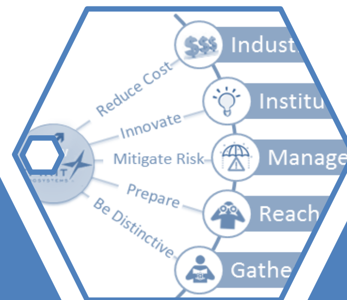
Spirit AeroSystems, Inc.

A Pathfinding Experience to an Additively Manufactured Ti Airframe Part

Paul Toivonen

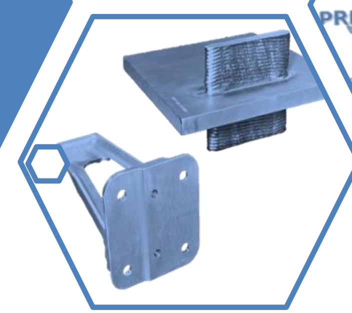
EASA - FAA AM Event
November 7, 2019
Köln, GR



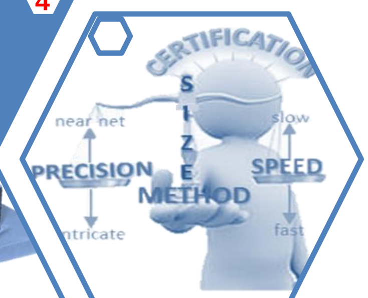
1 Plan for AM

2 AM To Date

3 1st AM Part



4 Next Steps



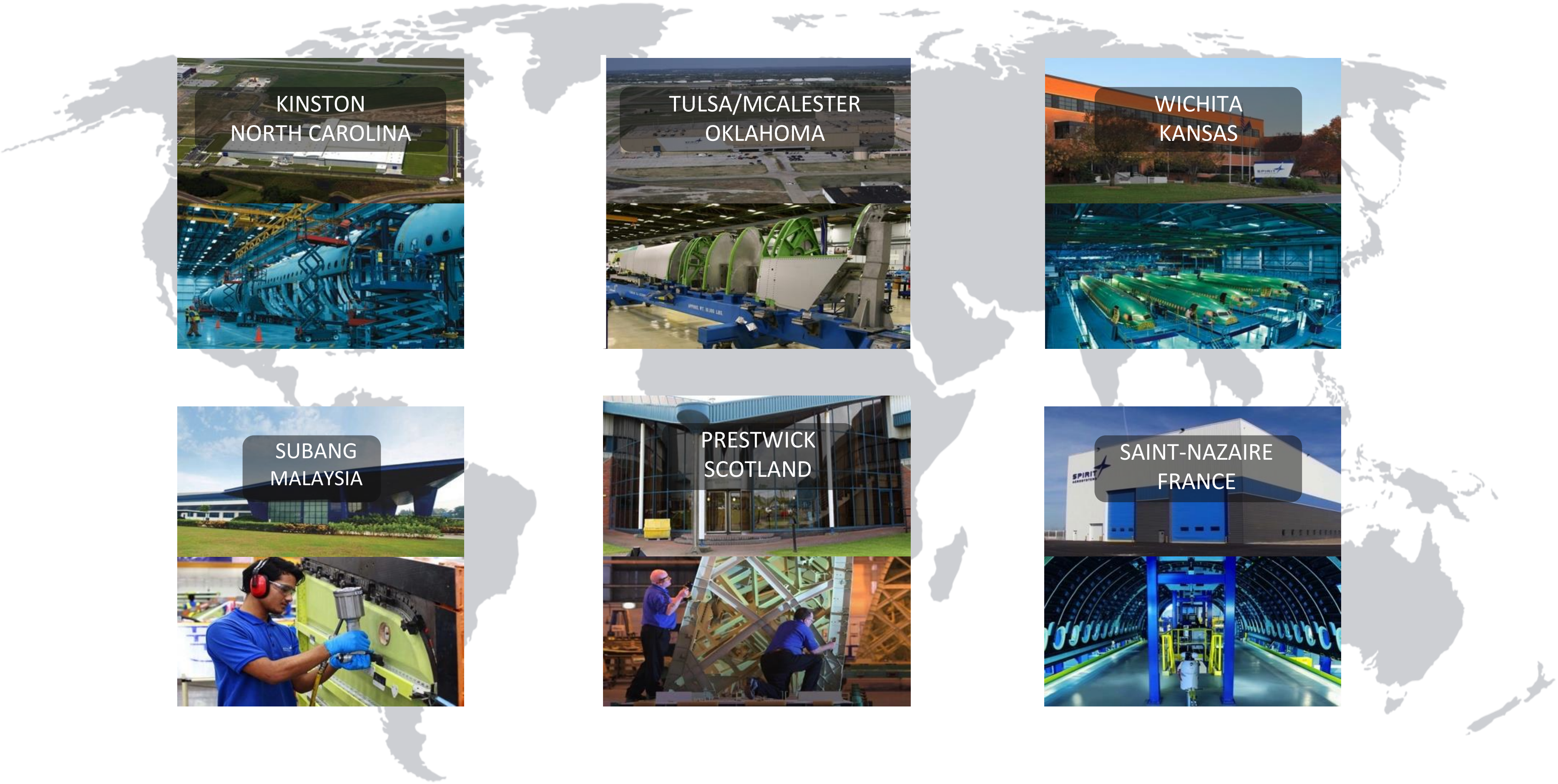
SPIRIT AEROSYSTEMS ®

WHERE FLIGHT BEGINS™

Outline

- **Overview of Spirit AeroSystems**
  - AM Strategy
  - Airframe Opportunity
- **Spirit's history with additive materials**
  - Landscape of Materials & Processes
  - Process and Allowables Development / Insights
- **Spirit's path to additively manufacturing a flying part**
  - Certification Challenges
  - Pathfinder Part – First into Production
- **Other current additive manufacturing applications**
- **Spirit's next steps**

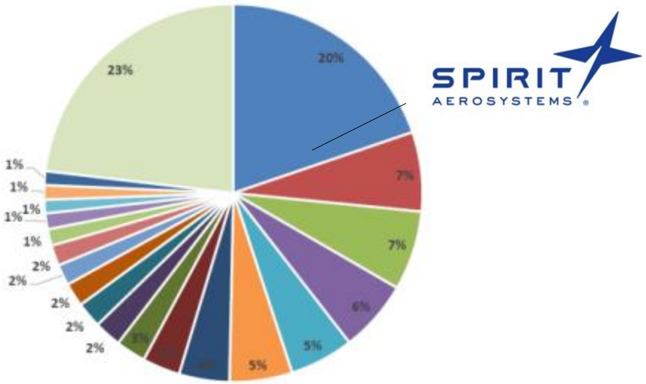
Spirit Has a Global Footprint



~15,000 Employees across 15M square feet of facilities

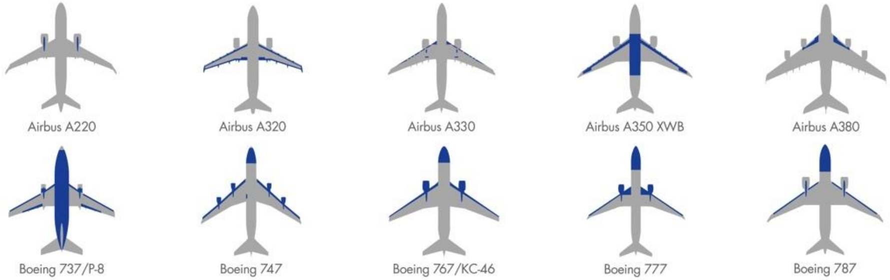
Spirit Is the Leading Global Aerostructures Tier 1 Supplier

Global aerostructures leader



Source: Counterpoint

On all of 12,600 Boeing/Airbus backlog



SPR backlog = $47B

With a balanced aerostructures portfolio

Fuselage (52%)

Propulsion (26%)

Wing (22%)

