EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

The Aircraft Airworthiness & Sustainment Conference

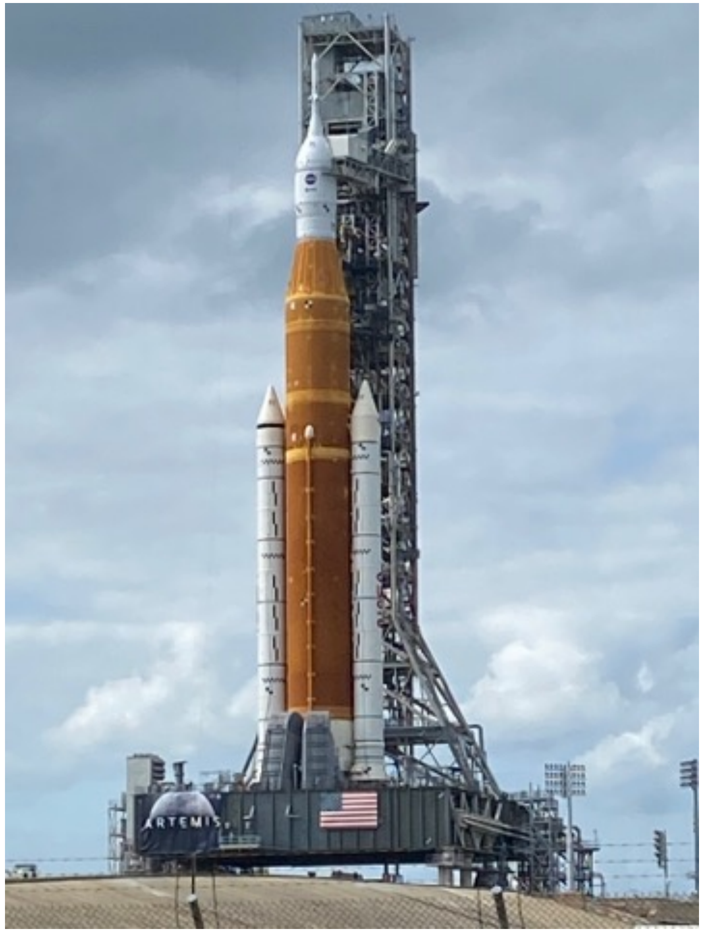
Digital Twins – An Imitation of Life

"Somewhere, something incredible is waiting to be known." Carl Sagan

John Vickers I Principal Technologist I NASA Space Technology Mission Directorate

September 1, 2022

How We Explore… NASA Manufacturing



Digital Twin

Definition of *digital*

adjective: composed of data in the form of especially binary digits, of, relating to, or using calculation by numerical methods or by discrete units

noun: **:** media (such as a photograph) in a digital format

Definition of *twin*

adjective: made up of two similar, related, or connected members or parts, paired in a close or necessary relationship, having or consisting of two identical units

verb: to bring together in close association

What is a Digital Twin?

"Must a name mean something?" Alice asks Humpty Dumpty: "When I use a word… it means just what I choose it to mean, neither more nor less." - Lewis Carroll.

A Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. – Grieves, Vickers

A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organization, person or other abstraction. - Gartner

The ultimate vision for the digital twin is to create, test, build, and operate our equipment in a virtual environment.
– Economist: John Vickers (2015)

A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity. – Digital Twin Consortium

A Digital Twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help decision-making. – IBM

An integrated multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by the Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities and performance over the life of its corresponding physical twin. – Defense Acquisition University

Chronology and Origins

Next-Generation Manufacturing
A Framework for Action
1997

Intelligent and Integrated Manufacturing Systems (IIMS)
National Science and Technology Council
Interagency Working Group on Manufacturing Research and Development
2004

Manufacturing the Future
National…, Interagency Working Group on Manufacturing R&D 2008

Radical Innovation in Design and Manufacturing
A workshop – Disneyland
2009

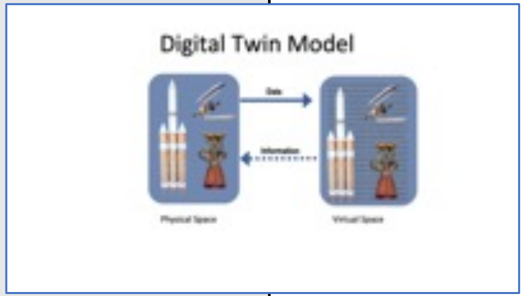
NASA Materials and Manufacturing Technology Roadmap
2010 **Digital Twin

SME Magazine (Kip Hanson) - Where the 'Digital Universe' Is Going and Where Wild Savings Can Be Had Today
2021

Vickers/Grieves introduction 2007

"Conceptual Ideal for PLM"
Product Lifecycle Management (PLM) Center
University of Michigan
2002

Product Lifecycle Management: Driving the Next Generation of Lean Thinking: 2006



Product Lifecycle Management and the Quest for Sustainable Space Exploration
AIAA SPACE Conference & Exposition
2010

