The Institute for iacmi Advanced Composites Manufacturing Innovation

THE COMPOSITES INSTITUTE

Digital Revolution in Composites Manufacturing

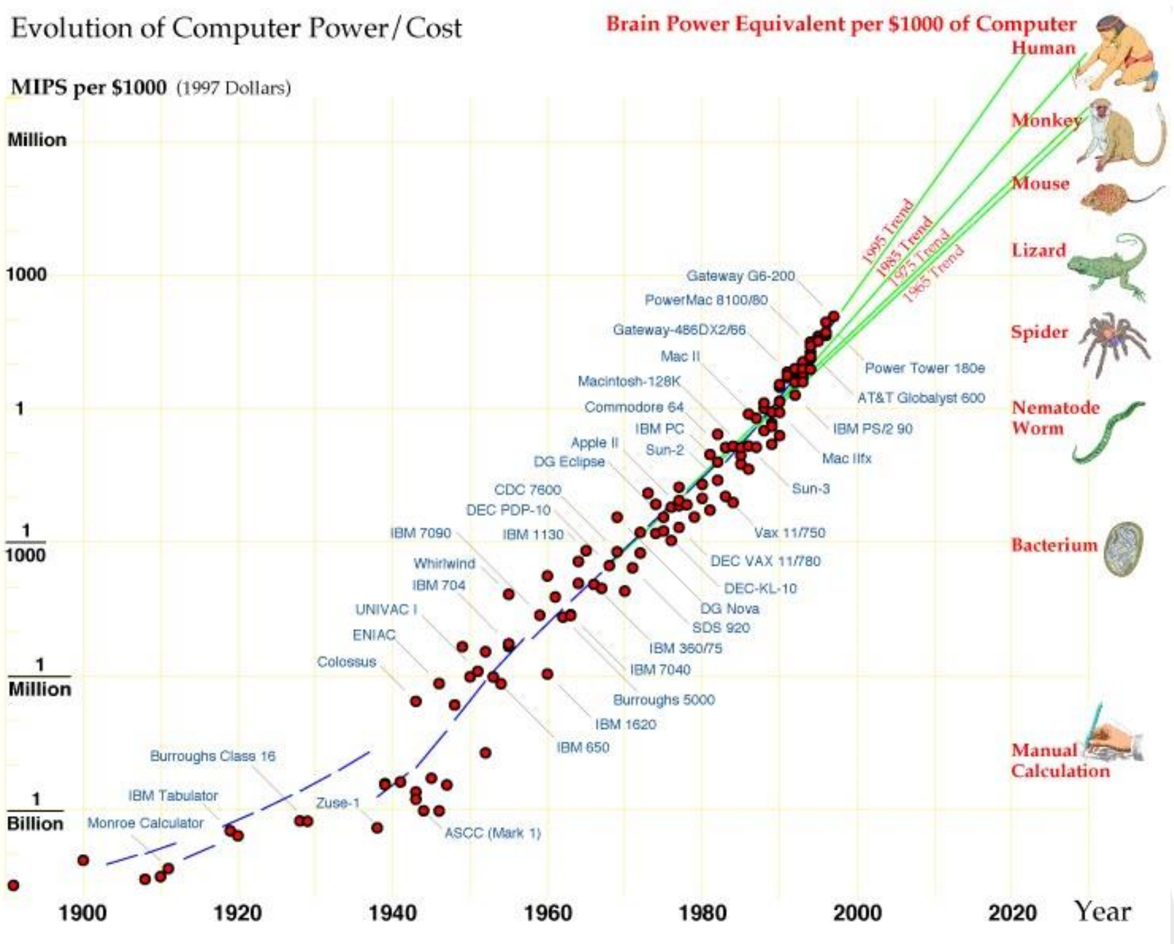
CENTER OF EXCELLENCE
ADVANCED COMPOSITES
Dassault Systèmes

Composites Manufacturing & Simulation Center™

PURDUE UNIVERSITY

Most important change in technology in the last five decades?

Computing power has grown by a factor of 10,000,000,000 since 1970!



