National Aeronautics and Space Administration

NASA

# Optical Measurement Techniques for Rocket Engine Testing and Component Applications

*Digital Image Correlation and Dynamic Photogrammetry*

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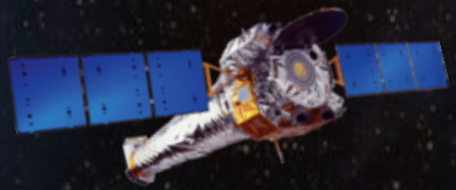
MARSHALL
SPACE FLIGHT CENTER

# Marshall Mission Areas

Traveling To and Through Space

Living and Working in Space

Understanding Our World and Beyond



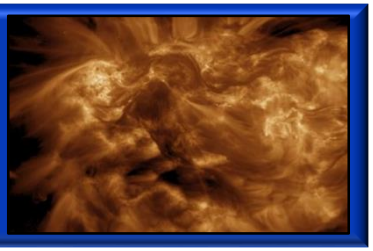
# NASA Marshall's Role in Agency Missions

## Space Transportation/Launch Vehicles

## Propulsion Systems

## Space Systems

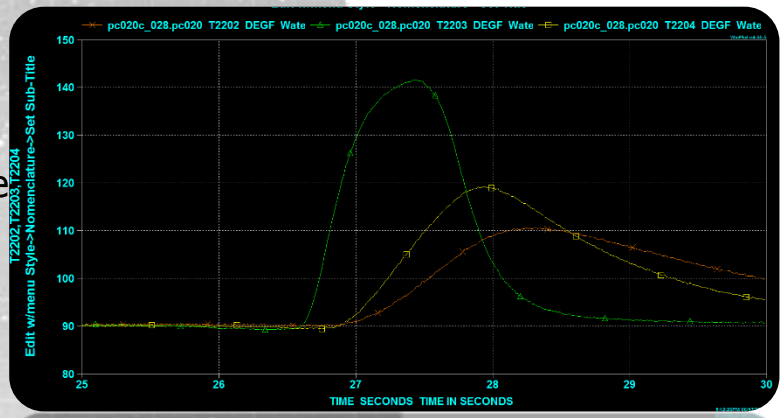
## Scientific Research



# Motivation for Technology

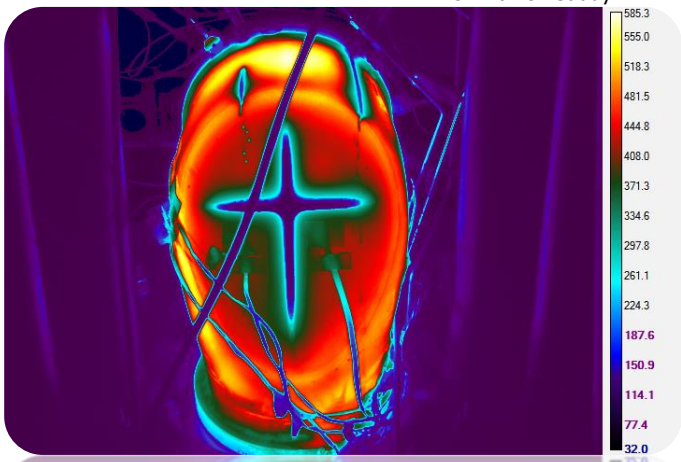
- Subscale and Full-scale testing requires expensive and labor intensive instrumentation to better understand hardware performance
  - Design Modifications and Performance Predictions based on “discrete” point instrumentation
    - Thermocouples, Pressure Transducers, Accelerometers, Strain Gages

ARAMIS = Strain Gage
IR = Thermocouple




Discrete Points

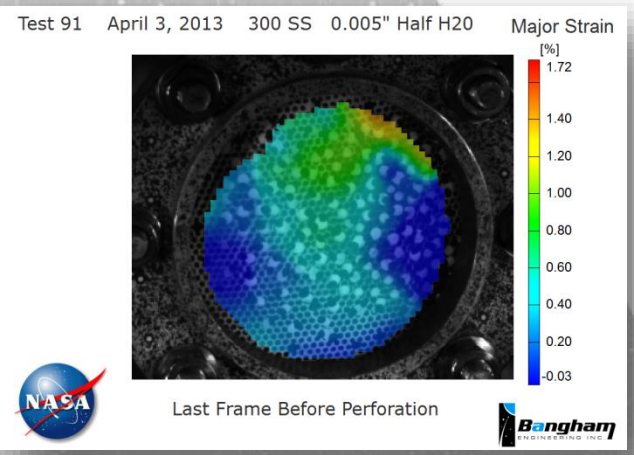
Ref: Darrell Gaddy



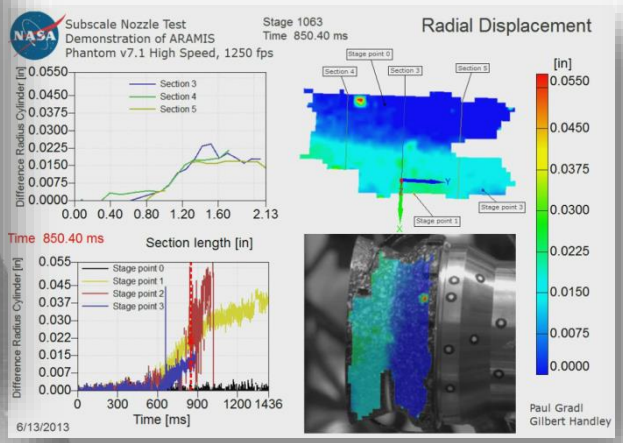

Full Surface

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

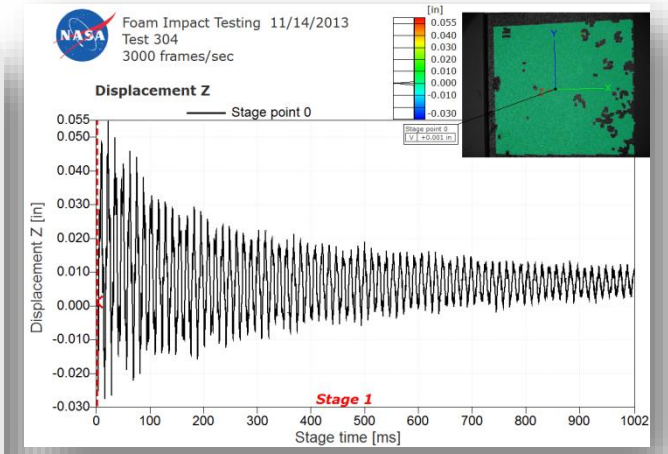
# Applications and Development work for Digital Image Correlation at NASA



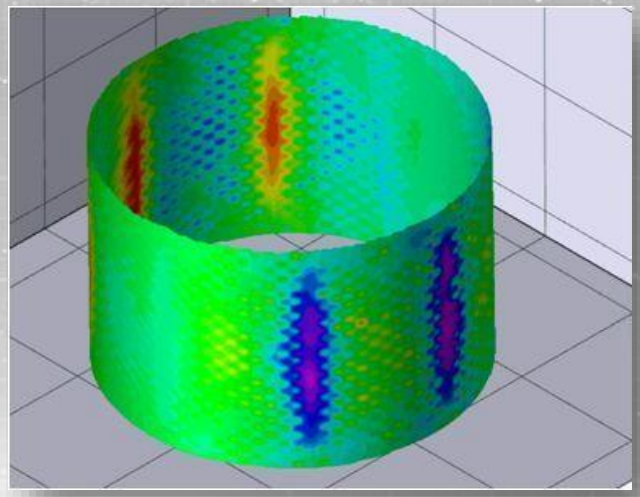

Blast Pressure Wave Tracking at 70,000 fps




Subscale Nozzle Displacements at 1700F

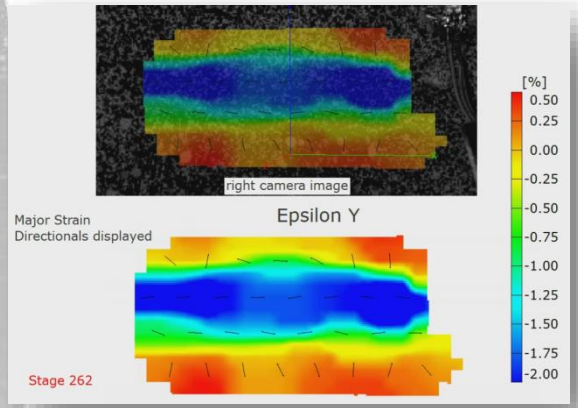



Debris Impact Testing – Eliminated Strain Gages

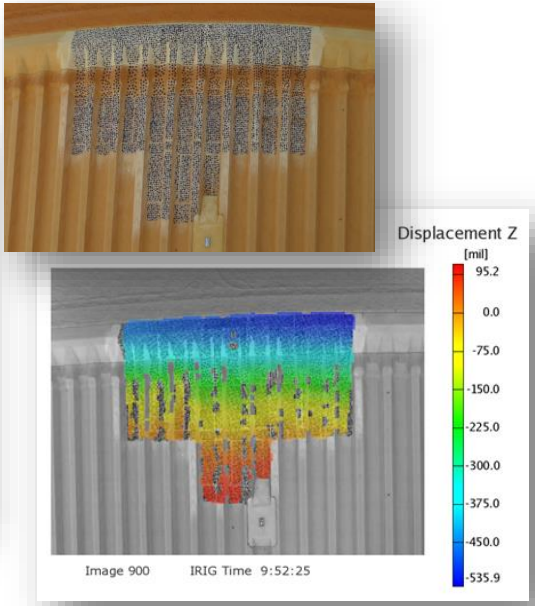


Full-Field Strain and Displacements of 18-ft Dia Tank

Ref: Todd Boles, MSFC/ET30




High Speed Composite Compression – Direct Application of Major Strain

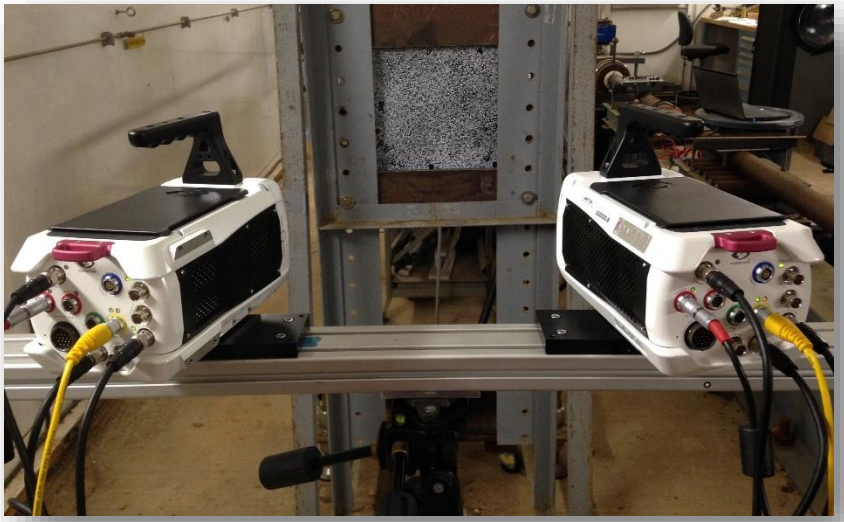



ET (on Pad) Cryo tanking test to observe stringer displacement

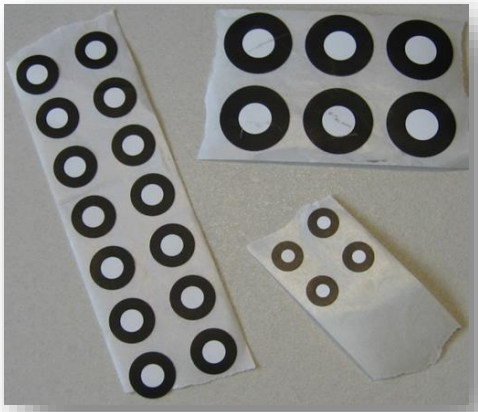
# Digital Image Correlation - Overview of Technology

- Uses paired high speed video cameras calibrated to a volume to full field surface data
- Post-processing of paired images to determine **Displacement of surface, strains, acceleration, velocity**
- High Speed cameras can provide high frame rate although frame rate limited by duration of test and current post-processing techniques (tremendous amounts of data)

