Rapid Qualification of AMT Components – Is it Rocket Science?

- **Moderators:** Raj Iyengar (NRC) and Dirk Cairns-Gallimore (DOE-NE)

- **Panelists/Speakers:**
  - Richard W. Russell (NASA)
  - Thierry Lebarbe (CEA, France)
  - Matt LeVasseur (BWXT)
  - Josh Brost (Relativity)

NASA's Certification and Qualification Strategies for Additively Manufactured Hardware

Rick Russell, NASA Technical Fellow for Materials

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2022 NRC Standards Forum
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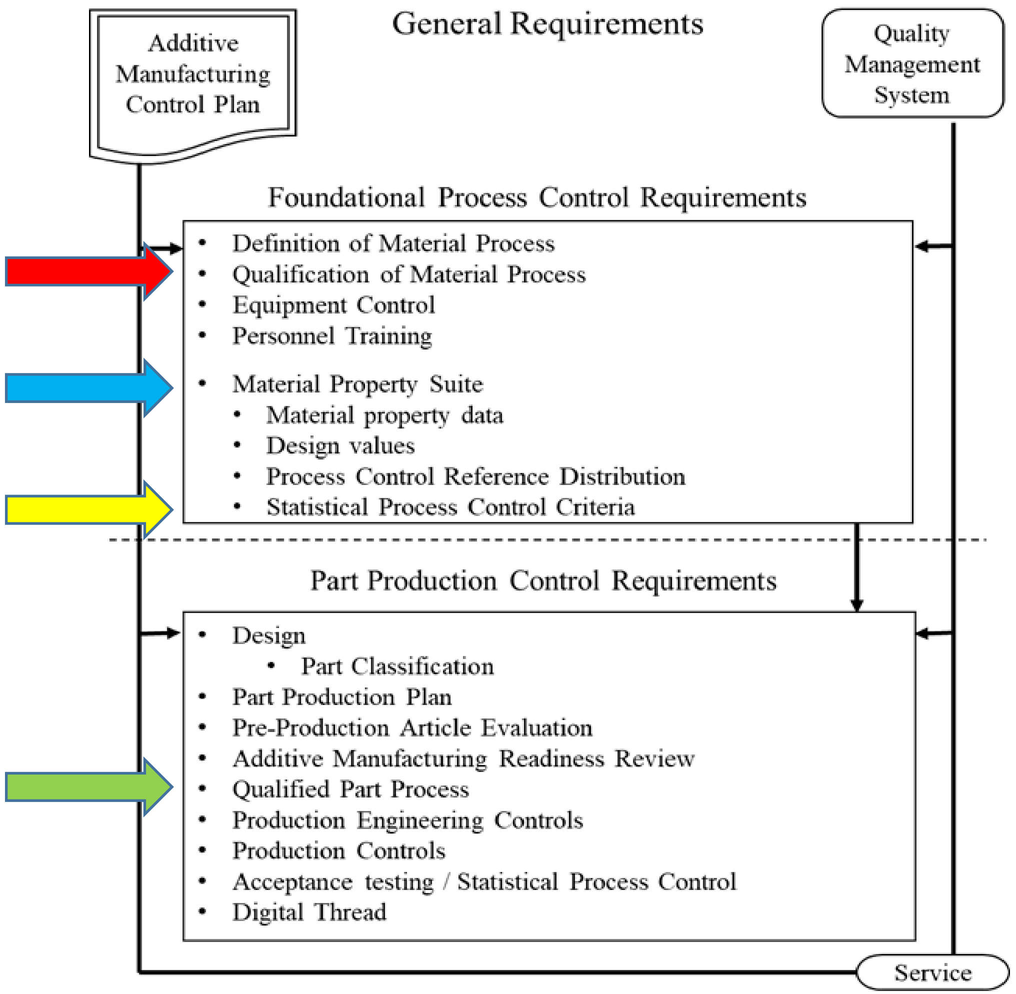
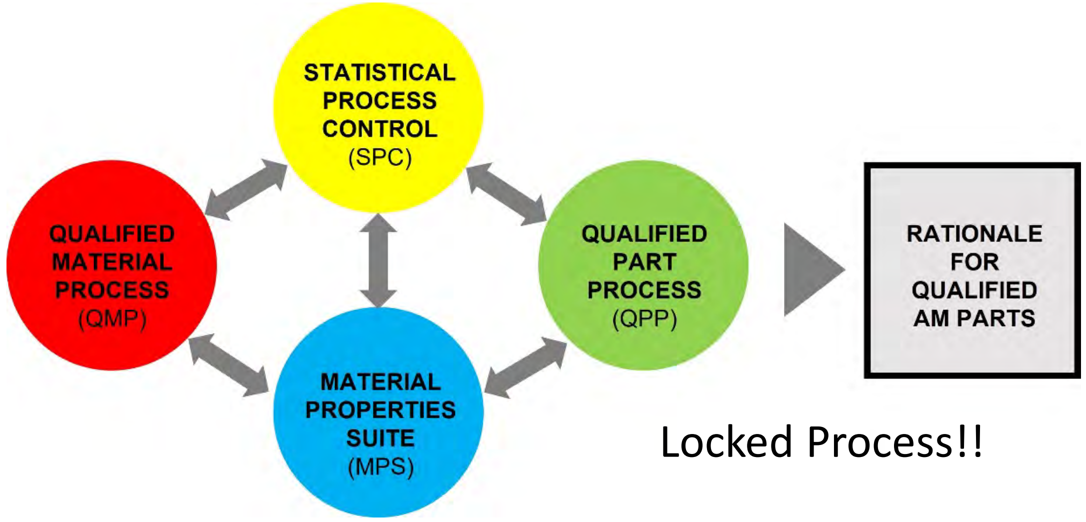
Additive Manufacturing at NASA