The digital revolution in engineering enterprises

- The digital revolution has not been uniform across the manufacturing industries
- Leading Manufacturing OEMs are investing in the digital transformation
- Supply chains are especially problematic in the deployment of digital manufacturing methodologies
- Much of manufacturing supply chain remains highly empirical, especially in large scale products

Why is the digital revolution slow to be adopted by the manufacturing supply chain?

- New digital products are needed that enhance supply chain technologies that do not require current levels of investment for use to achieve ROI.
- The benefits of the digital revolution require significant investment in digital technology and human talent.
- The supply chain ROI in current digital technology appears distant to supply chain leadership.
- Digital products and services require entirely new business approaches.

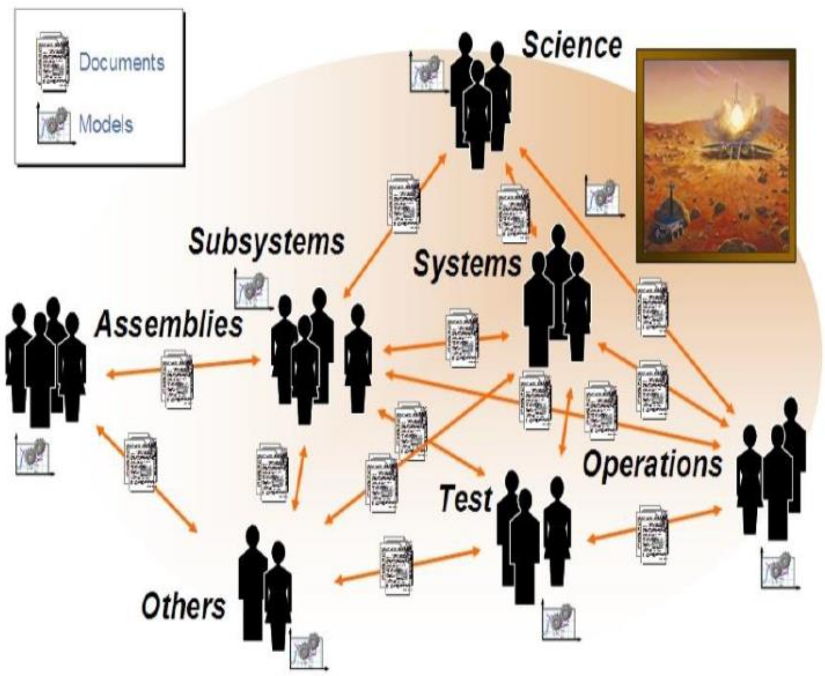
The digital revolution in engineering enterprise

- Model-based systems engineering
- Engineering enterprise in the shared systems environment
- Digital systems models
- The Virtual Twin
- A vision for the digital revolution in advanced composites manufacturing
- Examples of success

Model-based systems engineering

- Model-based engineering consists of Digital Systems Models (DSM) and Digital or Virtual Twins
- Digital representation is the central competency
- Computing power since 1970 has increased by 1,000,000,000,000 times
- Digital representation replaces words and 2D drawings with 3D geometry and physics-based information
- Virtual reality replaces tactile reality