Photos by: Paul Gradl and Gilbert Handley

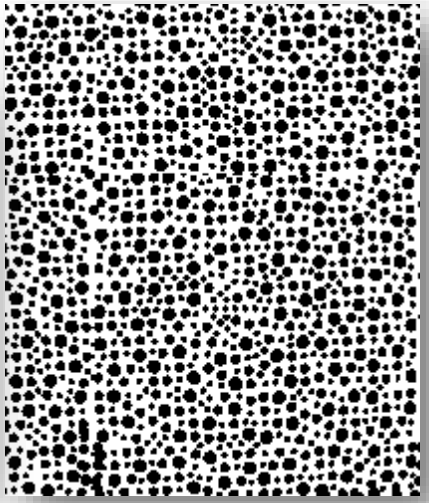


PONTOS



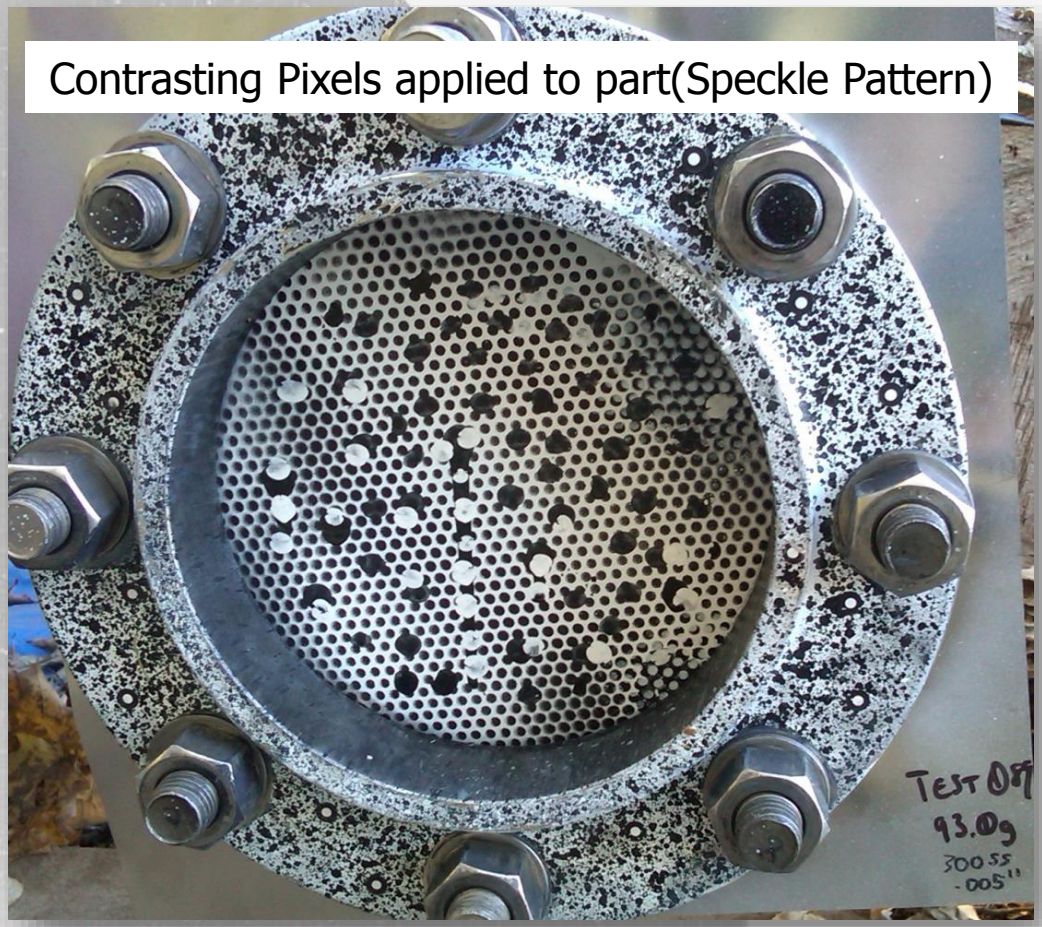
*Discrete Point Setup*

ARAMIS



*Full Surface Setup*

# What is Digital Image Correlation?

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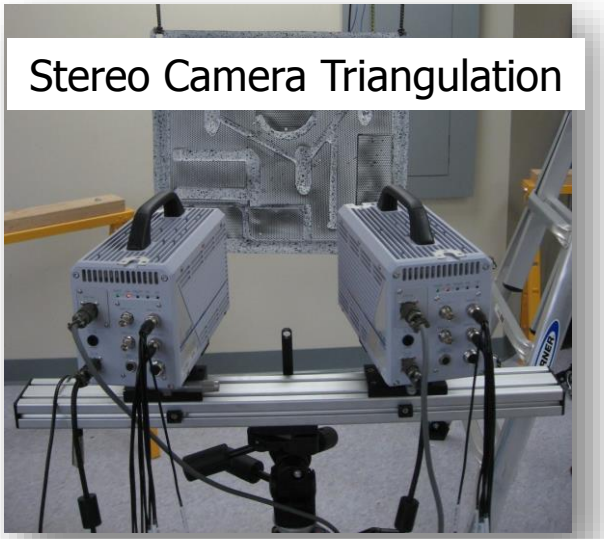
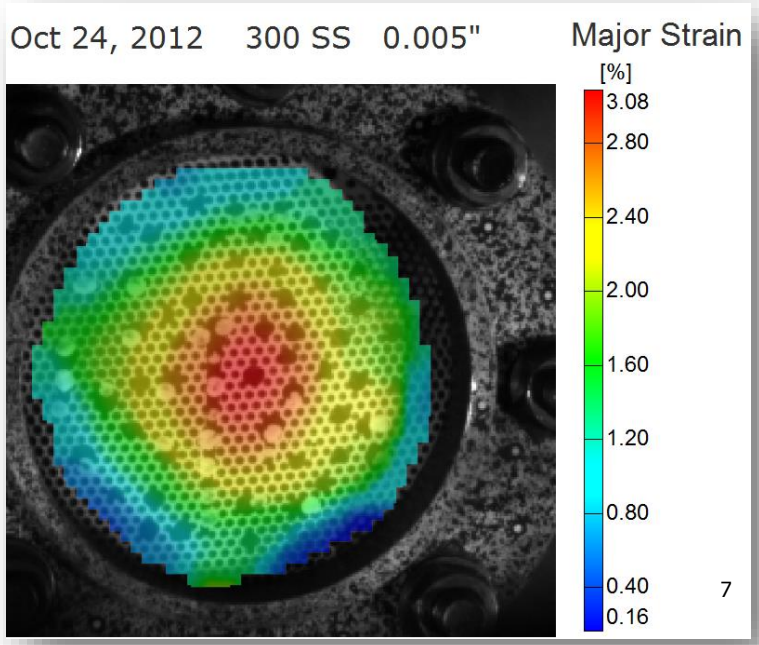
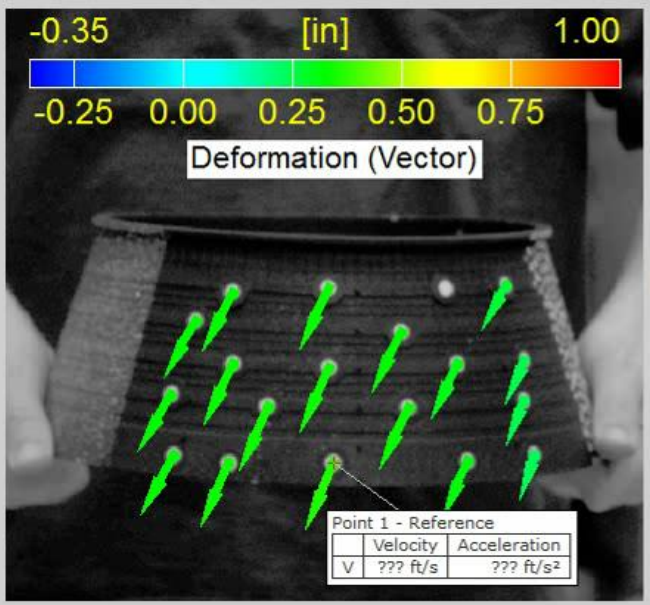



Photo Provided by: Tim Schmidt / Trilion

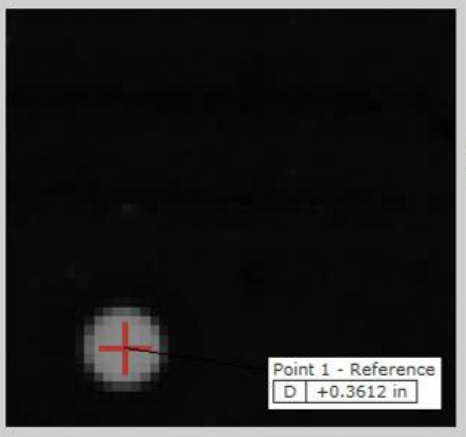
= Full Field Displacement and Strain Measurements