And an emerging presence in Defense

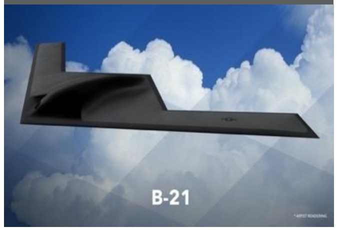
Sikorsky CH-53K

Bell V-280

P-8A, P-8I

KC-46A Tanker

Northrop Grumman B-21



Spirit Engineering

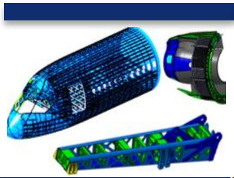
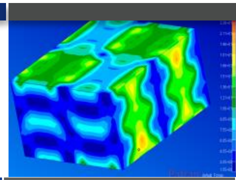
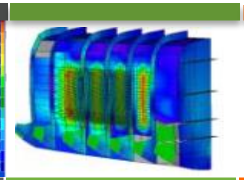
Focused on Execution & Innovation

- **People:**
  - Capable and experienced workforce
  - Strong working relationships with OEMs
- **Processes:**
  - Active measures to monitor performance
  - Integrated with OEM Product Definition
  - Continuous improvement
- **Tools:**
  - Leverage Spirit developed tool sets
  - Utilization of integrated OEM tools

Leverage Successes into Future Partnerships

Spirit Research and Technology
Seven Distinctive Capabilities

Additive spans multiple DCs



Performance Architectures

Next gen aircraft configs, topology optimized, additive

Material Optimization

Advanced material allowables, joule forming, simplified finish system

Product Development Tools

Composite analysis tools, Engineering & design automation

Lean Metallic Structures

Automated skin quality, sealant tech, alternate coolants

Ultracompetitive Composites

Infusion, thermoplastic, NDI methods, next gen. AFP

Competitive Tooling Solutions

Right-lifed adaptable tooling, improved maintenance

Accelerate Learning Curves

Digital thread, flexible automation, multi-sensor CMM



SPIRIT AEROSYSTEMS

WHERE**FLIGHT**BEGINS

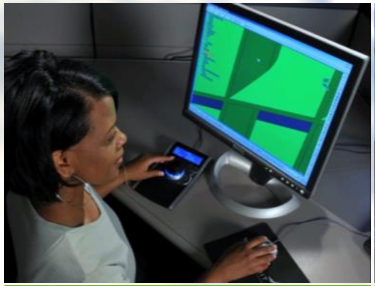
Additive Manufacturing Working Group

Aviation's Application of AM Hinges on Safety

On average, around the clock,
an airplane takes off every second…
putting 9,000 aircraft and 1.2 million souls
in the air at any typical moment

flightaware.com
Air Traffic Control Association
International Air Transport Association

Putting Safety First
Means Assuring Robust Engineering



DESIGN

BUILD

SUSTAIN

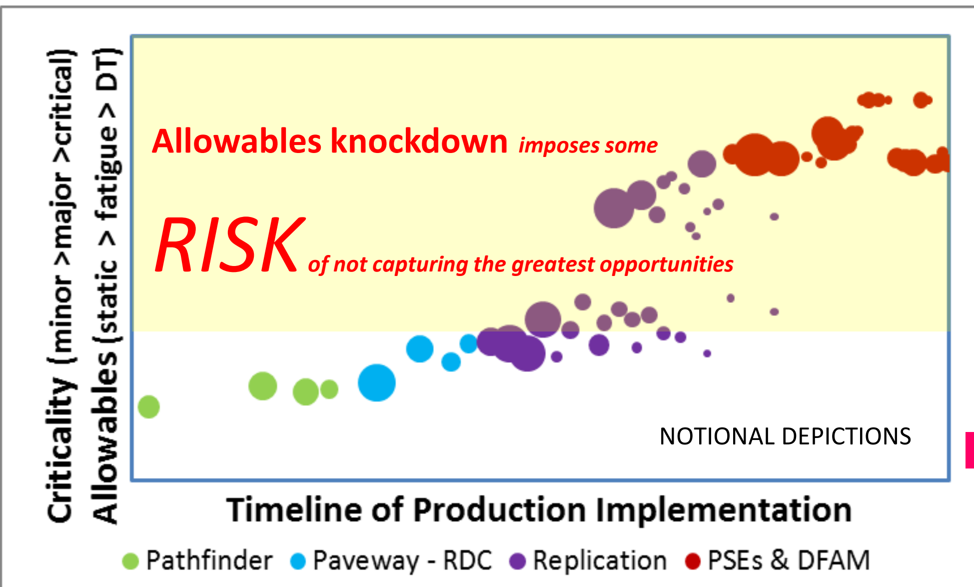
SPIRIT AEROSYSTEMS

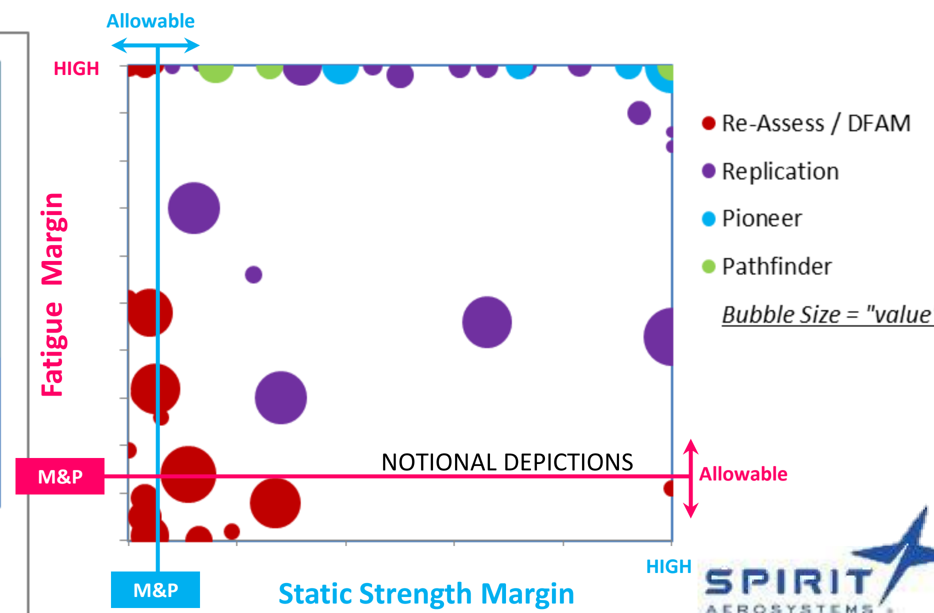
Spirit's Strategic Steps in Additive Manufacturing

Execute 5 Key Business Initiatives
Targeting AM Industrialization, Certification, and Innovation

Airframe Opportunity - Focus on Metal AM (Ti 6Al-4V)

- **Legacy Designs** → drop in equivalent parts (material system alternatives)
- **Titanium** → **$ $ $ $** (limited supply / hard metal machining / waste recyclability)
- Business Insertion Phasing: **PATHFINDER** ➔ **PAVE(the)WAY** ➔ **REPLICATION** ⏩ **PSEs/DFAM**
- **Candidate Parts**: selected based on printer suitability and application of best practices (printable?); then prioritized based on **criticality**, availability of **allowables**, and on the **business case**
  - *Buy-to-Fly ratio valuation is a significant driver of the business case, reflecting both machining time reduction (or increase!) and material savings*
  - *Post-printing processes with AM add cost over conventional machining, e.g., powder/support-removal, stress relief HT, HIP, NDE, surface finishing*
  - *Non-Recurring Engineering to establish material alternative & Quality Assurance*
  - *Supply chain lead time trades may make the business case*





