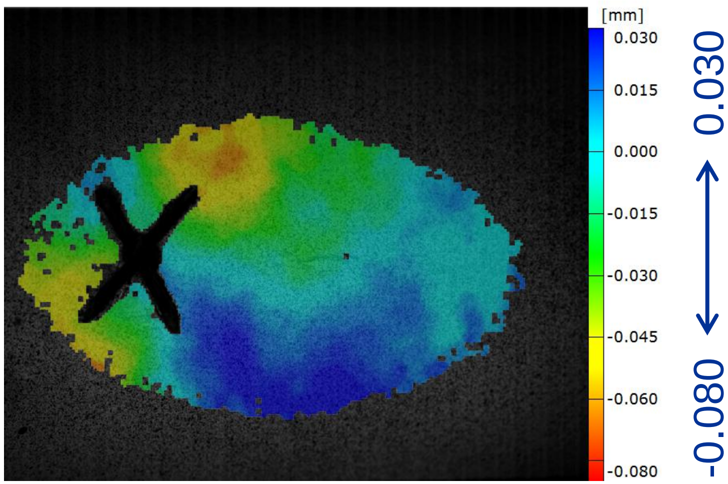
¼" drilled hole and mold line defect are clearly visible while operating at 5000 rpm, low torque

Dynamic Testing of Composite Tube: "X" Damage at 1130 Nm, 5000 rpm

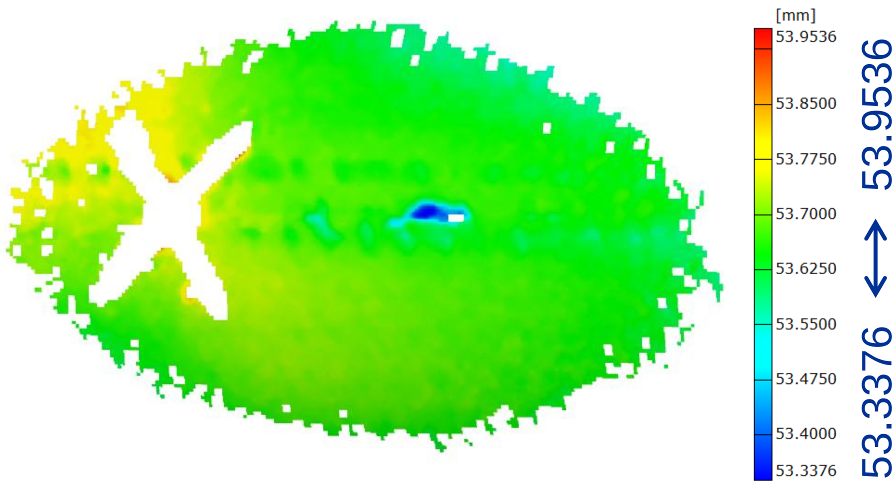
Twist Angle (deg)



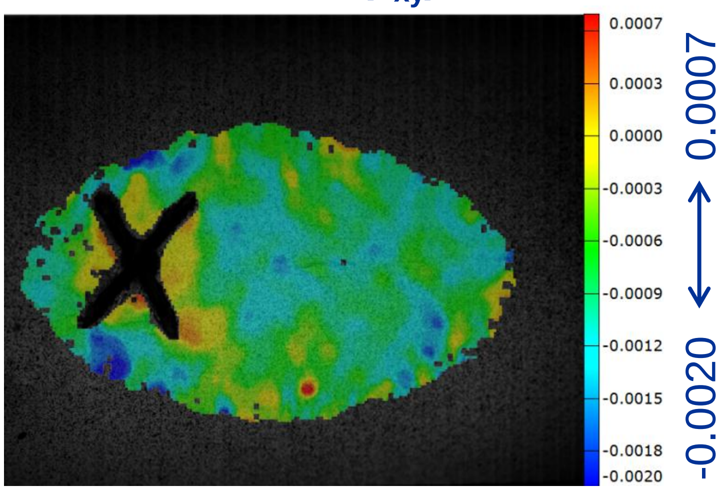
Difference in Radius (mm)



Radius (mm)

