

Digital Image Correlation (D.I.C.) Techniques Applied to Large Scale Rocket Engine Testing

*July 25-27, 2016
AIAA Joint Propulsion
Conference*

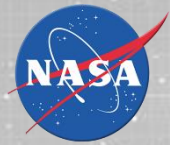
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National Aeronautics and
Space Administration



MARSHALL
SPACE FLIGHT CENTER

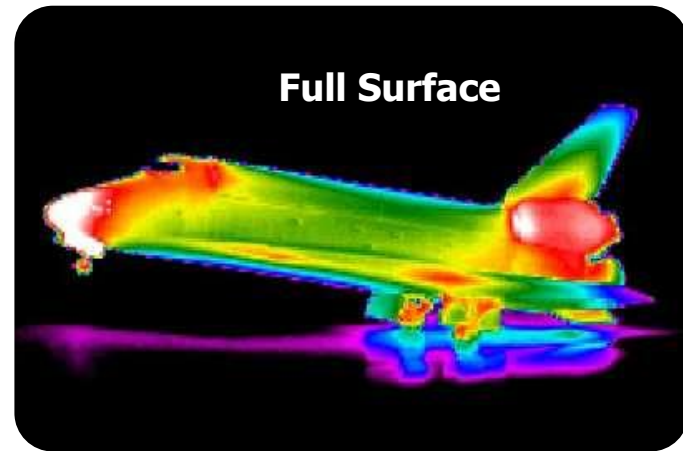
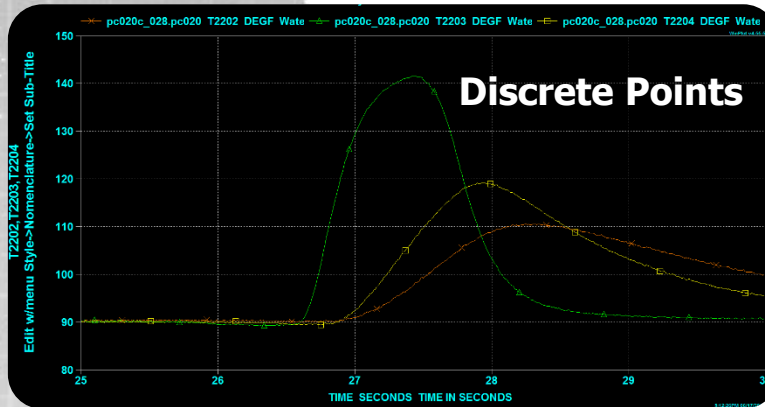


Motivation for Technology

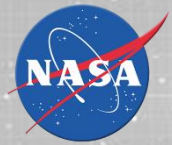
- Subscale and Full-scale testing requires expensive and labor intensive instrumentation to better understand hardware performance
 - Design Modifications and Performance Predictions based on “discrete” point instrumentation
 - Thermocouples, Pressure Transducers, Accelerometers, Strain Gages
- **Challenge: Measure highly dynamic elevated temperature components**

Full Surface > Point
IR > Thermocouple
D.I.C. > Strain Gage

*D.I.C. = Digital
Image Correlation*

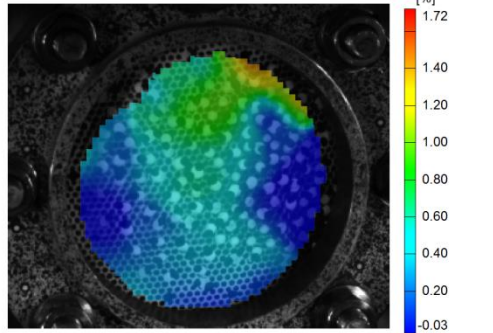


Goal: Augment Traditional Gages to gain a better understanding of hardware and environment loads to design more efficient components and systems



Applications and Development work for Digital Image Correlation at NASA

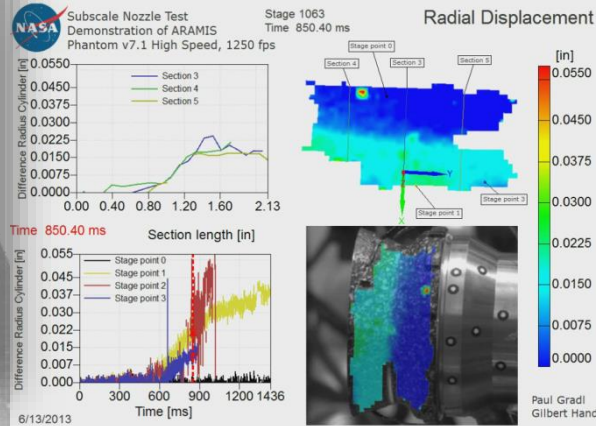
Test 91 April 3, 2013 300 SS 0.005" Half H2O Major Strain



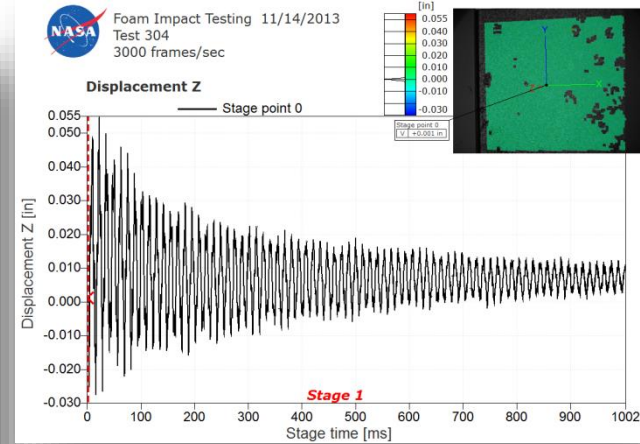
Last Frame Before Perforation



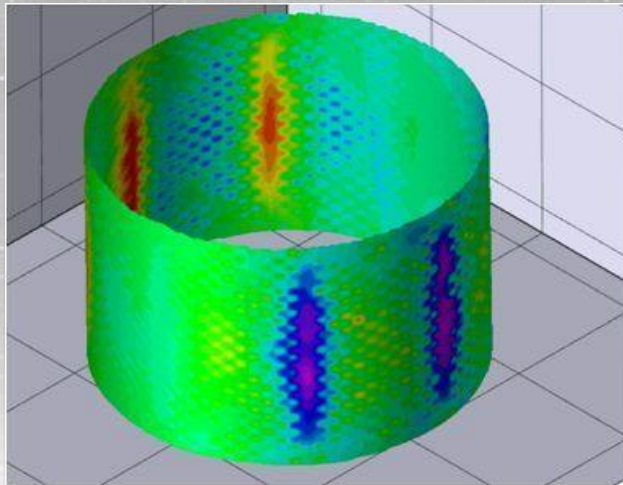
Blast Pressure Wave Tracking at 70,000 fps