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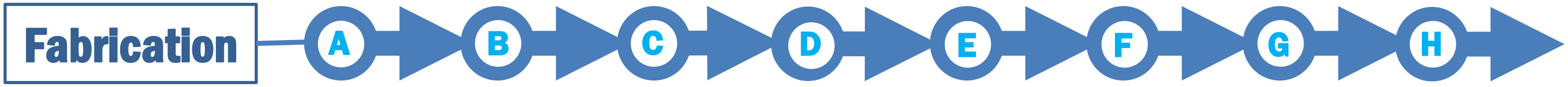
Metal AM Value Stream

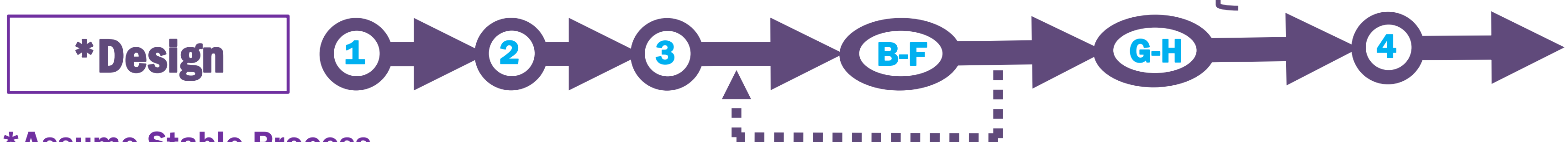
• = Spirit
• = Collaborate
• = Vendor



- (A) Feedstock / Build-plate
- (B) Deposit Material (make/buy)
- (C) Part Removal
- (D) NDI (x-ray, CT, etc.)
- (E) Heat Treatment / Stress Relief
- (F) Surface Treatment, Finish, & Deburr
- (G) NDE Final Part
- (H) QA / Inspect

FPQ
FAI

Metallurgical Evaluation
Property Verification
Part # Specific or sampling



Iteration

*Assume Stable Process

- *Feedstock Specification*
- *Process Specification*
- *Machine-to-Machine Qualification Process*
- *Material Characterization*
  - *Allowables*
  - *Properties*

- (1) Identify Structural Application and Process Spec.
- (2) Optimize Design for Additive Manufacturing
- (3) Analyze and Develop Part Process Schedule
- (4) Certification (w/ OEM)

Choosing Ti, DED, then *RPD™, from the AM Landscape

Material
Titanium
Aluminum
Stainless Steel / CRES
Invar
Inconel
Nickel
Tool Steel
…
Custom Alloys
Engineered Material Sys

Feedstock
Powder (Bed / Nozzle Blown)
Powder & Binder
Wire
Foil
Rod
(hot / cold - extrusion)
Filaments
…
Multiple Feedstocks

Consolidation
Sintering
Fusion Melting
Binder (jetted) & Fired
Atomic Diffusion
Electrochemical Plating
Friction Welding

Environment:
Room Air
Vacuum
Argon / Nitrogen
Chamber/Gas Shielding

Energy
Laser
Electron Beam
Plasma Transfer Arc
Ultrasonic
Kinetic
Friction Stir
Electrical Resistance
Electrochemical
…

AM Process
Powder Bed
Direct Energy Deposition
blown / jetted
fed (stock)
Extruded
Ultrasonic Lamination
Cold Spray
Electrochemical
Friction Stir
…

3-axis, 4-axis, 5-axis
Hybrid with Subtractive

Machine (Vendor)
production supply

Make
or
Buy

Fabricate Titanium parts suited for drop-in equivalency, relatively fast, with near-net-shape buy-to-fly benefit, teaming with a technology partner with supply chain capacity, and on a favorable path to certification

*RPD™: Rapid Plasma Deposition, (Norsk Titanium)