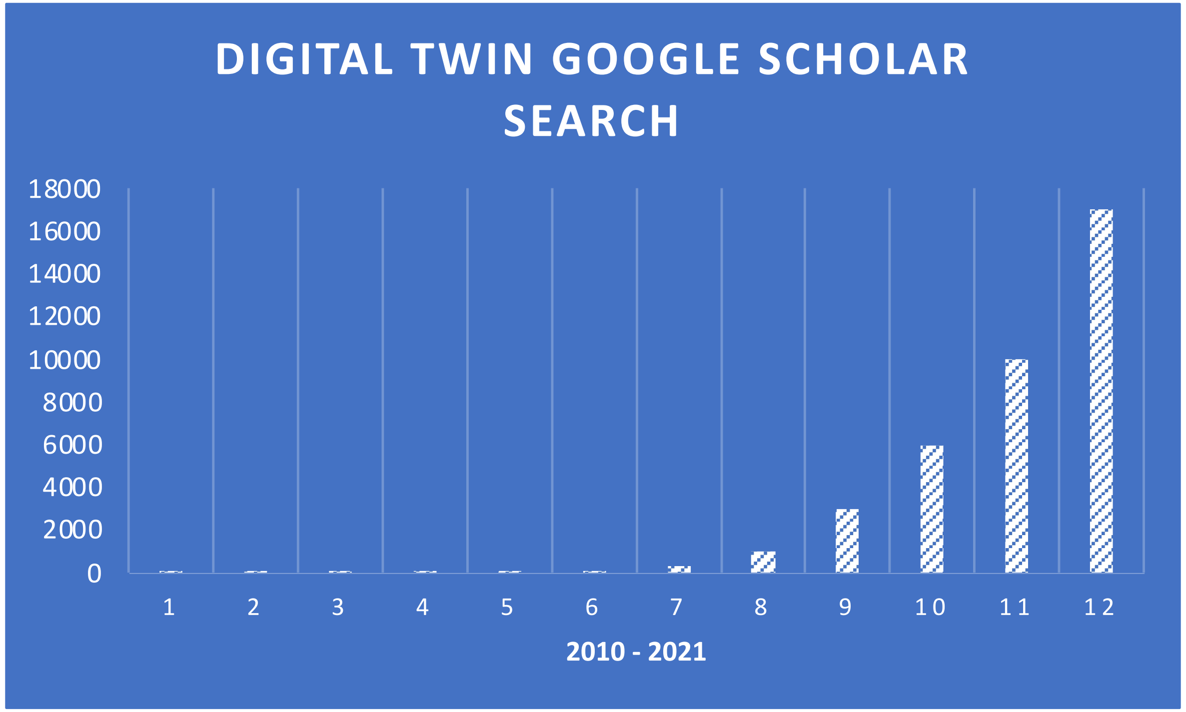
Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management
2011 ** Digital Twin

Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems (Grieves, Vickers) 2017

Holst Memorial Lecture and Award 2022

Digital Twin Expansion

*Google Scholar about 38,800 results vs Google about 9,240,000 results



Expanding the Digital Twin Economy
Digital Twin Consortium
ASME Digital Twin Summit
MxD/DMDII, CESMII, IACMI, America Makes
Centre for Digital Built Britain, European Space Agency (ESA)
IBM, Siemens, Dassault, PTC, NVIDIA, Autodesk

The first direct consequence of the IoT is the generation of huge quantities of data, where every physical or virtual object may have a digital twin in the cloud… European Research Cluster, WP on the Internet of Things, December 2010

"Tomorrow's winners will have very different characteristics than today's winners."
Lester C. Thurow… "The Future of Capitalism"

Digital Twin Expansion

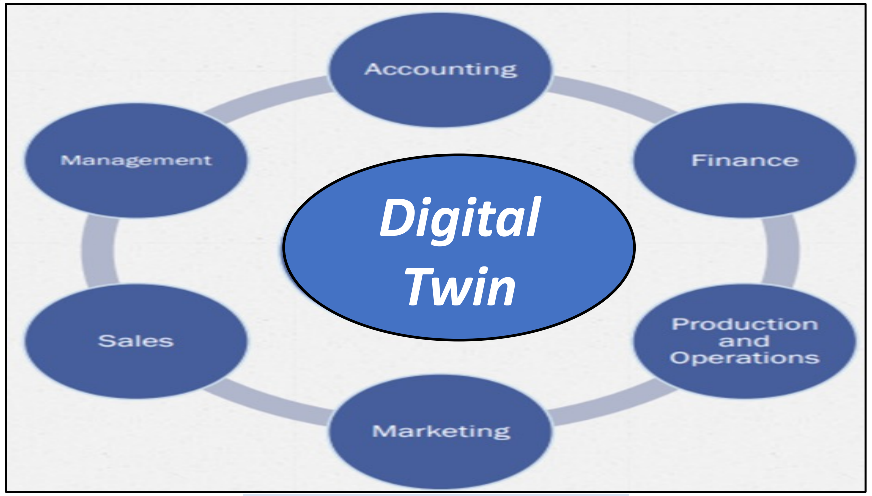
Credit: Jeff Winter

Where does the industrial base stand on adopting digital manufacturing?

1) 292,825 factories in the United States. The vast majority (268,000) have less than 99 employees. There are 846 factories that employee 1,000 or more employees (Source: https://lnkd.in/enEQzYxM)

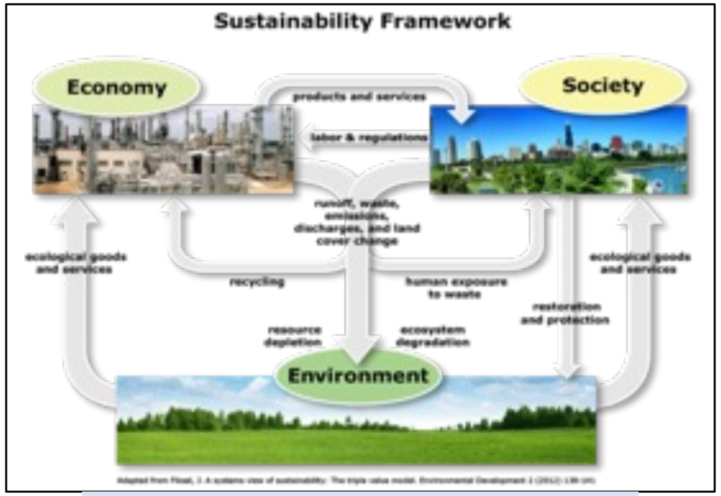
2) Roughly 12.8 million people are employed in manufacturing, making it the 5th largest employer (Source: https://lnkd.in/eNSDg2T2)

Digital Twin Broad Transformation



Business

Health



Environment

Digital Twin of Life

"Designed by pch.vector / Freepik"

You Can't Always Get What You Want

What Digital Twins Are and Not about!