Subscale Nozzle Displacements at 1700F

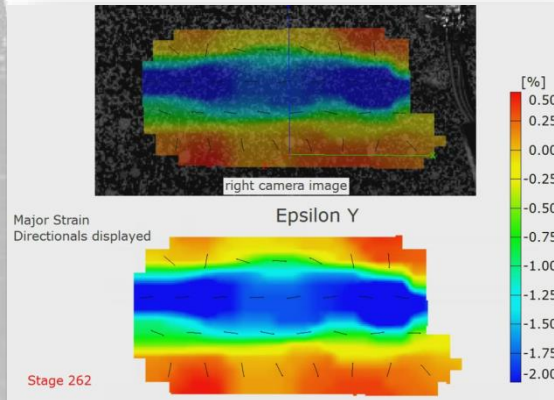


Debris Impact Testing – Eliminated Strain Gages

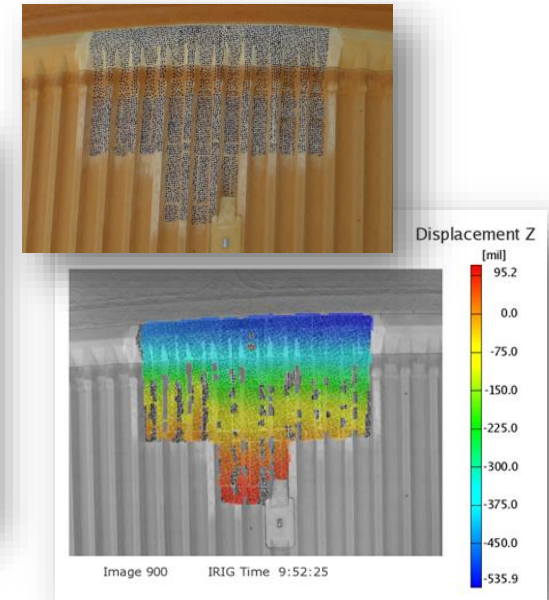


Full-Field Strain and Displacements of 18-ft Dia Tank

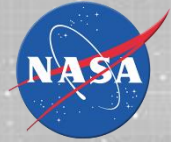
Ref: Todd Boles, MSFC/ET30



High Speed Composite Compression – Direct Application of Major Strain

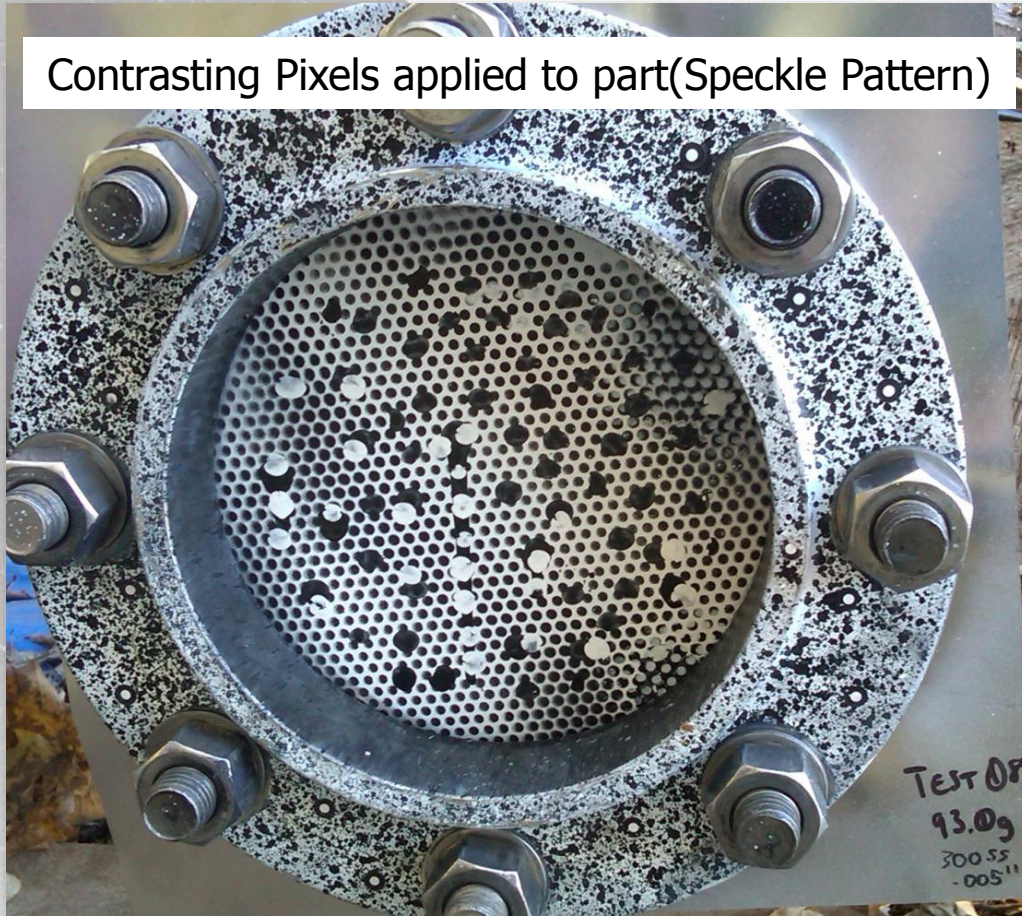


ET (on Pad) Cryo tanking test to observe stringer displacement



What is Digital Image Correlation?

Contrasting Pixels applied to part(Speckle Pattern)



Stereo Camera Triangulation



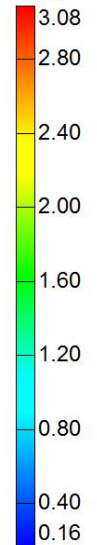
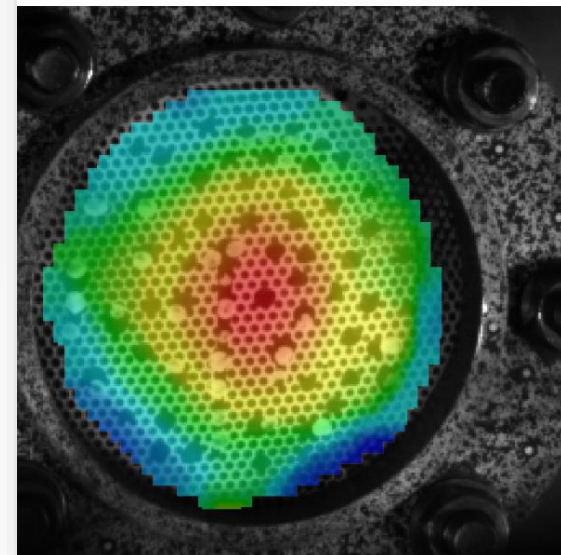
Photo Provided by: Tim Schmitt / Trilion

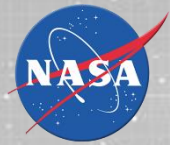
= Full Field
Displacement and
Strain Measurements

Oct 24, 2012 300 SS 0.005"

Major Strain

[%]

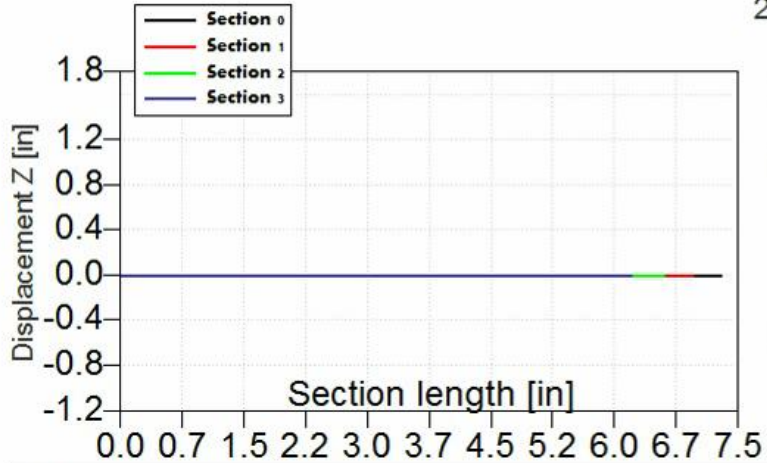




ARAMIS Lab Experiments – Displacement

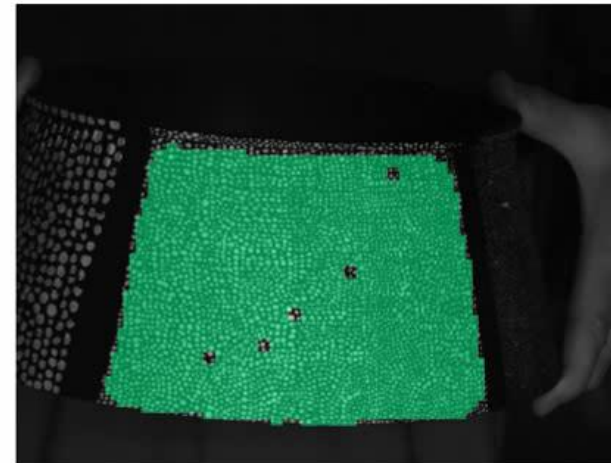
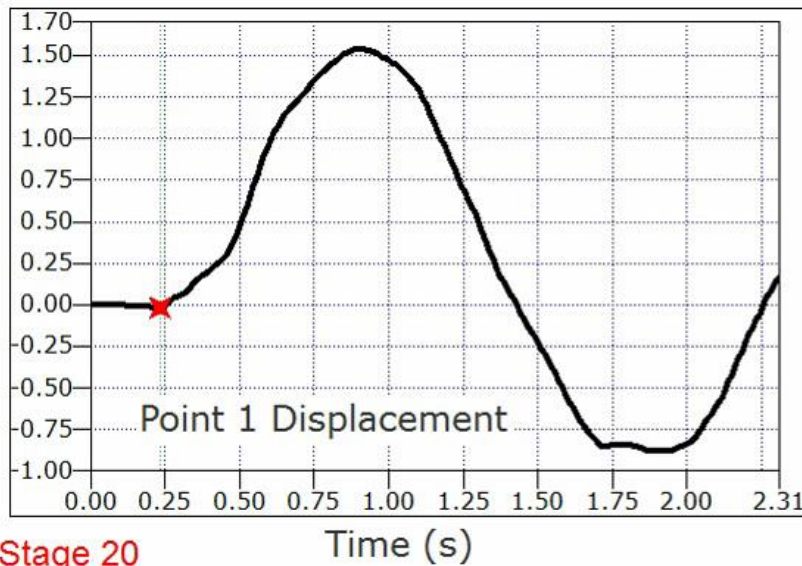
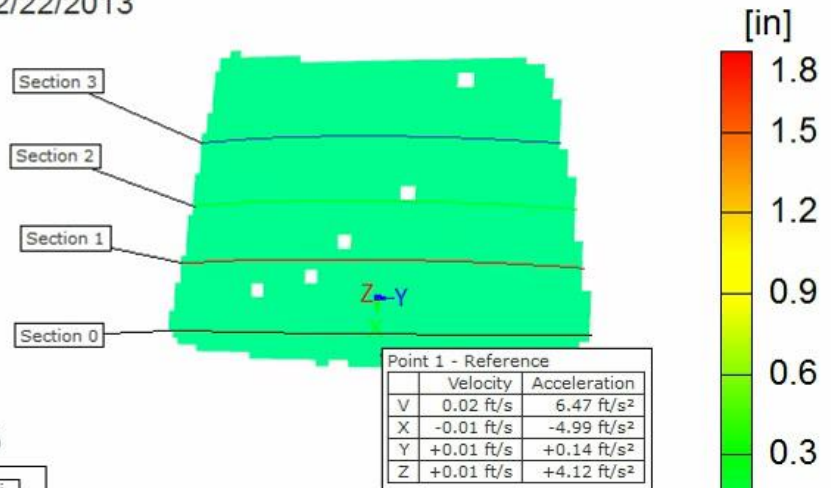
Stage 20