- Fully embraces advantages of AM
  - Cost/lead time/part count reduction, new design and performance opportunities, rapid design-fail-fix cycles
- While fully understanding the challenges
  - Especially in delivering high value, high performance AM hardware
- NASA has dual roles
  - Drive and foster AM technology research and development in support of broad industry adoption and industrialization
  - Develop protocols for spaceflight hardware certification for access to space that can safely meet mission objectives ⇐ Today's focus

NASA-STD-6030: Summary of Methodology

- General Requirements
  - Additive Manufacturing Control Plan (AMCP) and Quality Management System (QMS)
  - Backbone that defines and guides the engineering and production practices
- Foundational Process Control Requirements
  - Includes the requirements for AM processes that provide the basis for reliable part design and production
- Part Production Control Requirements
  - Includes design, assessment controls, plans (PPP), preproduction articles and AM production controls





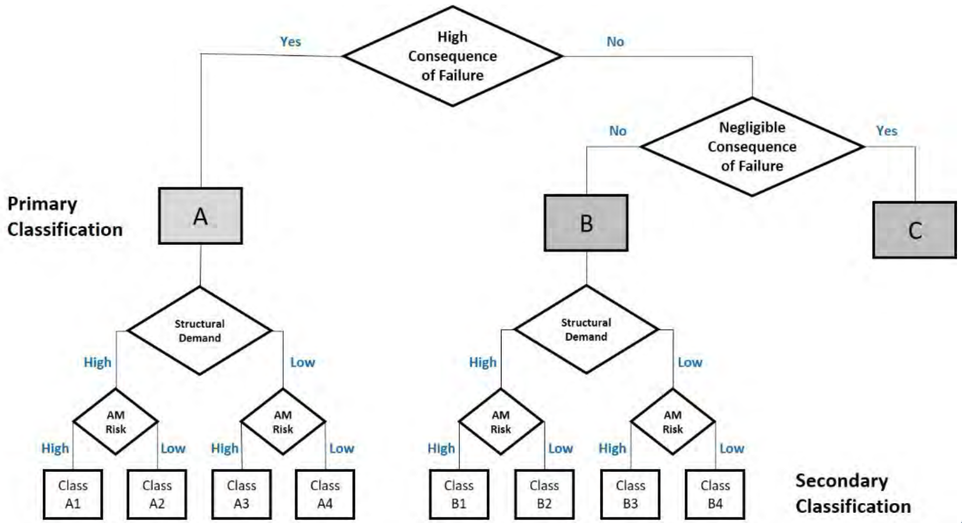
Locked Process!!

NASA-STD-6030: Key Elements

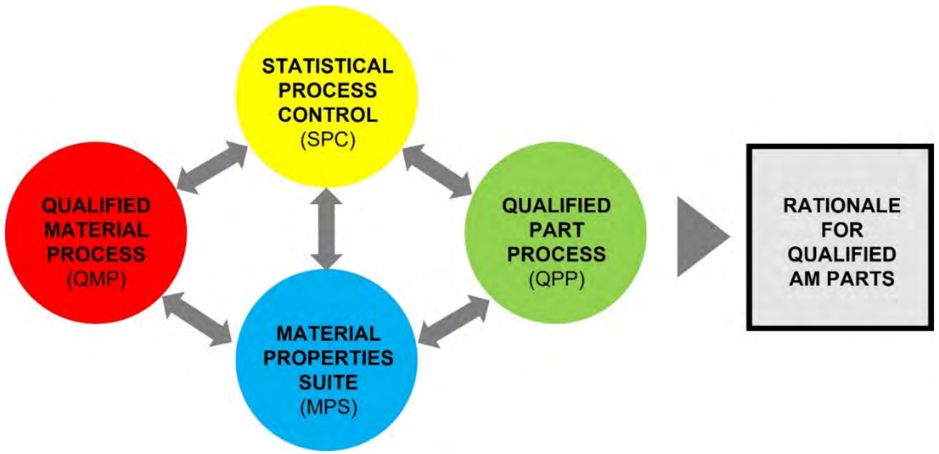
Applicable Technologies

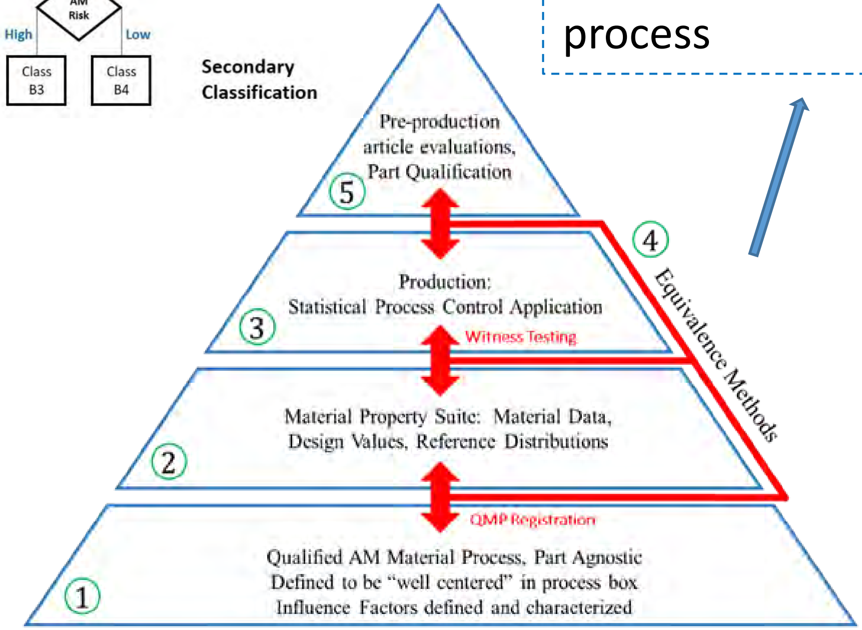
Category	Technology	Materials Form
Metals	Laser Powder Bed Fusion (L-PBF)	Metal Powder
	Directed Energy Deposition (DED), Any Energy Source	Metal Wire
	DED, Any Energy Source	Metal Blown Powder
Polymers	L-PBF	Thermoplastic Powder
	Vat Photopolymerization	Photopolymeric Thermoset Resin
	Material Extrusion	Thermoplastic Filament