Spirit's Metal AM to *RPD™ Material Learning Curve

Sciaky EB

Norsk PTA (*RPD™) …

BA Allowables

Gen 2 Gen 3 Gen 4

2001 2003 2005 2007 2009 2011 2013 2015 2017 2019

LAM Aeromat

BMS7-361

Spirit AeroSystems Formed

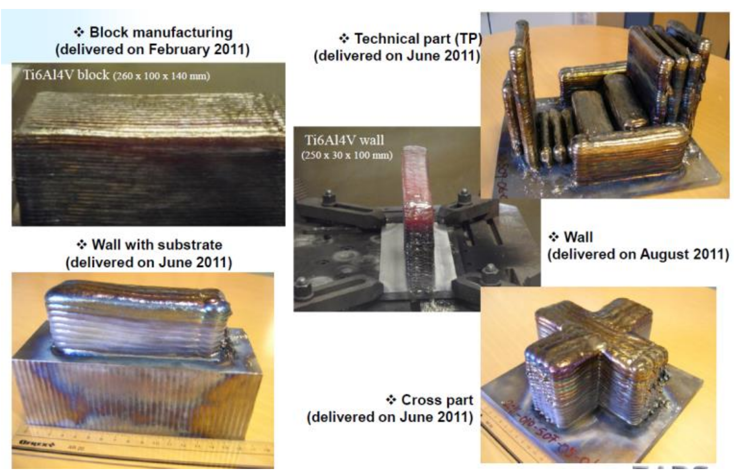
SMS-110281-A

+BA

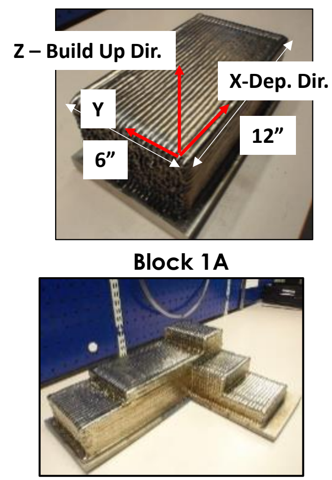
BMS7-361-B

Pathfinder

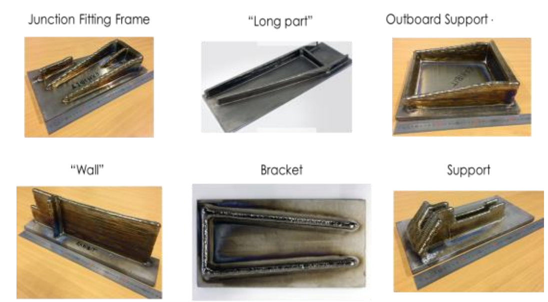
Process Maturity Testing



Allowable blocks



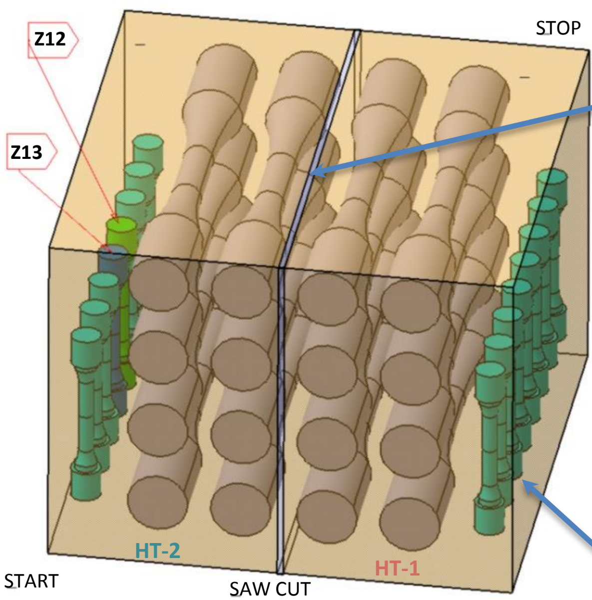
Thin walled parts



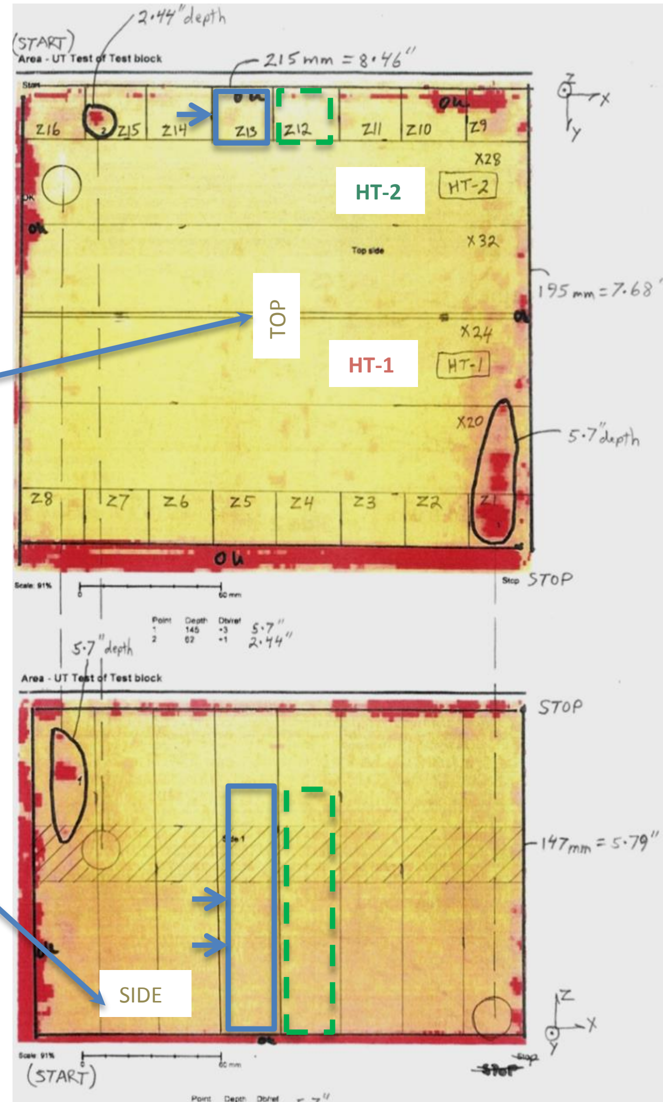
Source Image – Norsk Titanium

*RPD™: Rapid Plasma Deposition, (Norsk Titanium)

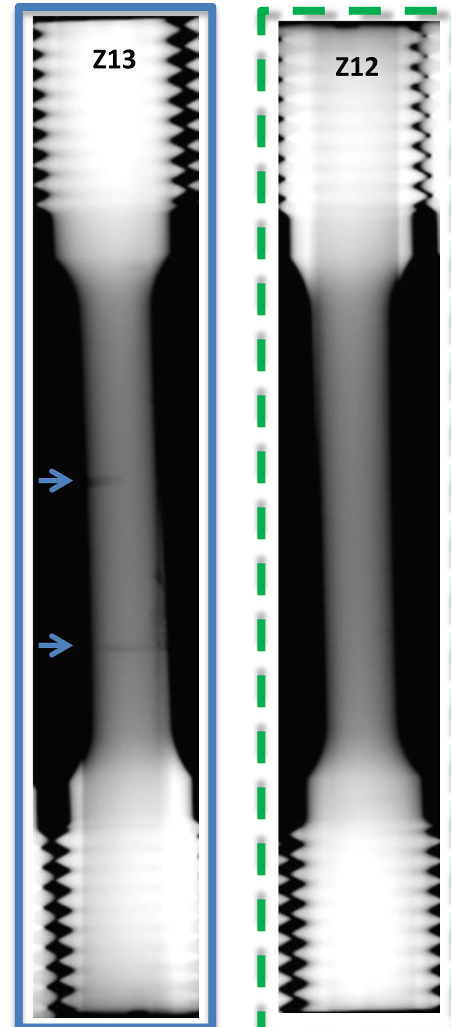
Inspection of a Sample Gen 3 PTA DMD Block



Immersion Ultrasonic NDE of Block



X-ray of specimens



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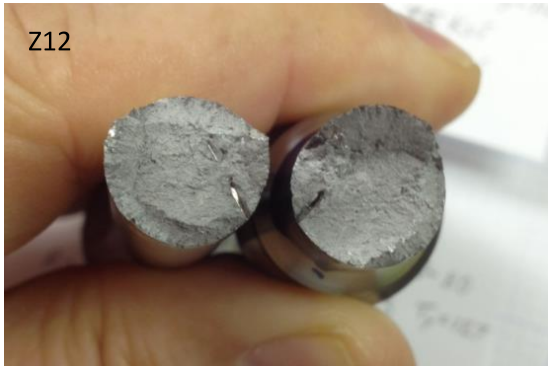
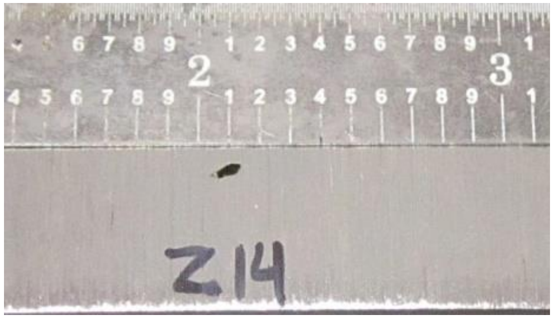
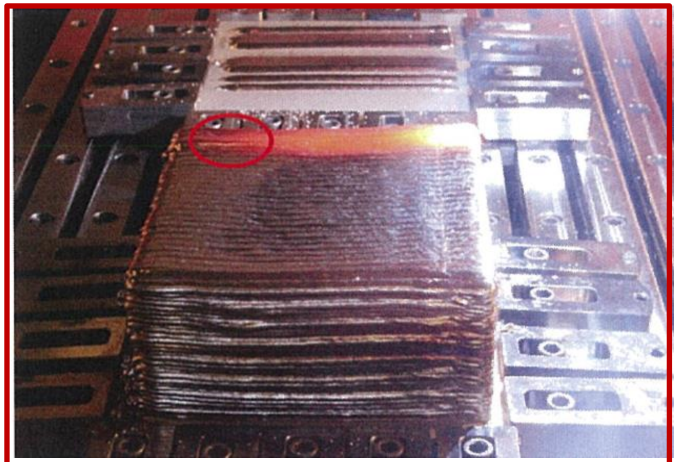
Anomalies (Rare… but Non-conforming) Within a G3 Block