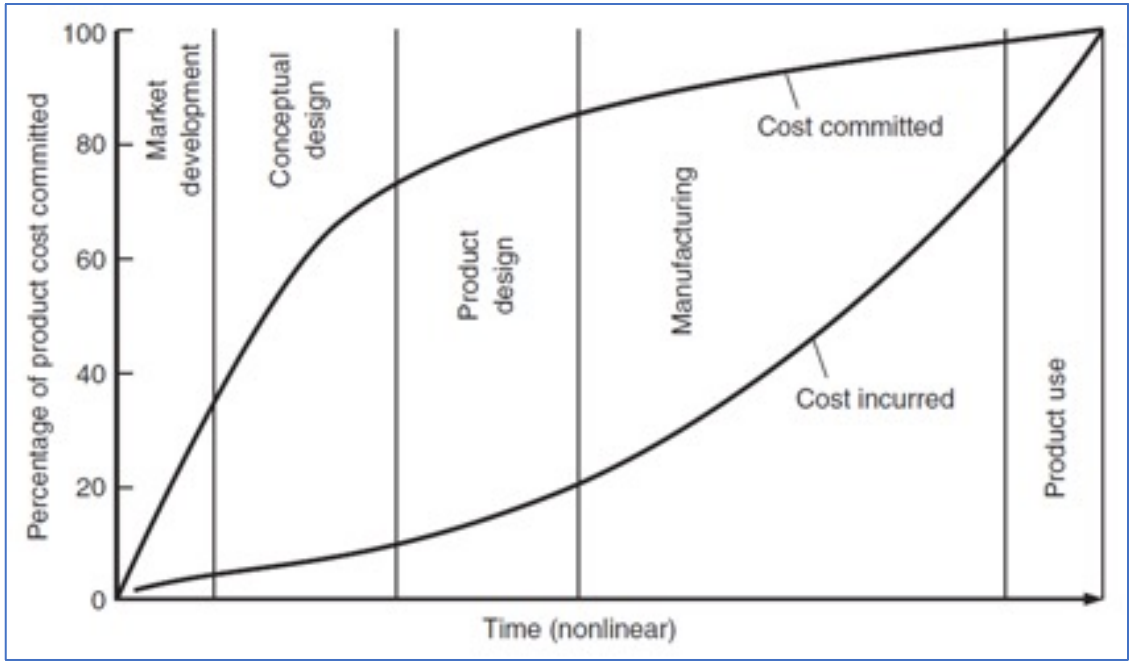
- ✓ Interdisciplinary - analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole
- ✓ Model Based - Model of Models (MBx – model based everything)
- ✓ Collaborative--Predictive--Descriptive--Investigative--Cognitive—Corrective
- ✓ As-Designed – As-Built – As-Operated

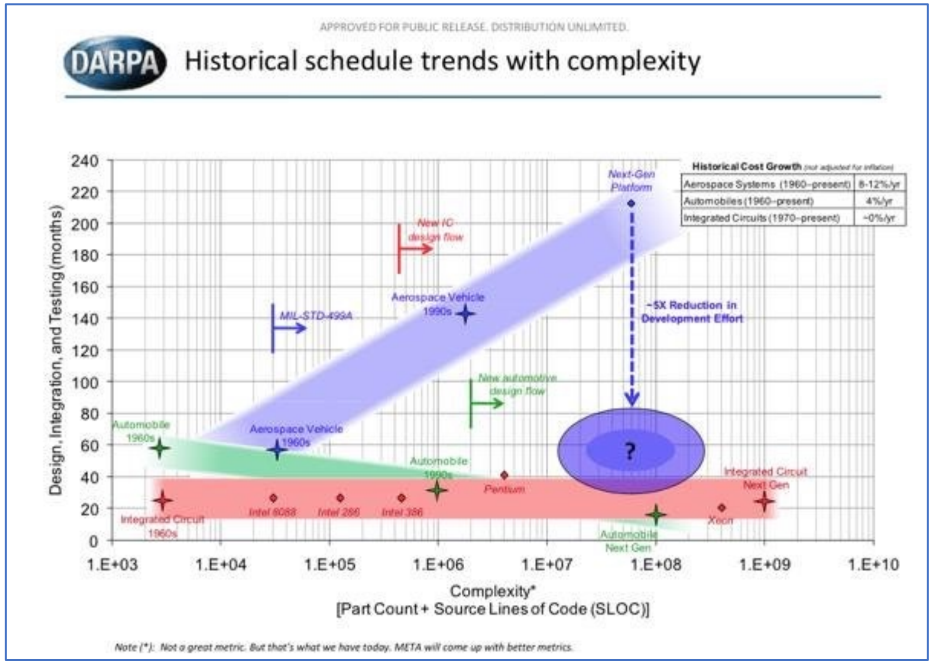
- 🚫 Digital Twin requires a physical asset (apologies to my AIAA friends)
- 🚫 Multidisciplinary - draws on knowledge from different disciplines but stays within their boundaries
- 🚫 Renaming other technology - MBSE, Digital Thread
- 🚫 Siloed environments – "throwing it over the wall"