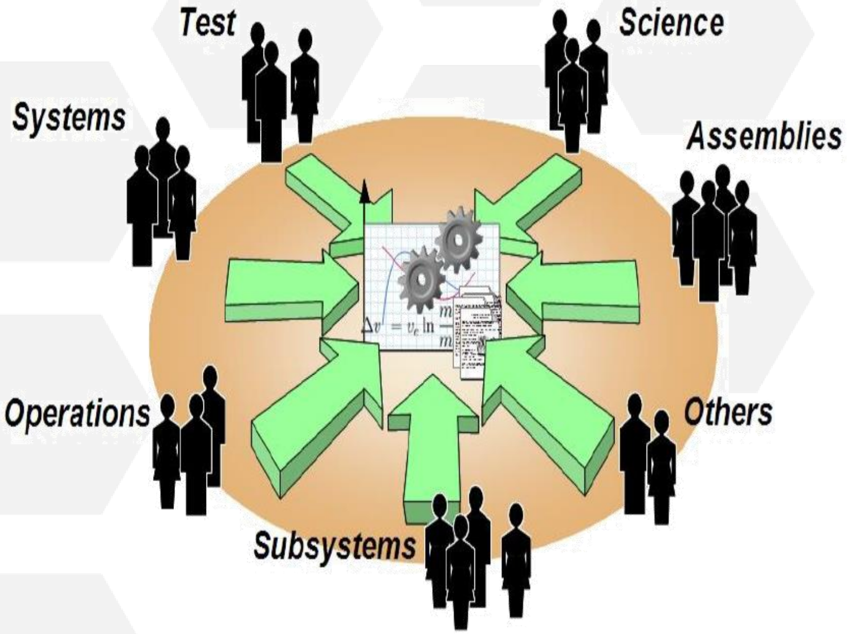
Document-based Engineering



Saulius Pavalkis
CATIA NO MAGIC -CYBER SYSTEMS
Industry Business Senior

- Development of large-scale engineering operations has been largely document-based.
- Complex systems require numerous iterations between competencies that hold sub-sets of the knowledge required for decisions.

Shared systems of the future



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Industry Business Senior

- Integrated models replace documents
- Competencies can simultaneously participate in developing knowledge required for decisions
- The savings in decision making time and the degree of optimization possible are empowering
- Decisions can be traced over the life of the product

What is a Digital Systems Model?

The Digital Systems Model (DSM) is a surrogate of a product. Its level of fidelity and its elements provide a framework for the enduring source of truth for data driven decisions about the product or process.

Adapted from "Boeing Digital System/Digital Twin"

What is a Virtual Twin?

A Virtual Twin (VT) is a virtual representation of the properties and behaviors of a physical system or process that enables optimization of performance and represents the physical system throughout its operational life.

Adapted from "Boeing Digital System/Digital Twin"

The Vision for the Digital Tools of the Future

- They replace empirical trial and error with information for rapid "first time right" decisions in manufacturing
- Characteristics of the digital manufacturing tools
  - Ease of use by typical practitioner
  - Only modest support by computer science experts
  - Complete digital representation of the process or product
  - AI enhanced functionality
  - Real time results
  - Access to evolving ideas and requirements
- This class of tools will work on your smart phone & tablets and be AI-based

The Vision for the Digital Manufacturing Revolution in Advanced Composites

- Digital Systems Models (DSM) and Virtual Twins (VT) in manufacturing and performance
- Advanced thermoplastic composites for high-rate manufacturing processes
- The integration of thermoplastic materials, Manufacturing Digital Systems Models and Virtual Twins
- Partnerships between engineering enterprise, software platforms and academia
- The beginning of a revolution in engineering with first benefits to composites manufacturing

Indiana Manufacturing Institute

3DEXPERIENCE

3DEXPERIENCE CENTER OF EXCELLENCE ADVANCED COMPOSITES

- Dassault Systèmes **3DEXPERIENCE** provides the platform
- Model composites manufacturing-based performance
- Virtual twins of composites manufacturing and performance is multi-physics with AI
- World-class research and education
- Bridge between the academic and industrial communities
- Hosts the University Preeminent Faculty Team in Advanced Composites Manufacturing
- Full-time technical staff, post-doctoral researchers, twenty graduate students
- State-of-the-art manufacturing and characterization facilities
- One-stop-shop for composites design, manufacturing, prototyping and model validation