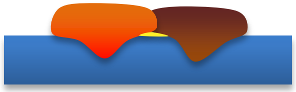




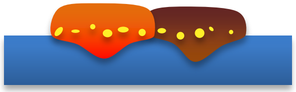


Non-Conformance Report (NCR) noted special incidents during production

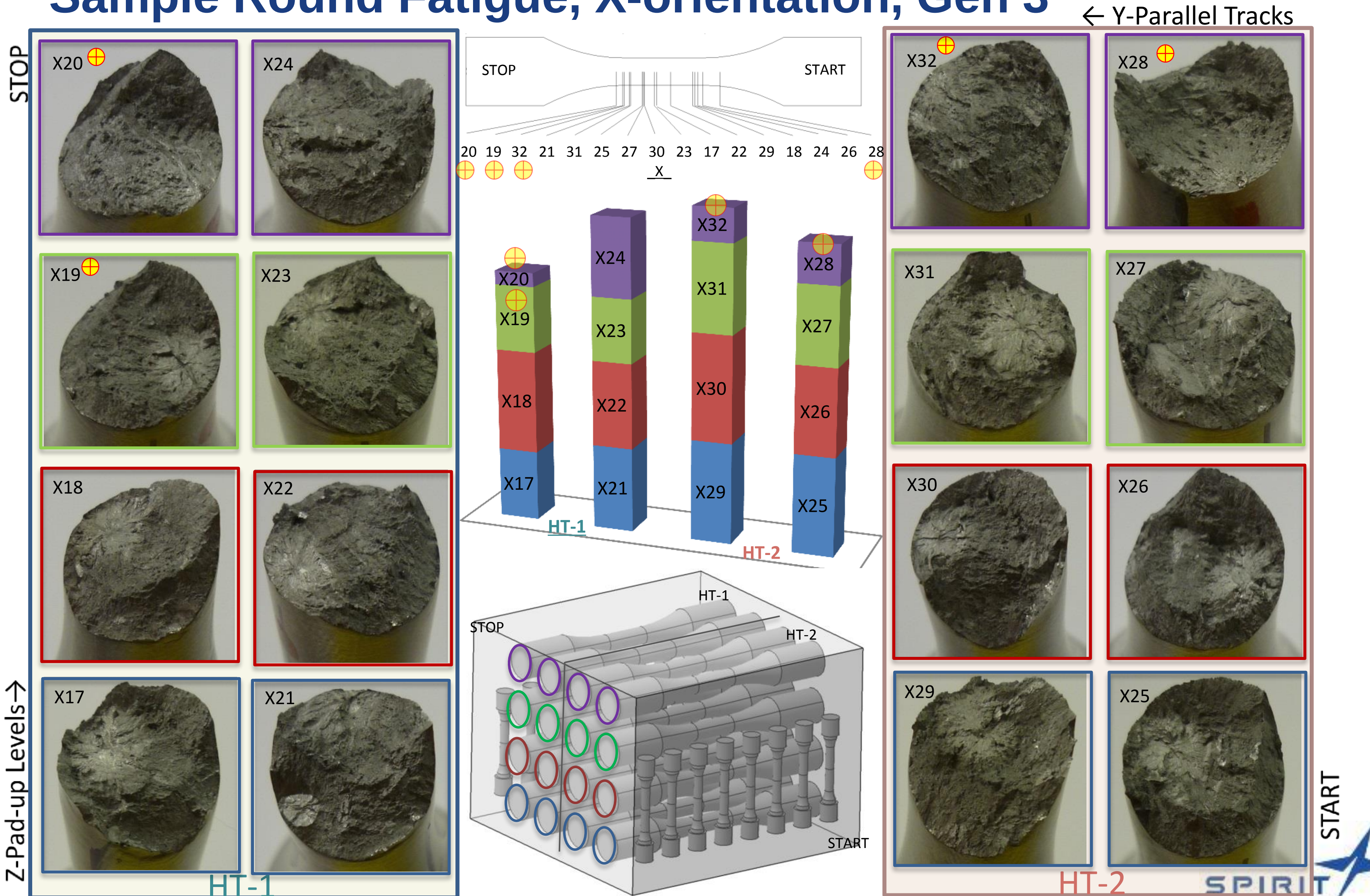
Cross section sketch typical of LoF defect due to incomplete melt-in:



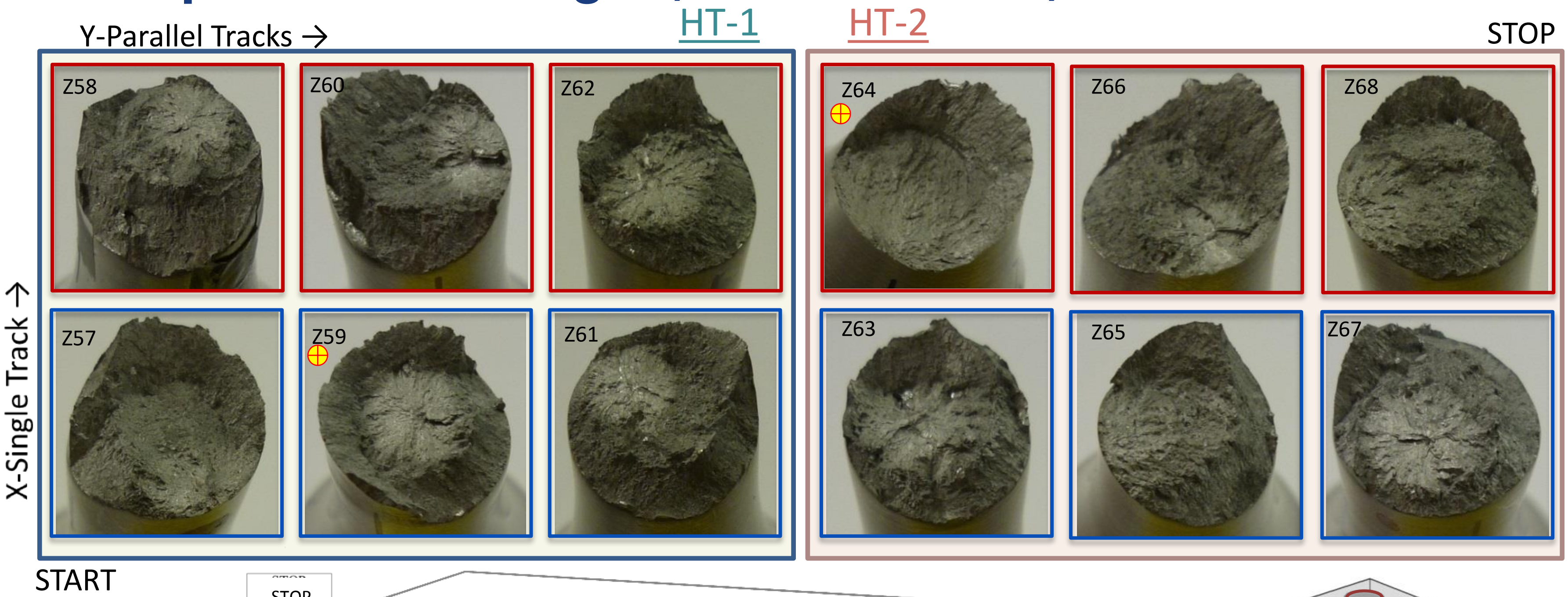
Cross section sketch typical of porosity defect due to contamination:

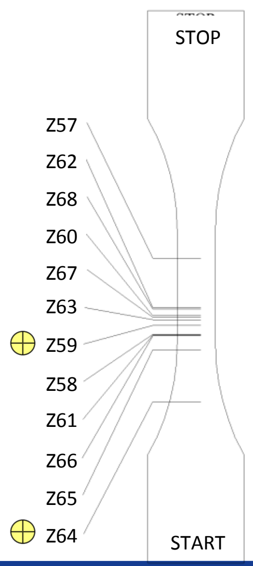


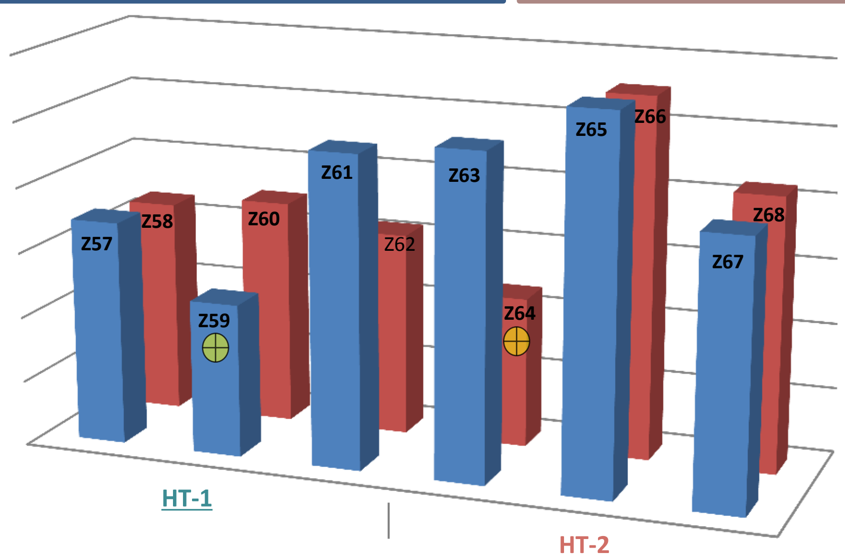
Sample Round Fatigue, X-orientation, Gen 3