Classification System



Approach is heavily rooted in metallurgical understanding and respecting the evolving and meticulous metallic AM process





Equivalency

- One of this standards key strengths is its reliance on material engineering equivalence
  - Methodology for evaluating the quality of AM materials that acknowledges the broad range of characteristics that must be assured for an alloy to meet all of its expectations.
  - The enabler that allows the AM material ecosystem to remain healthy and self-consistent in the face of sensitive processes with a multitude of known and unknown failure modes.
  - Requires reliable and diverse datasets, depth of knowledge in materials, good engineering judgement, and collaboration between engineering and quality assurance organizations.

Process → Structure → Property → Performance

Fracture Control Framework for AM Parts

- Fracture control is reliant on understanding the design, analysis, testing, inspection and tracking of hardware.
  - The adaptation of state-of-the-art AM technologies introduces new and unique challenges
    - e.g. Multiple lasers and adaptive technologies
  - For AM applications the application of conventional NDE techniques is questionable
  - There is a need to produce alternate approaches through the adaptation of a Probabilistic Damage Tolerance Approach (PDTA)
    - Computational modeling for AM
    - Understanding the “Effects of defects”
    - In-situ monitoring and inspection

These items MUST Work together not separate

Rapid Qualification – Is there a path?

- Following NASA-STD-6030 the path to “rapid qualification” will be difficult
- Understanding the part classification is key
  - Consequence of failure followed by risk evaluation
- Maturity of data is a must have
  - Full understanding of existing data
  - Establishment of machine-to-machine equivalency
  - Material Equivalency
- Implementation of in-situ inspection, computational materials and machine learning is beginning – but there is a long road ahead of us
  - Attention to this subject is **high!!**

FROM RESEARCH TO INDUSTRY

Rapid Qualification of AMT Components – Is it Rocket Science?

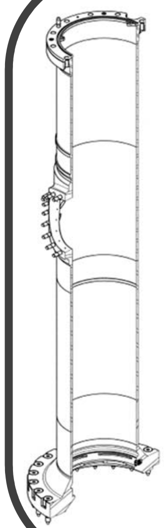
Feedback from CEA standardization experts

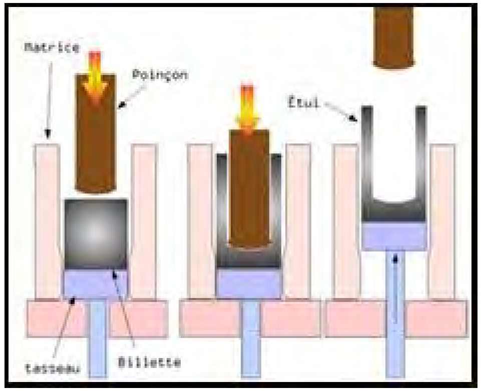
T Lebarbé – C Pétesch

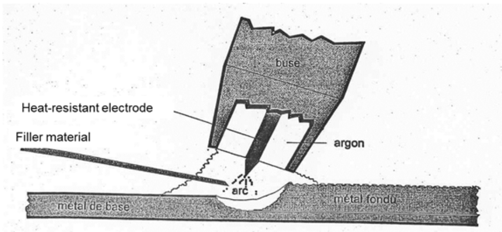
Why it seems complicated?

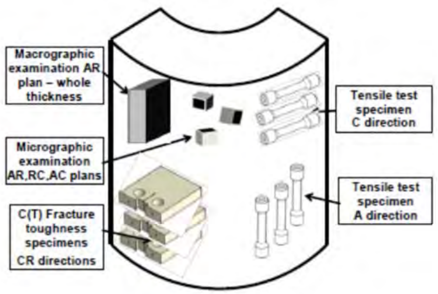
A code is not only <u>a process</u> or <u>a material</u>

- VOLUME I Design
- VOLUME II Materials
- VOLUME III Examination Methods
- VOLUME IV Welding
- VOLUME V Manufacturing operations









Tools are already available

Methods to implement new material or new process in all codes and standards are already existing…

The table of contents of the **Material File** shall be:

1. Introduction

- Presentation of the grades
- Codes and standards dealing with these parts or products
- **Reference Procurement Specifications in Tome 2**
- Industrial application and experience

2. Physical properties

3. Base metal and welded joints mechanical properties for design and analysis

- Justification of the applicability of the Design Rules (RB 3000) for the specified usage conditions
- Basic mechanical properties
- Mechanical properties when creep is significant (if necessary)
- Mechanical properties when irradiation is significant (if necessary)
- Guaranty of the consistency between the properties of the final part laid-on the plant and the material properties used to design the component

4. Manufacturing

- Industrial experience
- Metallurgy

5. Fabrication

- Industrial experience
- Forming operation ability

6. Welding

- Weldability (RS 1300)
- Industrial experience for the welding procedure qualification
- Industrial experience for the repair welding procedure qualification

7. Controllability

8. In service behavior

- Thermal ageing, corrosion, erosion-corrosion, irradiation, …

RCC-MRx

RCC-M

M 116 SPECIFIC USE OF A NON-REFERENCED MANUFACTURING PROCESS

Manufacturing processes not referenced by the RCC-M can exceptionally be proposed by the Manufacturer, for a particular application. In these conditions, and prior to the procurement of the materials, the Manufacturer must submit the following items to the Contractor for approval:

a) A procurement specification; for this purpose, it shall most frequently use a similar existing Reference Technical Specification, or a compatible standard, stating the options systematically adopted

b) A first part qualification, according to the principle described in M 140

c) A document package justifying the use of the grade for the targeted application. This document package shall include at least the following items:

- References to the existing standards and technical specifications
- The data needed for design
- Evidence that the material obtained by this new manufacturing process is suitable to be employed for the targeted application
- Evidence that the acceptance (destructive and non-destructive tests) is appropriate for the inspections of the products resulting from this new manufacturing process
- Performance under the service conditions, for the targeted application
- Experience feedback: status for similar applications.