DARPA - if the experts are laughing at you then you're on the right track

Faster, Better, Cheaper

Faster, Better, Cheaper: A maligned era of NASA's history… Elizabeth Frank





Culture eats strategy for breakfast… Peter Drucker

“Incremental progress through existing regulations that provide a framework of the gradual requirements scale as a function of the application’s criticality”

“The largest obstacle to low-cost innovation is the belief that it cannot be done”…. Howard McCurdy

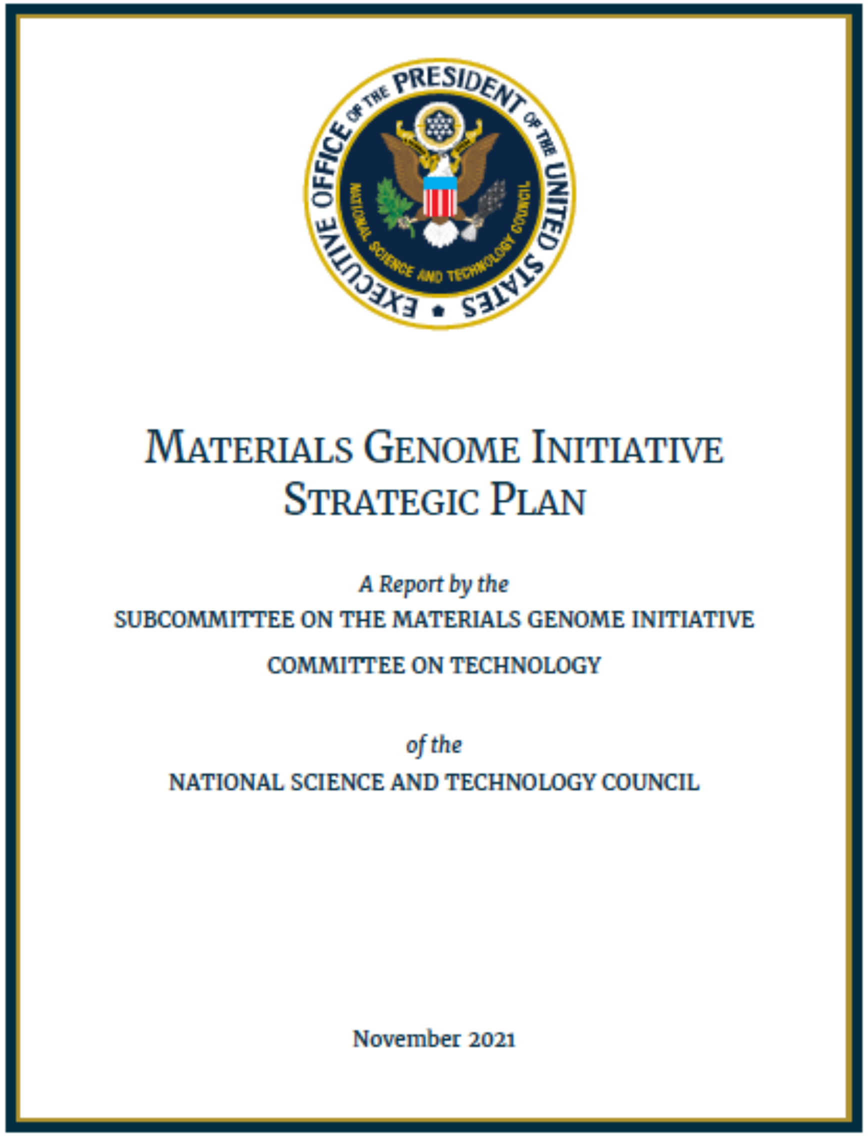
Materials Genome Initiative Strategic Plan

The Materials Genome Initiative was launched to accelerate the discovery, design, development, and deployment of new materials, at a fraction of the cost, by harnessing the power of data and computational tools in concert with experiment.

Significant advances have been made from academia, industry, and government in both expanding understanding and building the foundation of the required infrastructure of models, computational and experimental tools, and data.

Three primary goals for the next five years:

1. Unify the Materials Innovation Infrastructure
2. Harness the Power of Materials Data
3. Educate, Train, and Connect the Materials R&D Workforce



EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

MATERIALS GENOME INITIATIVE STRATEGIC PLAN

A Report by the

SUBCOMMITTEE ON THE MATERIALS GENOME INITIATIVE

COMMITTEE ON TECHNOLOGY

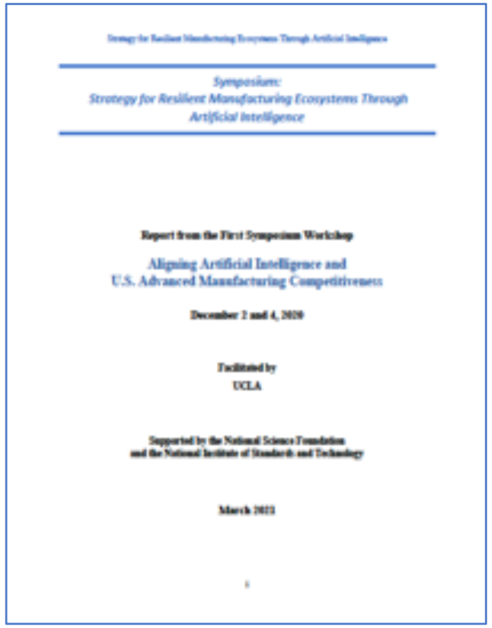
of the

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

November 2021

“Aligning Artificial Intelligence and U.S. Advanced Manufacturing Competitiveness”

