Open Manufacturing

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New Manufacturing Technologies: Perception is *NOT* Reality

Perception: PROMISE

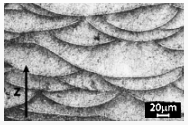
Greater component design flexibility

Lower buy-to-fly ratio

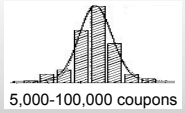
Improved time efficiency and legacy capability

Reality: CHALLENGE

Current manufacturing environment does not capture process data



Poor understanding and control of materials, machines, and processes



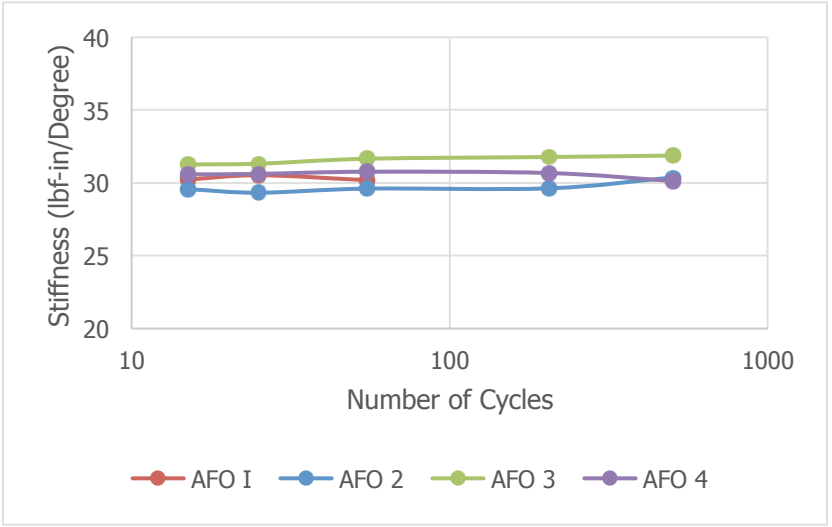
“Make and break” qualification approach is too costly

Challenges are barrier to transitioning technologies to production

3D Printed Polymer AFO Fatigue Test

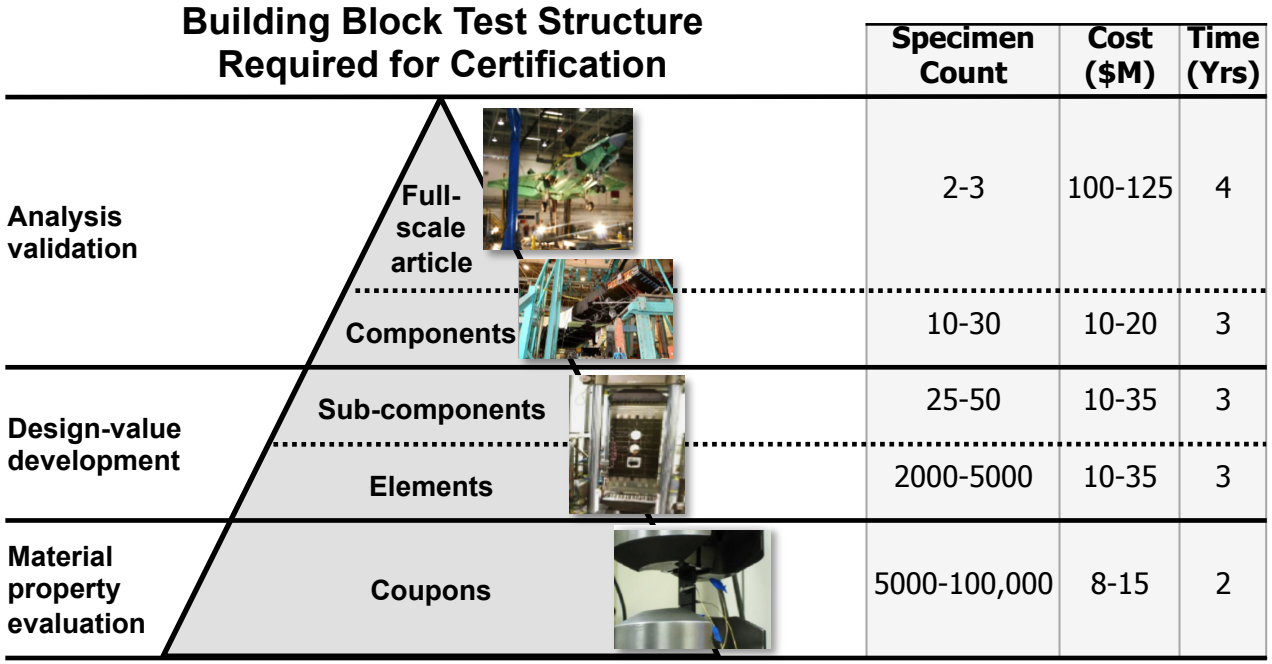
AFO	Cycles to Failure	Failure Location
I	85*	Neck (Under Cuff)
II	690	Neck (Under Cuff)
III	589	Neck (Under Cuff)
IV	546	Neck (Under Cuff)