Nozzle Displacement Z

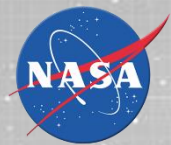


Stage 20
Time 0.23 s
2/22/2013

Displacement Z



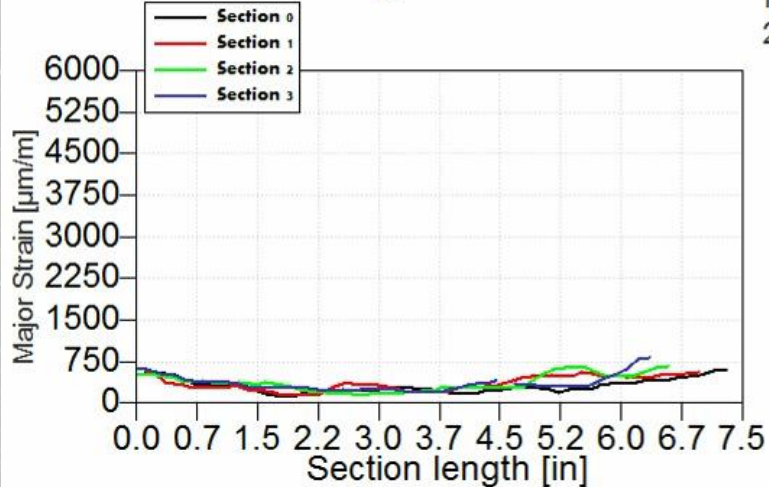
Stage 20



ARAMIS Lab Experiments – Principal Strain

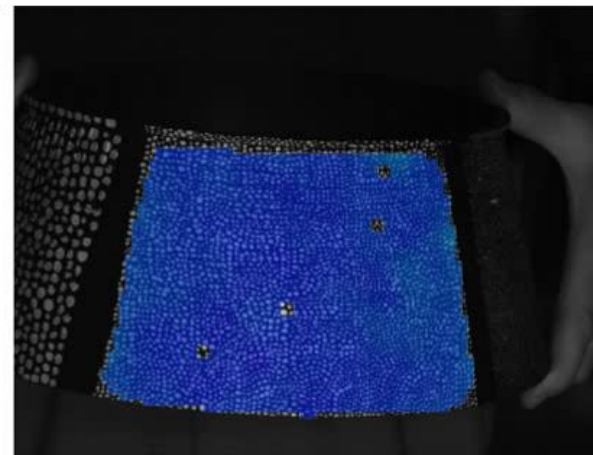
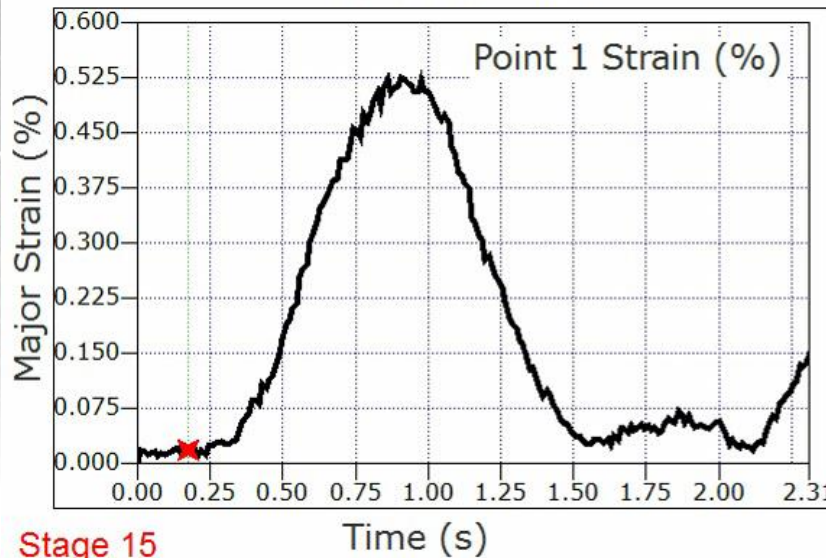
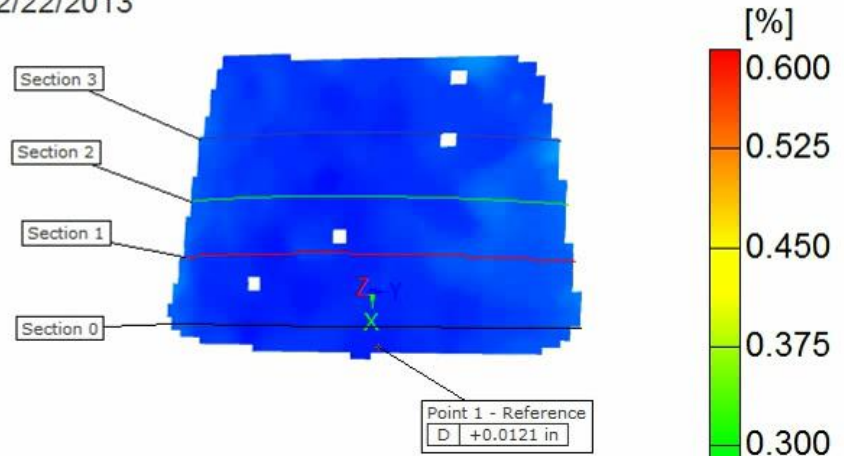
Stage 15