Strategy for Resilient Manufacturing Ecosystems through Artificial Intelligence


Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence

Symposium:
Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence

Report from the First Symposium Workshop

Aligning Artificial Intelligence and U.S. Advanced Manufacturing Competitiveness

December 2 and 4, 2020

Facilitated by
UCLA

Supported by the National Science Foundation and the National Institute of Standards and Technology

March 2021

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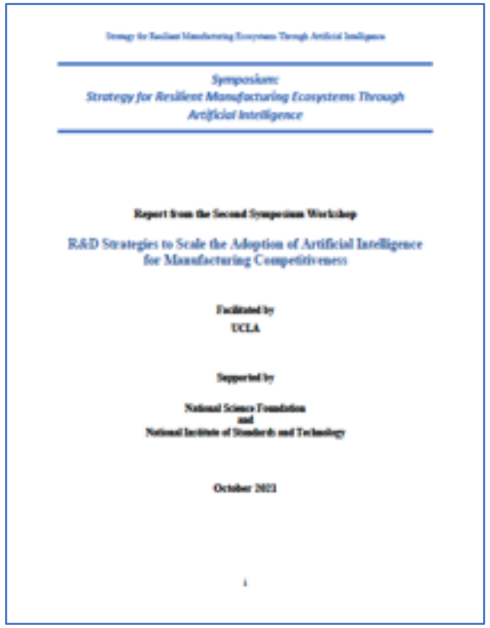
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Symposium:
Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence

Report from the Second Symposium Workshop

R&D Strategies to Scale the Adoption of Artificial Intelligence for Manufacturing Competitiveness

Facilitated by
UCLA

Supported by

National Science Foundation
and
National Institute of Standards and Technology

October 2021

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https://oarc.ucla.edu/nsf-nist-symposium

- **Goal 1: Support small and medium-sized manufactures (SMMs) to digitalize their operations**
  - **Layer 1: Factory floor machine/process asset management**
- **Goal 2: Incentivize large companies to work within their established supplier networks to implement AI methods**
  - **Layer 2: Entire factory and supply chain interoperability**
- **Goal 3: Enable new business models**
  - **Layer 3: Supply chain ecosystem resilience as a result of scaled access to US manufacturing capabilities**

Digital Twin for Composites Manufacturing

Goal

- Digital Systems Models and Digital Twins in manufacturing and performance
- Virtual twins of manufacturing manufacturing processes accelerate product development
- Provide the scientific foundation and applied research for Large-Scale Additive Manufacturing to enhance confidence and success of this new technology

Extrusion Deposition Additive Manufacturing

THERMWOOD LSAM RESEARCH LABORATORY

PURDUE UNIVERSITY

AIAA Complex Aerospace Systems Exchange

ASCEND™ 24-26 OCTOBER 2022 LAS VEGAS & ONLINE

CASE Complex Aerospace Systems Exchange

AIAA Forum 360
Addressing Increasing Complexity in Aerospace Systems

- **The complexity of aerospace systems has been rapidly increasing and promises to do so at an increasing rate. This increasing system complexity has profound consequences for system performance, reliability, affordability, manufacturability, supportability, and other characteristics. These issues may be addressed and mitigated by new technologies such as Digital Twins (DT), Virtual Reality (VR), Artificial Intelligence (AI), Machine Learning (ML), etc.**

- **In this session, we will hear our panel of experts in the AIAA Complex Aerospace System Exchange (CASE) discuss how increasing system complexity and systems engineering is being addressed in their organizations.**

https://www.aiaa.org/events-learning/events/Complex-Aerospace-Systems-Exchange-CASE

NASA Space Technology Research Institute

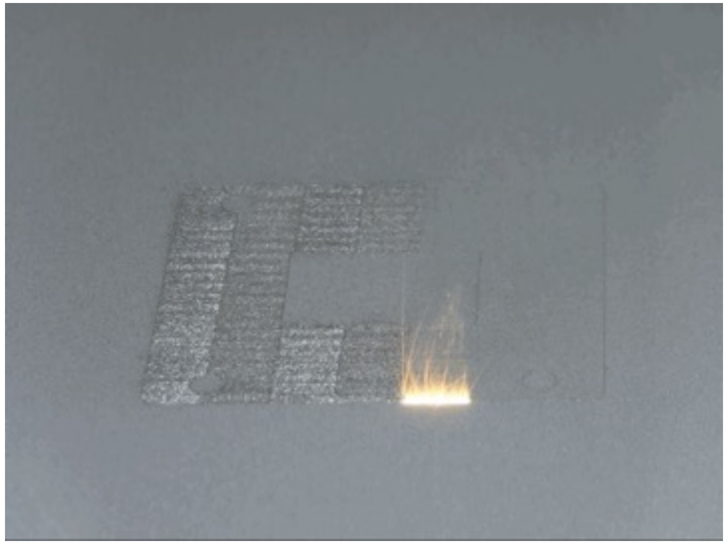
Accelerating Additive Manufacturing Certification with Model-Based Tools

The goal of the institute is to conduct ground-breaking interdisciplinary research to exploit new advancements in computational tools in concert with experimentation to advance the use of model-based tools for accelerated certification of critical additively manufactured aerospace products.