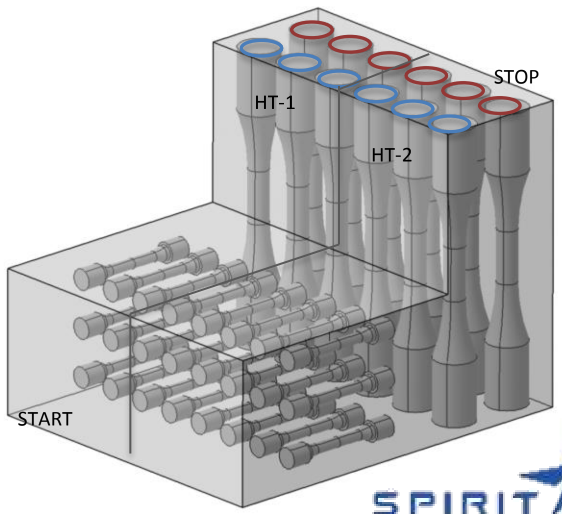


Sample Round Fatigue, Z-orientation, Gen 3

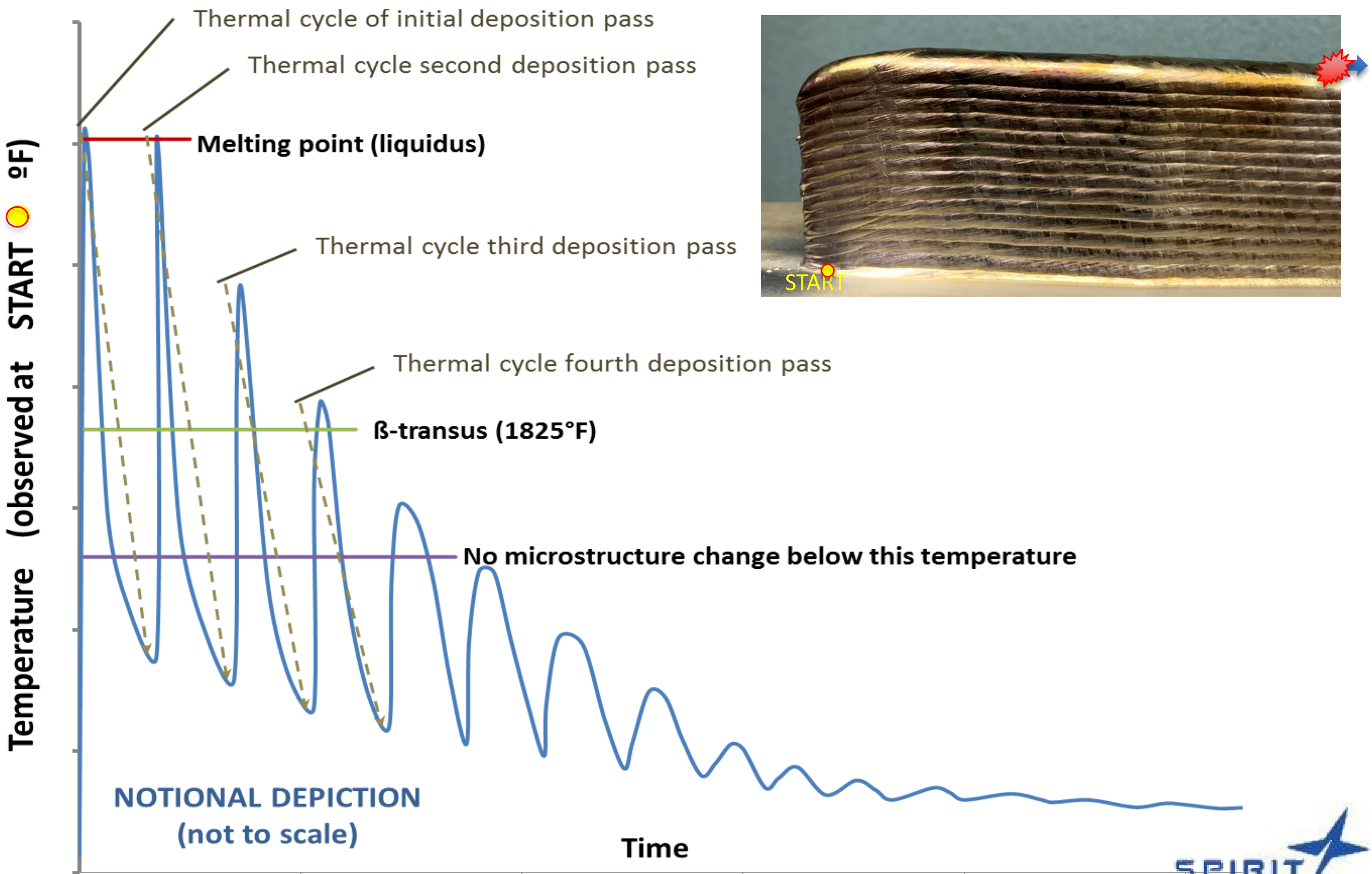






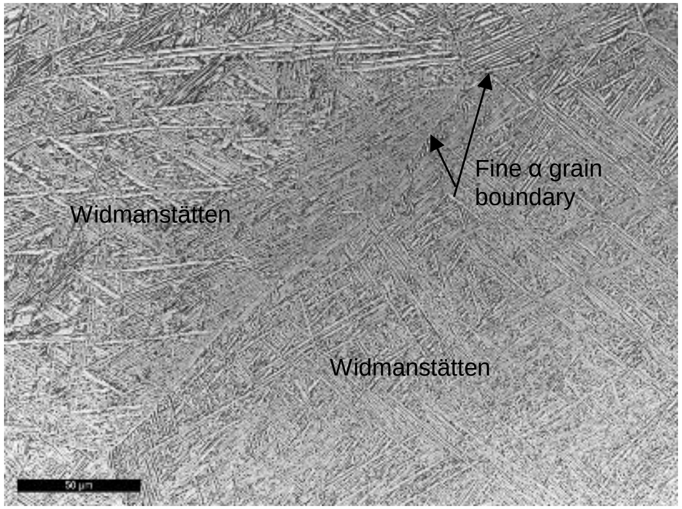


Representation of Thermal Cycling – Fixed Location

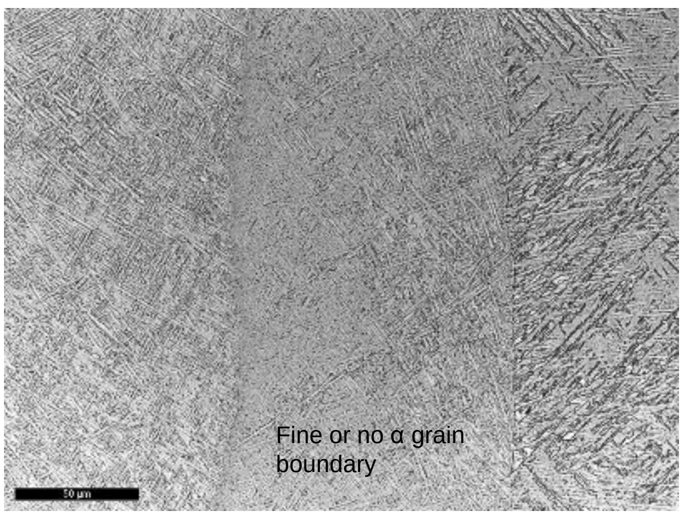


Microstructure – Throughout Part Height

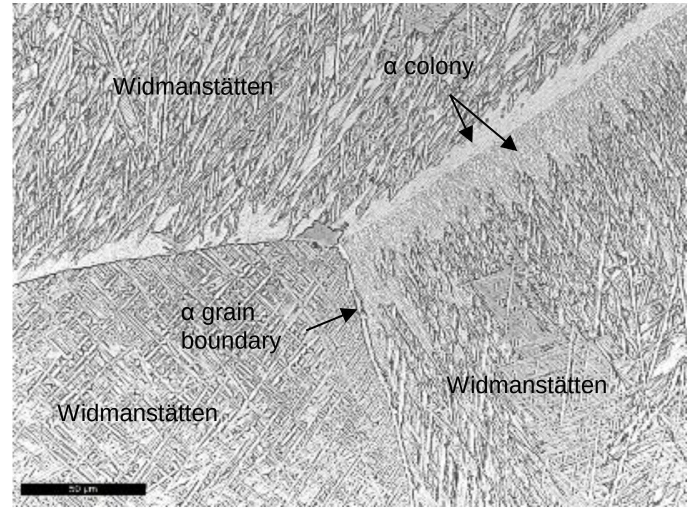
Image – Norsk Titanium



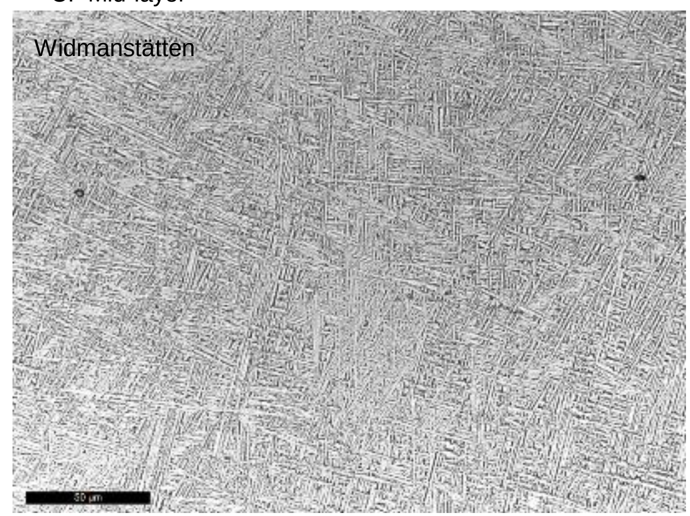
A: Heat Affected Zone in substrate



B: Initial Layer



C: Mid-layer

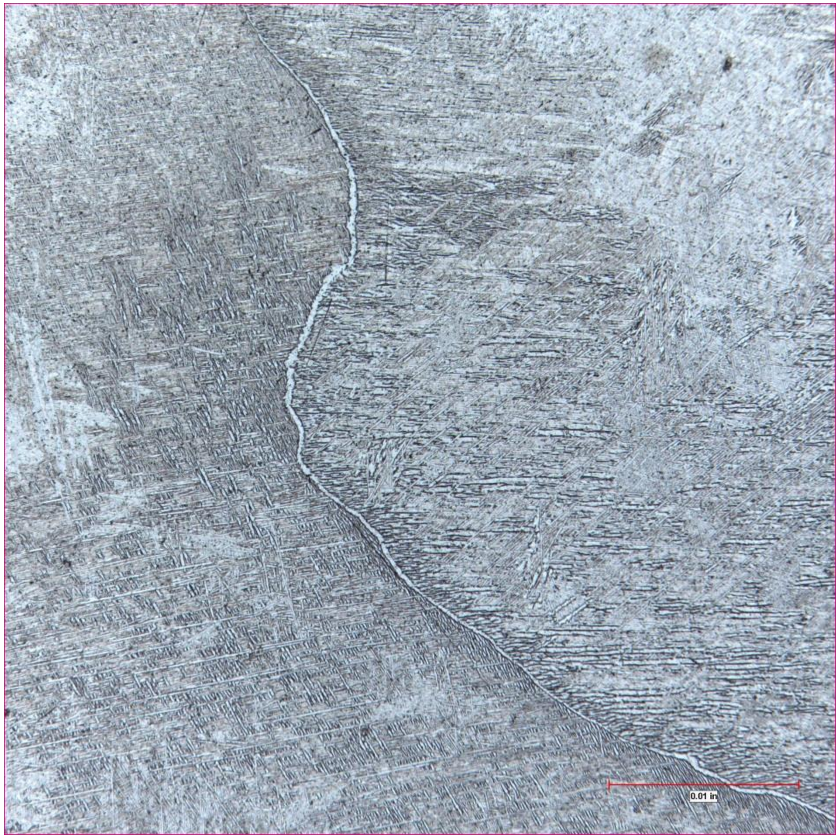


D: Near-top Layer (within one β grain)

Microstructure Comparison by Heat Treatment

The Range of Microstructural Features and Dimensional Characterization Observed Throughout a Given DMD Block Is Similarly Exhibited When Comparing Characterization of Two Blocks of Either Heat Treatment

HT-1 somewhat finer transformed β microstructure



HT-2 more continuous grain boundary α

Managing Airworthiness of AM Applications

Certification

The challenge is - **Additive Manufacturing can yield a complex material system:**

Mechanical performance reflects the balance of properties produced by both the AM process and the structure, underscoring the importance of key structure/microstructure - processing - property relationships