Nozzle - Major Strain



Stage 15
Time 0.17 s
2/22/2013

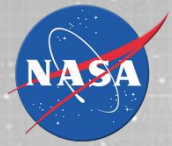
Major Strain



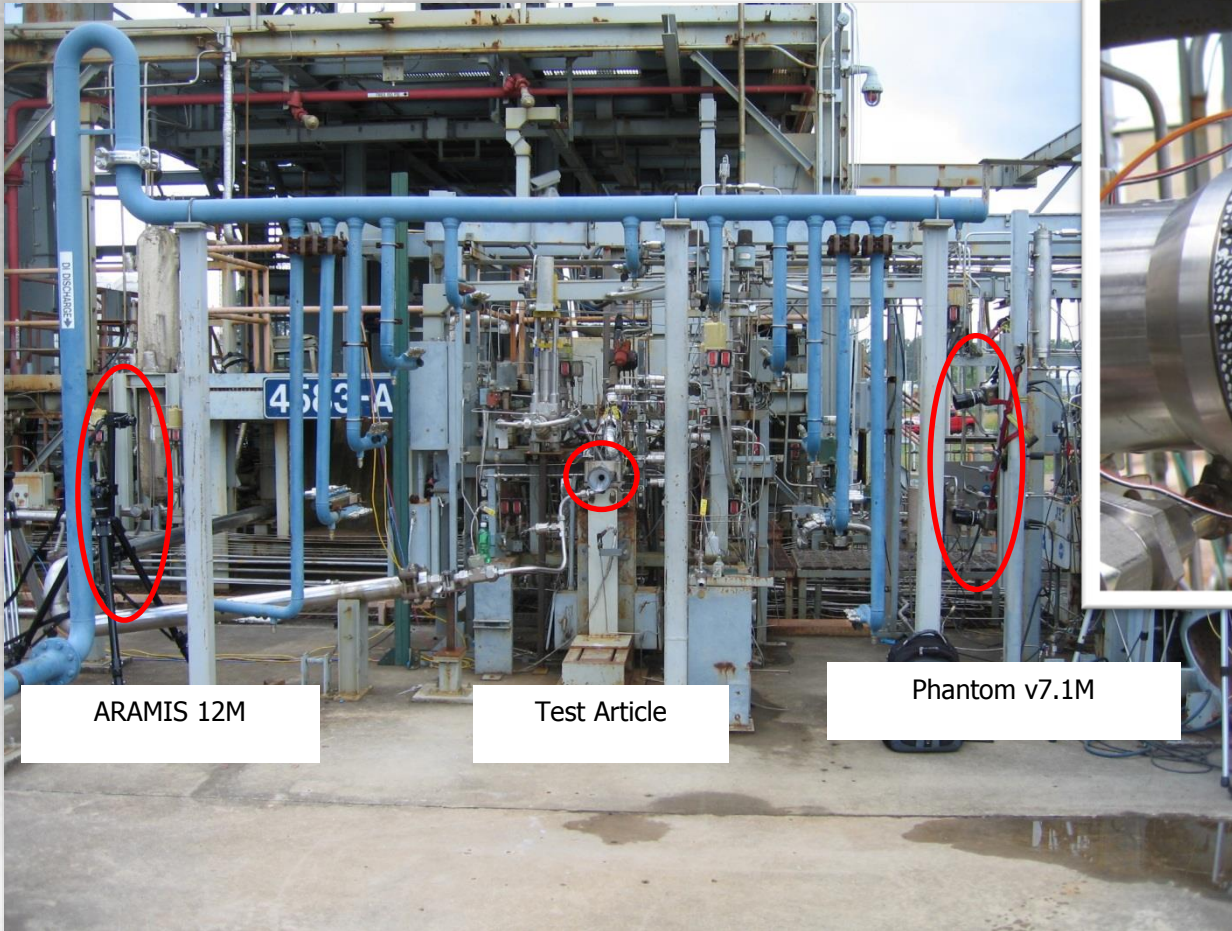
Stage 15

Paul Gradl
Gilbert Handley





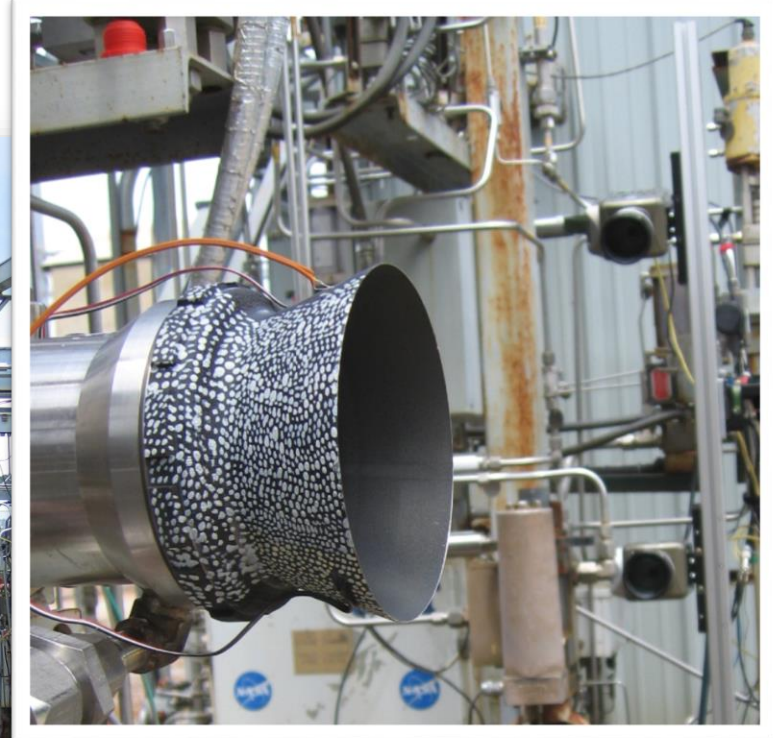
Subscale Hot-fire Nozzle Testing



ARAMIS 12M

Test Article

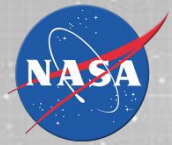
Phantom v7.1M



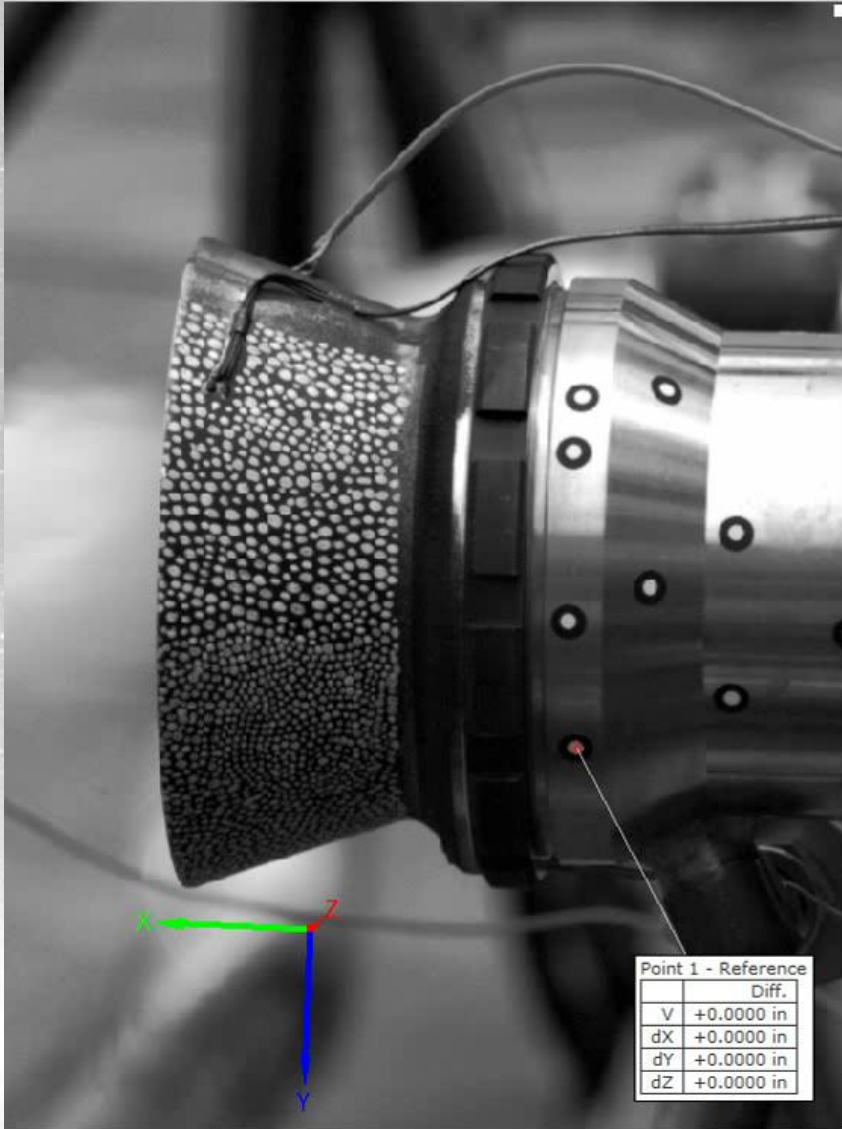
Additive Manufactured Radiative Cooled Nozzle Extension

Test Photos and Data Collection:

Paul Gradl
Gilbert Handley
Sandy Elam Greene



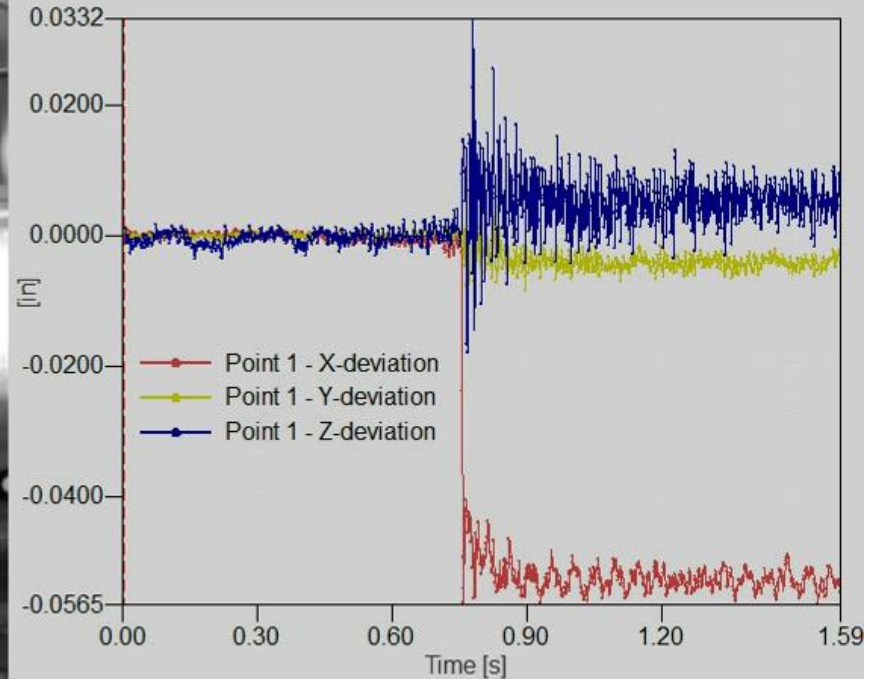
Bench Testing Doesn't Always Translate into the Field...