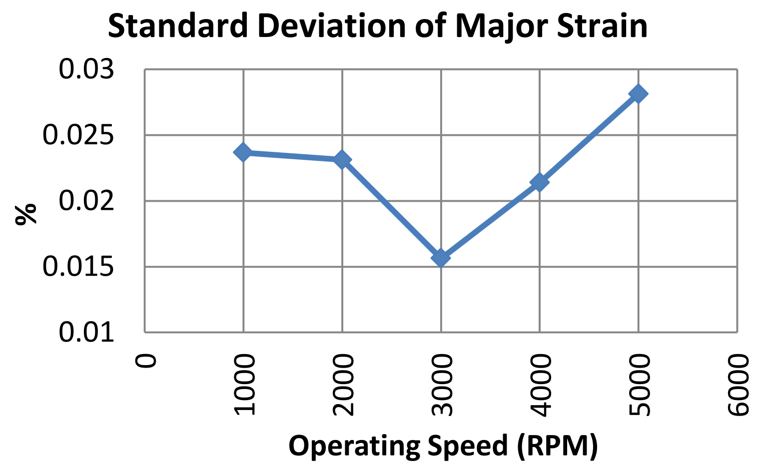


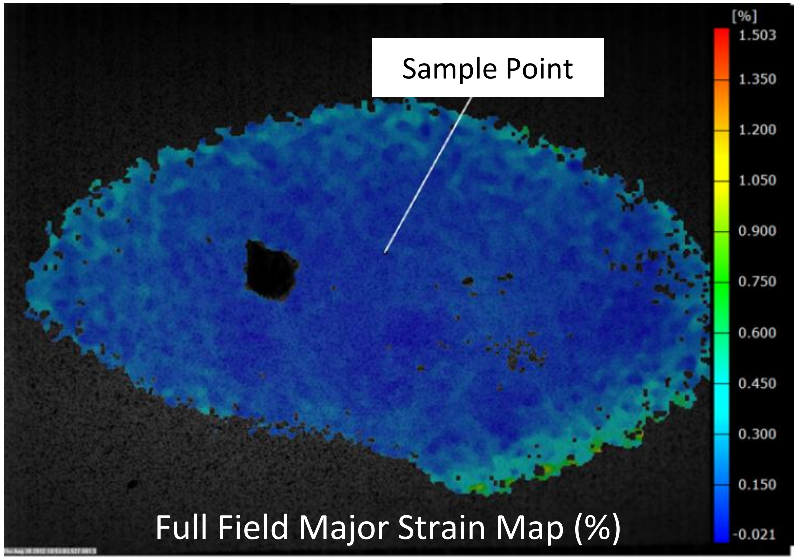
Shear (ε_{xy})



Noise/Error Reduction

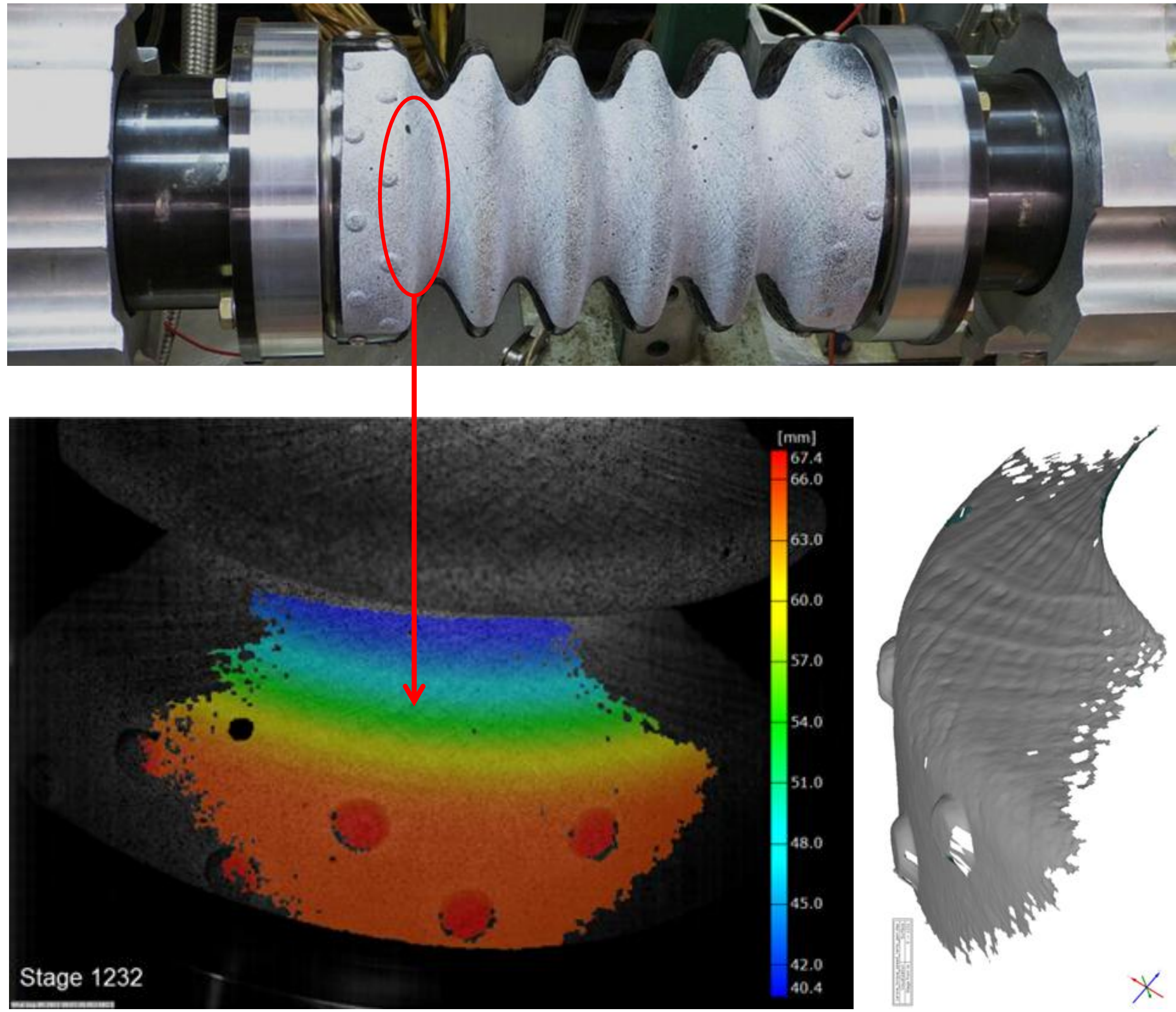
- 113 Nm (1000 in-lbs) torque applied to drilled hole composite tube
- 10 images were collected at each operating speed
- Data was processed using 0.3 pixel intersection deviation (default setting)
- The value of major strain at a single sample point was collected and the standard deviation calculated for each operating speed
- The intersection deviation parameter did not need to be increased
- The standard deviation did not change significantly with speed