- Four 3D Printed AFO Tested – custom stiffness/geometry
- Fatigue Test to Failure – did not meet 3M cycles
- Stiffness requirements drive to unrealistic thicknesses



*Had undergone some use prior to test

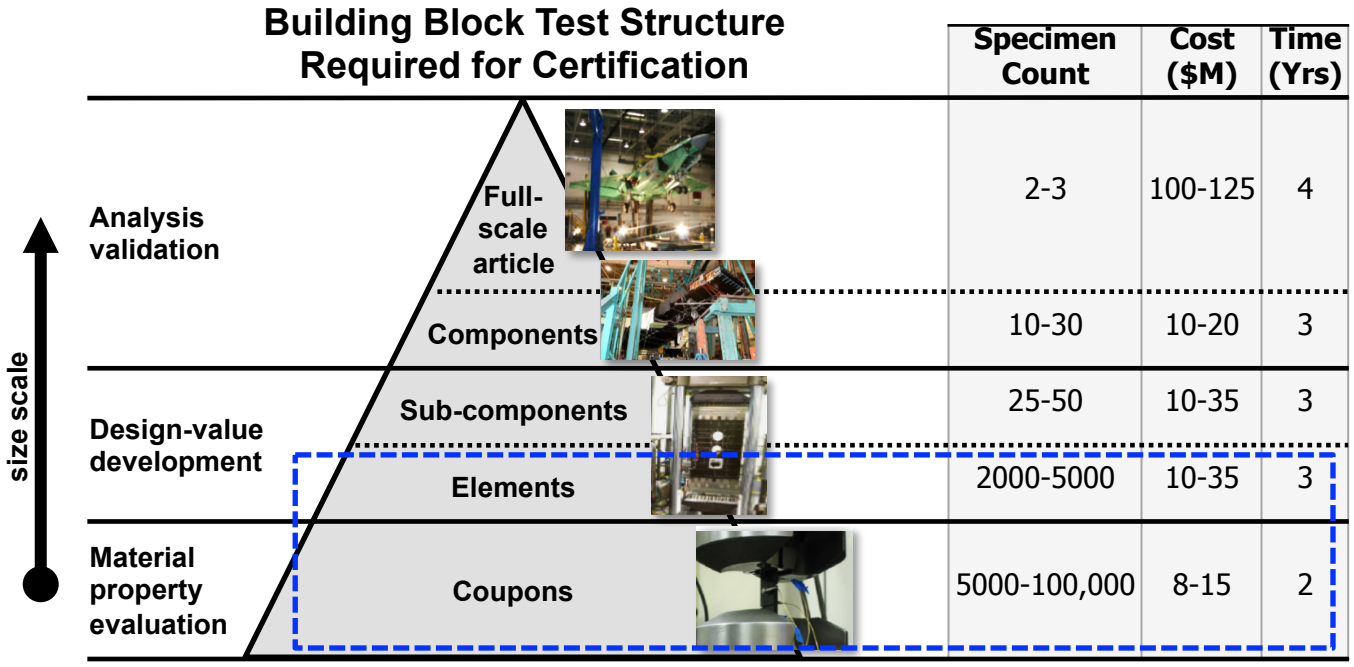
Typical DoD Qualification/Certification Approach