- The overall approach focuses on utilizing computational methods for AM through integrated computational materials engineering (ICME), materials genome initiative (MGI), and other model-based tools.
- This approach is desired instead of the traditional building block approach of trial-and-error experimental methods that progress step-by-step from the coupon level up to the final full-scale products, which “takes too long and costs too much”.

Award Information

- **Expected duration: 5 years**
- **Award amount up to $3M per year over 5 years**
- **Award instrument: grants to U.S. universities**
- **Low to mid TRL**
- **Preliminary Proposals Due August 3**
- https://www.nasa.gov/directorates/spacetech/solicitations



Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

1) Additive post-processing techniques for internal surfaces to improve flow performance and mechanical properties; 2) Evolution of enabling materials for high performance and extreme environments; and 3) <u>Advanced materials and process modeling and validation to enable additive digital model twin.</u>

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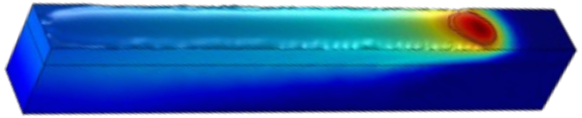
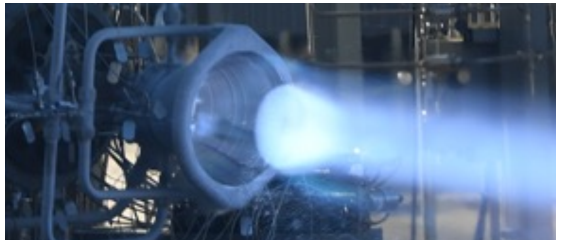
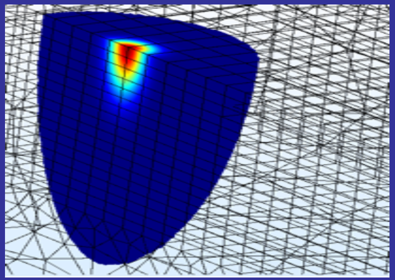




Computational Materials for Material Processing

TACP - Transformational Tools & Technologies Project



Volumetric Heat Source

Microstructure Evolution

Simulate Fundamental Physics Governing Processing

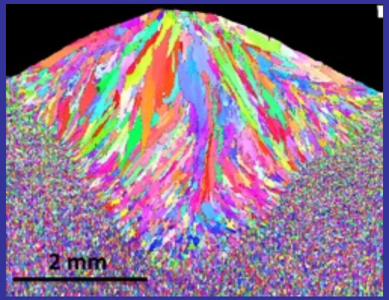
- Determine role of processing parameters on location-specific properties
- Simulate physical processes including heat transfer, powder melting, fluid flow and solidification at the melt pool
- Simulate microstructure and defect evolution

Develop Physically Correct Models Needed to Support Certification of AM Feed Stock and Manufacturing Process

Characterize Material Evolution using Experimental Methods

- Employ heavily-instrumented AM machine and synchrotron beam lines
- Produce coupon-size specimens using well-controlled parameters
- Understand details of the relationship between processing parameters and resulting microstructure