With possibility to test and improve:
Code Cases, Rules in Probationary Phase….

Qualification objectives through the qualification file:

- ***Demonstrate the capability to manufacture the component***
- ***Define validity domain of the manufacture program***
- ***Check that the final component has the requiered properties***
- ***Define the relevant delivered conditions and criteria***

A qualification file can be modulated:

- ***Depending on the material use***
- ***Depending on the component type***
- ***Depending on the environment***
- ***Depending on the dammages***
- ***Depending on the code classification***
- ***Depending on the safety classification***
- ***…………..***

AM Qualification steps overview

Filer products Qualification
Procurement spec
Filer products Powder / fil

Acceptance of filler materials
- Chemical composition
- Mechanical properties
- Accepance tests

Operators Qualification Tool Qualification
machine

Operator Certificate ?
Tool Certificate?

Process Qualification
Manufacture programme
Qualification component

Technical qualification report (essentials parameters)

caracterisation

Acceptance tests

Part Qualification
Reference procurement spec
Production component

Acceptance tests

HIP Qualification
Heat treatment

Acceptance tests

AM between material and process

For us, Rapid Qualification of AMT Components is NOT a Rocket Science BUT:

- ***Need to clarify the process and steps of qualification***
- ***Need to define the range of expected feedback***
- ***Need to plan the feedback acquisition, maybe faster :***
  - *for small parts*
  - *for parts with low safety or pressure level*
- ***Need to discuss with safety authorities or notified body***

To keep in mind that

- *The nuclear industry has specificities in term of quality insurance and qualification that could make the transfer from R&D to industry really challenging*
- *Codes and standards and more generally standardization can facilitate the transfer from research to industry*
- ***A strong collaboration is needed between all partners in a supported framework***

Thank you for your attention

Predictive Technologies and Nuclear Product Qualification

Matthew LeVasseur, Director of Research
BWXT Advanced Technologies LLC

Advanced Reactor Development

Rapid qualification to change the economics of new nuclear

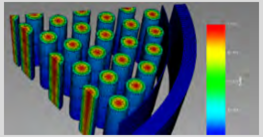
- Qualification is ultimately about confidence in system behavior. Three predictive approaches:
  1. Multi-physics simulation
  2. Predictive manufacturing
  3. Digital Twin

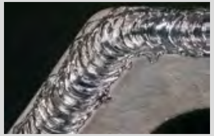
BWXT is developing a capability for rapid and optimized:

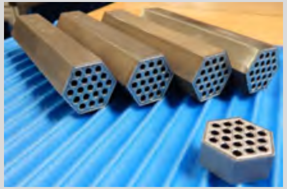
- Design
- Manufacture
- Qualification of nuclear products