Point 1 - Reference	
	Diff.
V	+0.0000 in
dX	+0.0000 in
dY	+0.0000 in
dZ	+0.0000 in

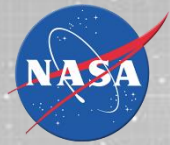


Nozzle Extension Skirt Buckling Test
Intentional Predicted Failure
May 22, 2013



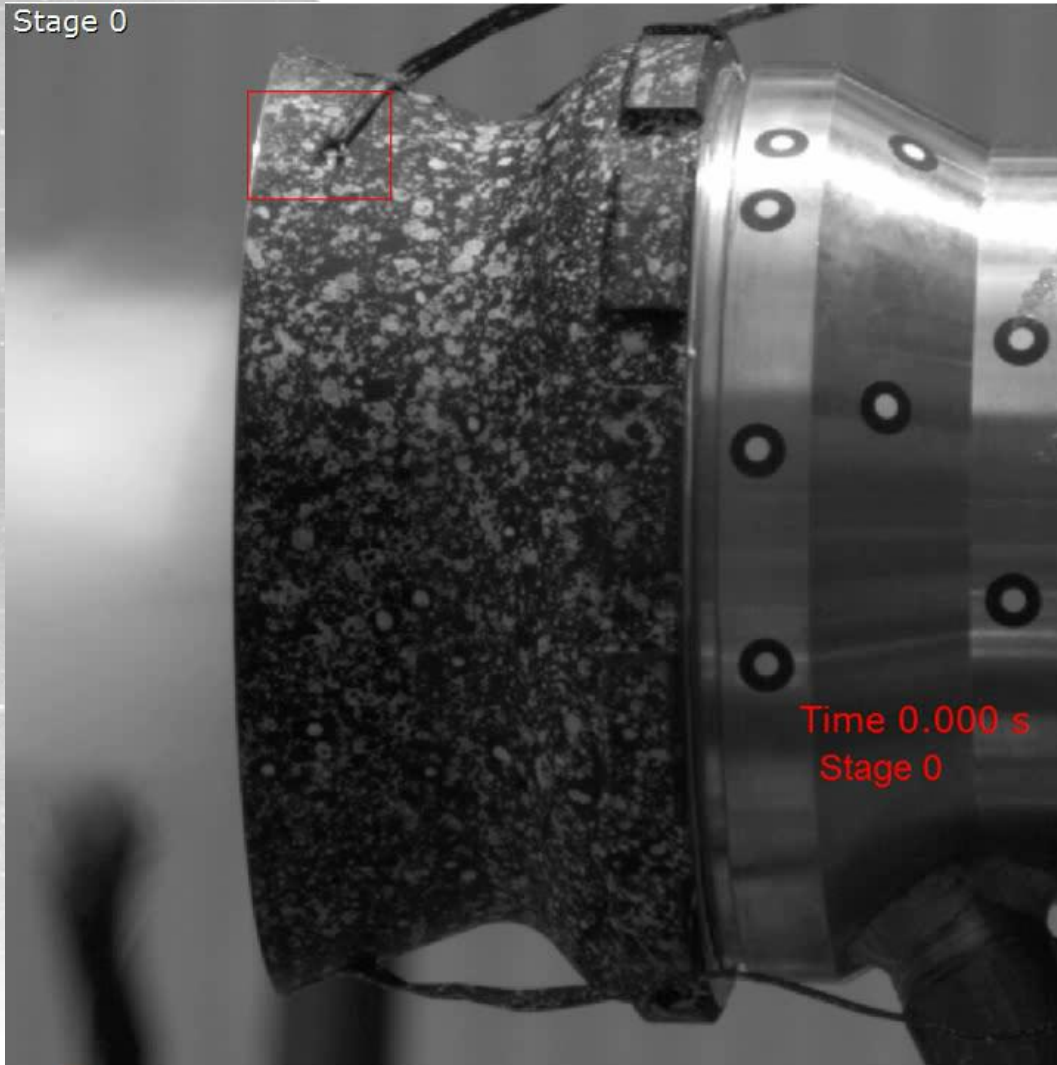
Time: 0.000000 s from trigger

Phantom High Speed v7.1M
750 fps
135mm lens @6ft

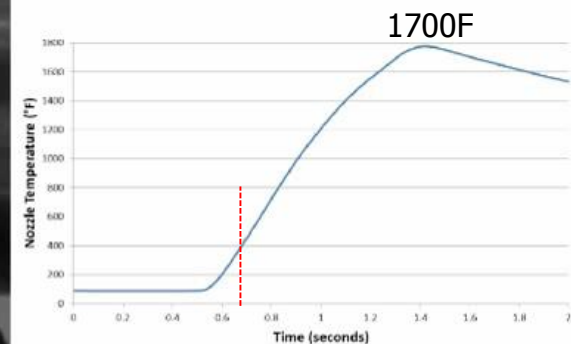


Motivation to Develop Technique

Stage 0



Nozzle Strain Gage 1



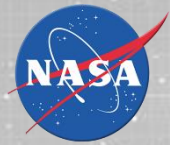
Strain Gage Failure at ~400F



Subscale Nozzle Hotfire Demonstration
Phantom v7.1 M, 1250 fps

6/13/2013

Paul Gradl
Gilbert Handley



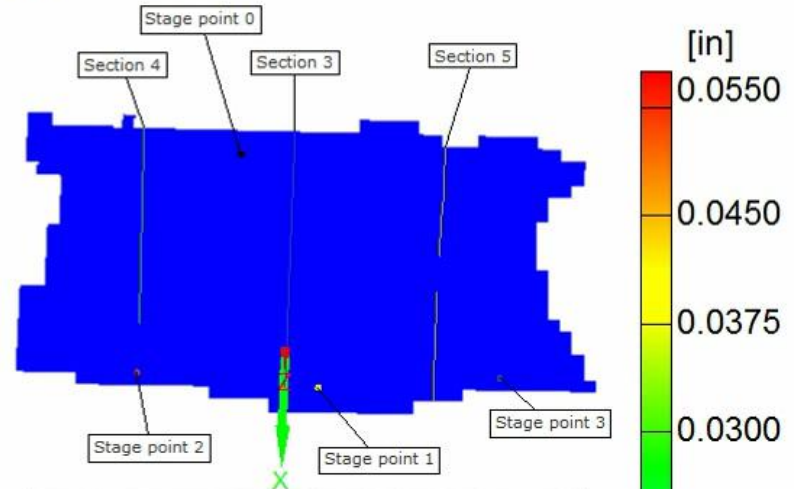
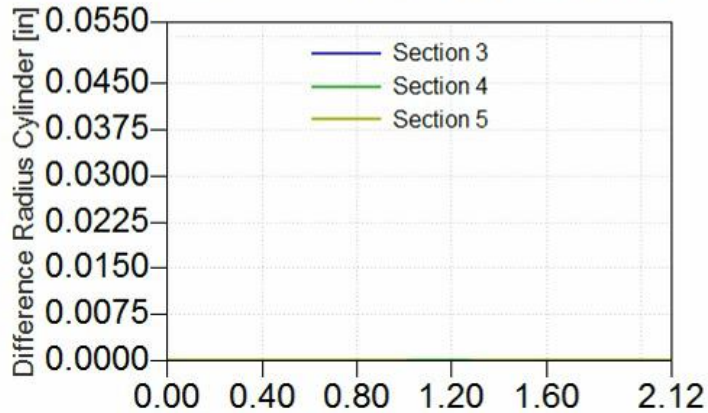
Subscale Hotfire Testing on Nozzle



Subscale Nozzle Test
Demonstration of ARAMIS
Phantom v7.1 High Speed, 1250 fps

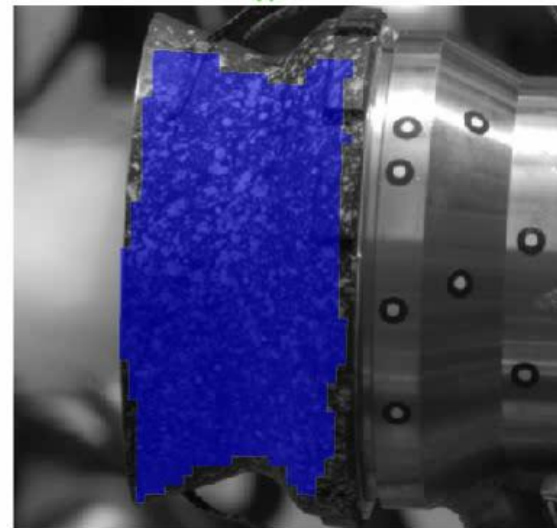
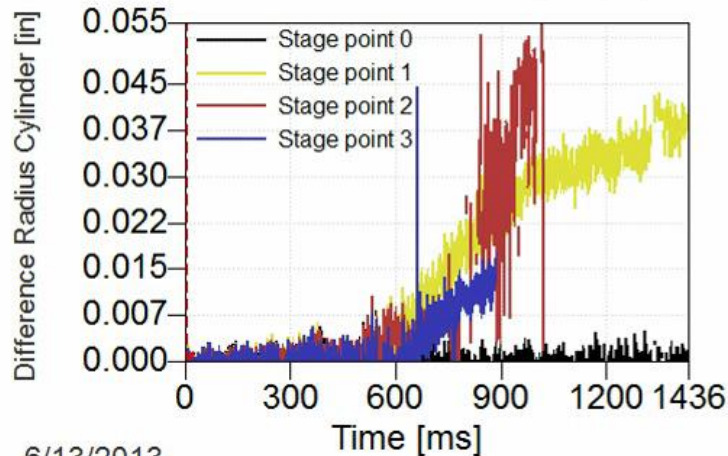
Stage 0
Time 0.00 ms

