Technology Development and Trends Liquid Rocket Propulsion

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Advanced Manufacturing Enables Propulsion

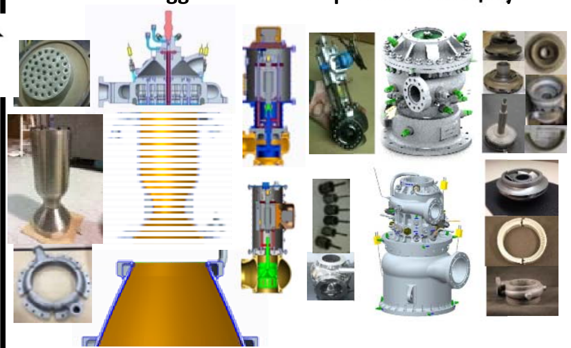
Marshall Space Flight Center

Fundamental Additive Manufacturing M&P Development

Push → Material Properties & NDE → Standards & Specs → Certification Rationale → Pull

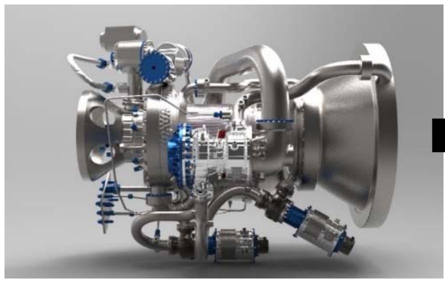
Parallel & Congruent Activities

Lean & Aggressive Development Philosophy



Relevant Environment Testing

Investment directly benefits prototype engine development and indirectly enables and facilitates technology across multiple current and future activities for NASA, DoD and industry.

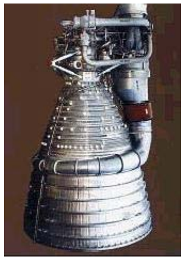


Advanced Manufacturing Demonstrator (AMD)

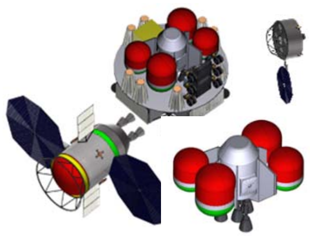
Building Foundational Additive Manufacturing Industrial Base

Stratasys · INCODEMA · LINEAR · RPM Innovations, Inc. · Additive Manufacturing LLC · RTI | Directed Manufacturing, Inc.