Selective Laser Melting



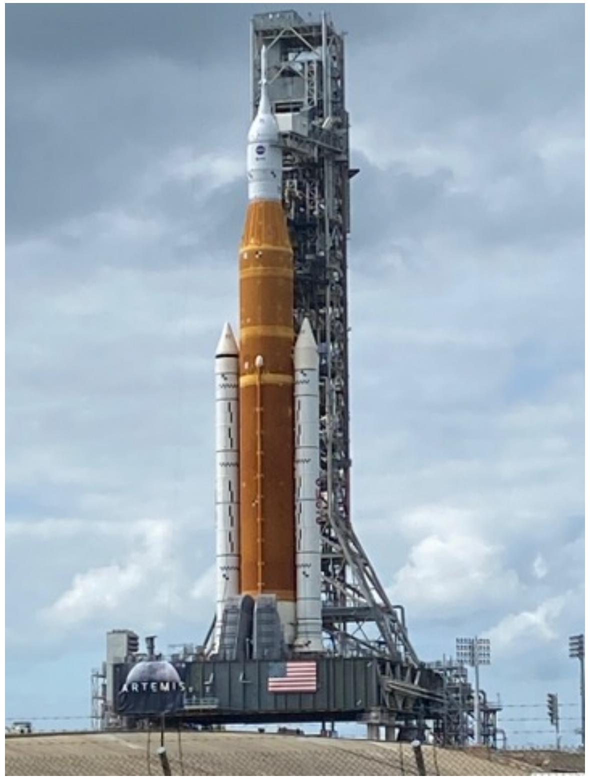
Grain Structure from Additive Process

Lunar Surface Systems Digital Twins

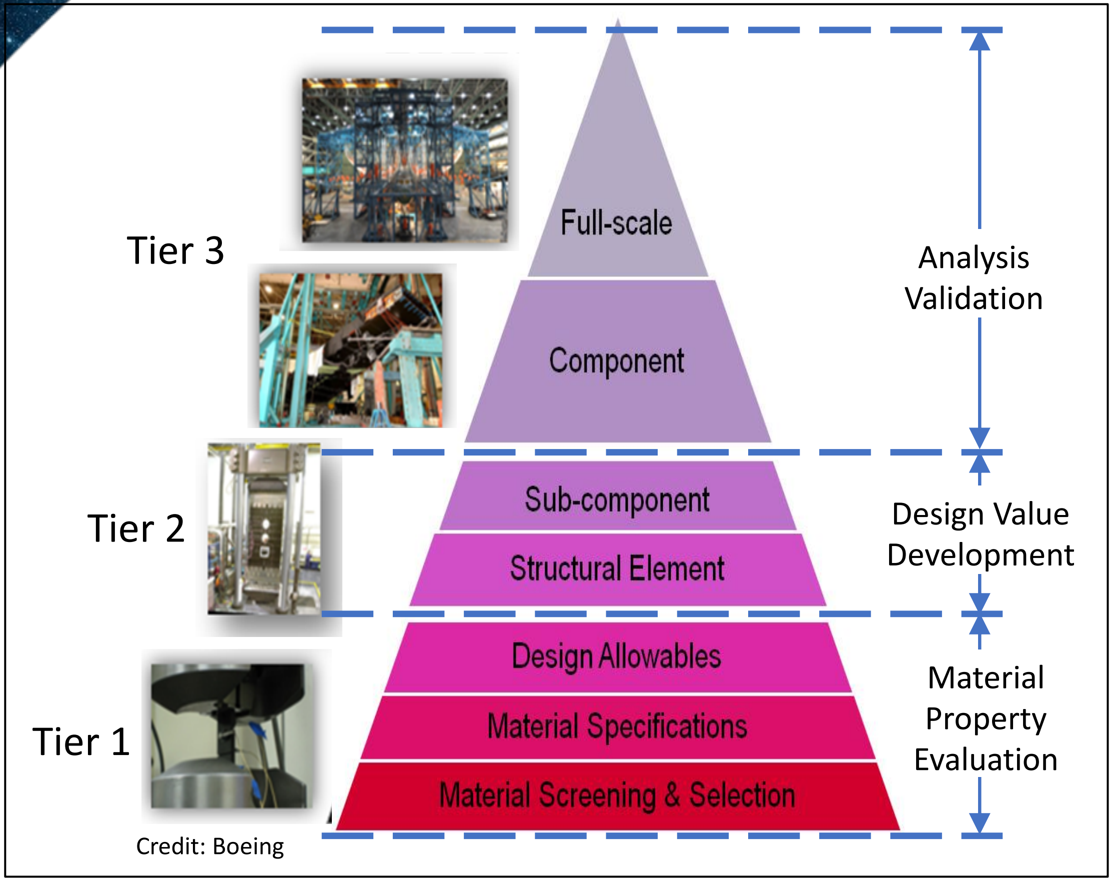
Digital Twins
Crucial to a Sustainable Presence on the Moon

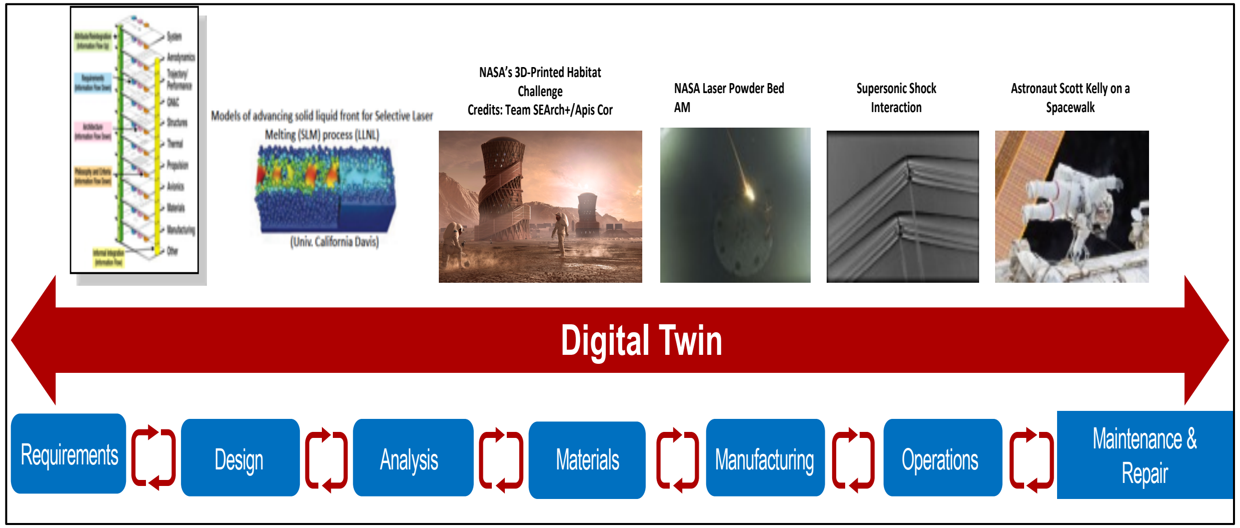
- Advances digital transformation and digital twins for exploration
- Creates a platform for simulation, prediction, sensing, and decision-making Accelerate gaps identification, innovation, and technology advancement
- Transforms research, design, and workforce
- Simulates technology scenarios and optimizes operations and sustainability
- Build a digital smart network of architectures and assets
- Enables collaborative interoperable systems
- Winning models continuously updateable with later experimental data maximizing ROI of future efforts