Radial Displacement



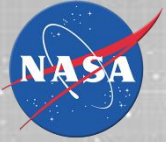
Time 0.00 ms

Section length [in]

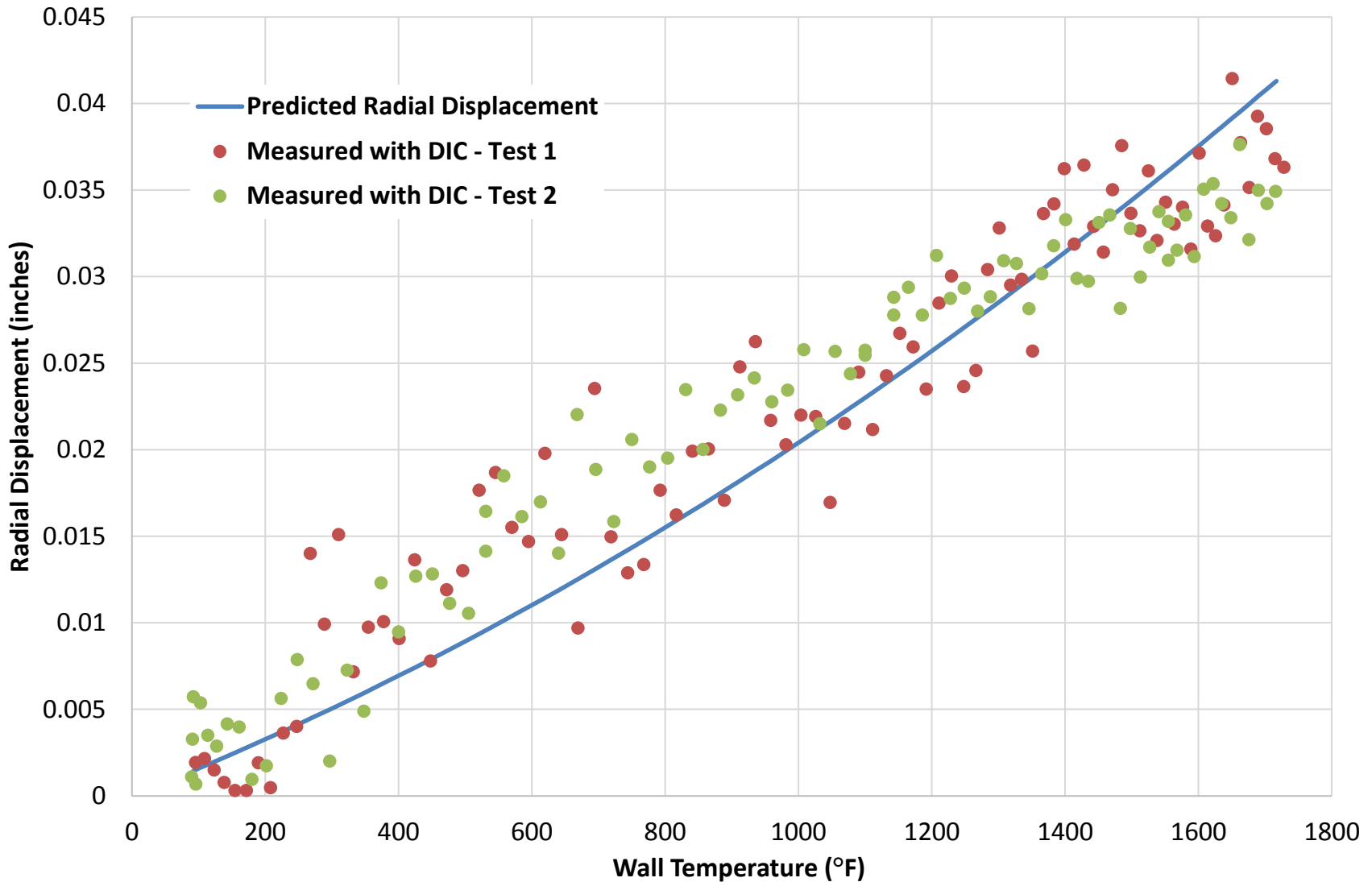


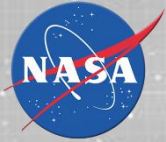
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Gilbert Handley

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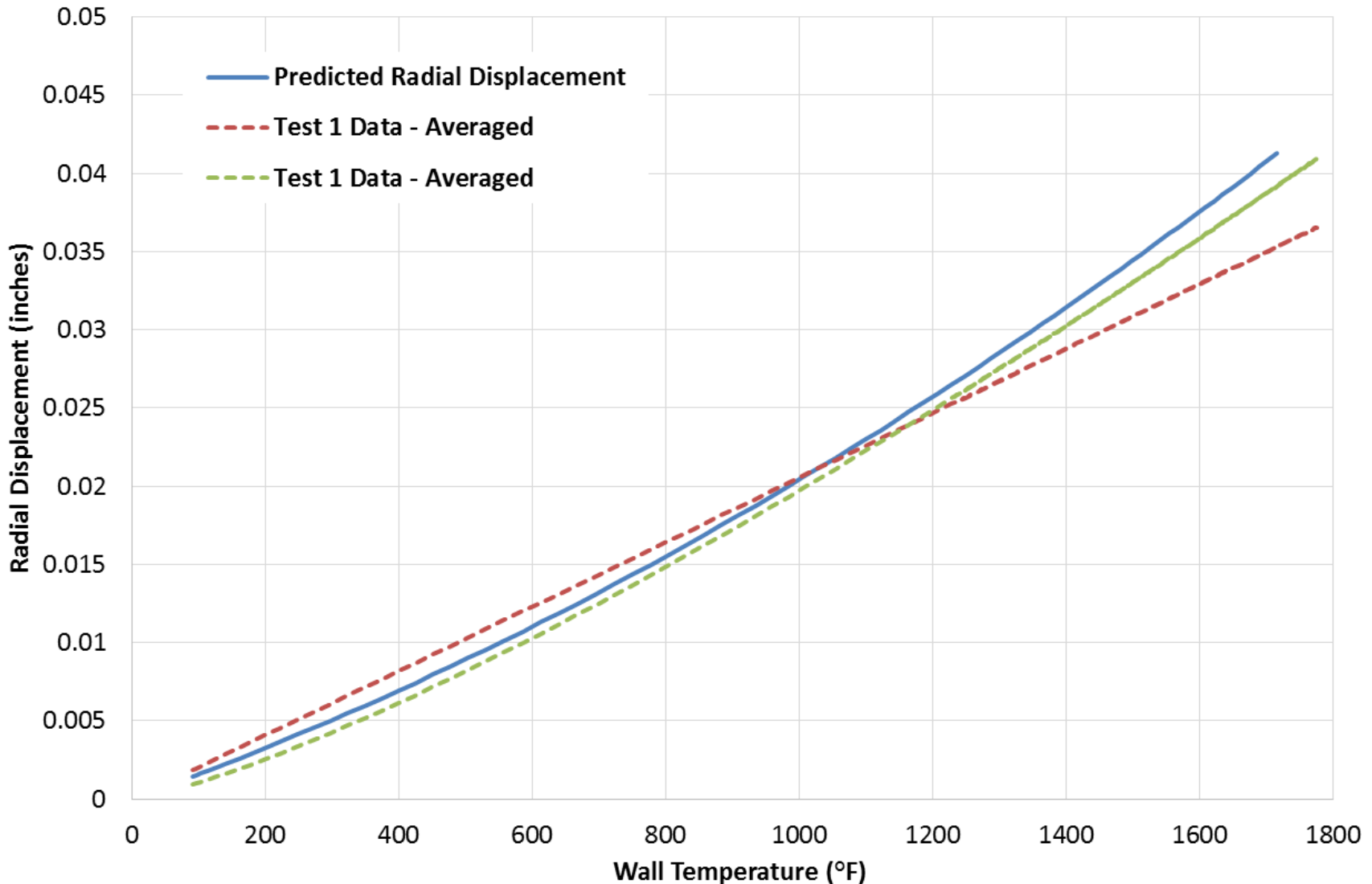