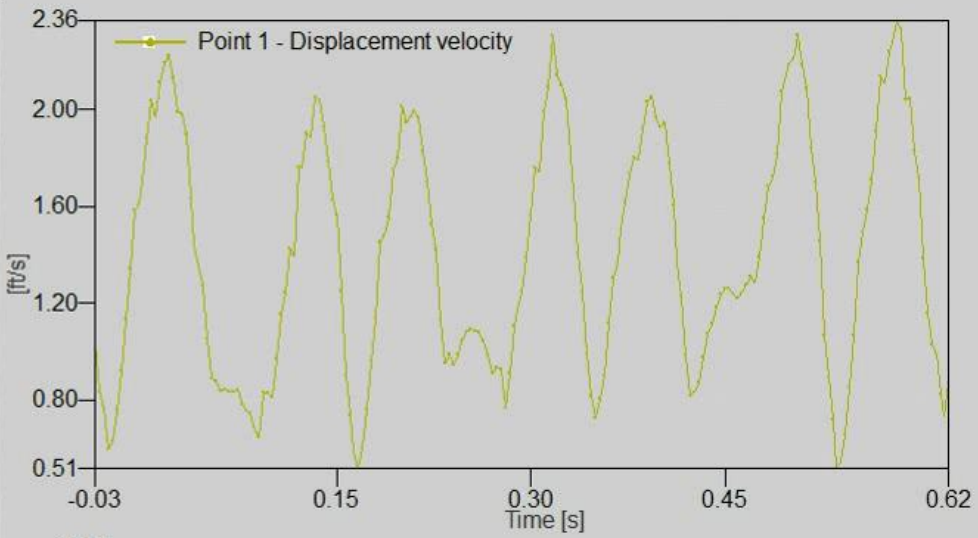


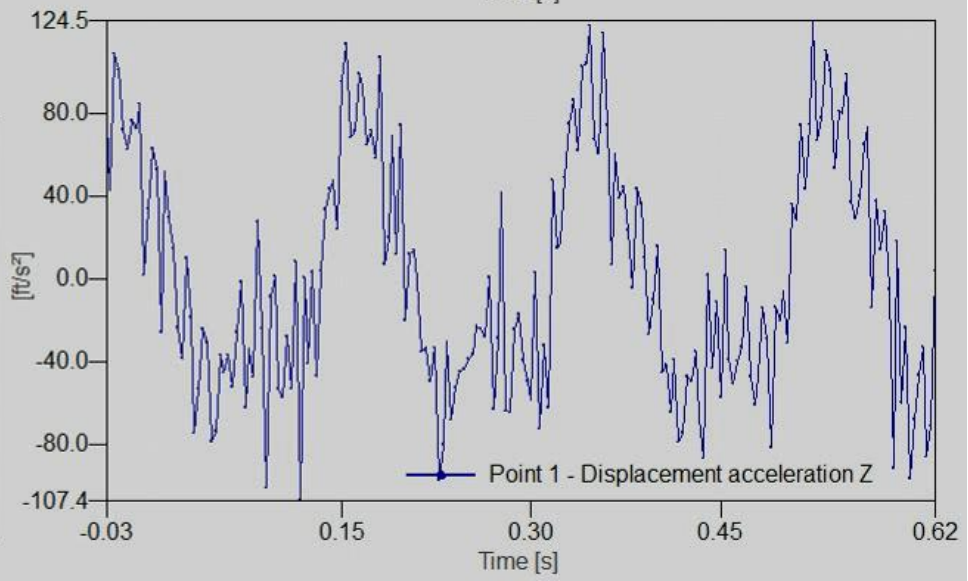
# PONTOS Lab Experiments




Nozzle Deformation
Date: 4/2/2013
0.000000 sec
Phantom 7.1M HS
50mm lenses

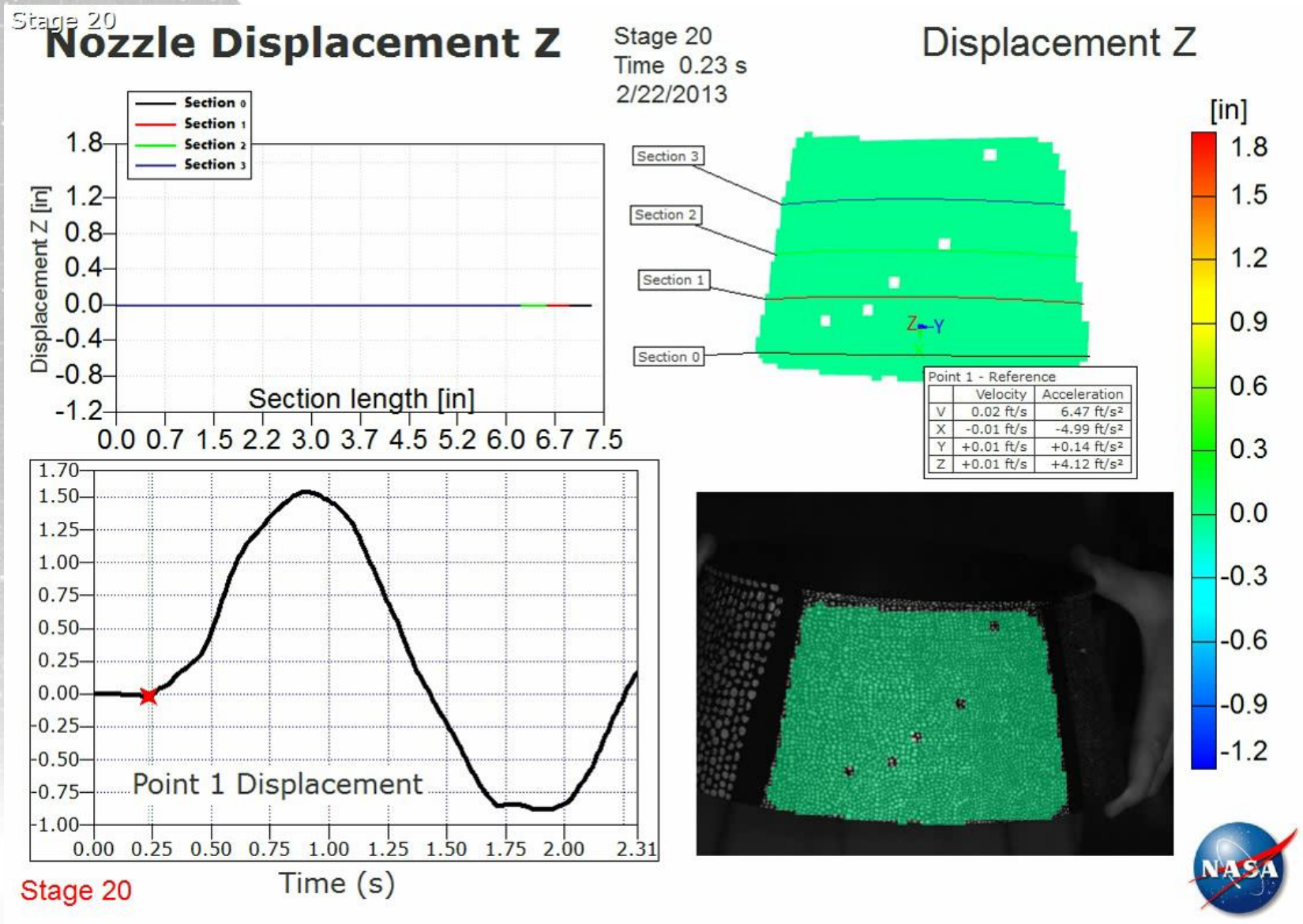


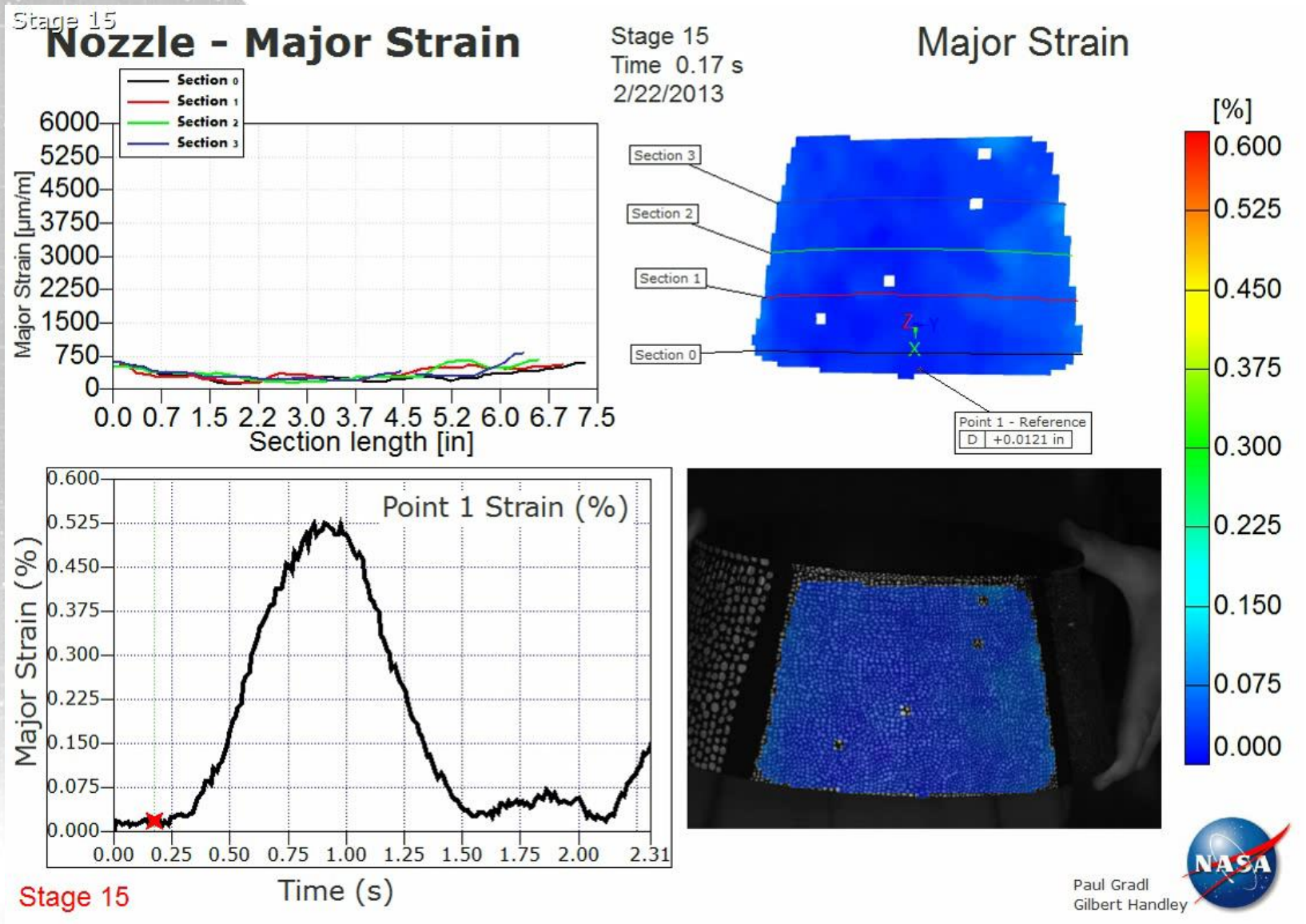




Paul Gradl
Gilbert Handley

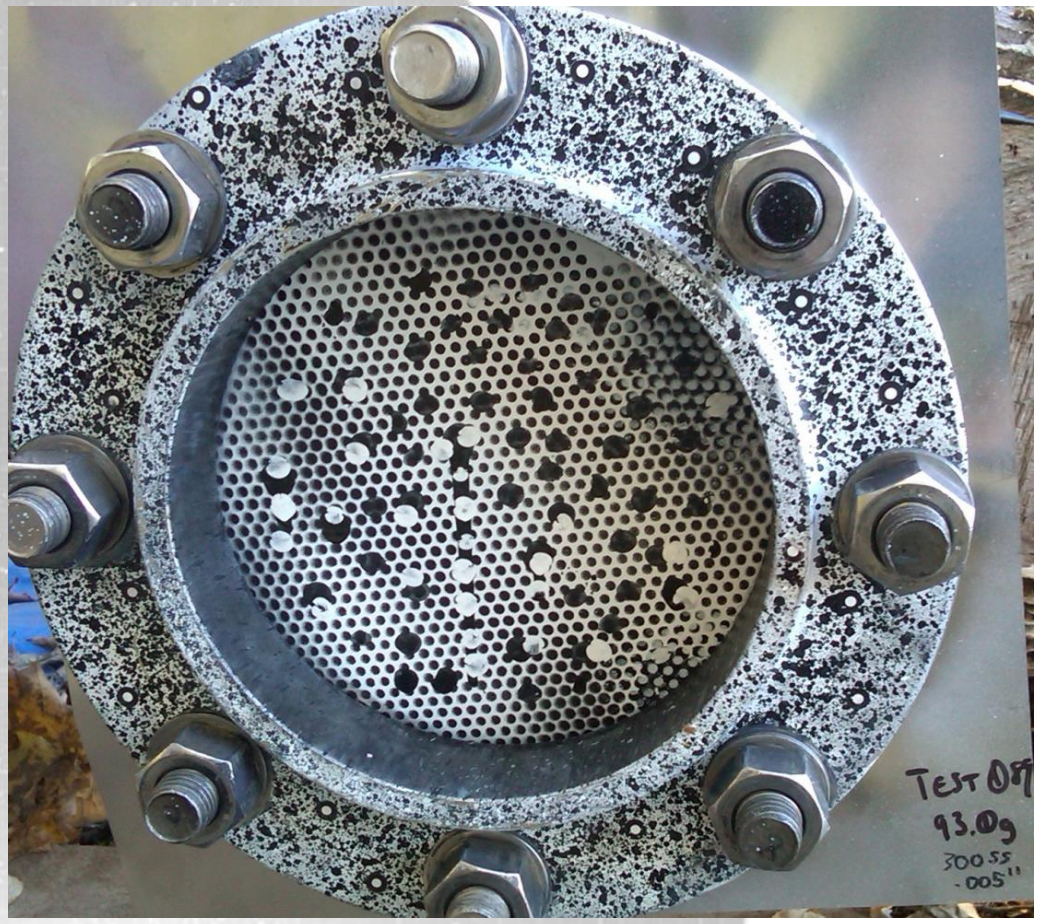
# ARAMIS Lab Experiments – Displacement



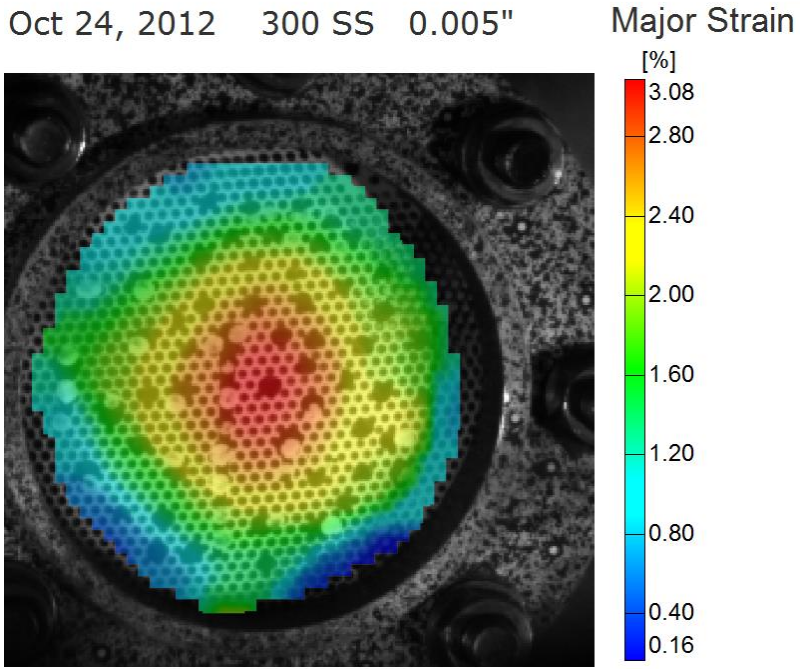
# ARAMIS Lab Experiments – Principal Strain

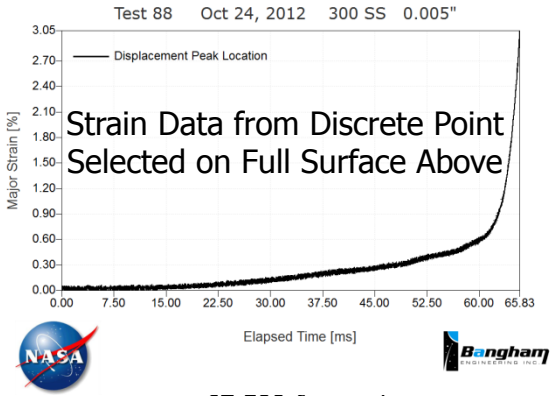


# Blast Testing High Speed Example




Speckle pattern applied to component using Rustoluem 1976 Black

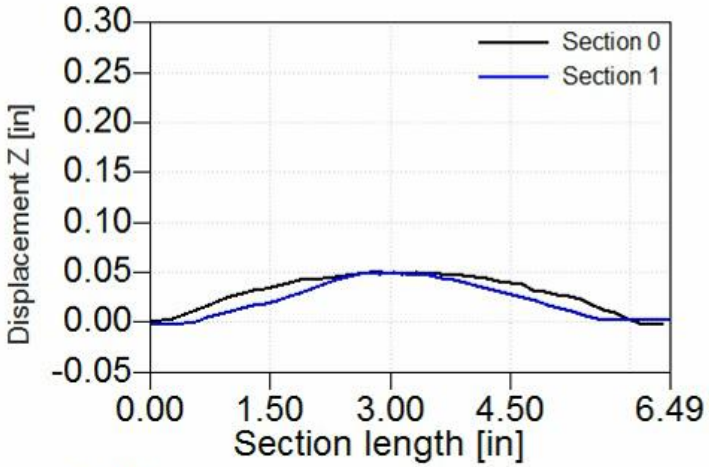


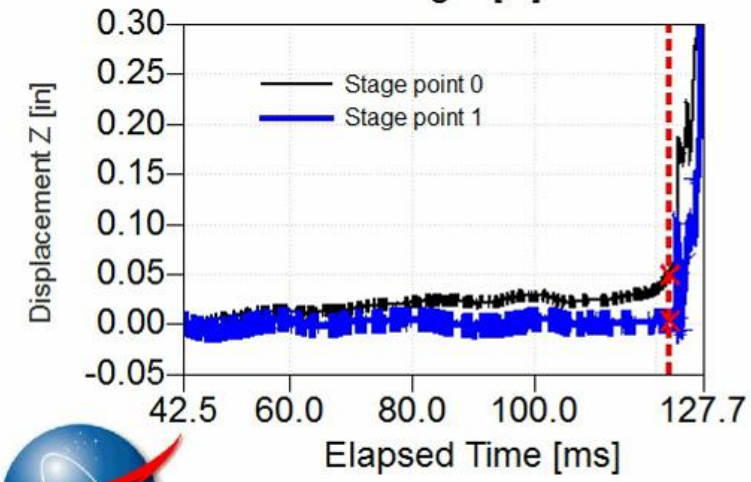




67,500 frames/sec

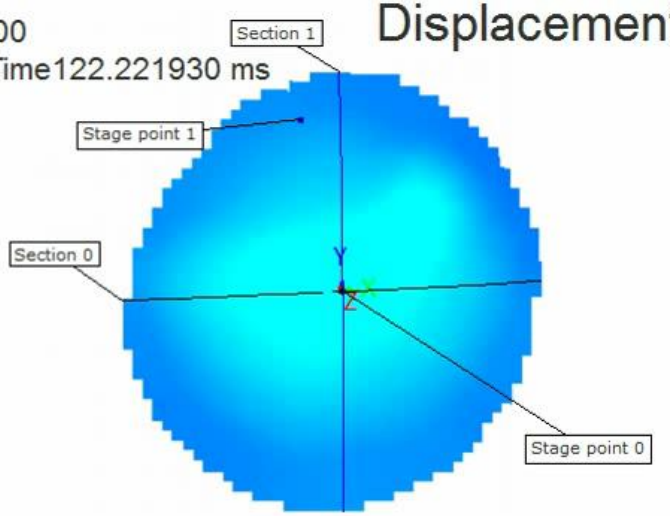
# High Speed Fragmentation Testing

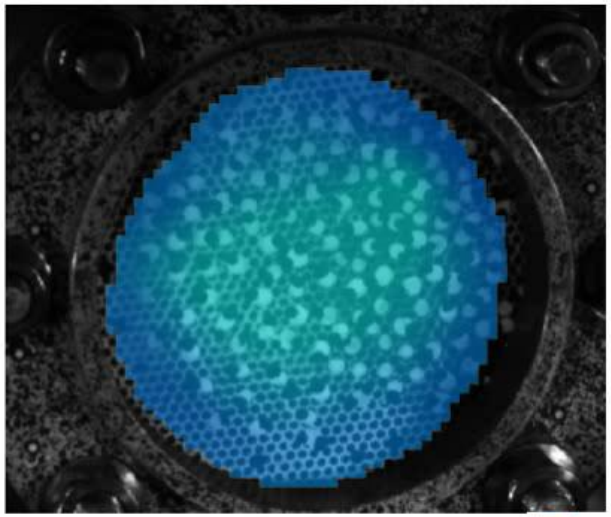
Test 91 April 3, 2013
300 SS 0.005" Half H20