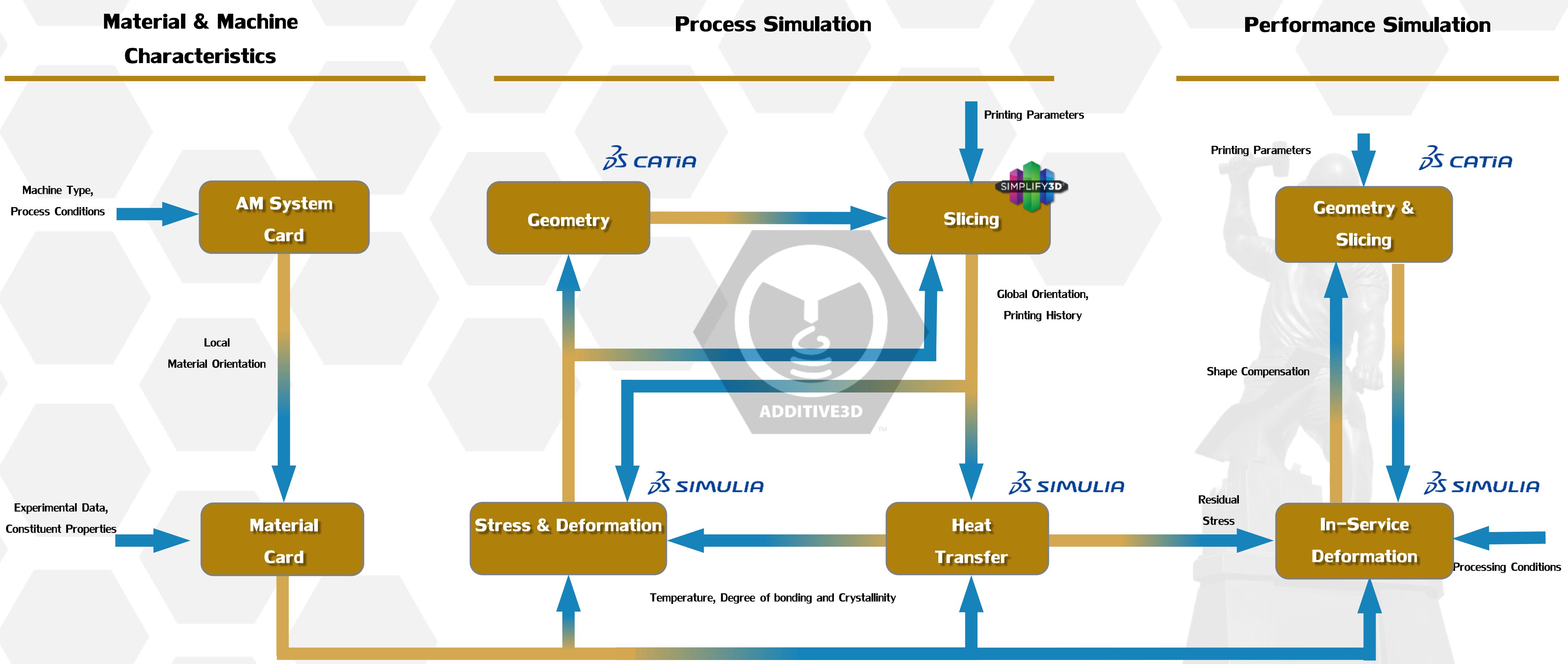
Virtual Twin examples of success

- Large-Scale Composites Additive Manufacturing
- Stamp Forming with Thermoplastic Composite Systems
- 3D Printed Large-Scale Composites Autoclave Tooling
- Tool Shape Compensation for Autoclave Tooling
- Tool Shape compensation for Thermoplastic Composite Stamp Forming