BWXT Capability: Rapid Product Development

Early R&D







Design, fabrication development; surrogate specimen development

Lab Scale | Pilot Scale

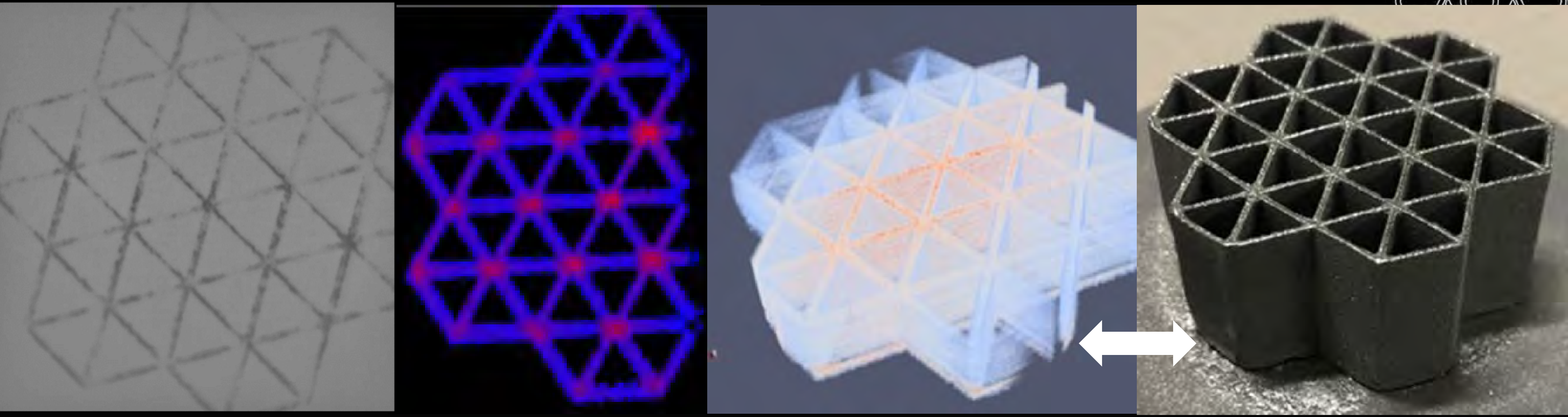
Sol-Gel kernels and PVD coating

Production NRC Cat 1

Reactors and fuel elements for a variety of customers

MRL / TRL 1	MRL / TRL 4	MRL / TRL 6	MRL / TRL 9

Manufacturing Data for Confidence in the As-built



Raw image
detected features

Computer Vison
enhanced detection

AI/ML data model
infer quality
characteristics

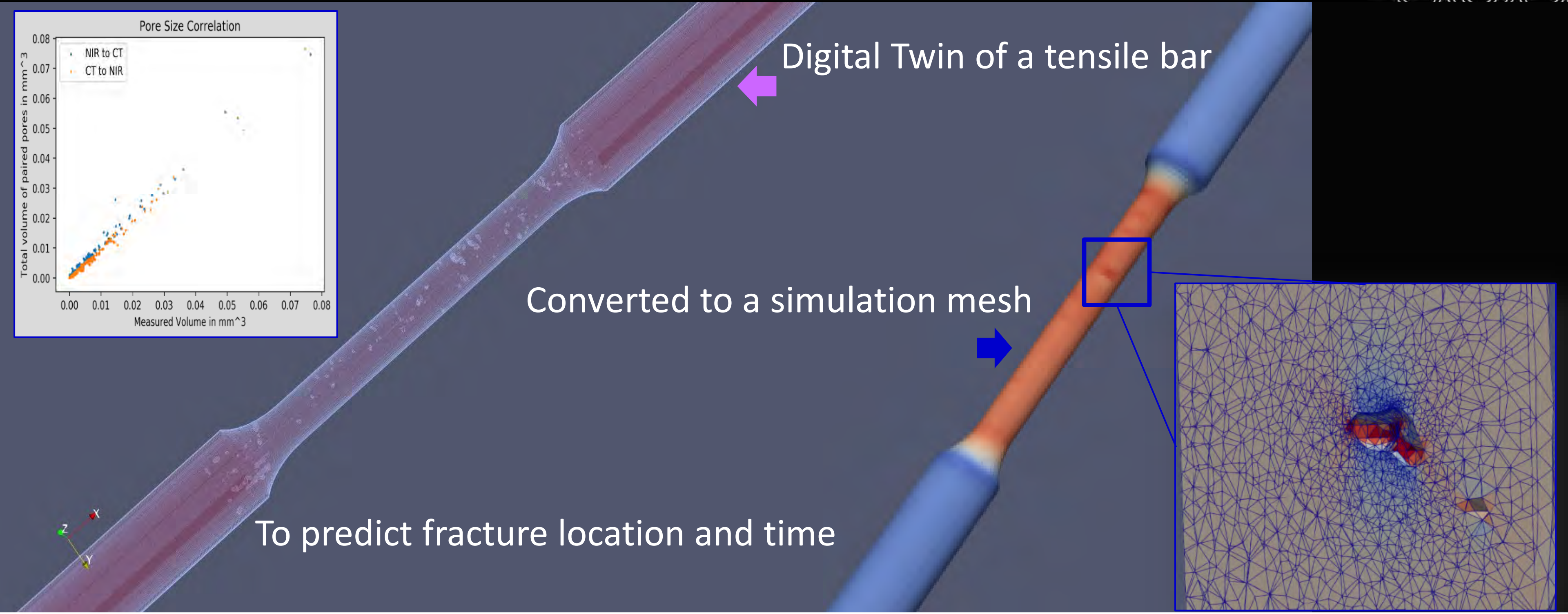
Digital Twin of As-Built

Data for understanding components and systems from the inside out

Process data patterns to characterize as-built for quality features of interest
to promote successful design, build and test

BWXT

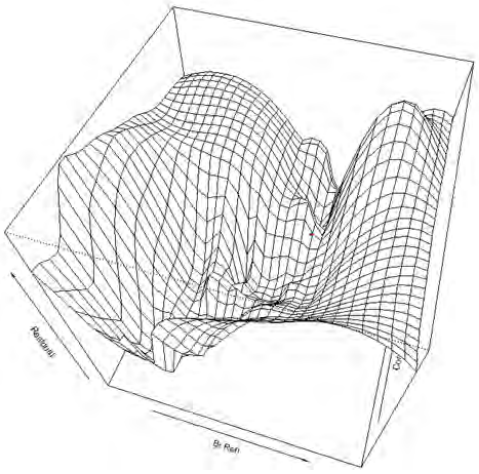
Multi-Physics Simulation for Predictive Behavior



Integrated mechanical, thermal and/or neutronics simulation and analyses

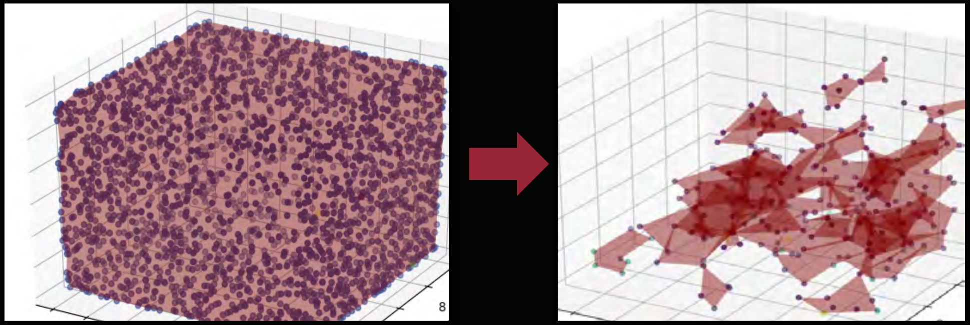
Design Iteration, Optimization and Predictive Performance

CORTES™ Engineering Design Platform is a BWXT patent pending, Ai-driven nuclear design suite, here identifying valid design space.

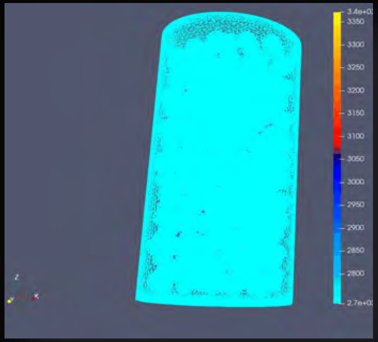


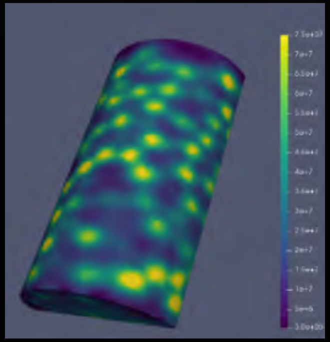
Reduce trial and error

Virtual space-filling experiments for non-linear, hyper-dimensional design region



TRISO thermal and transient simulation experiments





BWX Technologies, Inc.