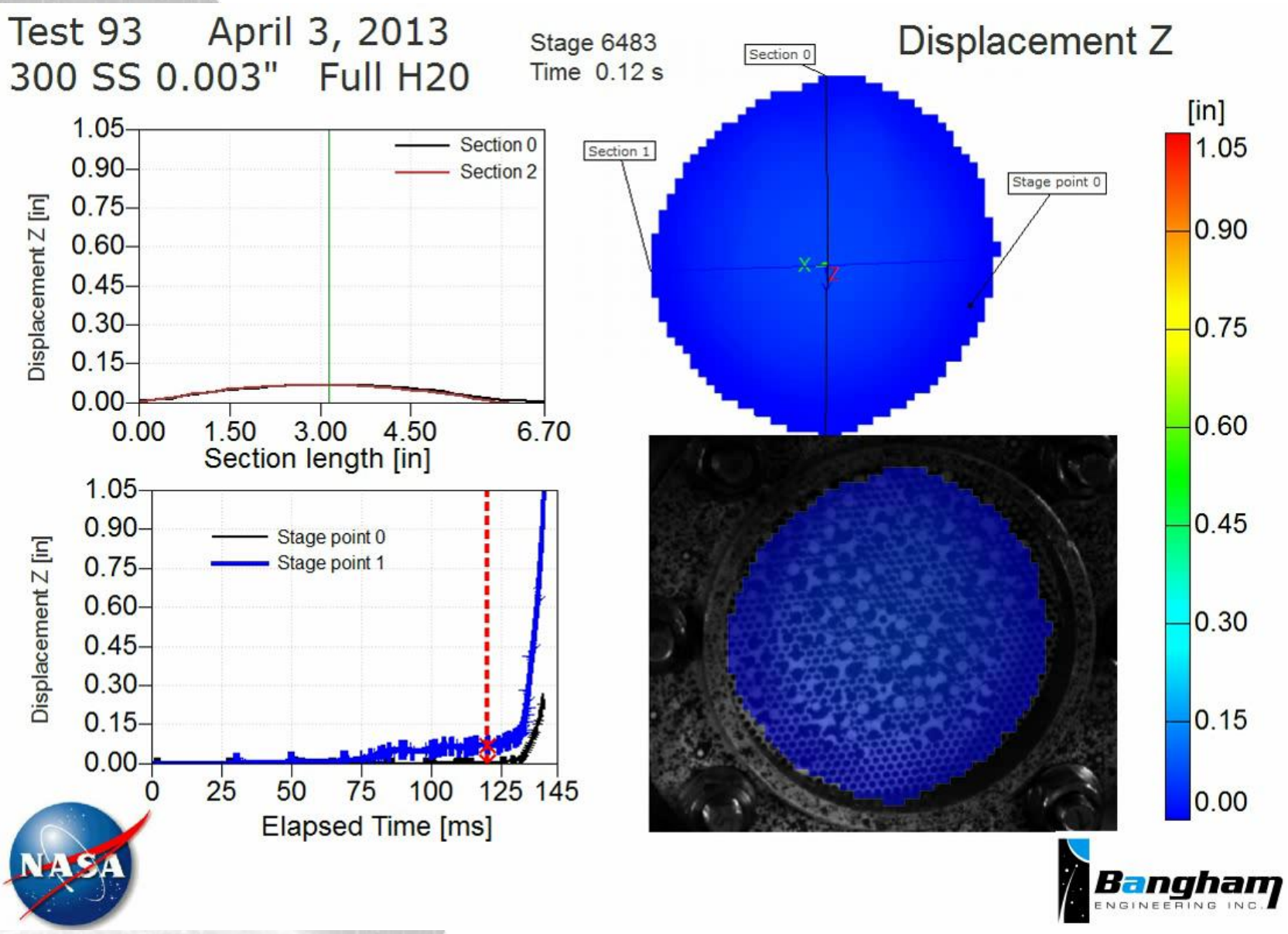




Stage 4300
Elapsed Time122.221930 ms

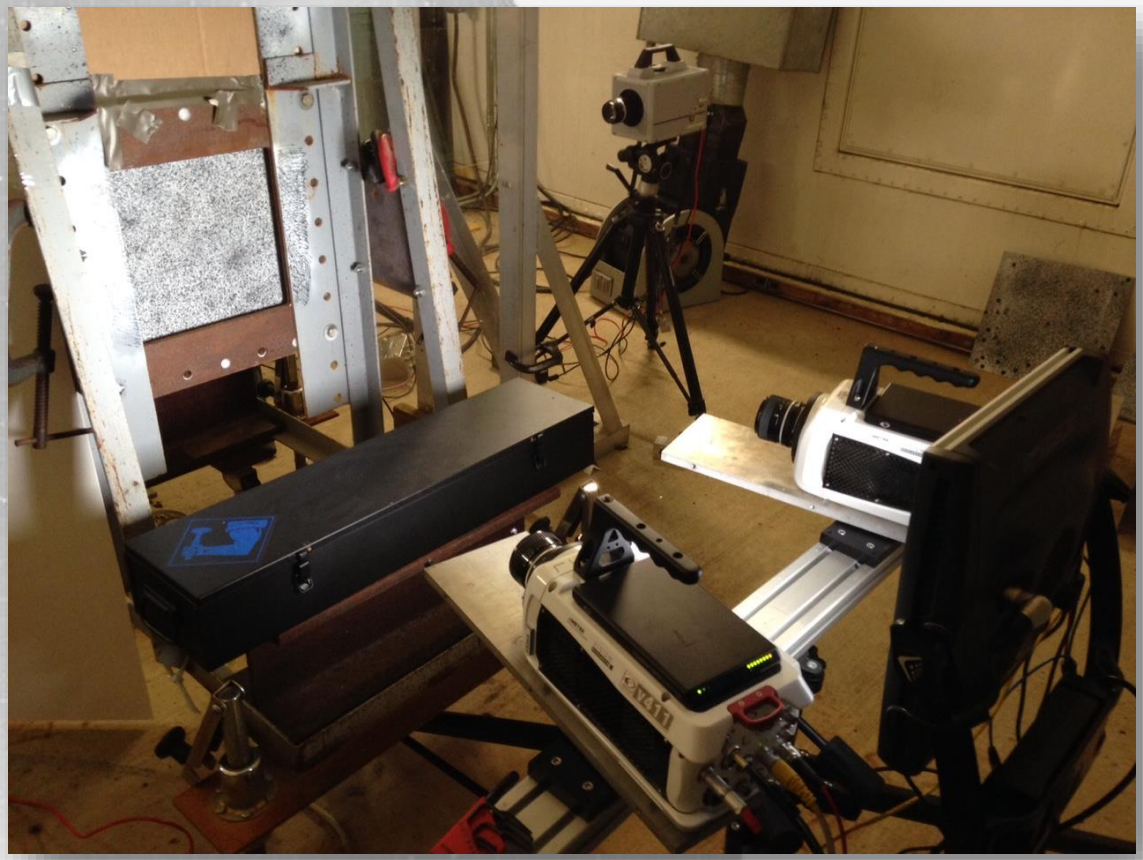


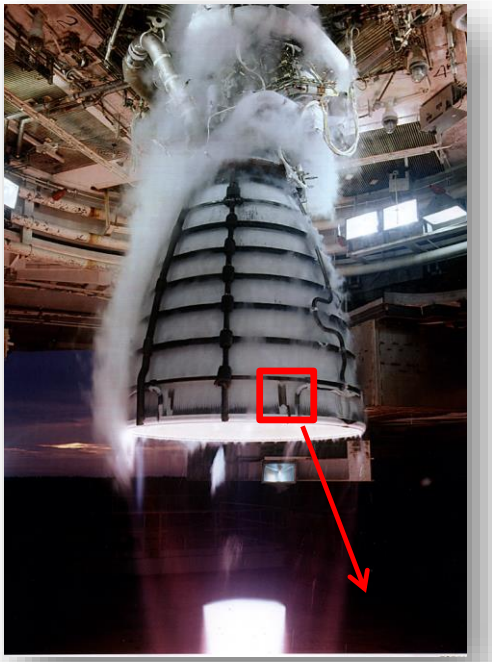



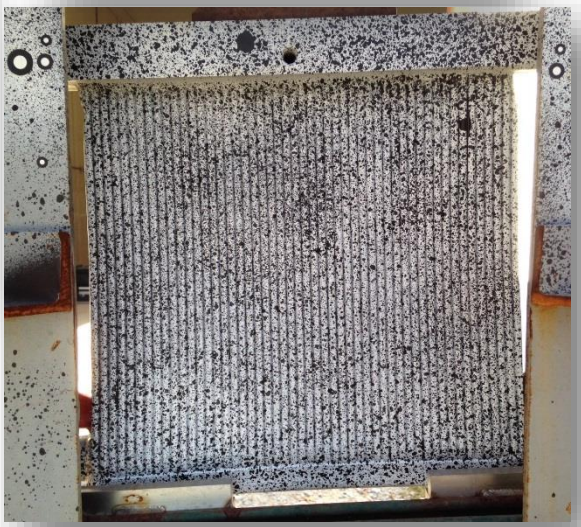
# High Speed Fragmentation Testing (cont)



# Space Launch System (SLS) Debris Impact Testing



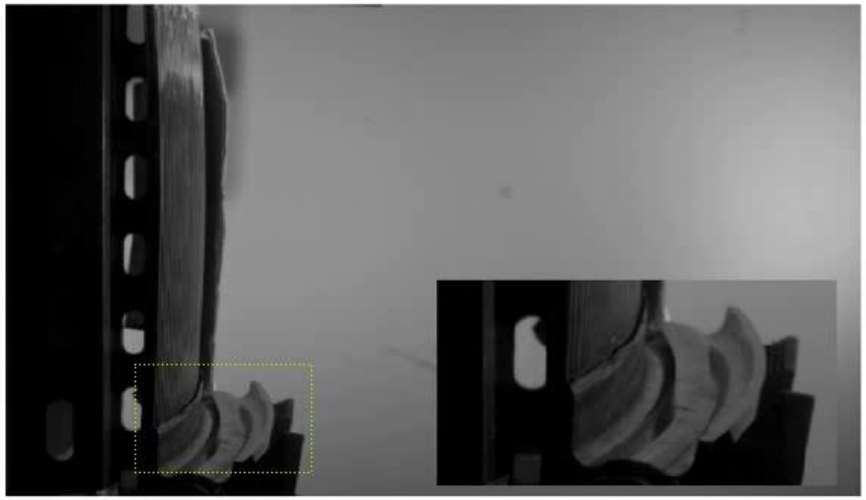


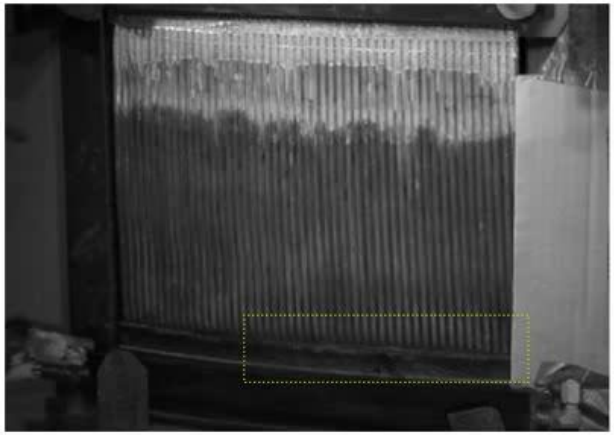


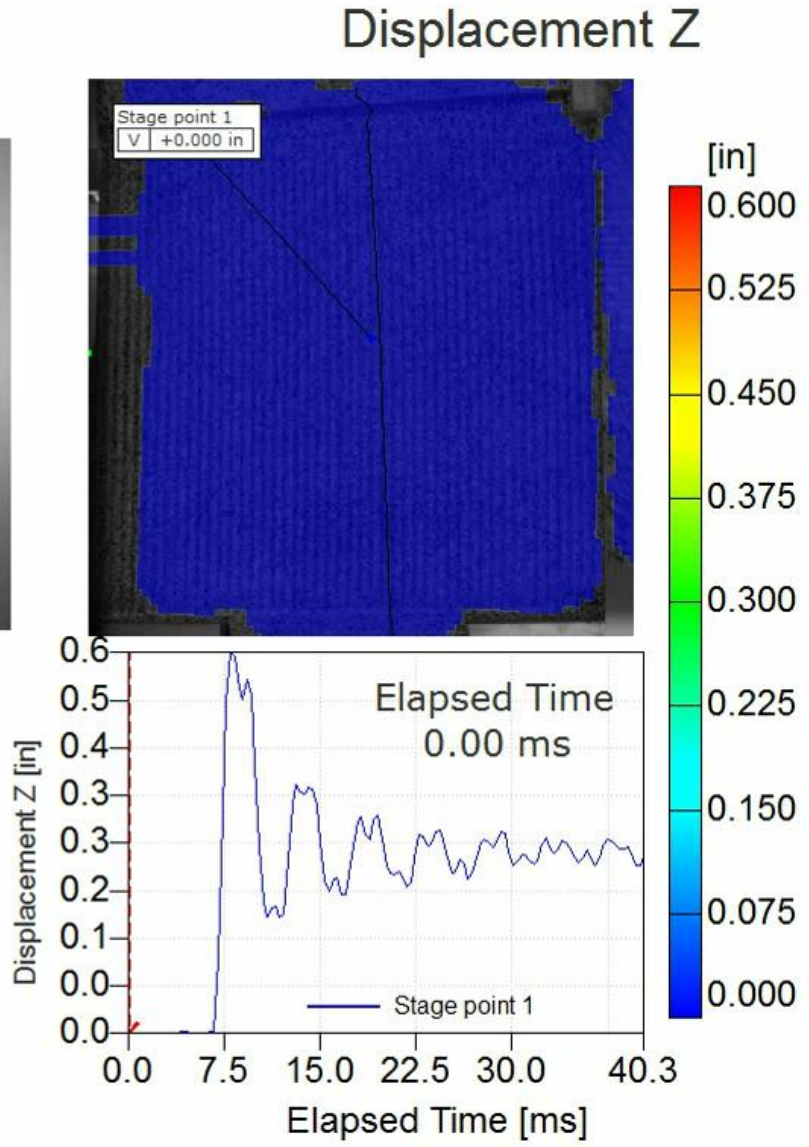
**Test provided by**: Paul Gradl and Cory Medina
Chip Kopicz, Perry Gray, Bart Suggs