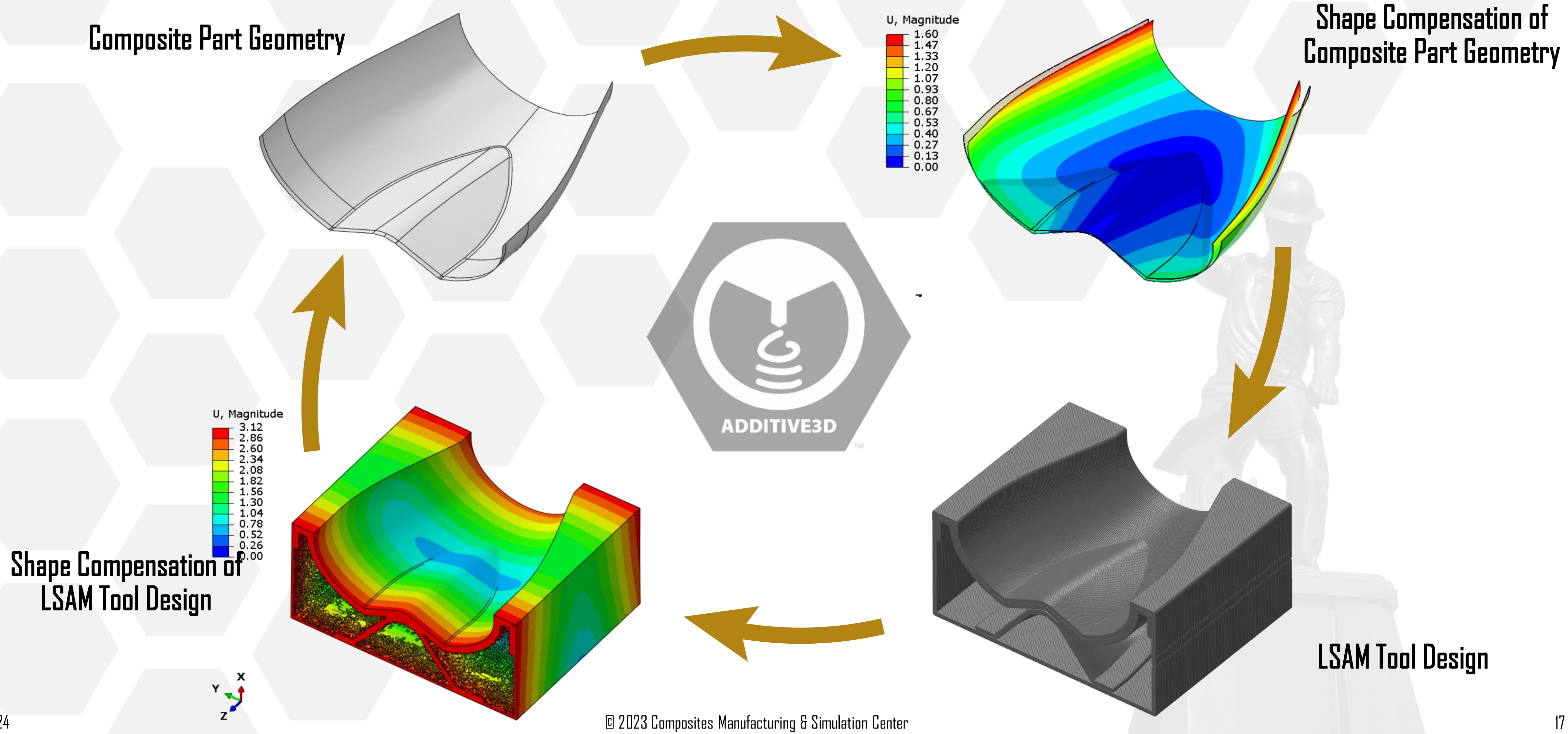
Thermwood LSAM Research Laboratory at Purdue

Goal: Provide the scientific foundation and applied research for Large-Scale Additive Manufacturing to enhance confidence and success of this new technology.