Thank You!

Relativity

NRC Standards Forum

Josh Brost
Vice President of Business Development
jbrost@relativityspace.com

WE DESIGN, BUILD, & FLY ENTIRELY 3D PRINTED ROCKETS

AEROSPACE HAS FALLEN BEHIND OTHER INDUSTRIES

Automotive

60 → 15

Silicon Fab

20 → 20

Aerospace

60 → 180

NUMBER OF MONTHS TO DESIGN, INTEGRATE, AND TEST PRODUCT
TRENDS OVER THE LAST 50 YEARS
DARPA TRACKED DATA, 1960-2010

WE CREATED AN ENTIRELY NEW VALUE CHAIN

Our Full Stack Approach Radically Simplifies the Supply Chain, Reduces Capex Needs, and Rewrites the Incentives

Traditional Aerospace	Relativity
	
RIGID FACTORIES: FIXED TOOLING, TECHNICIANS	SCALABLE AUTONOMOUS PLATFORM
100,000-1M Part Count	~1,000 Part Count
18-month build time **48-month** iteration time	**2-month** build time **6-month** iteration time
Complex Supply Chain (~X,000 vendors)	**Simple** Supply Chain (<100 vendors)
High **Physical** Complexity	High **Digital** Complexity
$Billion Factory CapEx	**$Million** Factory CapEx

Fundamental Change to
PRODUCT CONSTRAINTS

100x Fewer Components, delivering more reliable vehicles

100x Fewer Suppliers, minimizing supply chain risks

100X less Touch Labor, reducing cost and increasing reliability

9x Faster Production, enabling responsive manufacturing

8x Faster Iteration, enabling faster improvements


EXIT
SKYJACK
800-UR-RENTS
Relativity

3D PRINTER TECHNOLOGY

EXPERTISE ACROSS ADDITIVE PLATFORMS

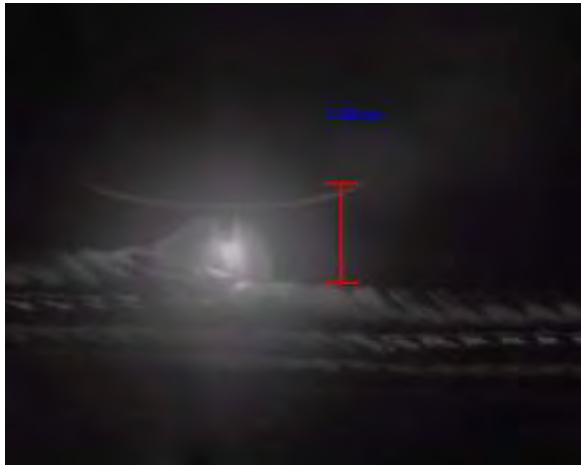
Two basic printing methods span sub-millimeter to 10s of meters, multiple metals, and unparalleled scalability

PRINTER TYPE	POWDER BED FUSION PRINTERS	STARGATE WAAM PRINTERS BY CLASS		
		DEVELOPMENT		PRODUCTION
Primary application	Engine Component Manufacturing: Injectors, Thrust Chamber, & Nozzle Manufacturing	Materials and Controls R&D	Short Barrels, Tank Domes	Payload Fairing & Stage 1

STARGATE – WIRE ARC ADDITIVE MANUFACTURING

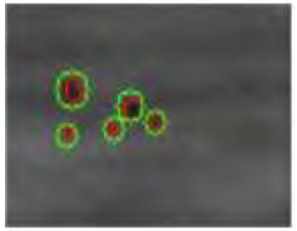
Relativity is the first commercial company to use WAAM for large-scale operational applications

- Stargate is the proprietary 3D-printing platform in our Factory Operating System, created to produce large-scale metal structures
- Enabled by Relativity's innovative tech stack, which leverages autonomy, advanced simulation, machine learning, and robotics
- Able to perform additive manufacturing, in-situ monitoring, NDE and subtraction capabilities in a single print cell
- We are developing the capability to print using all weldable metals