# SLS RS25 Nozzle Pressurized Panel

**SLS RS25 Pressurized Panel Testing**
**13 Nov 2015; 6# Foam**

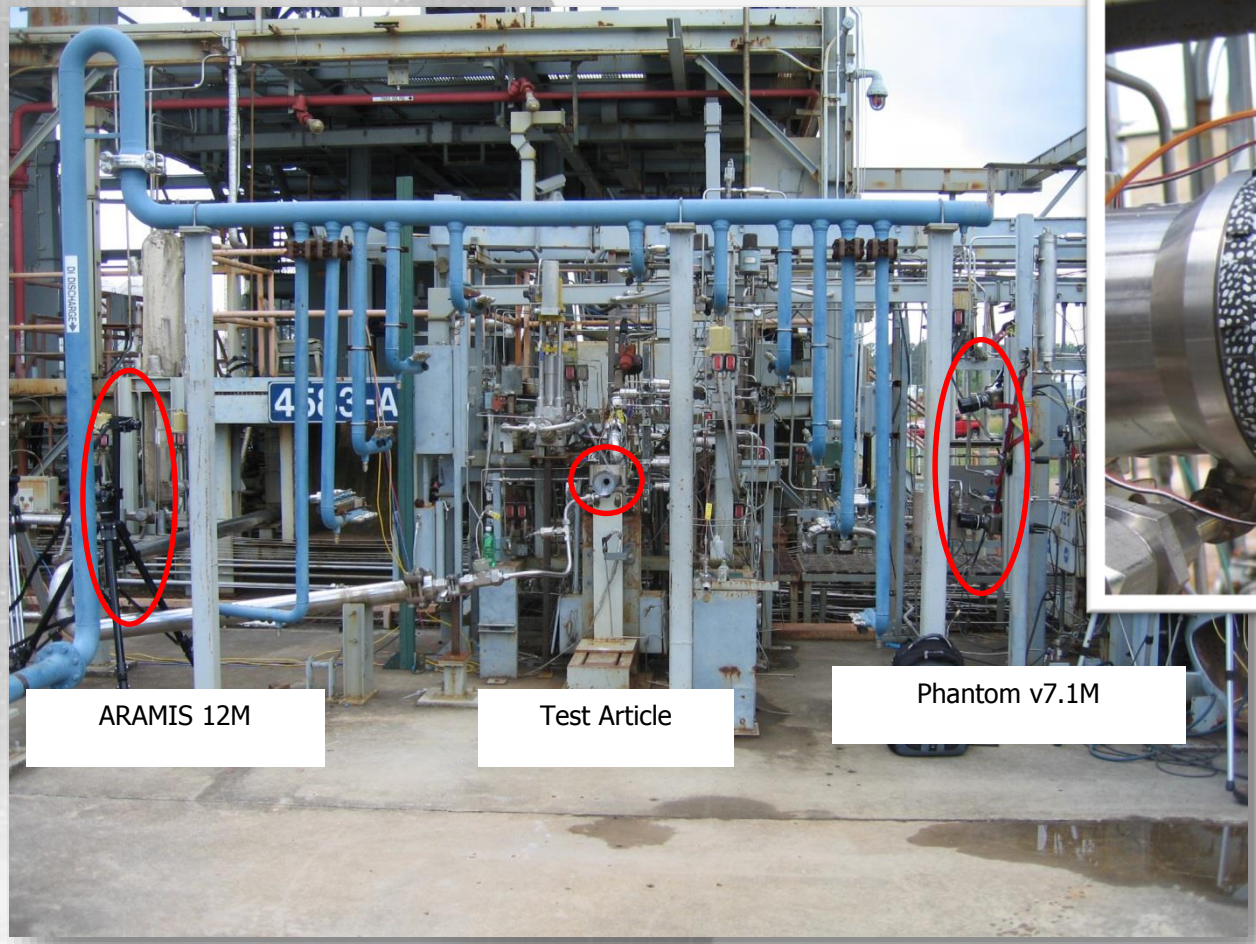


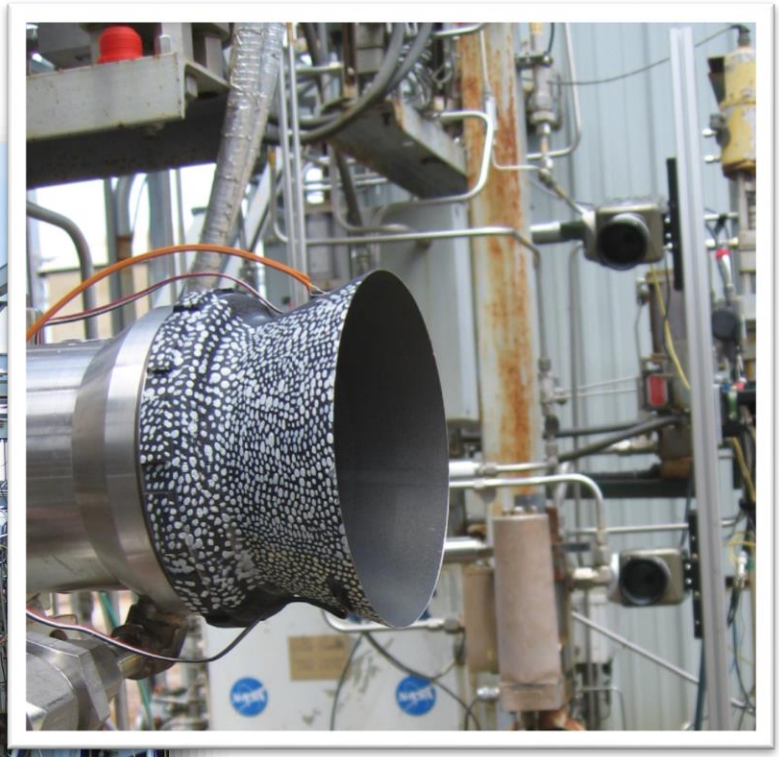





Paul Gradl Cory Medina Chip Kopicz

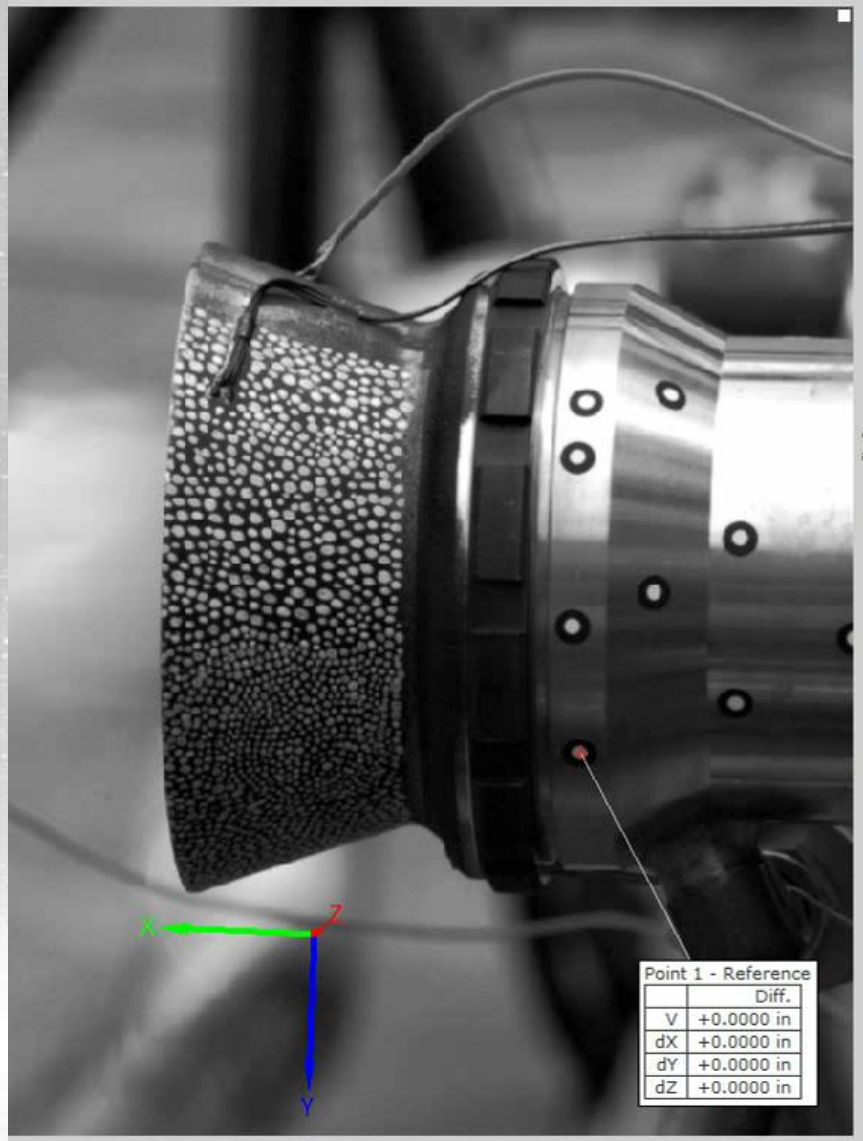
# Subscale Hotfire Nozzle Testing

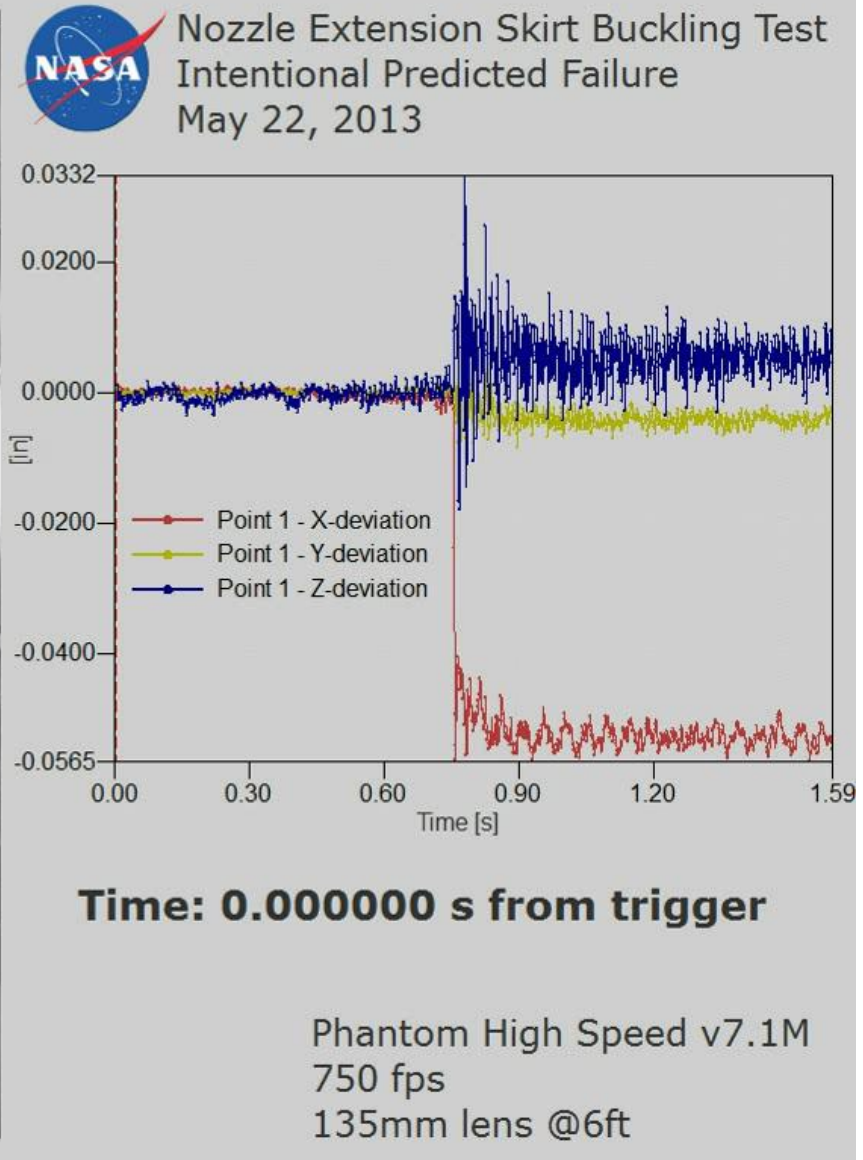


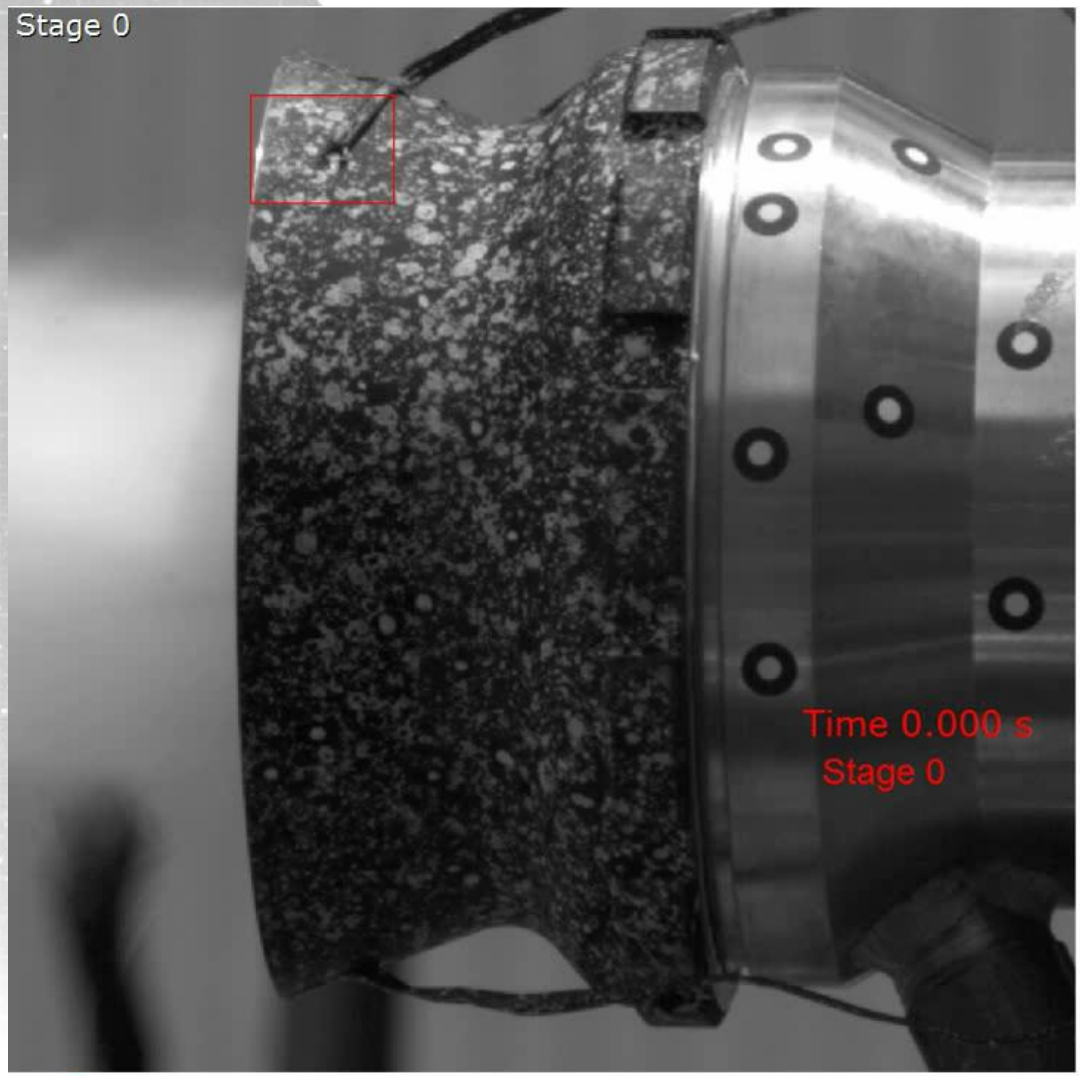
**Test Photos and Data Collection:**
Paul Gradl
Gilbert Handley
Sandy Elam Greene

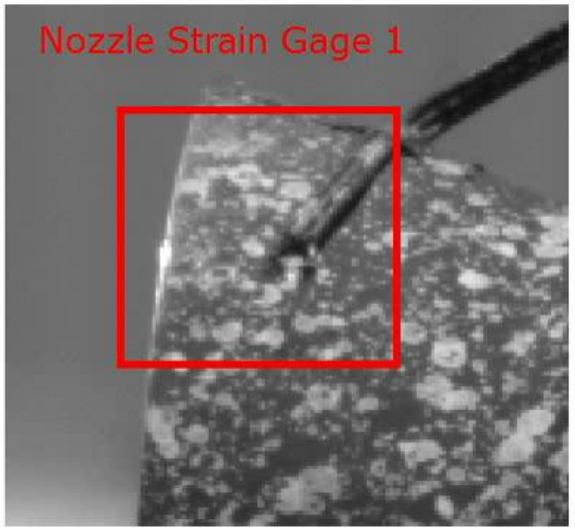
# Bench Testing Doesn't Always Translate into the Field…