EDAM Virtual Twin ADDITIVE3D™



Simulation Driven Part & 3D Printed Tool Shape Compensation

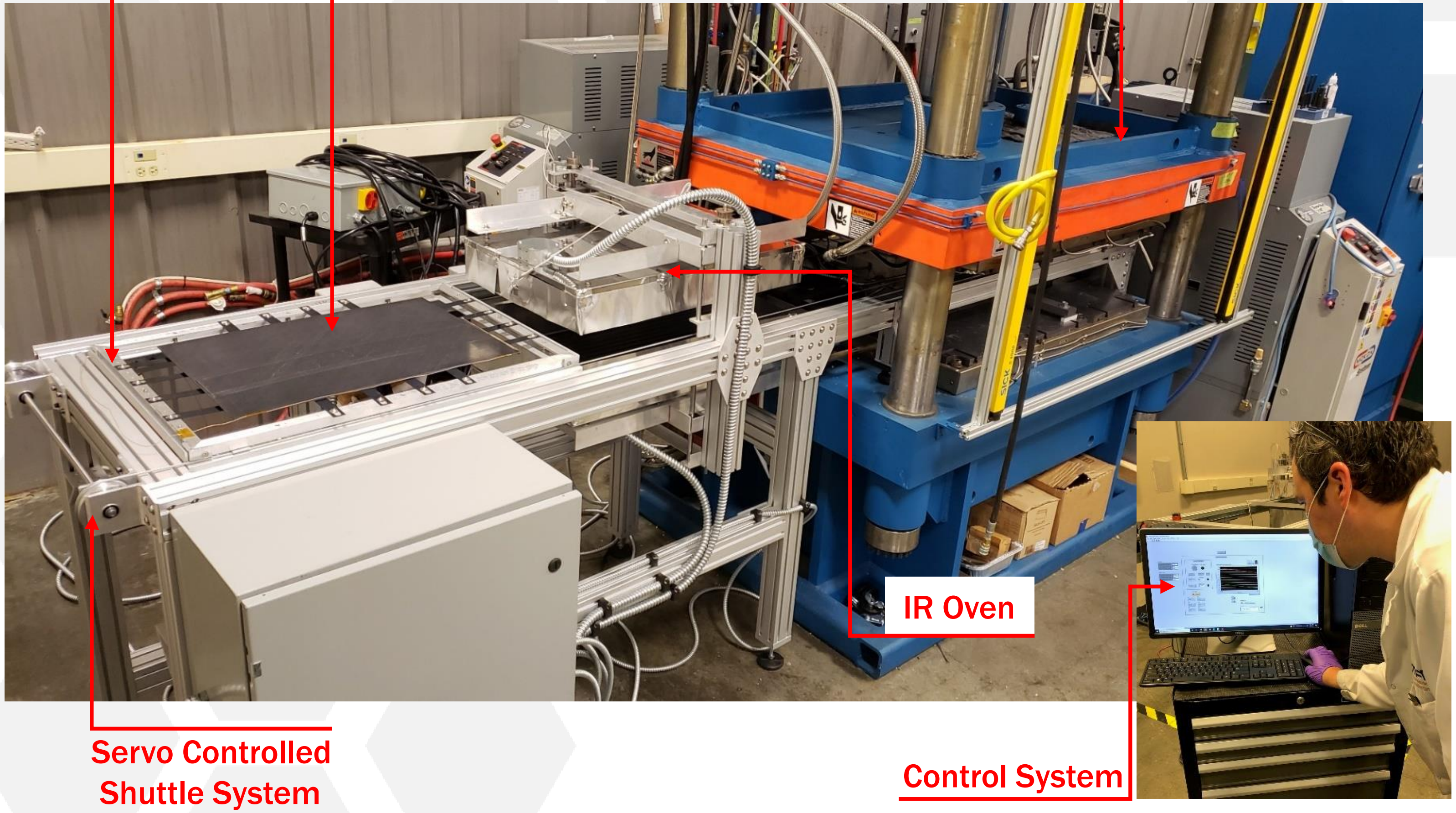


Thermoplastic Stamp Forming

Picture Frame for Mounting Blank

Blank

250 T Press

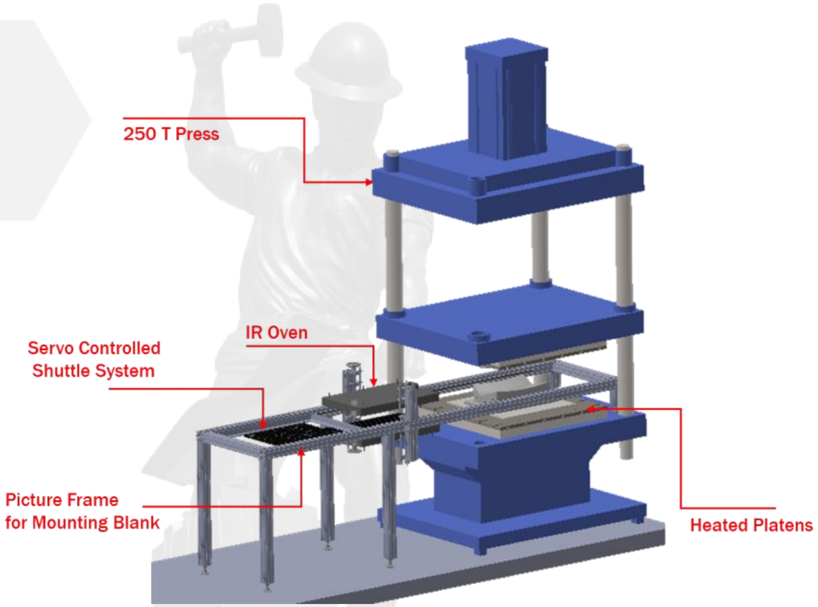


IR Oven

Servo Controlled Shuttle System

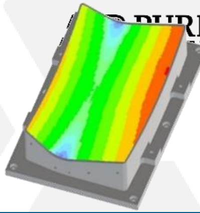
Control System

CAD Forming System



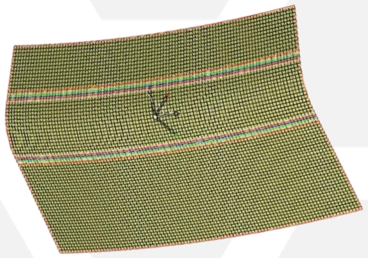
Thermoplastic Composite Stamp Forming Virtual Twin

FORM3D ™



3DEXPERIENCE | CATIA

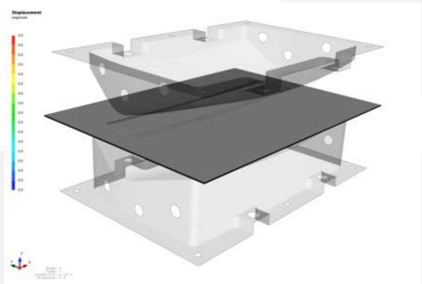
python™ SIMULIA Abaqus



3DEXPERIENCE | CATIA

Catia 3DX: Composite Design

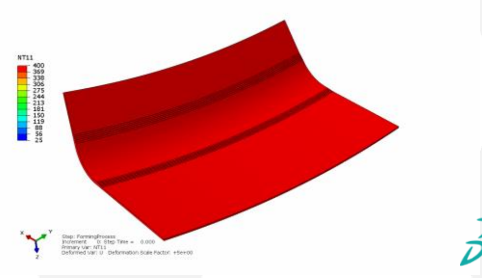