Specimen Count	Cost ($M)	Time (Yrs)
2-3	100-125	4
10-30	10-20	3
25-50	10-35	3
2000-5000	10-35	3
5000-100,000	8-15	2

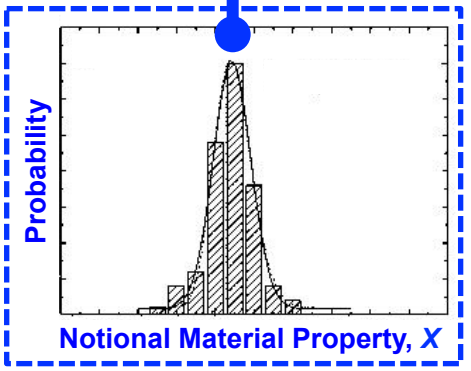
Comprehensive understanding of manufacturing variation at different scales is needed

Current Approach Does Not Capture Impact of Manufacturing Variability Across Size Scales



	Specimen Count	Cost ($M)	Time (Yrs)
Full-scale article	2-3	100-125	4
Components	10-30	10-20	3
Sub-components	25-50	10-35	3
Elements	2000-5000	10-35	3
Coupons	5000-100,000	8-15	2

- **Collect statistically valid populations of properties for small size specimens**
- **Base larger scale structure designs on measured material character**



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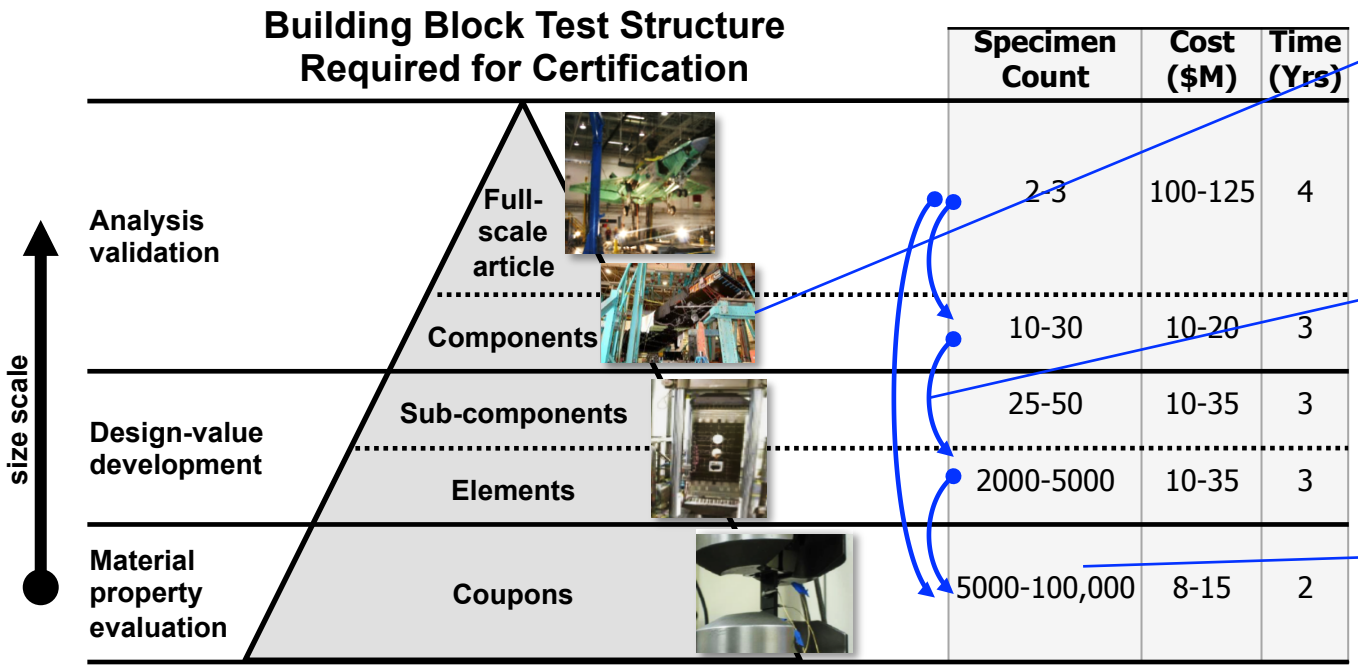