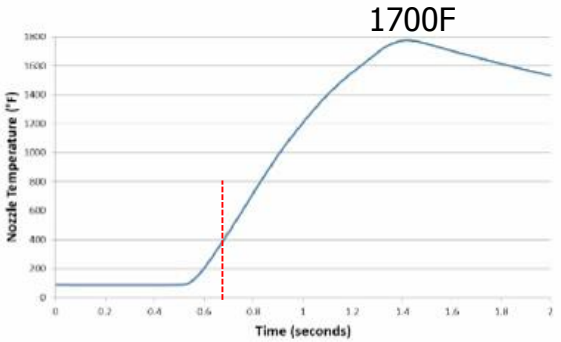


# Motivation to Develop Technique



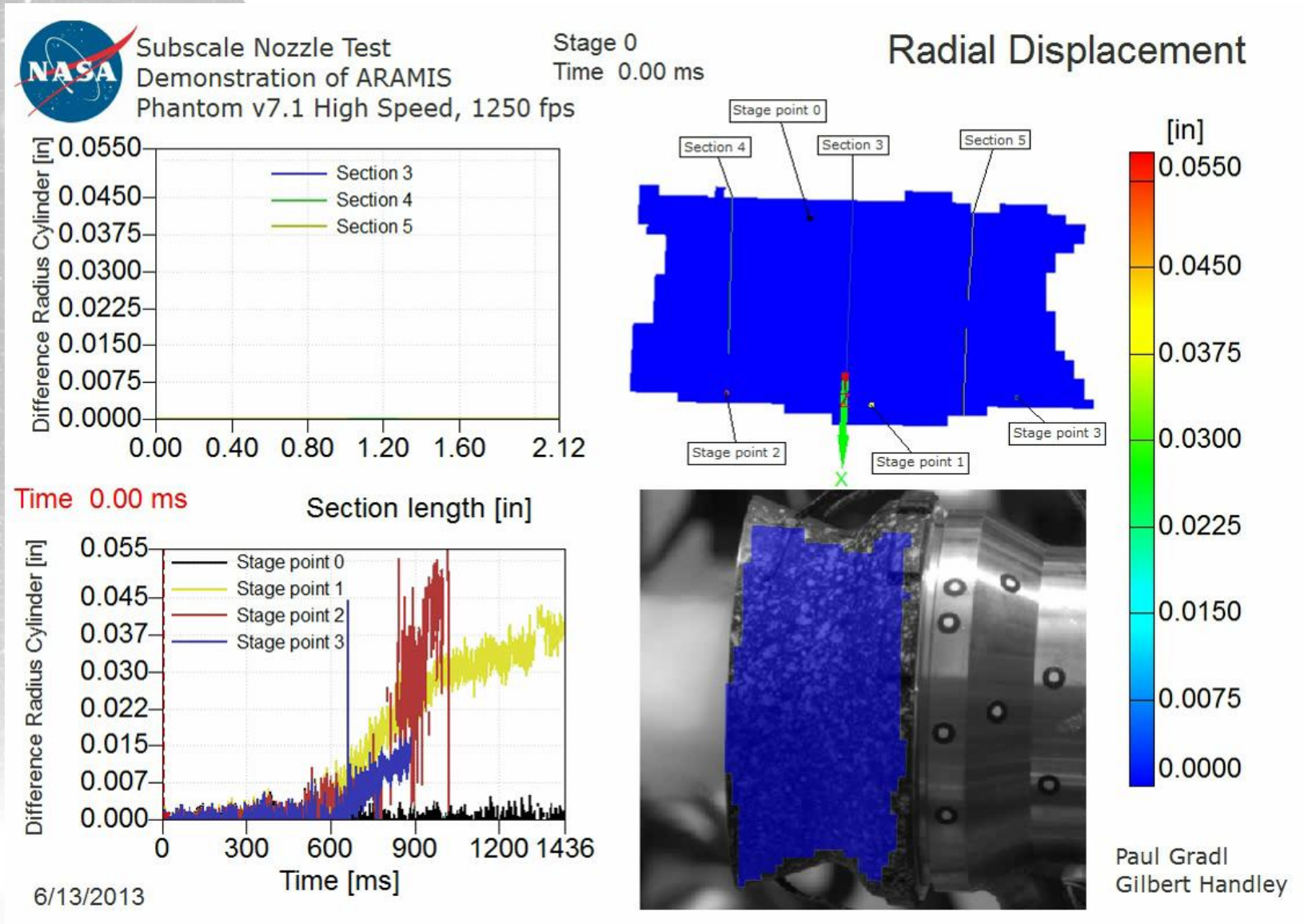

**Strain Gage Failure at ~400F**

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

6/13/2013

Paul Gradl
Gilbert Handley

# Subscale Hotfire Testing on Nozzle

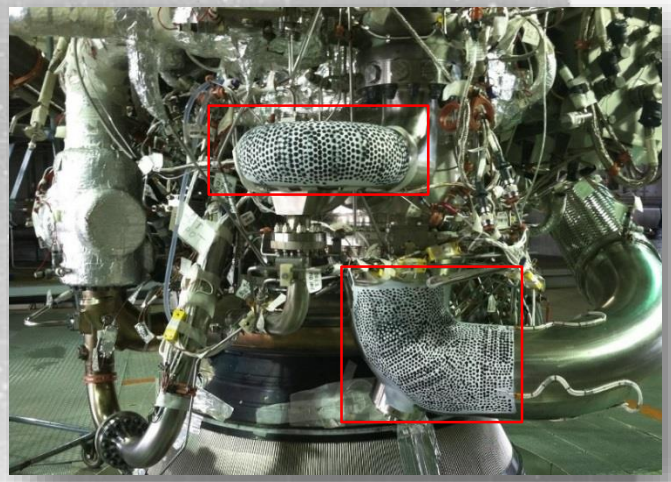


# Large Scale D.I.C. for Engine Hotfire Testing

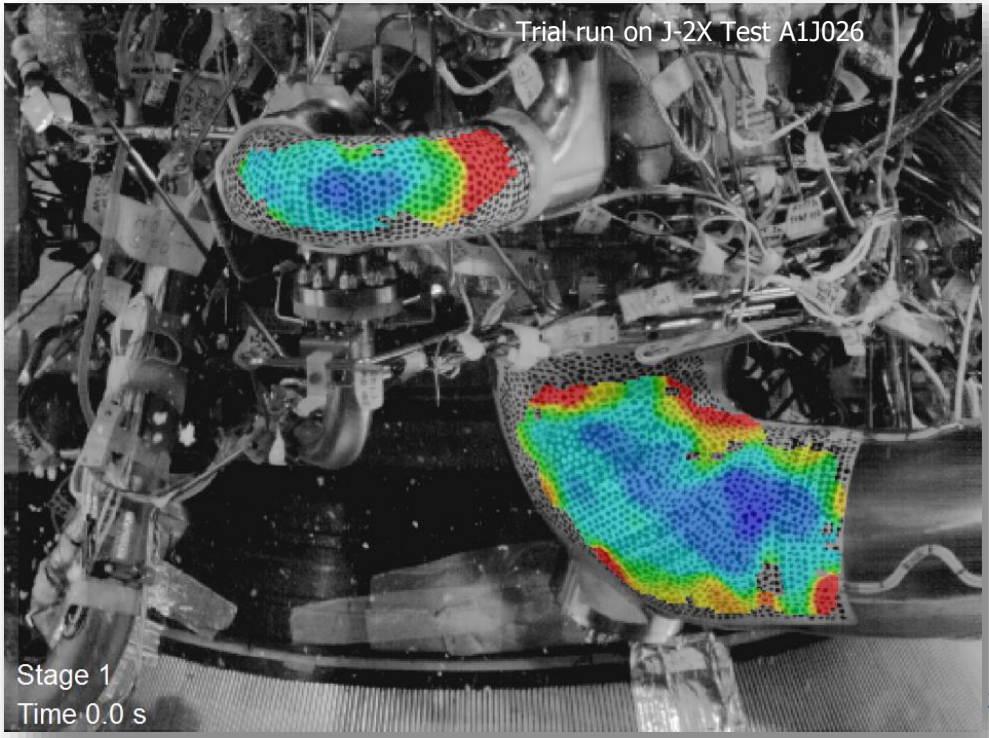
MSFC has developed new optical measurement techniques to augment or replace traditional gages in harsh environment engine testing or manufacturing operations

**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**

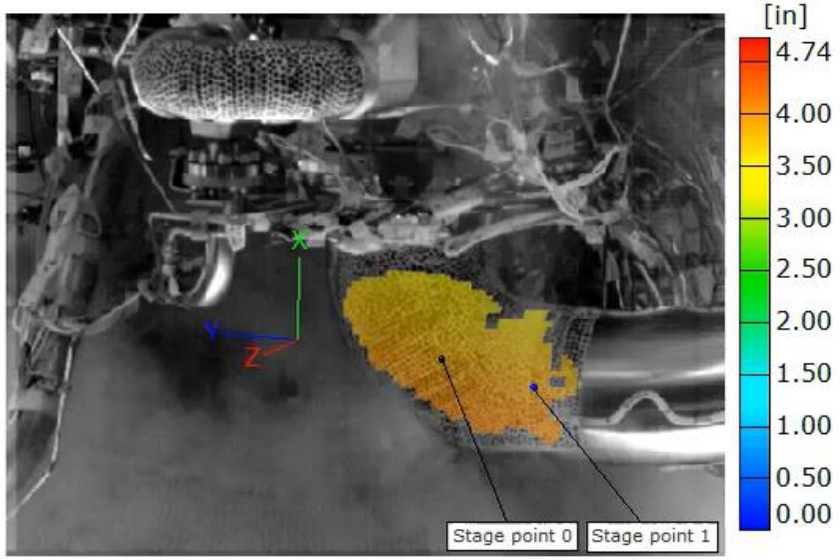


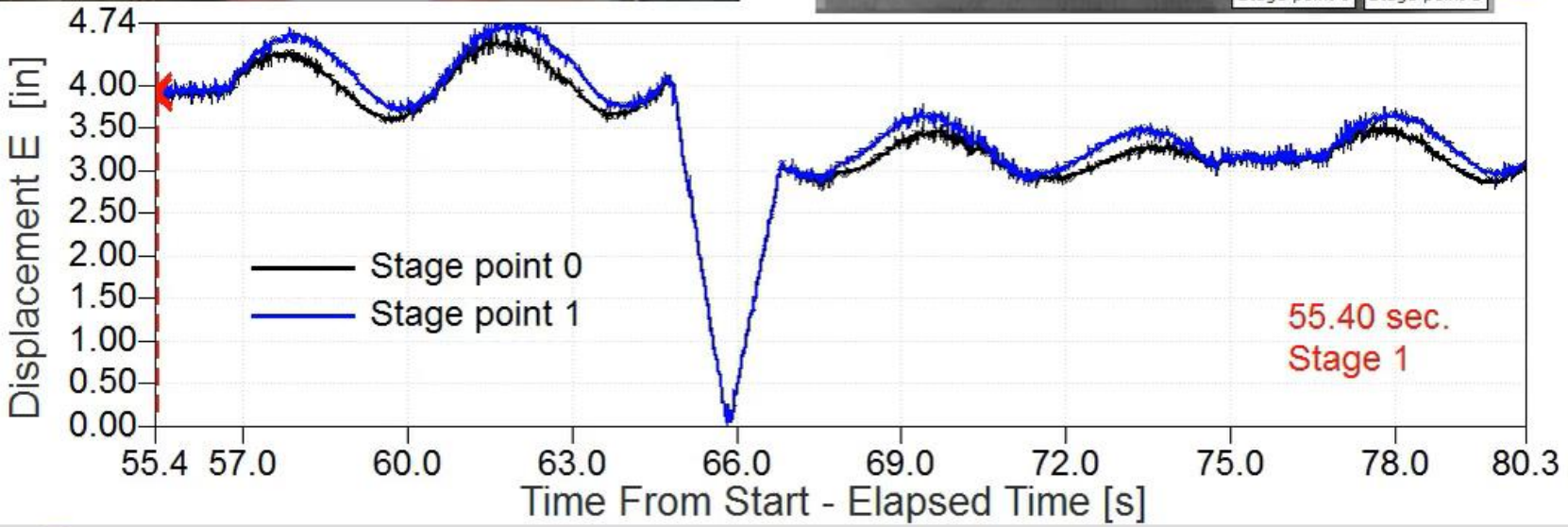
# ARAMIS high speed cameras



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

# 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)**

# 2.75” Hydra Testing Demo

**Test Support:** Paul Gradl/MSFC, Cory Medina/MSFC, John Tyson/Trilion, John “*Yanni*” Psilopolous/Trilion

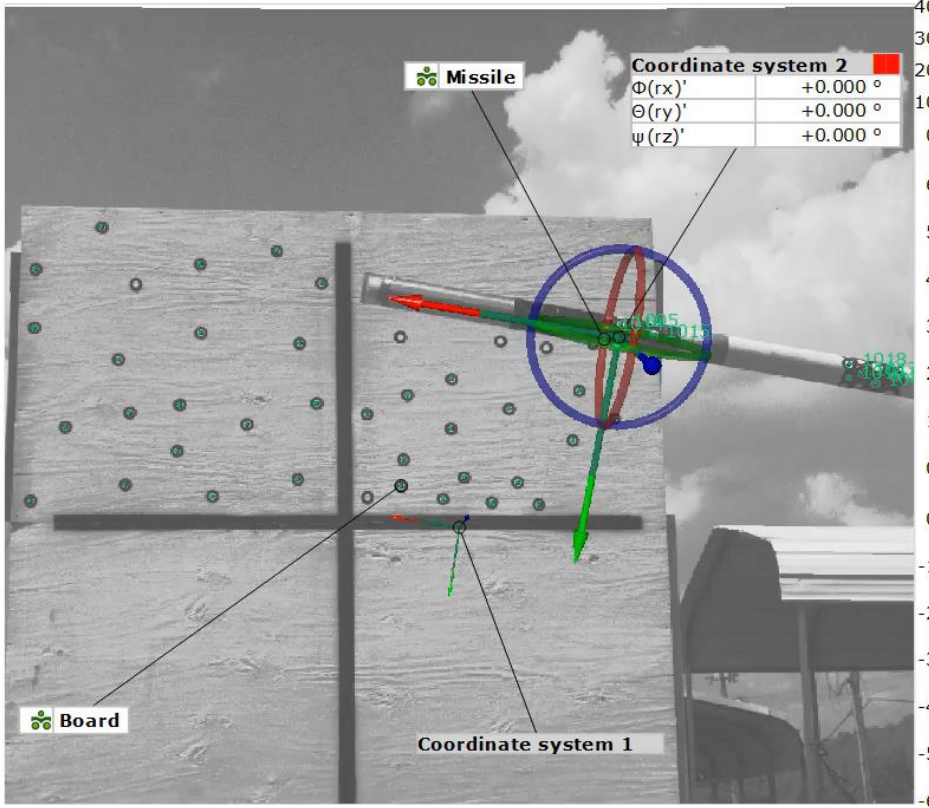
Demonstrated initial feasibility of using photogrammetry and digital image correlation for range testing of missile burst testing.