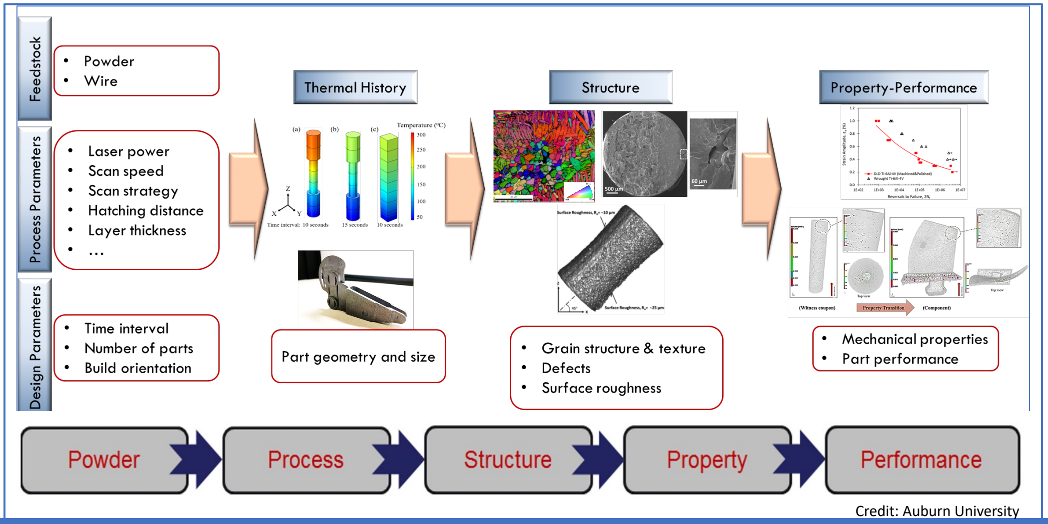
Digital Twins Creating a Next Generation Capability for NASA's Michoud Assembly Facility



Digital Twin! "A Little Less Conversation A Little More Action Please"



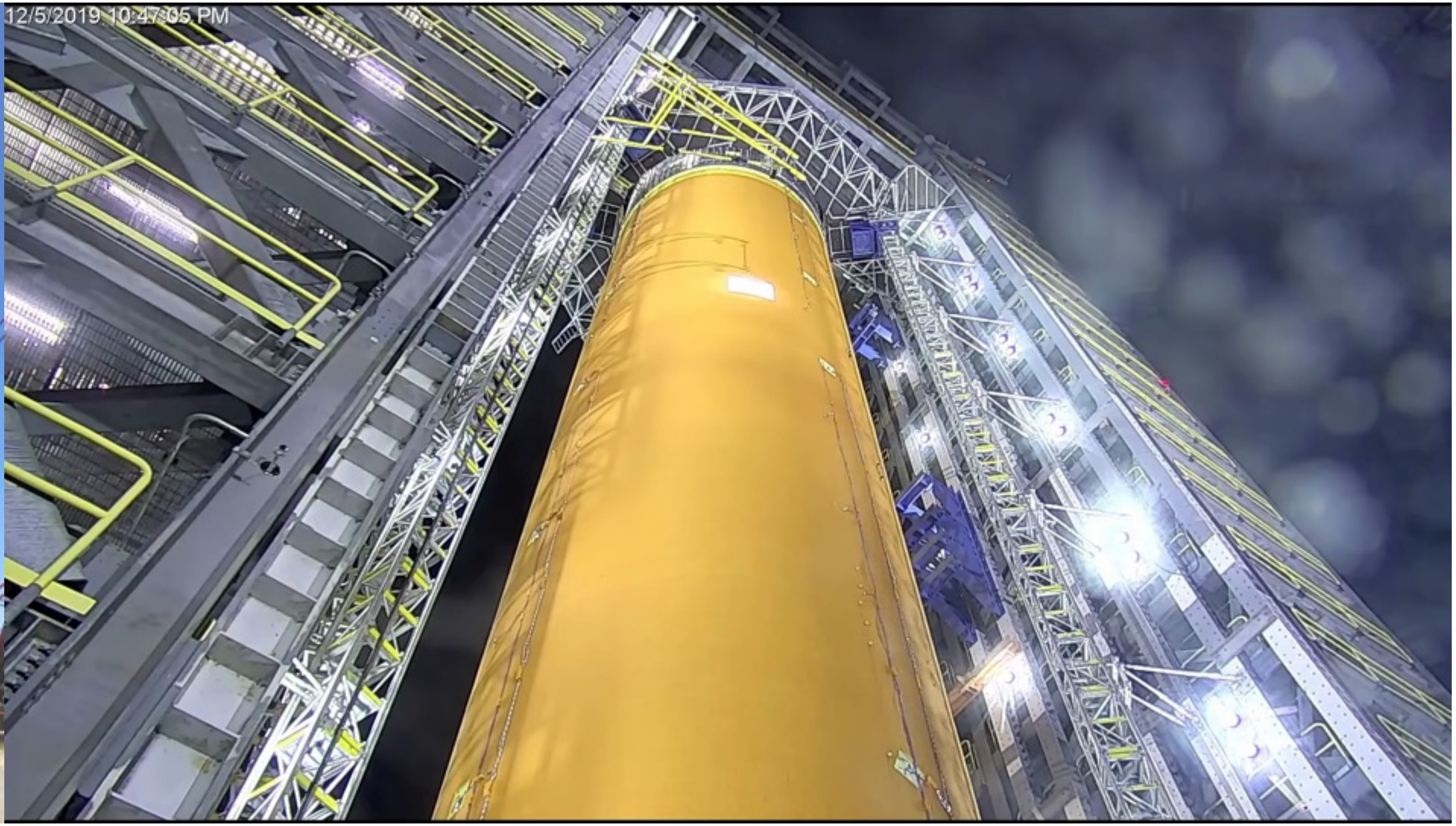




Product Development, Testing and Certification Today

"It takes too long and costs too much to certify aerospace structures" - Exhaustive testing done to support analysis

Testing and Certification Today



Past is Prologue

Linkages between Science, Technology and Commerce

A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill. *Vannevar Bush, head of the U.S. Office of Scientific Research and Development during World War II*


Technology Drives Exploration
Thank You!
john.h.vickers@nasa.gov