Effects of scale-up are not captured until the sub-component / component level testing

Redesign/Rework Iterations result in budget escalation and schedule delays

Impact: Contemporary platforms reuse traditional approaches to reduce the cost and risk of qualifying new technology

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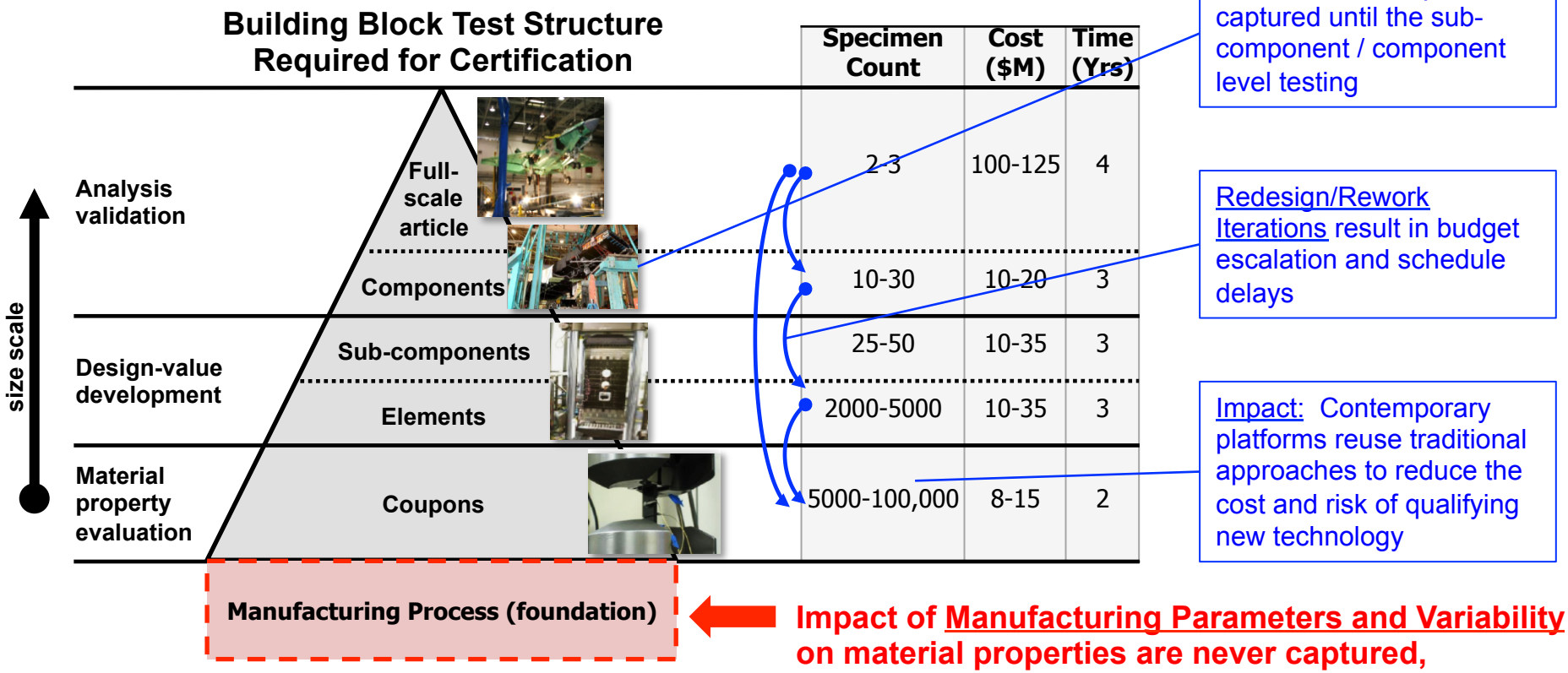