Subscale Hotfire Testing – Data Analysis

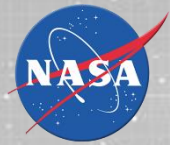




Subscale Hotfire Testing – Averaged Data



Optical test data tracking closely with predictions; error grows at elevated temperatures

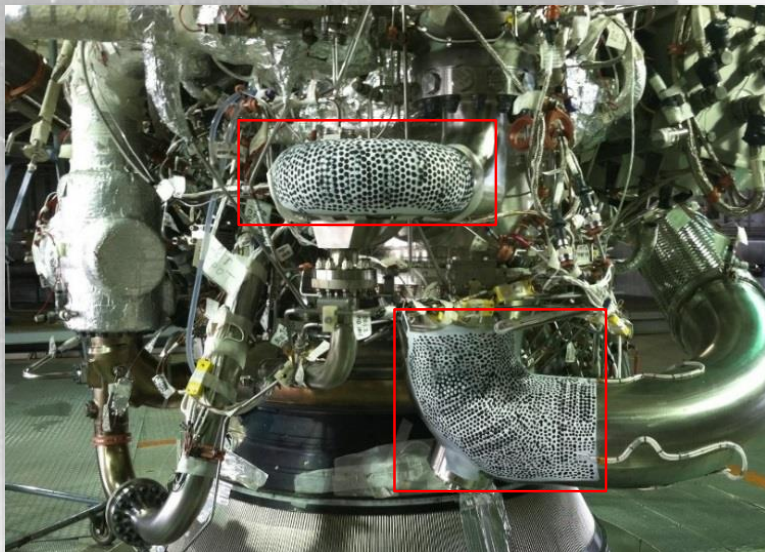


Large Scale D.I.C. for Engine Hotfire Testing

MSFC has developed new optical measurement techniques to augment or replace traditional gages in harsh environment engine testing or manufacturing operations

Stereo high-speed cameras measure full-surface displacements and strains using "speckle pattern" (calibrated triangulation)

- Leveraged basic techniques from NESC Shell Buckling Test and NASA & industry experts
- Developed speckle pattern and initial vibration damping in subscale hotfire testing at MSFC
- J-2X provided the test-bed environment to develop camera stability damping
- Industry-first attempt for high temperature, high vibration environments where traditional gages do not operate reliably



Stereo Cameras installed and Speckle Pattern Applied at Stennis A1 Stand

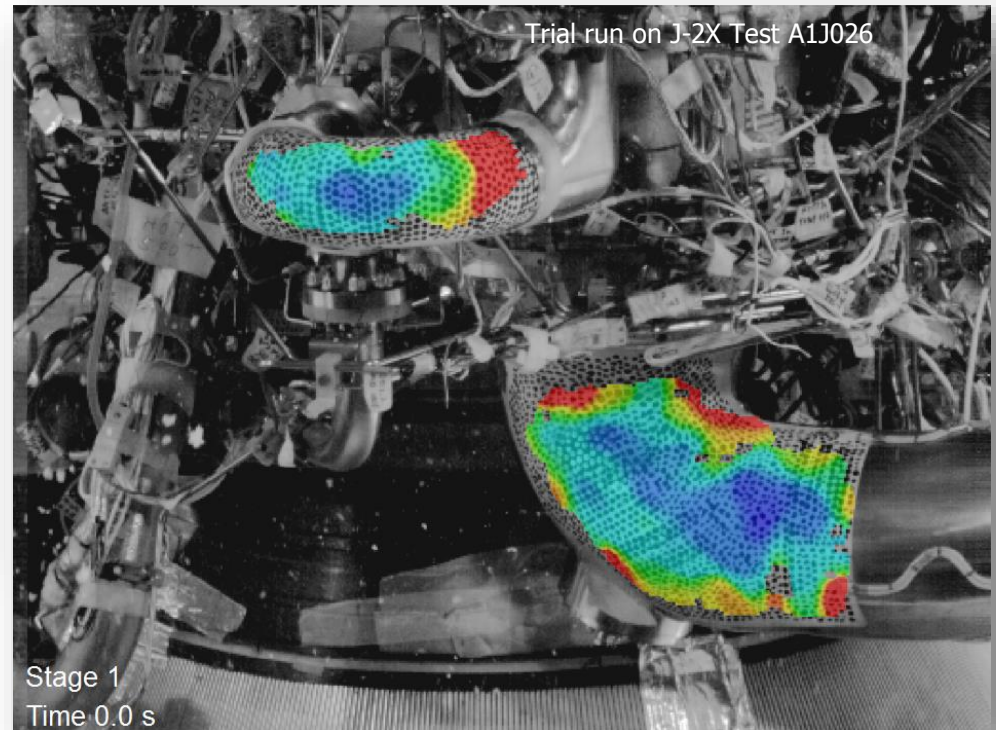
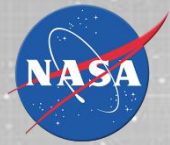