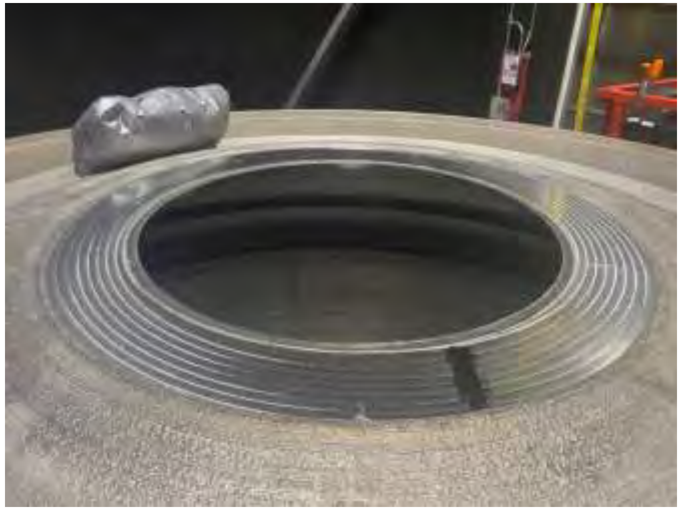


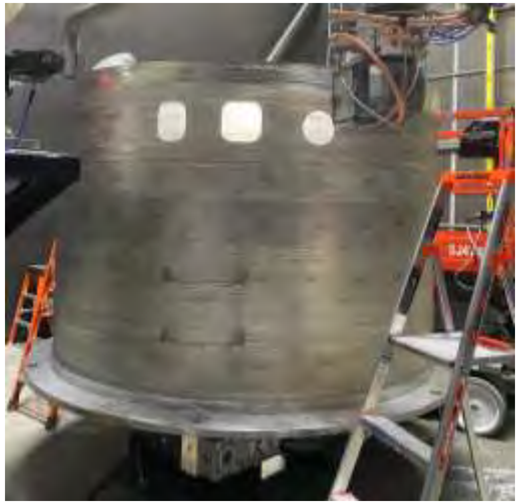
Human

Algorithm



Automated RT Review



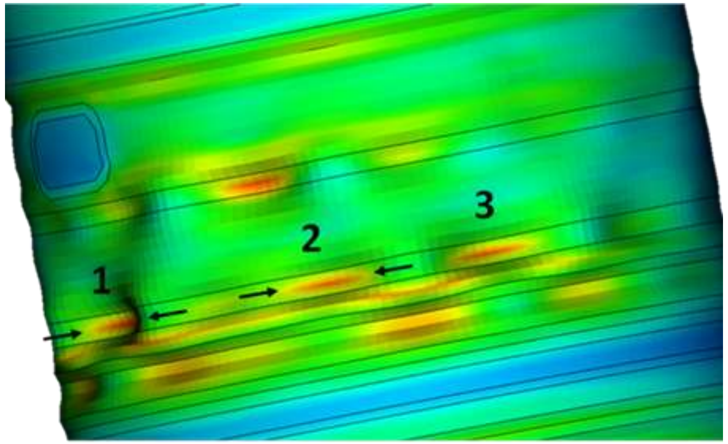


In-Cell Subtractive Capabilities

CURRENT INSPECTION & VALIDATION METHODS

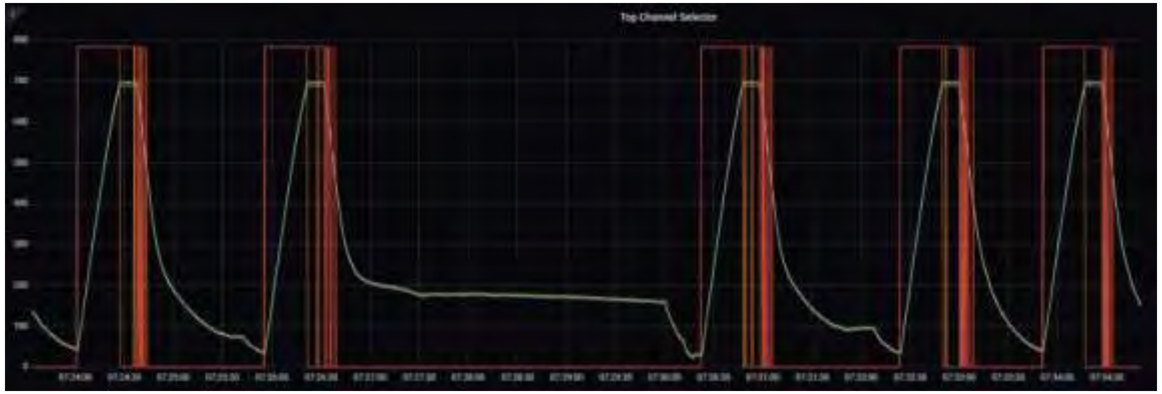
- **Nondestructive Evaluation (NDE) Methods:**
  - Automated Radiographic Testing (RT)
  - Visual Inspection Testing (VT)
  - (Fluorescent) Dye Penetrant Testing (PT)
  - Ultrasonic Testing (UT)
  - Electro Magnetic Acoustic Testing (EMAT)
  - Phased Array Ultrasonic Testing (PAUT)
- **Buckling Testing**
- **Post-test Analysis Correlation**
- **Redundant human data review to ensure part quality**

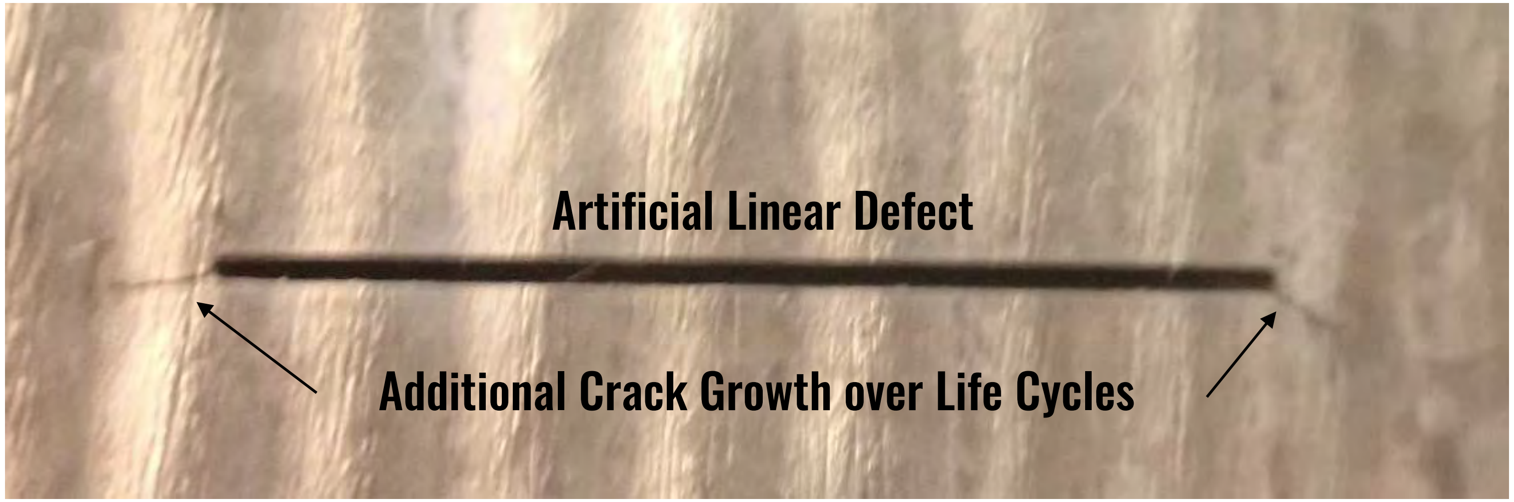
Stage 1 Iron Bird Testing



FLAW ACCEPTANCE CRITERIA SUBSTANTIATION

- Pressure cycles applied to pressure vessels with maximum allowable flaw sizes artificially induced.
- Tracking crack growth over cycles to validate fatigue and damage tolerance estimates.