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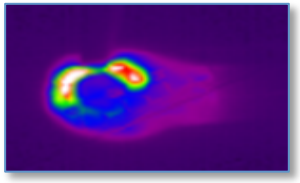
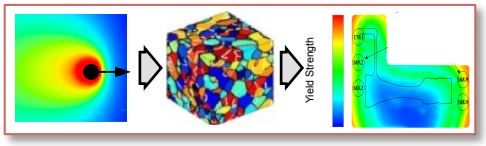
OM Approach and Goals

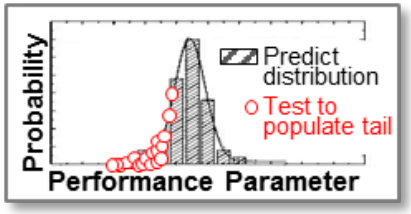
Probabilistic sensing and routine data-capture capabilities can be transferred to manufacturing environment



Maturing multi-physics and data-based models allow for understanding of process/microstructure/property relationships

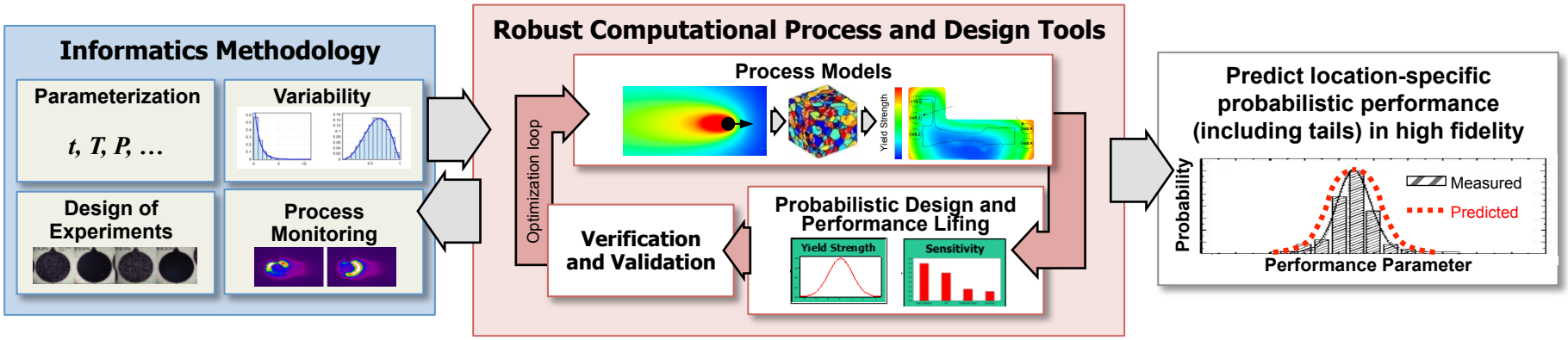


New probabilistic frameworks and verification and validation techniques can link data sources and simulation modules to output product performance with quantified uncertainty



Location specific probabilistic description of product performance for rapid qualification

Open Manufacturing fundamentally changes how manufacturing variability is captured, analyzed and controlled