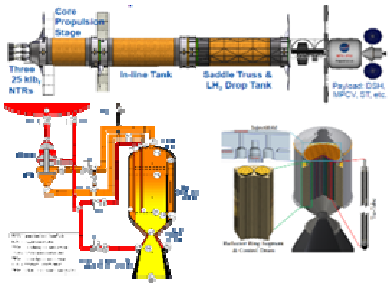
RP Engine



Methane Systems



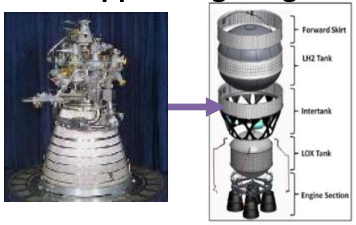
NTP



RS-25

CCP

Upper Stage Engine



Reduction in Parts Count with Additive Manufacturing

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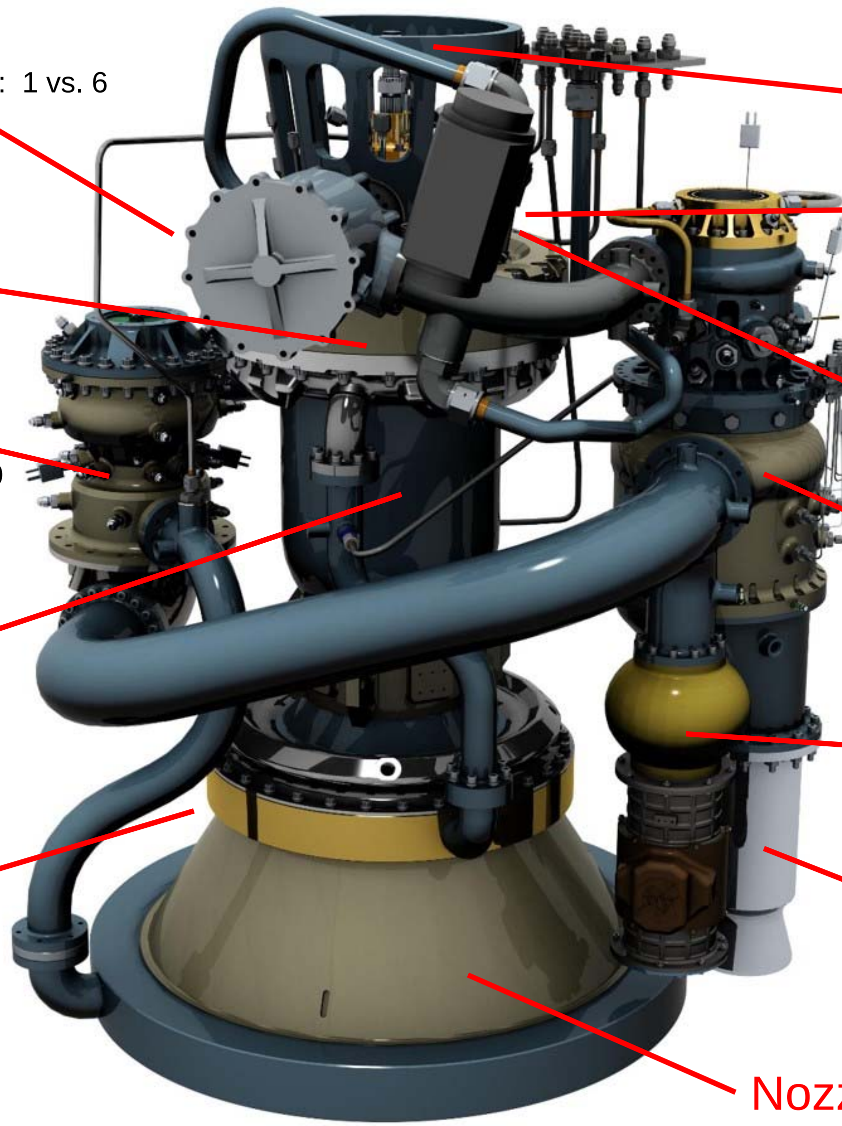
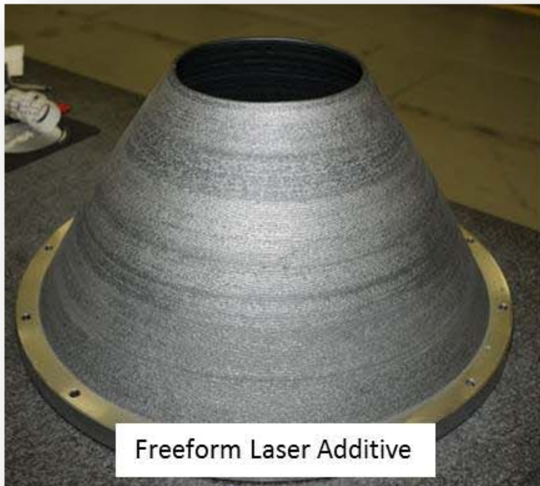


Note: Part counts examples are for major piece parts and do not include bolts, nuts, washers, etc

BACK-UP SLIDES

Technology Development – Rapid Fabrication of Regeneratively Cooled Nozzles

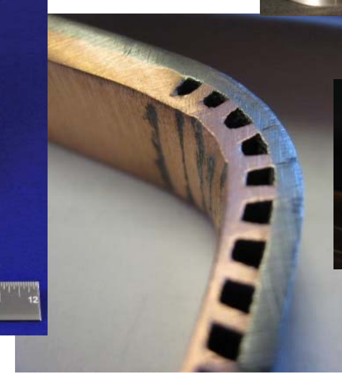


3 Days

3+ Weeks (w/tooling)

<5 Days

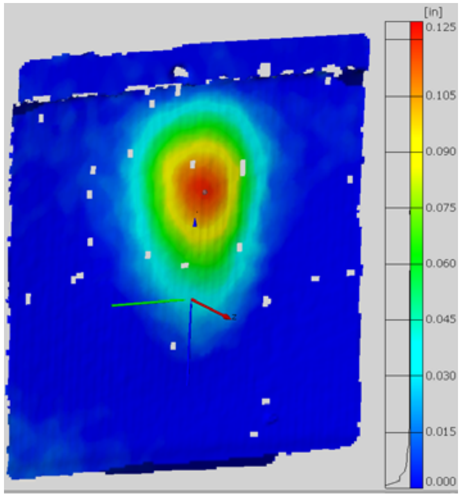
- Large scale freeform additive manufacturing processes being developed for channel wall nozzles
- Advanced abrasive water jet milling used to produce unique geometries for coolant channels
- Novel closeout techniques such as explosive bonding and hybrid additive manufacturing being investigated to rapidly reduce lead time and costs