- Propagated:
  - Initial part, blank and tool shapes
  - Layup with ply-drops
  - Create mesh and assign element types



ANIFORM VIRTUAL FORMING

AniForm: Forming Large Deformation

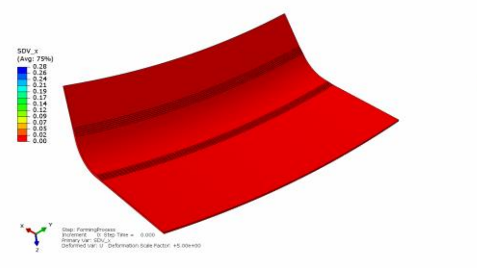
- Propagated:
  - As formed fiber orientations
  - Ply thickness
- Direct:
  - Wrinkle assessment



SIMULIA Abaqus

Abaqus: Forming Heat Transfer

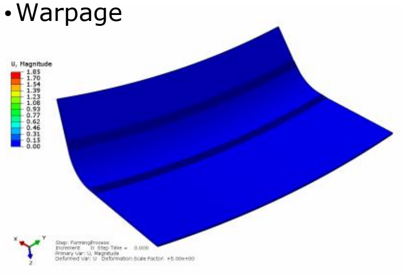
- Propagated:
  - Thermal history
  - Crystallization history
- Direct:
  - Crystallinity field



SIMULIA Abaqus

Abaqus: Forming Warpage

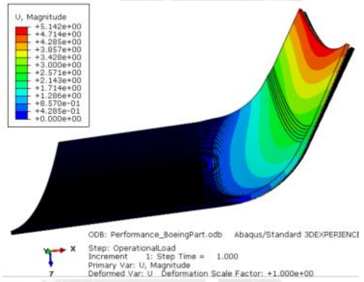
- Propagated:
  - Stress state
  - Warped shape
- Direct:
  - Warpage