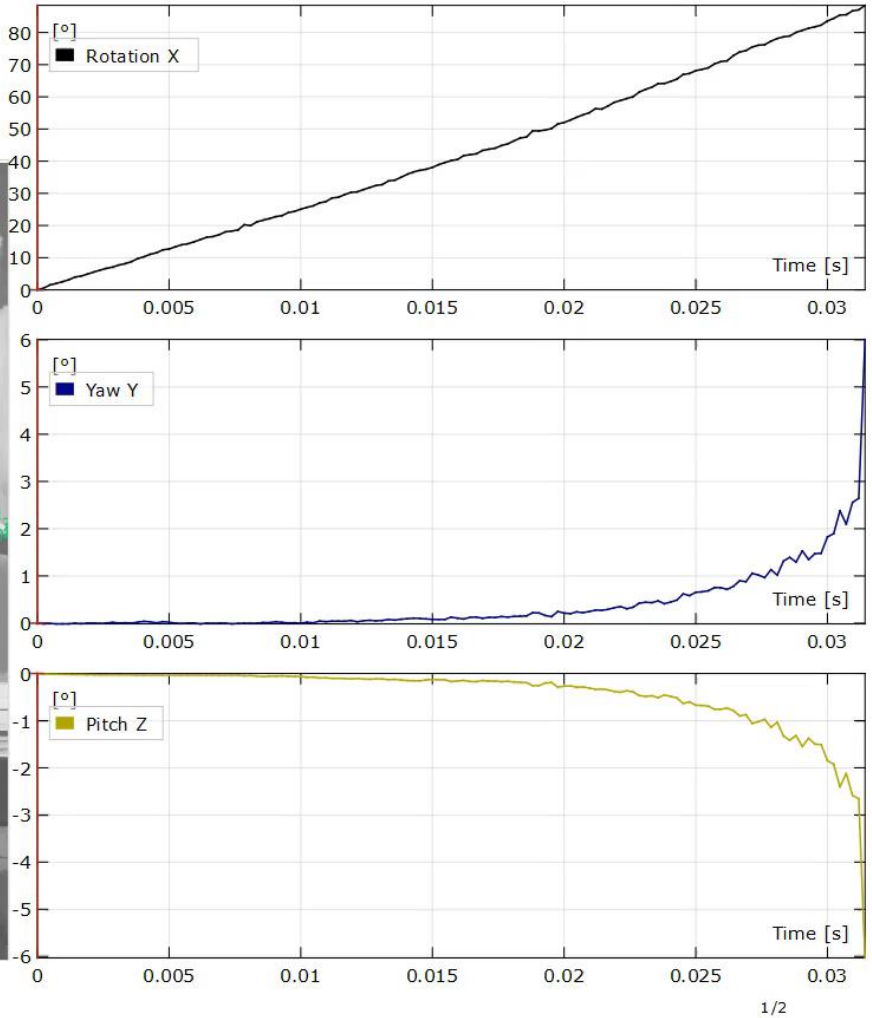
# Feasibility of 6-dof Analysis of Missile Testing

Report - PONTOS Testing

Test 62 - TM1 Hydra Missile Testing

**Test Data provided**:
Paul Gradl and Cory Medina



# Where are we going with this technology?

**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

**NASA and AMRDEC have signed agreements to advance and develop the technology further**

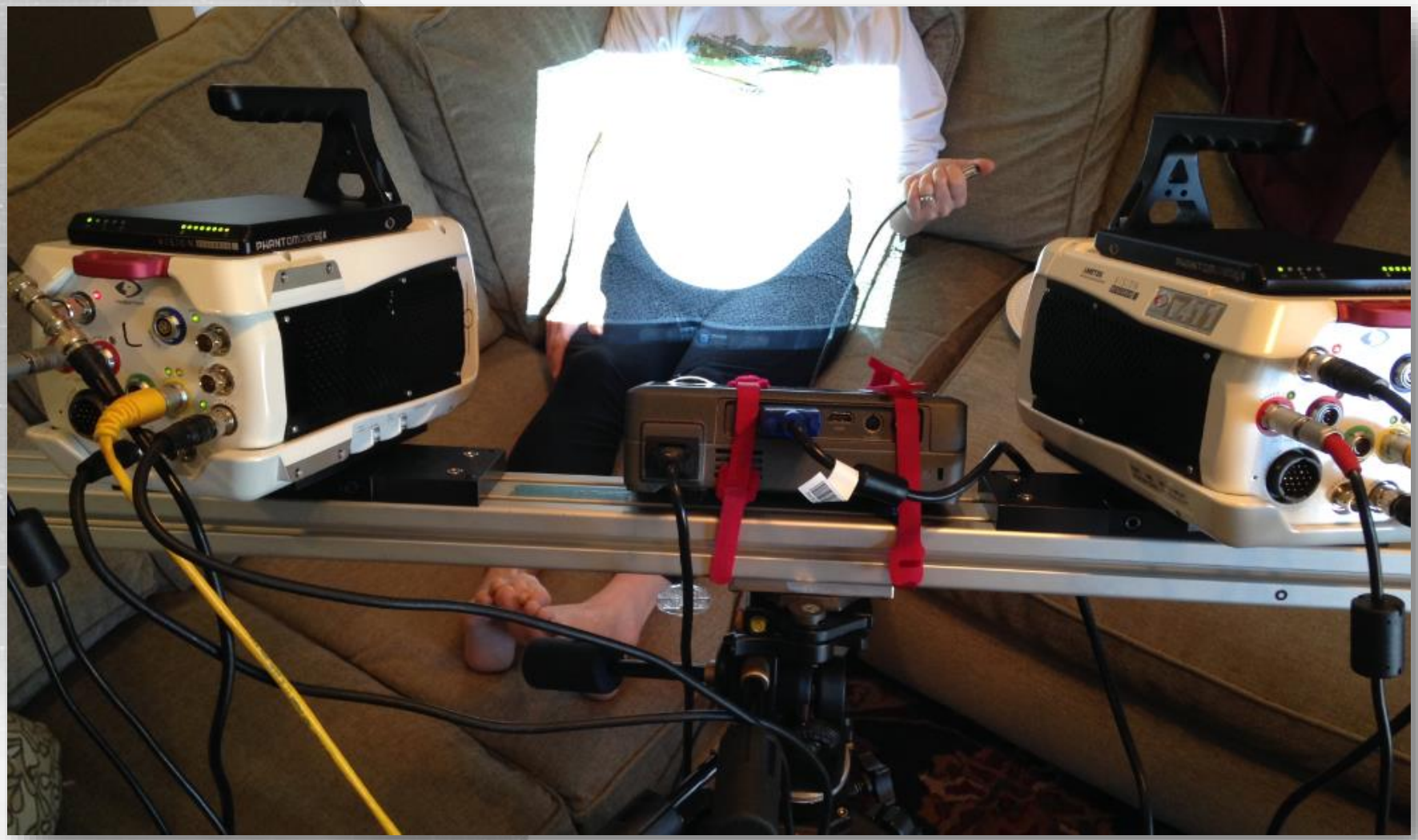
- Further develop techniques for harsh environments
  - Liquid rocket engine testing
  - Missile range testing
  - Static solid motor testing
- Lab environment, modal and dynamic testing

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

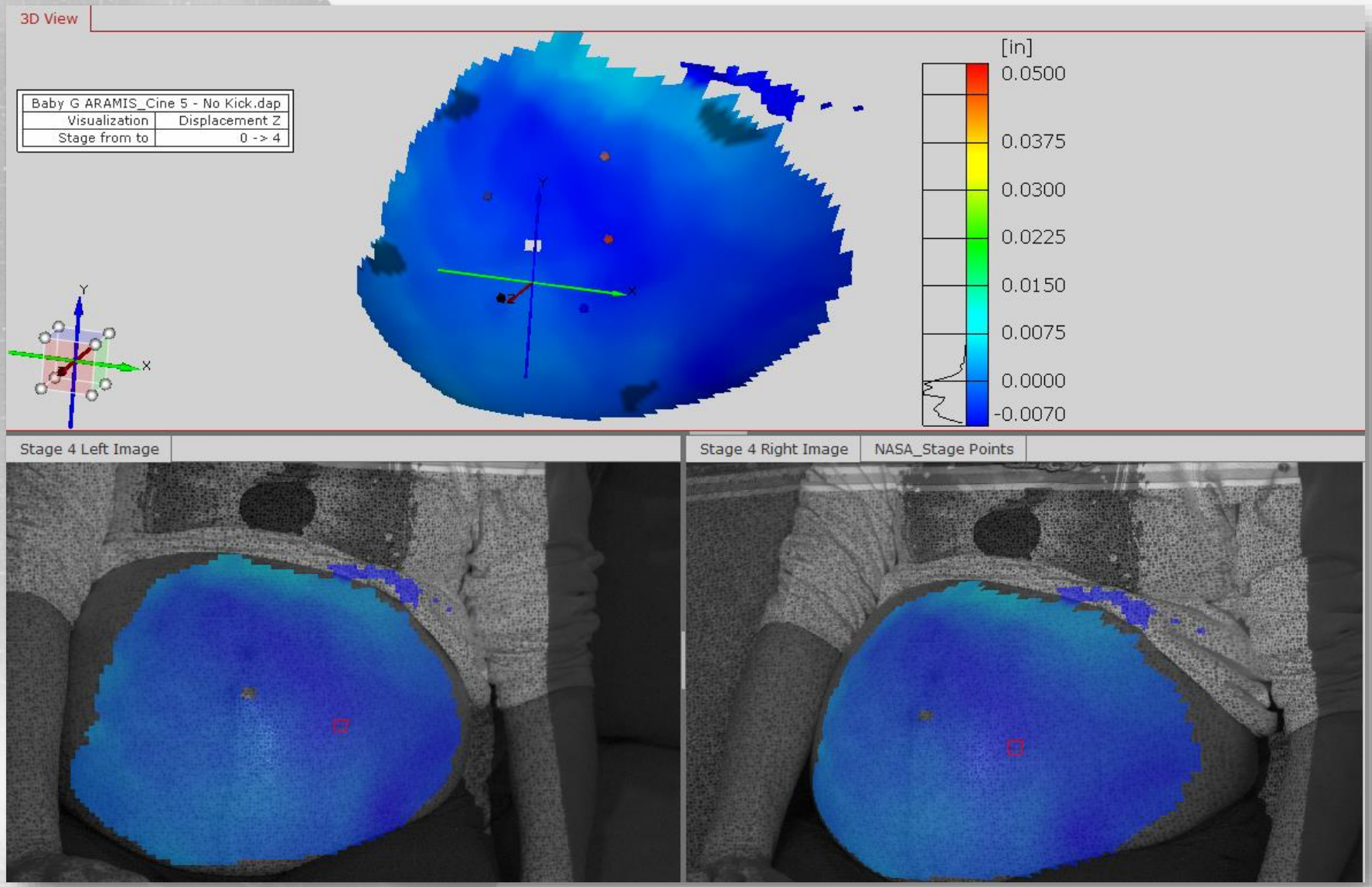
# The possibilities of dynamic data collection are endless…

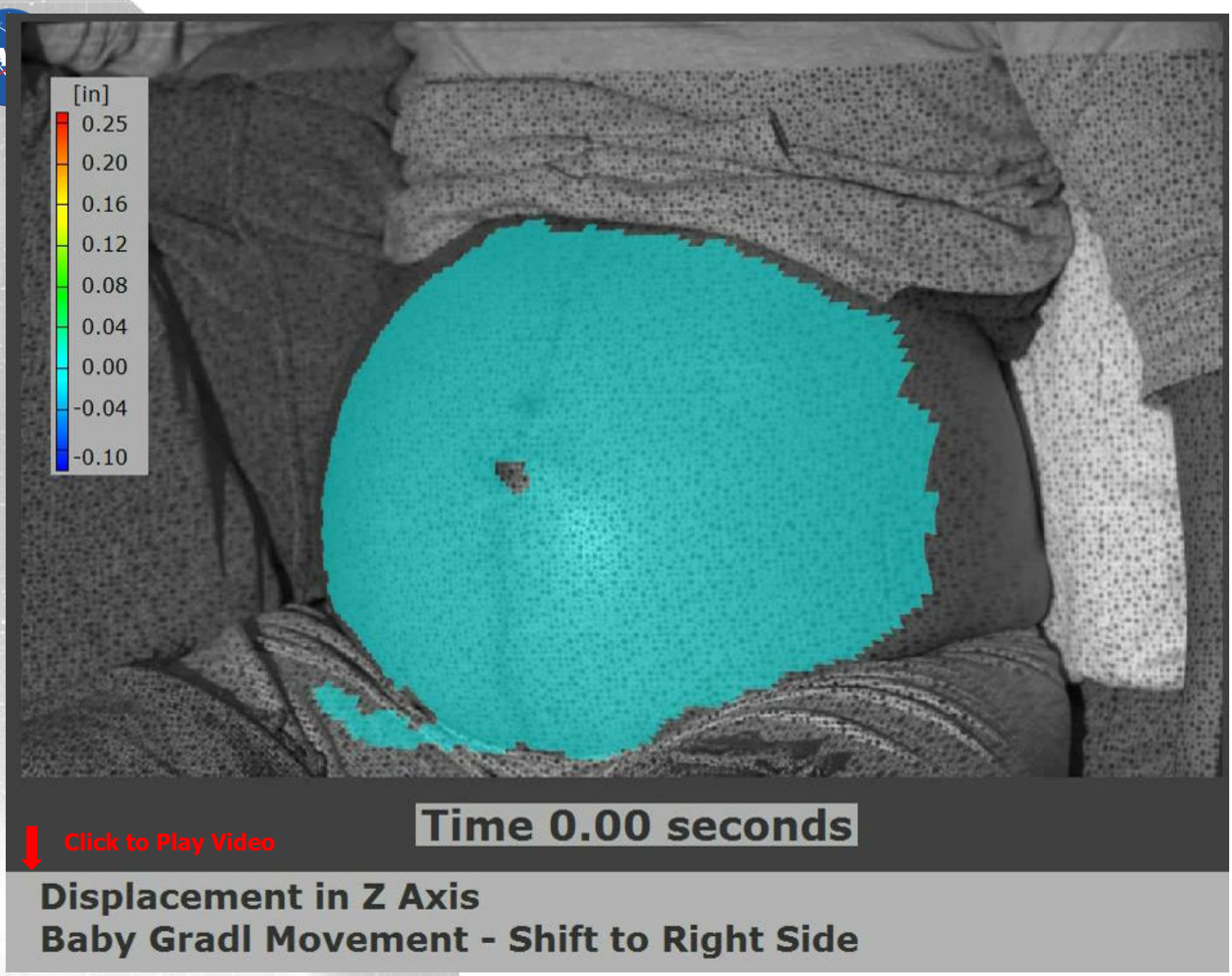
Dynamic responses require an input to excite the system…