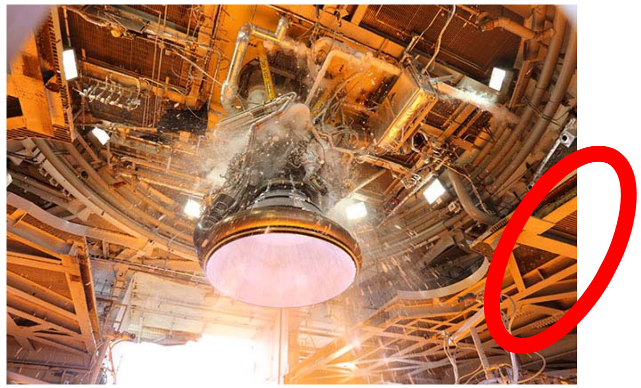


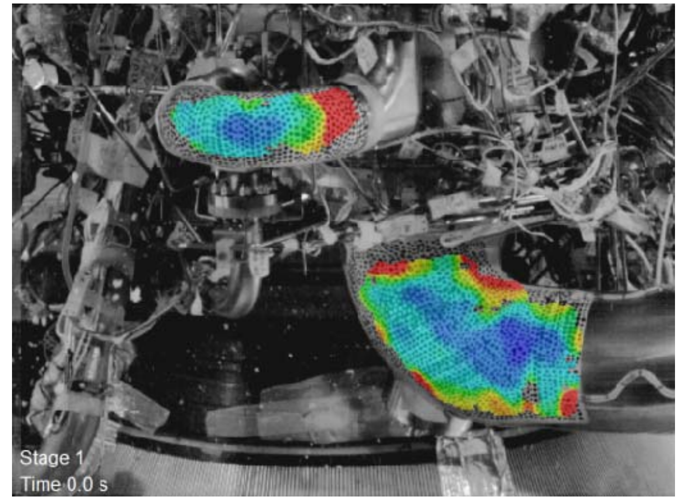
Composite Nozzle Extensions for Deep Space Missions

- NASA continues to invest in high temperature carbon-carbon nozzles for upper stage deep space missions
- Developed domestic supply chain with modern material systems and continue to work with international partners
- Produced a series of 24" diameter nozzles that will be hot fire tested
- Developing methodology to certify and fly composite extensions

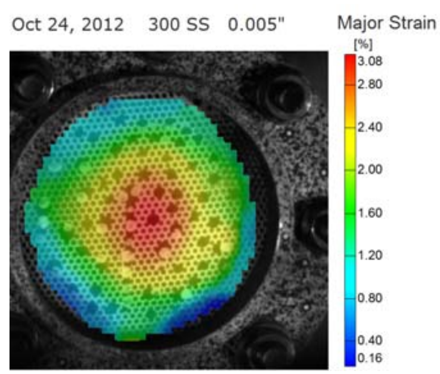
Advanced Static and Dynamic Measurement Techniques for Engines

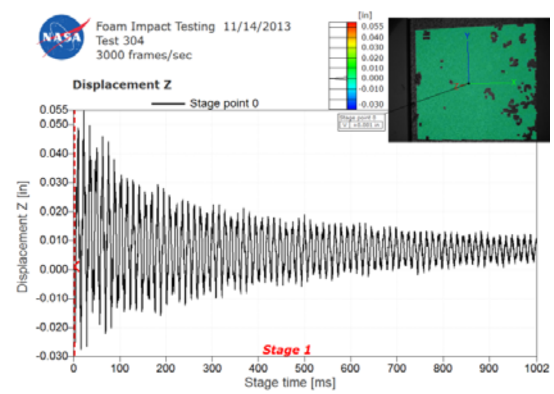






Advanced dynamic optical measurement techniques to significantly reduce instrumentation costs for component testing, real-time manufacturing process analysis, and engine testing.

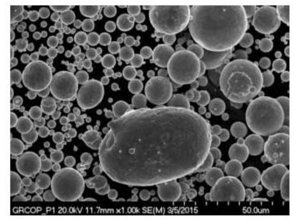




3D Printed GRCop-84 Chamber

The liner is printed using an astonishing 8,255 separate layers of this copper powder, which is sintered together one layer at a time to build up the final product. In all, it takes 10 full days and 18 hours to complete the printing process of this single part.

www.nasa.gov/sls



This electron microscope image shows raw copper powder used to build the 3-D printed copper liner. Scientists at NASA's Glenn Research Center in Cleveland, Ohio, where the alloy was invented, characterized the samples to understand how powder quality and characteristics impacted build qualities.
Credits: NASA/GRC/Laura Evans