Dynamic Testing of Flexible Element

- A small region was observed on a filament wound composite flexible element
- Pulsed LED illumination was used with the 4 megapixel Phantom V10 cameras
- 100 mm lenses were used to narrow the field of view
- Little deformation was observed due to the relatively low load on the structure
- Detailed surface texture was resolved and geometry measurement was performed at the 5000 rpm operating speed

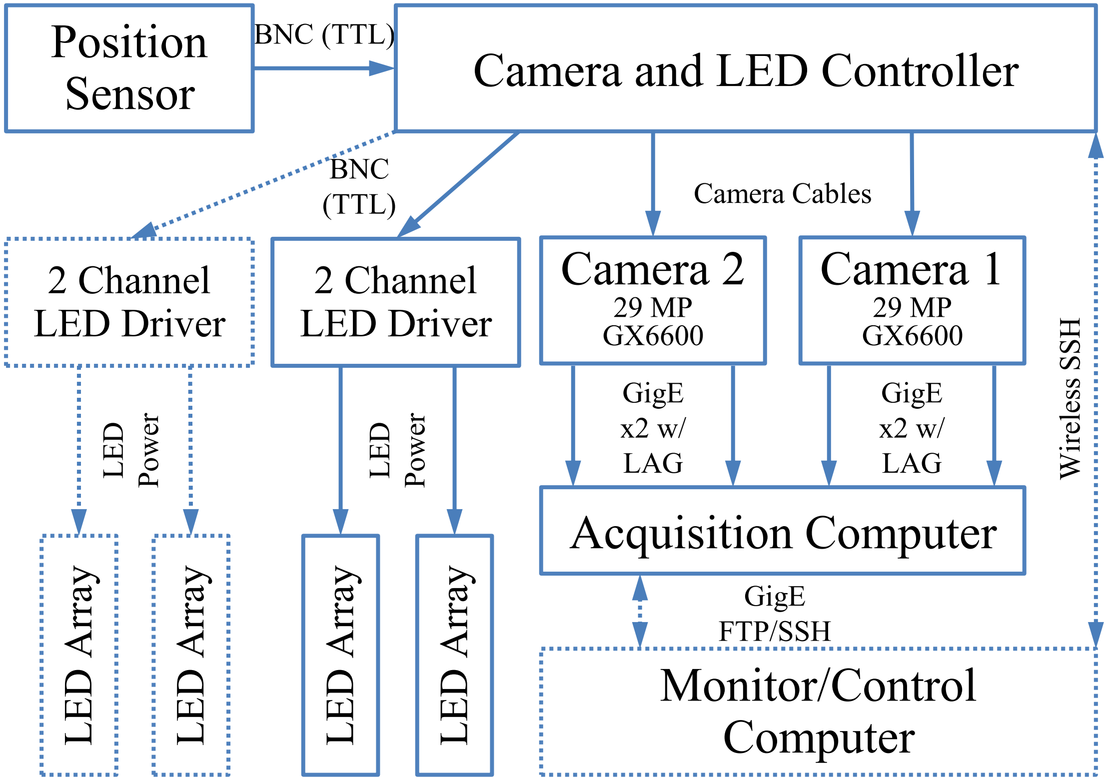


Next Steps: Ultra-high Resolution Synchronous DIC

- 2x 29 megapixel cameras (Prosilica GX6600)
- 2nd Generation LED arrays
- Raspberry Pi microcontroller based synchronization and control
- Dual Gigabit Ethernet image transfer with Link Aggregation for each camera to dedicated file write computer
- 100 mm lenses for small field of view