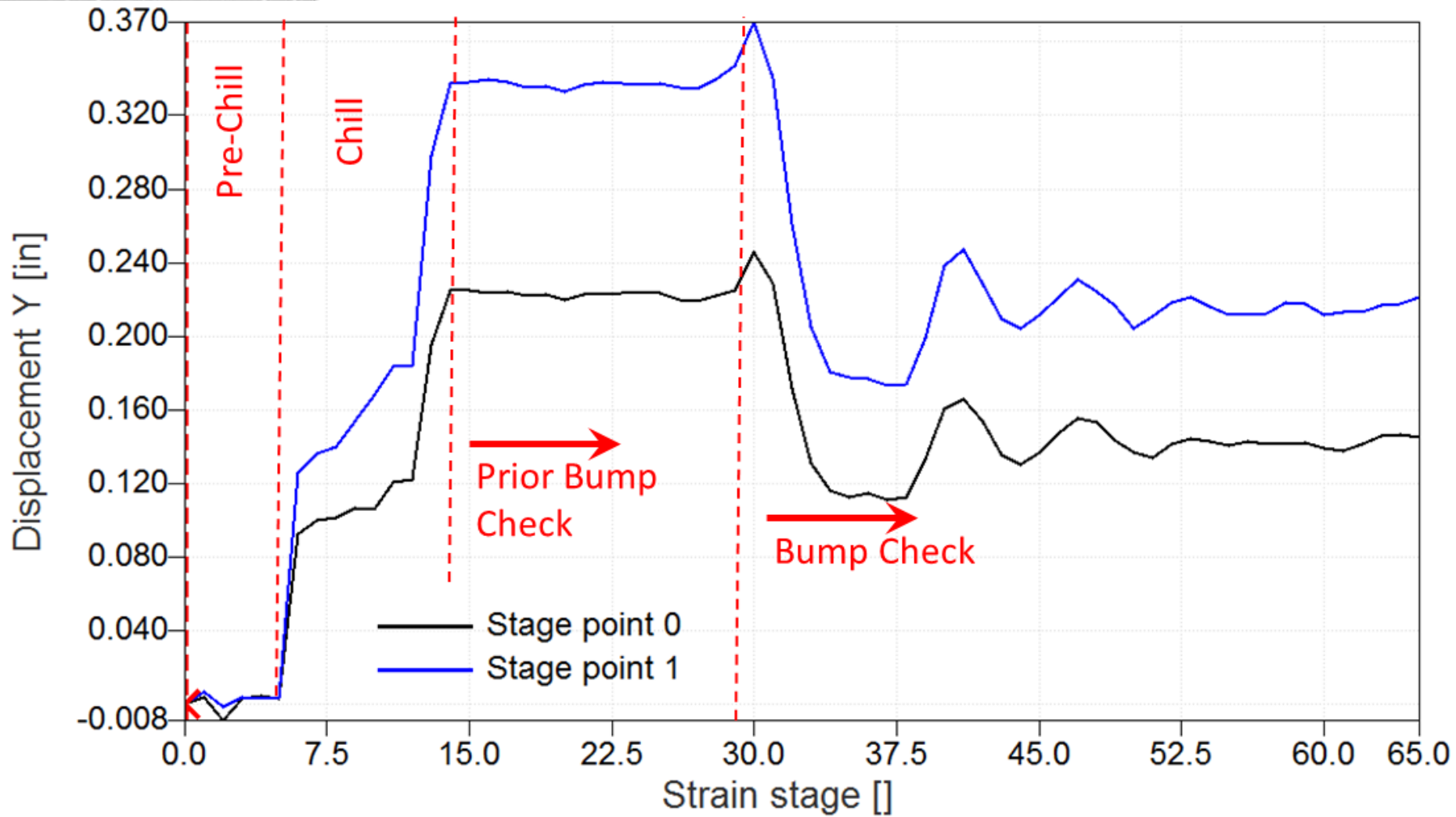
Photo Credit: Dan Goade

Test Data Collection:
Paul Gradl, Gilbert Handley, Brian West

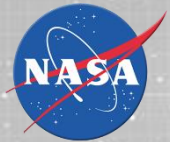
ARAMIS high speed cameras



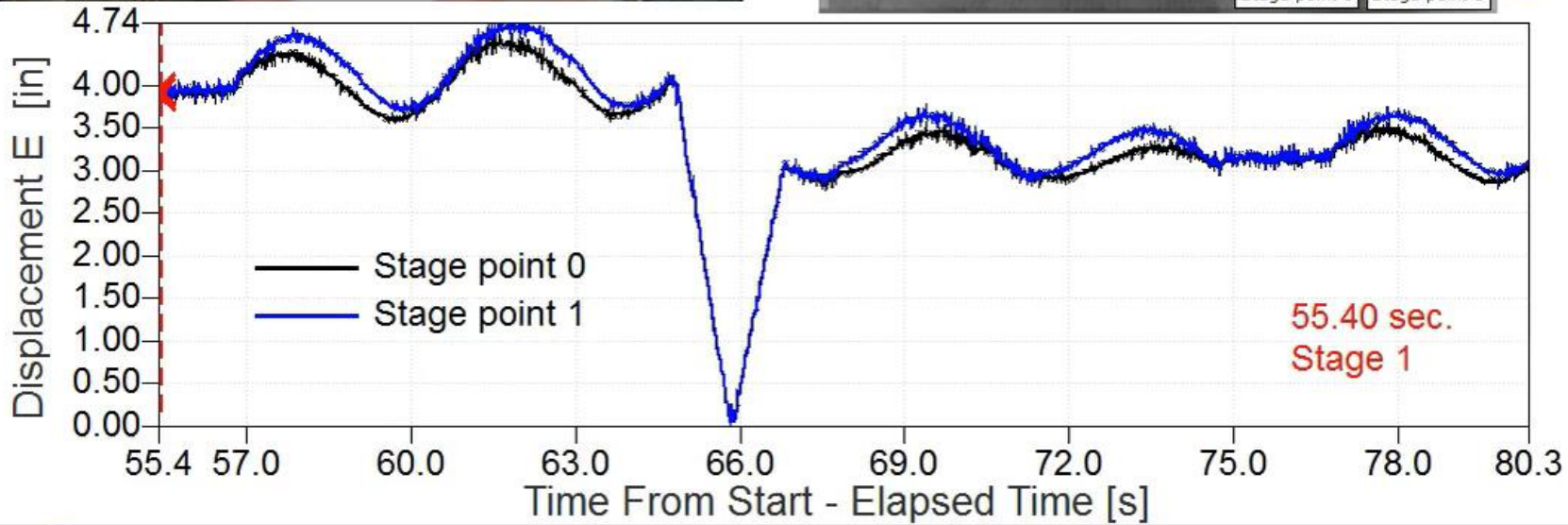
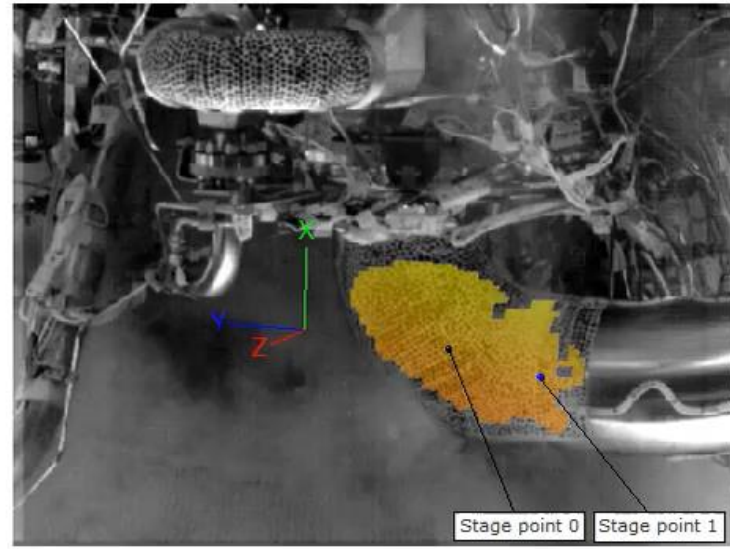
Engine Movement and Strains during Pre-test Ops



Ability to track engine during all chill and gimbal checkout operations



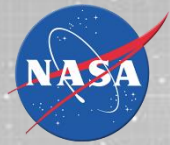
ARAMIS Full Surface Strain Measurement Proof of Concept Displacement during A1J028 Test



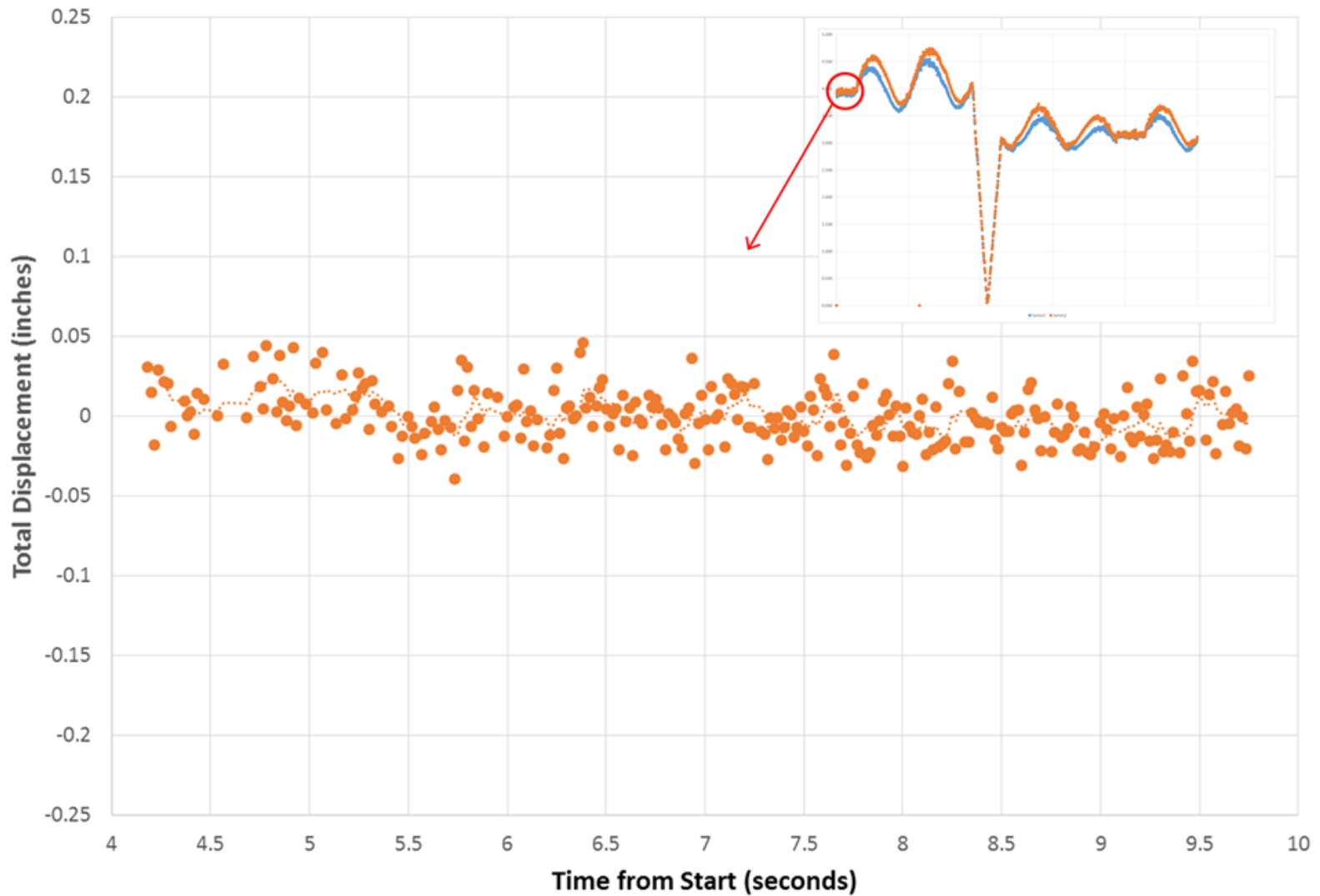
ARAMIS Trial on J-2X A1J028

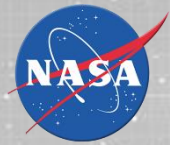
Paul Gradl
Gilbert Handley

Displacement E (Total X, Y, Z)



Error Associated With Measurements During Hotfire





Conclusions and Future Work

NASA MSFC has advanced a series of dynamic digital image correlation techniques for use during hotfire engine testing

- Subscale and full scale testing and analysis has demonstrated feasibility to accurately determine local and global displacements and surface strains

NASA will continue to advance this technology for rocket engine testing, subscale testing, component testing and bench top testing

- Replace traditional measurement systems
- Integrate with modern analysis tools
- Combine advanced techniques such as IR thermography and digital image correlation
- Continue to research and advance techniques for elevated temperature applications

Share lessons learned with industry and government through technical papers and presentations



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