This optical microscope image of an etched copper sample helped scientists at NASA's Glenn Research Center in Cleveland, Ohio, as they characterized the quality of the copper for various build parameters for the copper liner.
Credits: NASA/GRC/Ivan Locci

END

Game-Changing Aspects of Prototype Additive Engine

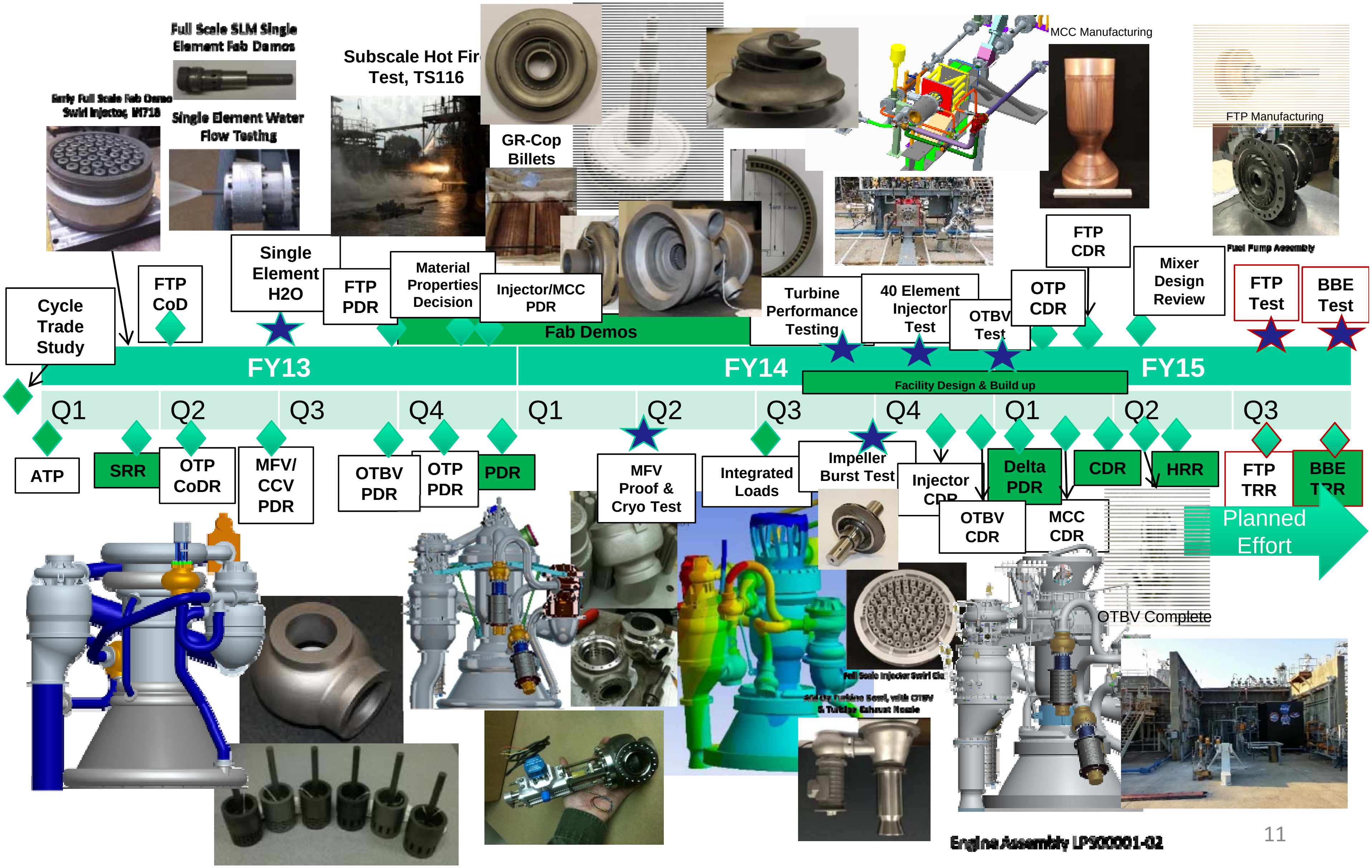
State of the Art for Typical Engine Developments

- DDT&E Time
  - 7-10 years
- Hardware Lead Times
  - 3-6 Years
- Testing
  - Late in the DDT&E cycle
- Engine Cost
  - $20 - $50 Million
- Applicability
  - Design for particular mission by a particular contractor
  - Often proprietary