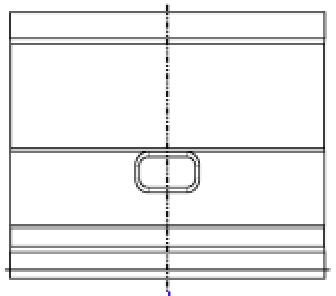




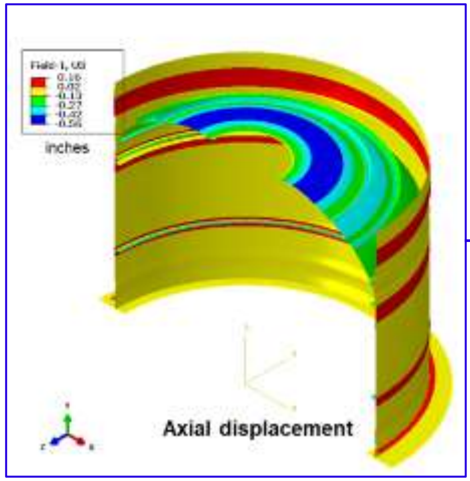
DISTORTION COMPENSATION

Additive technology requires compensation during the production process

DESIGN CAD

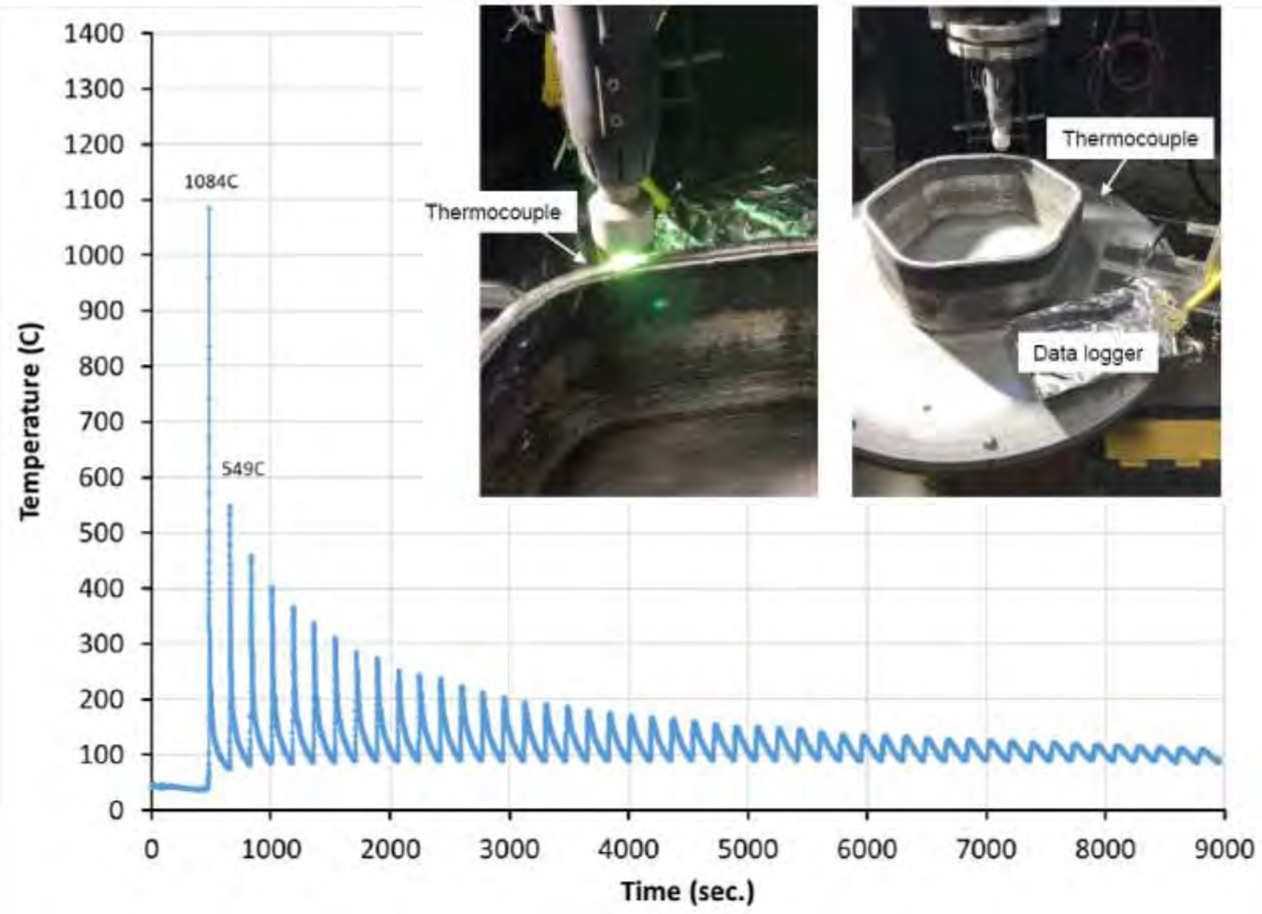


FEA MODELING: Thermo-Mechanical Model



Residual Stresses

Distortion Prediction



QUESTIONS?