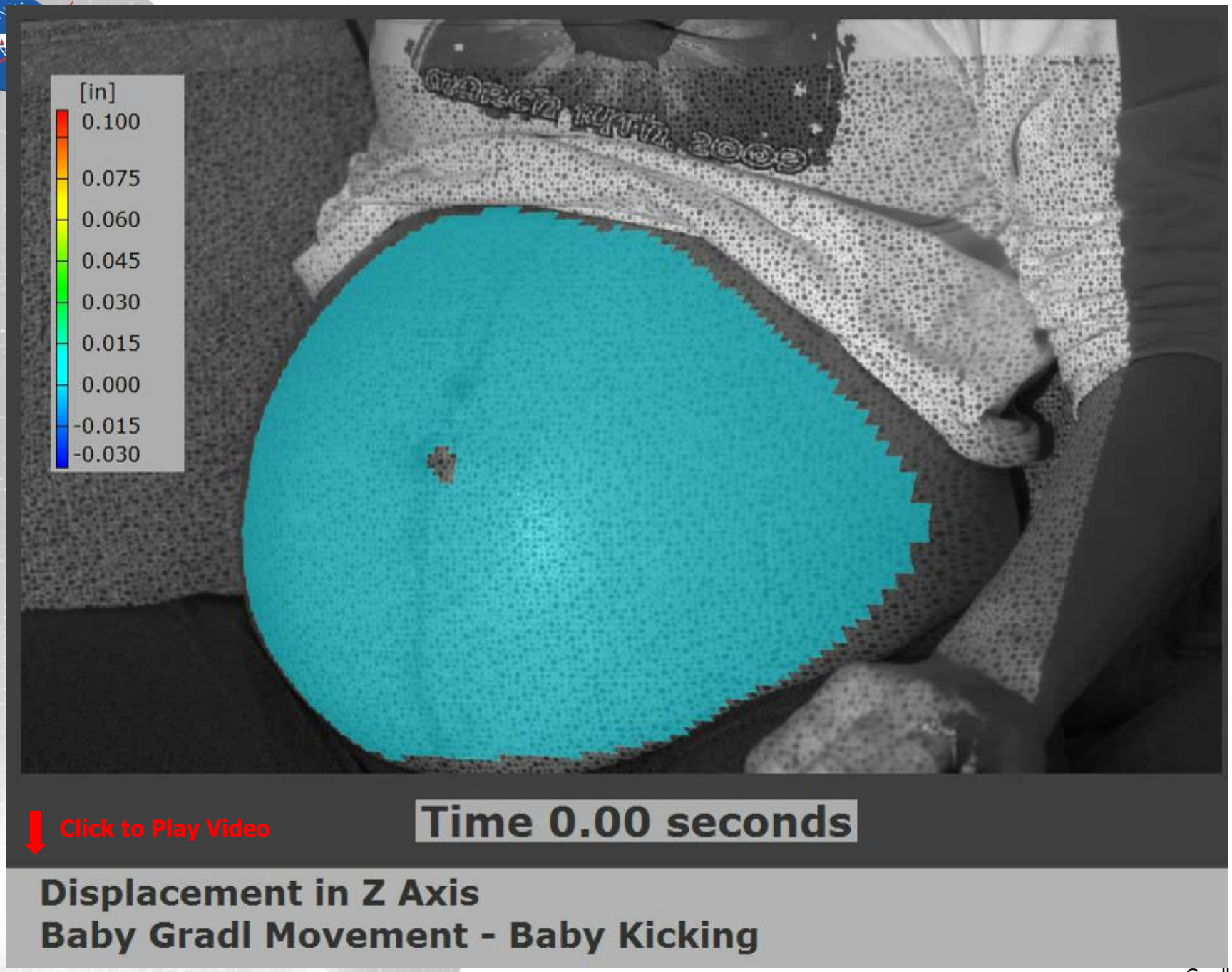
Images were collected using a projected pattern instead of painting a speckle pattern on her belly…
High Speed cameras were post triggered after movements felt.



To ensure that kicks and movement data was real a background test was conducted with no baby movement (to correct for breathing and body motion)




[in]
0.25
0.20
0.16
0.12
0.08
0.04
0.00
-0.04
-0.10
Time 0.00 seconds
Click to Play Video
Displacement in Z Axis
Baby Gradl Movement - Shift to Right Side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0.075
0.060
0.045
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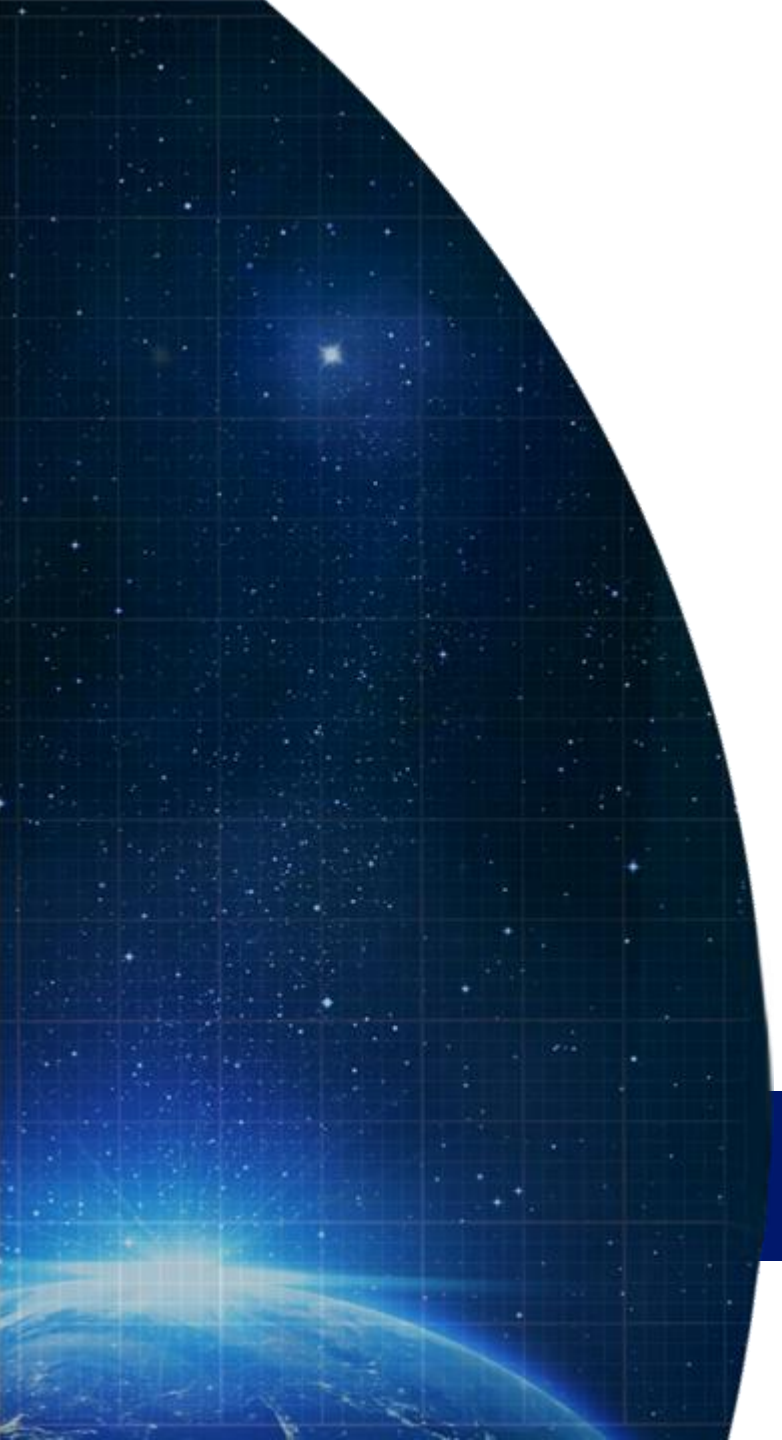
Click to Play Video
Time 0.00 seconds
Displacement in Z Axis
Baby Gradl Movement - Baby Kicking



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# BACKUP

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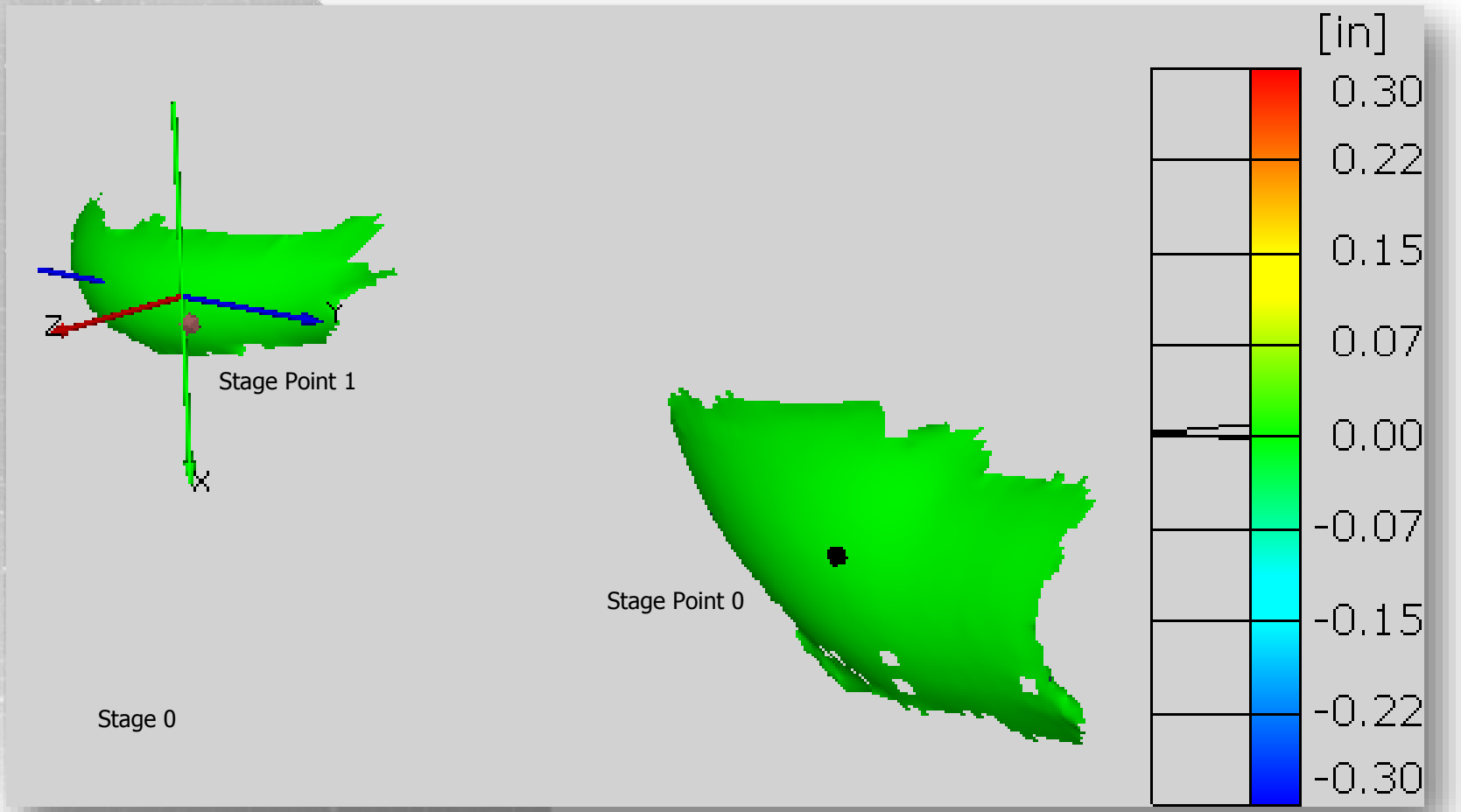
# ARAMIS Full Surface Models from Data Collection




Full 3D surface data collected for each "stage" or period of time

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## Profile

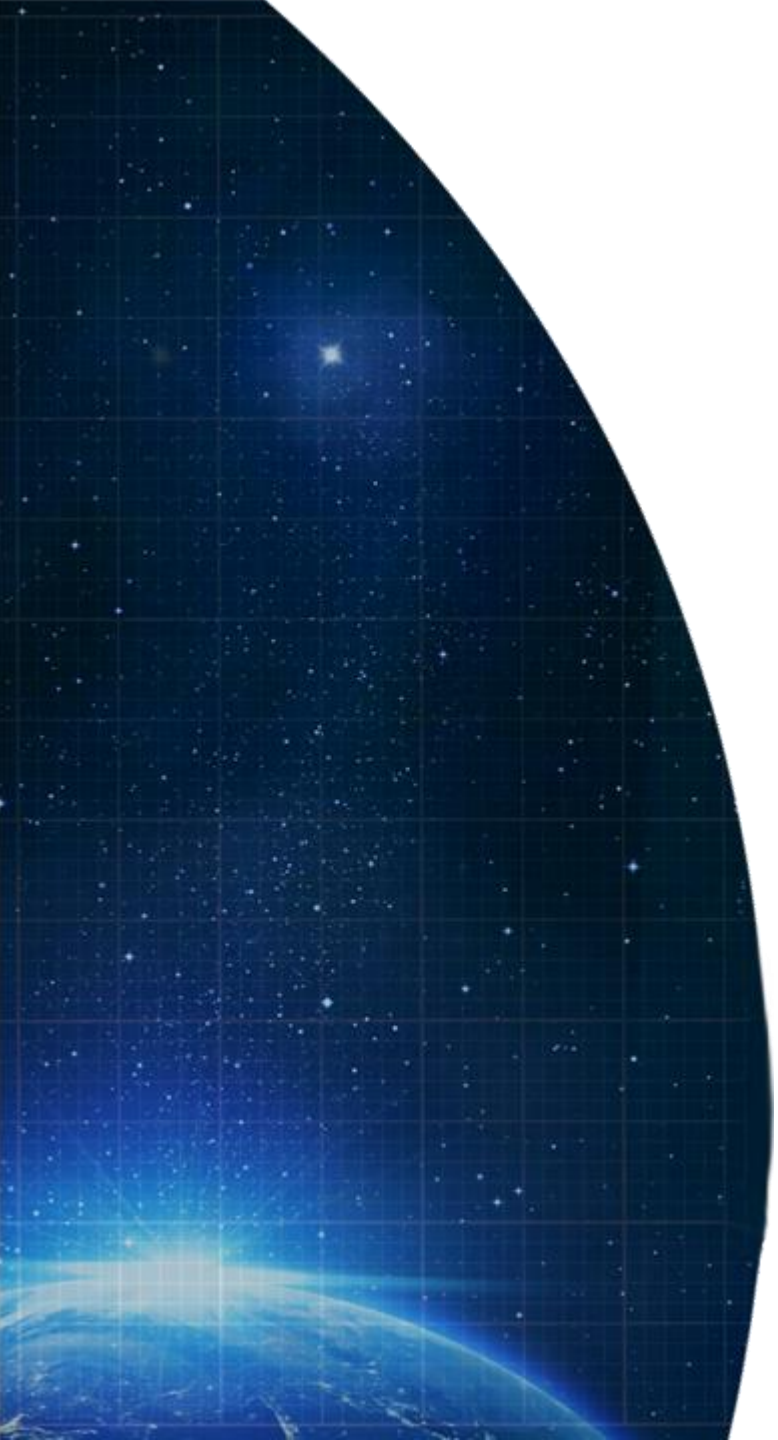
# Abstract

**Digital Image Correlation Techniques for Rocket Engine Testing and Component Test Applications**

Paul Gradl, Aerospace Engineer

*NASA Marshall Space Flight Center, Huntsville, AL 35812*

NASA Marshall Space Flight Center (MSFC) has been advancing dynamic optical measurement systems, primarily Digital Image Correlation, for extreme environment rocket engine test applications. The Digital Image Correlation (D.I.C.) technology is used to track local and full field deformations, displacement vectors and local and global strain measurements. This technology has been evaluated at MSFC through lab testing to full scale hotfire engine testing of the J-2X Upper Stage engine at Stennis Space Center. It has been shown to provide reliable measurement data and has replaced many traditional measurement techniques for NASA applications. NASA and AMRDEC have recently signed agreements for NASA to train and transition the technology to applications for missile and helicopter testing. This presentation will provide an overview and progression of the technology, various testing applications at NASA MSFC, overview of Army-NASA test collaborations and application lessons learned about Digital Image Correlation.

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