- Fully parameterize and monitor the factory-floor
- Capture probabilistic variability in laboratory and manufacturing environments

- Computational tools incorporate probabilistic variation into input parameters
- Rapid qualification schema that employ statistical methods for high-confidence prediction
- Rigorous model verification and validation
- Probabilistically predict location-specific process and part performance

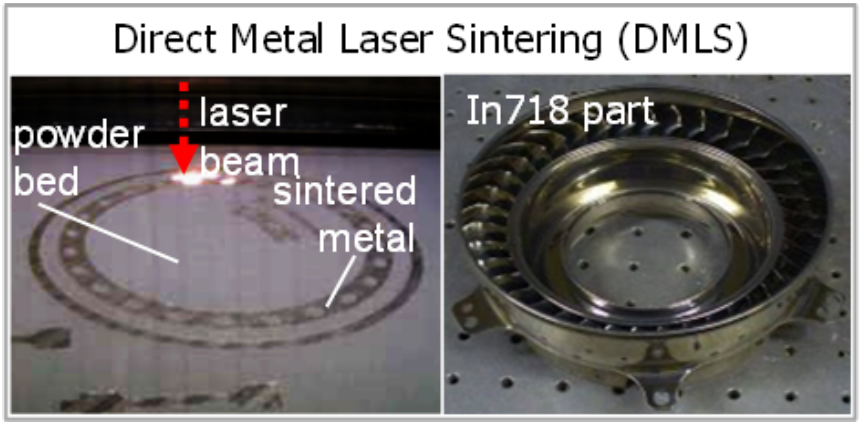
- Framework for rapid qualification
- Identify bounds of process window
- Build confidence in new technologies
- Optimize and control processes