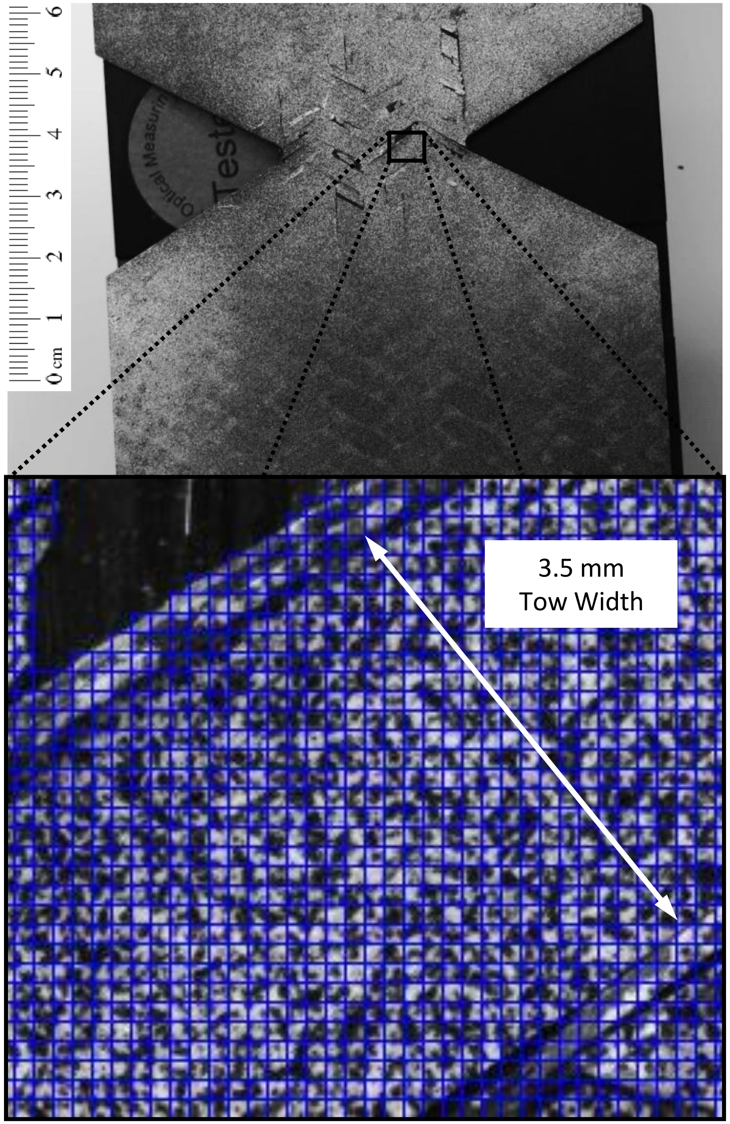
Mode of Operation

- Position sensors supply TTL signal to controller
- Microcontroller interprets sensor input and triggers cameras and LED drivers
- The dedicated Acquisition Computer saves the image files
- A separate computer can be used to monitor/control the Acquisition Computer and microcontroller using SSH/FTP



Resolution Sample

- Example of 29 megapixel image with 100 mm lenses
- Facet size 11, step 7 produces 8 data points per millimeter
- Offers higher resolution while maintaining a larger field of view that previously available static systems
- Lowest camera exposure of 30 microseconds will be effectively reduced using high intensity pulsed LED illumination
- Due to a frame rate limit of 4 fps, this system could be used for static testing or longer duration fatigue damage tracking



Conclusions

- Significant improvements over past high speed DIC was achieved using the pulsed synchronous LED lighting
  - High illumination intensity
  - Low specimen heating
  - Fast rise and fall of illumination and high repetition rate possible
  - Fast shutter speed reduces image blur and resulting noise in the data
- High resolution DIC demonstrated on complex geometry at 5000 rpm

Future Work

- Complete construction of the ultra-high resolution 3D DIC camera system with synchronous LED illumination
- Investigate deformation and local damage phenomena on complex geometry composite test articles
- Investigate deformation and local damage on other rotating structures

Thank you.

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