Process Development → Material Characterization → Supplier Qualification → Part Design Qualification → Quality Controls

The process, printers, & deposition plan must be robust, reliable, and repeatable; requiring solid understanding, characterization and deliberate control

Characterize
Control
Inspect
Maintain

================

Process
specification
build parameter DOE
machine setup/qual
machine-to-machine
FAI and qualification
In-situ monitoring

Structure
location
orientation
macro & micro views
anomalies
features
families

Properties
allowables
point design
special factors
densification/defects
part specific
probabilistic
ICME

Compliance Comes Collaboratively

include OEM and supply chain strength in being true to our lanes

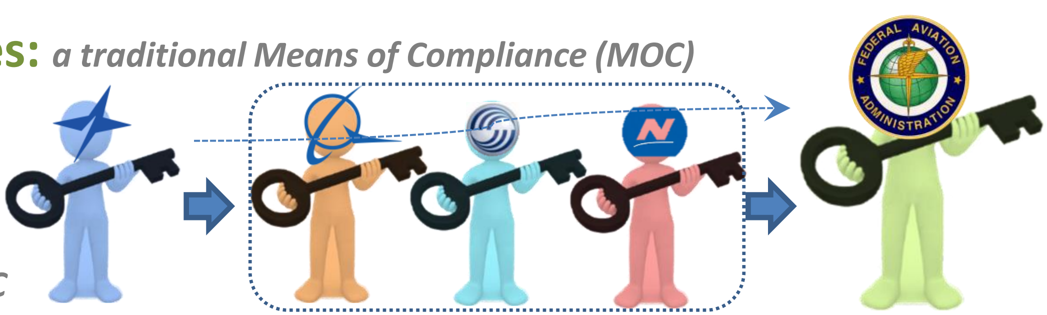
engage standards & regulatory working groups

AMWG, AMNT, SAE, ASTM, CMH-17, MMPDS…

Entity	Role in Compliance
Regulator	Ultimate Authority
OEM	Ultimate Responsibility
Tier 1 Supplier	Scope of Delegation
MRO	Can be same as OEM
Supply Chain	Accountability

Allowables: *a traditional Means of Compliance (MOC)*

Collectively, if we get to an accepted MOC we all stand to win.