Prototype Additive Engine

- DDT&E Time
  - 2-4 years
- Hardware Lead Times
  - 6 Months
- Testing
  - Testing occurs early in the DDT&E cycle
- Prototype Cost
  - $1-5 Million
- Applicability
  - Provide relevant data to multiple customers (SLS, Commercial partners, other government agencies)
  - Flexible test bed configuration can accommodate other's hardware / design concepts

LPS Timeline



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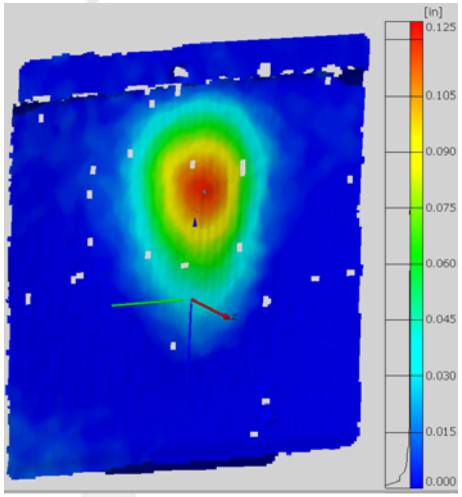

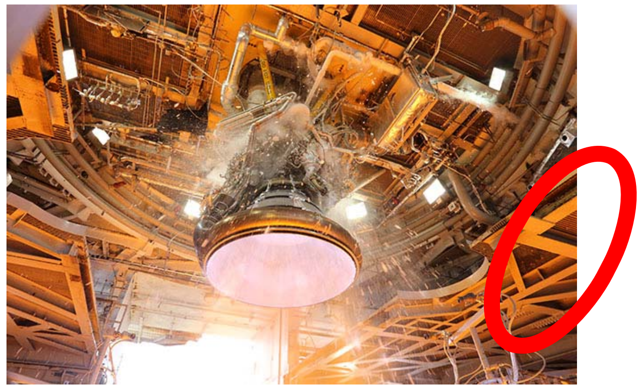

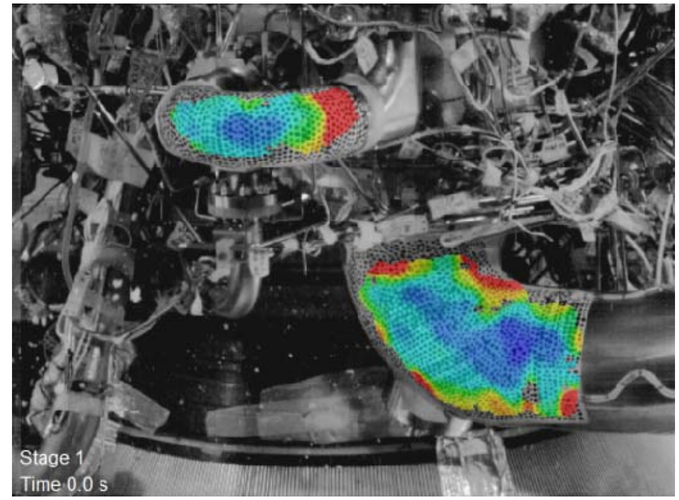

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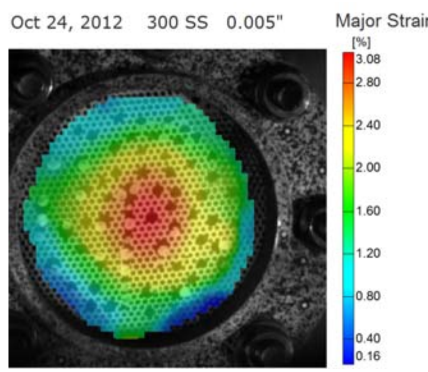

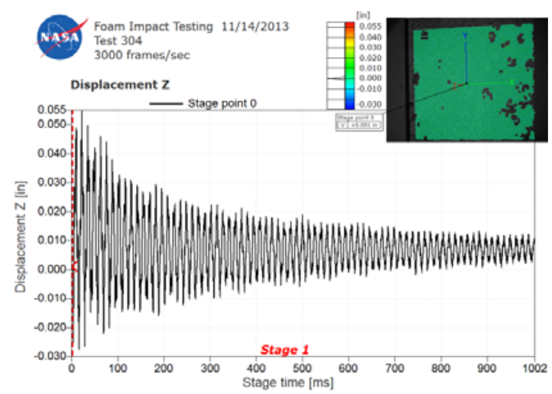

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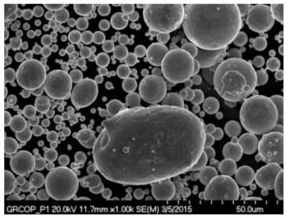

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