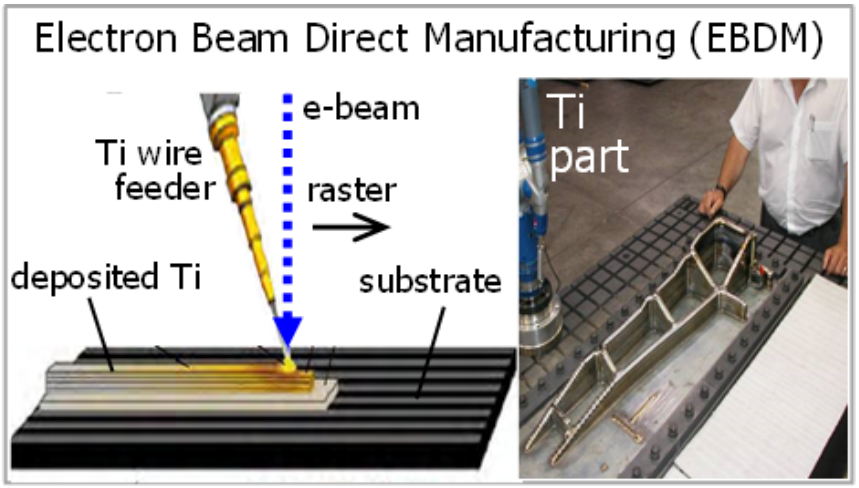
Open Manufacturing Focus Technologies

Two focus technologies chosen to apply and validate OM methodologies

Metals Additive Manufacturing

Emerging technology that is stuck with limited transition



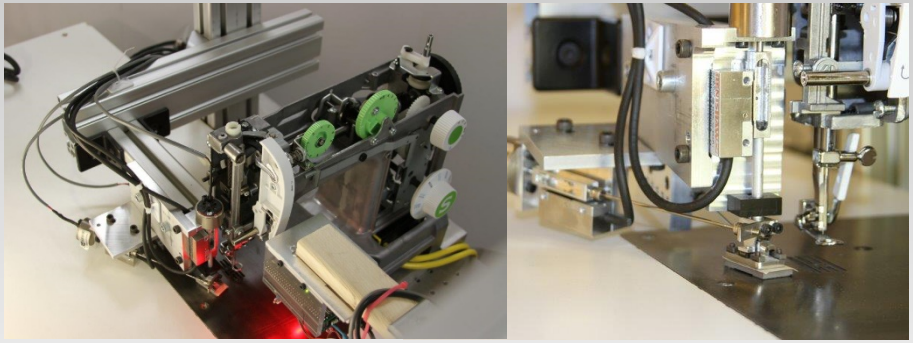


- Reduces material usage, eliminates costly and lengthy tool development, and provides design freedom
- Cost benefits of additive manufacturing are negated by high cost of traditional "make and break" qualification

Accelerate the manufacturing innovation timeline for these high impact processing technologies to unlock design and higher performance opportunities

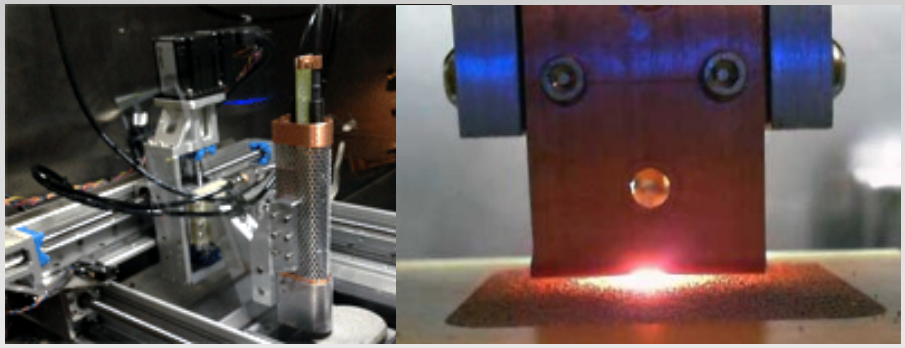
New Manufacturing Technologies

Seamstress-less Sewing



- Prototype demonstration of closed-loop thread-count-based 2-ply fabric motion control & sewing
- Capability to process 833 frames/sec for fabric speeds of up to 20m/min (typical industrial fabric speed)

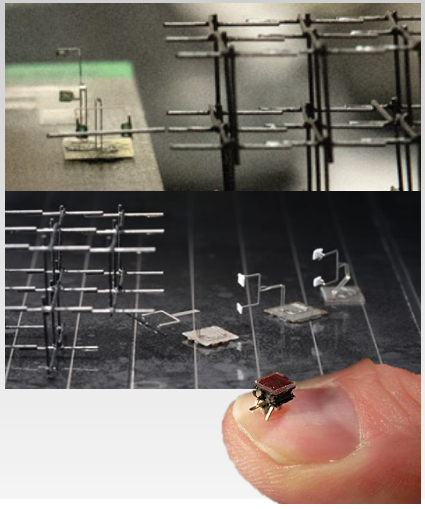
Micro-Induction Sintering (MIS)



- Consolidated γ-TiAl (melts 1460°C) and other powders
- Developed control system software/ monitoring platform

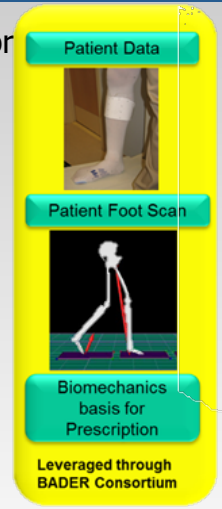
MicroFactory for MacroProducts

- Fabrication of 12 inch truss structure with integrated electronics showing proof-of-concept manufacturing of a structure that cannot be practically built today
- Demonstrated 1024 robots operating simultaneously, showing potential for massive parallelism



Rapid Manufacturing of Customized Orthoses

- Demonstrated framework for affordable, rapid manufacturing in quantities of one – enables increased number of patients, rapid device modifications, and improved durability
- Designs qualified for high-cycle fatigue (3M cycles)
- Reconfigurable tooling concept proven



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