Type Certificate Holders Responsible to FAA

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WHERE**FLIGHT**BEGINS

Norsk Titanium & SAE International Develop First Directed Energy Deposition Specifications for Additive Manufacturing Professionals Worldwide - *Feb. 15, 2019*

AMS7004 *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate Ti-6Al-4V Stress Relieved*

AMS7005 *Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process*

- Developed within the SAE Additive Manufacturing Committee (SAE AMS-AM)
- Establish the minimum basis required for the procurement of RPD™ Preforms from Norsk by an aerospace or non-aerospace customer
- Support the regulatory certification process by ensuring consistent process and quality control

https://www.norsktitanium.com/**media**/**press**/norsk-titanium-sae-international-develop-first-directed-energy-deposition-specifications-for-additive-manufacturing-professionals-worldwide

First Production AM Part Incorporated at Spirit

Spirit AeroSystems to Deliver First 3D-Printed Commercial Aircraft Part

NEWS PROVIDED BY
Spirit AeroSystems Inc. →
Dec 21, 2018, 12:58 ET

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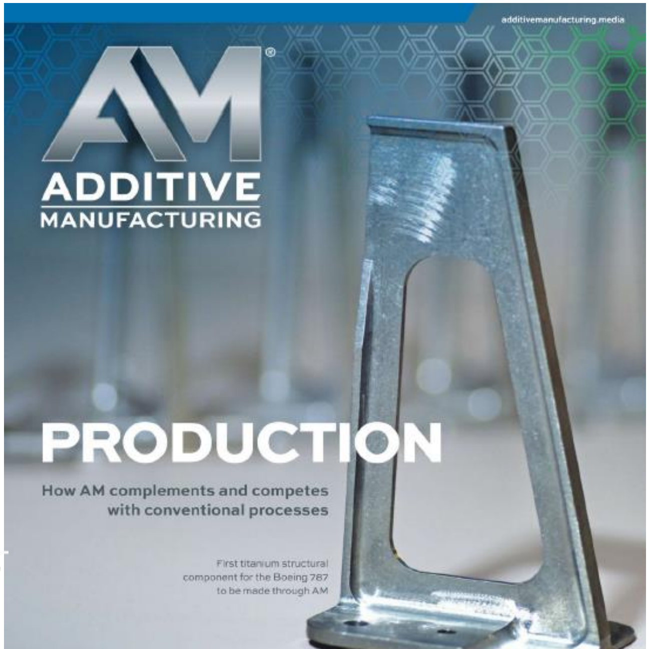
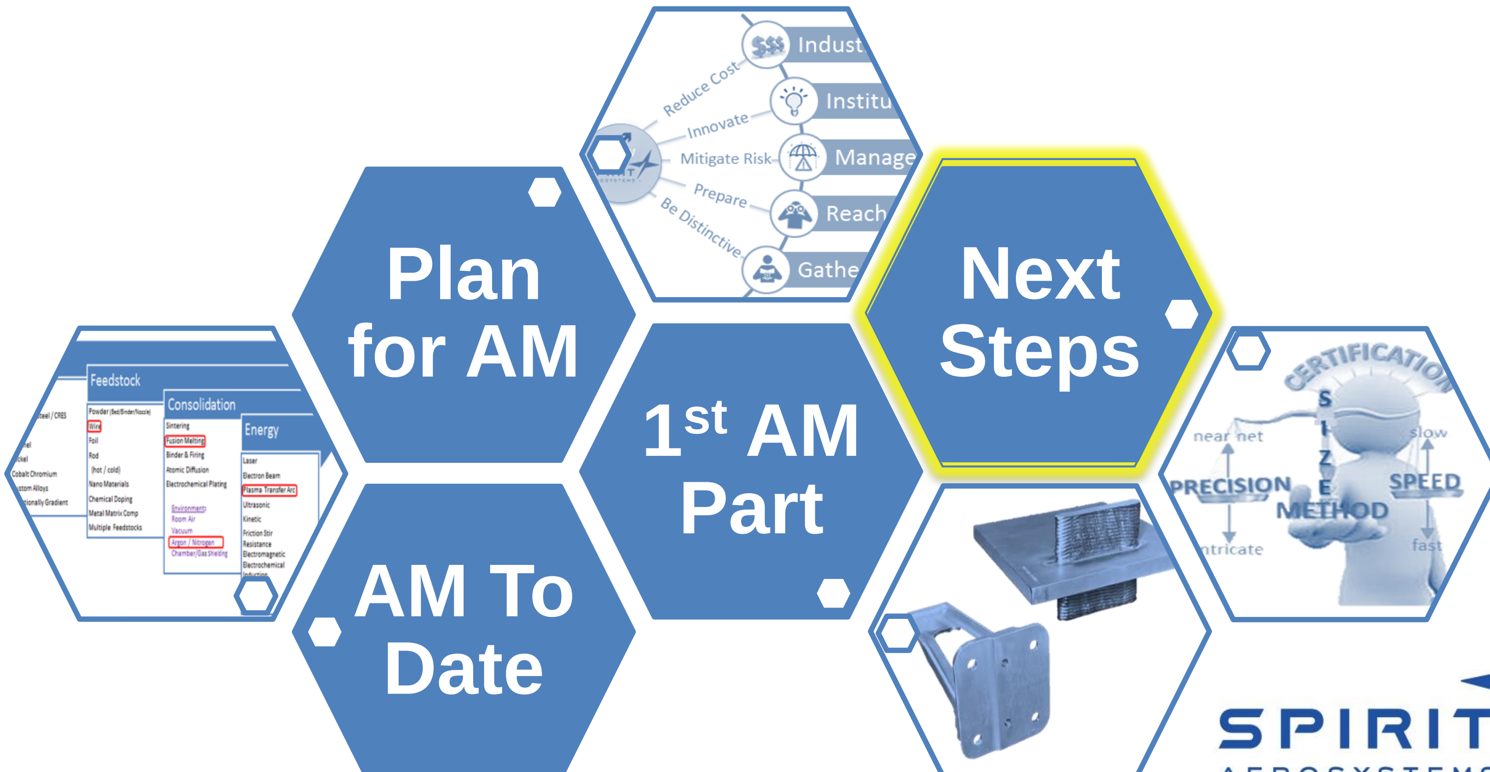
WICHITA, Kan., Dec. 21, 2018 /PRNewswire/ -- Spirit AeroSystems [NYSE: SPR] announced the receipt of its first additive-manufactured, titanium, structural component for the Boeing 787. The part, a back-up fitting for an access door latch, has been machined and finished at Spirit's Wichita site, and installed in a 787 forward fuselage. The forward fuselage will ship to Boeing's final assembly facility in January.



May 2019 Vol. 8 No. 3
screen image extracted from URL: additivemanufacturing.media

Other Steps and Next AM Processes and Technology for Development

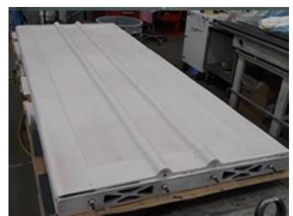


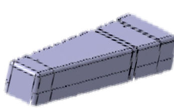
Tooling Demonstrator Projects (Polymer & Metallic AM)

Tooling for Composites

- High-Temperature autoclave layup tooling
- Tooling for low-temperature curing composites
- Low temp pre-pregs
- Resin Infusion Tools
- Hot Drape Form Tooling
- Honeycomb Form Tooling

- Key Developments:
  - Machinability
  - CTE
  - Sealants



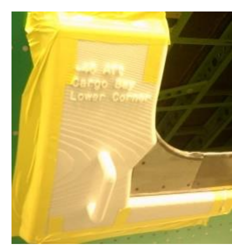



Tooling for Metals

- Hydro-Form tooling
- Stretch form tooling (planned)
- Assembly tooling
- Shop Aids
- CMM Tooling (planned)
- Protective fittings

- Key Developments:
  - Costs
  - Strength
  - Size
  - Surface finish



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Future AM Technology and the Factory of the Future

Source Image – Dreamstime.com

New M&P

Optimized Performance

Manufacturability, Assembly, Integration, and Supply Chain

Process	Performance
Innovation in Processes and Novel Printers for AM	Quantum Computing Probabilistic Methodologies
New Alloy Development & Functionally Gradient Tailored Performance	Artificial Intelligence Machine Learning
In-situ Process Monitoring, Control, and Anomaly Mitigation	Optimization Methodology Design for Additive Manufacturing
Material Testing / Characterization Anomaly Characterization	Integrated Computational Metallurgical Engineering

(Digital Tapestry)

Process: Repeatable, Robust, Reliable, Industrial

Performance: Modeling, Simulation, Optimization, Qualification

Thank You