SIMULIA Abaqus

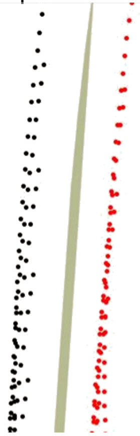
Abaqus: Performance

- Direct:
  - Misfitting stresses
  - In-service deformations and stresses

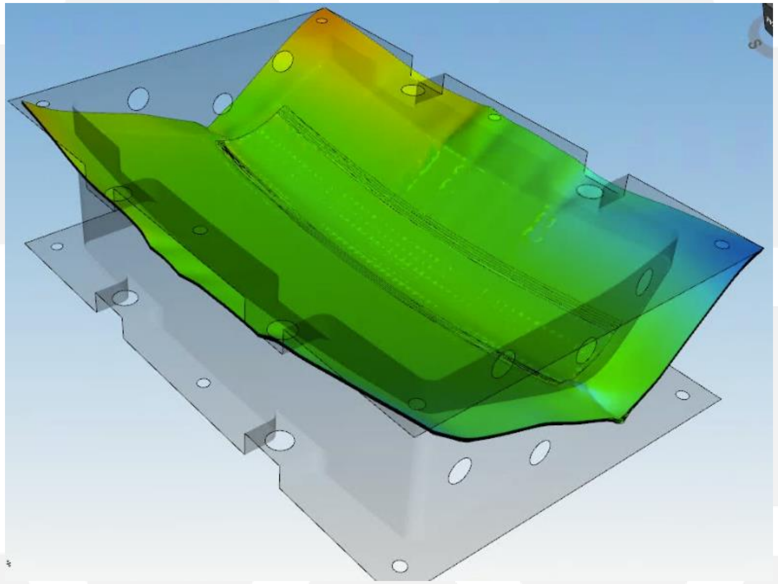


Python/Abaqus: Compensation

- Reverse nodal displacement of initial part surface to achieve desired final part shape.
- Used to compensate tool.

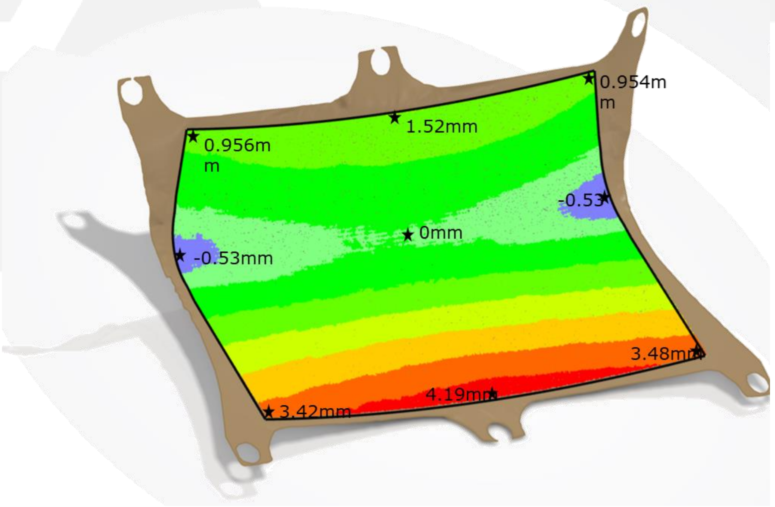


FORM3D Validation



FORM3D

Validation



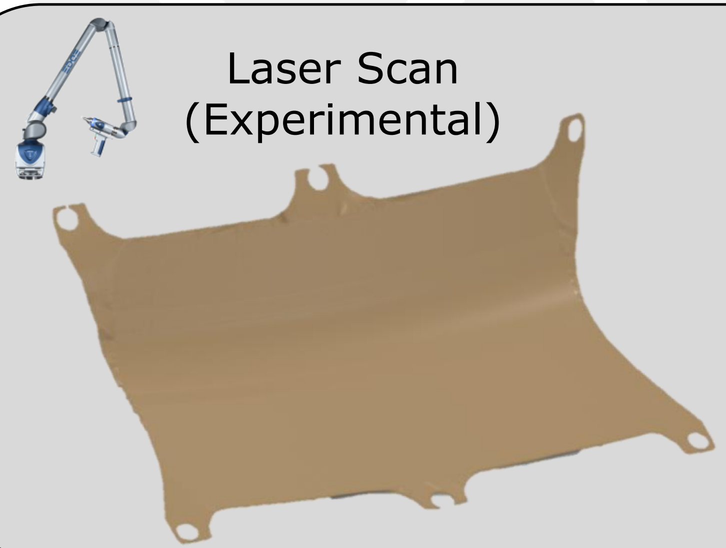
Experiment

What does FORM3D ™ Deliver?

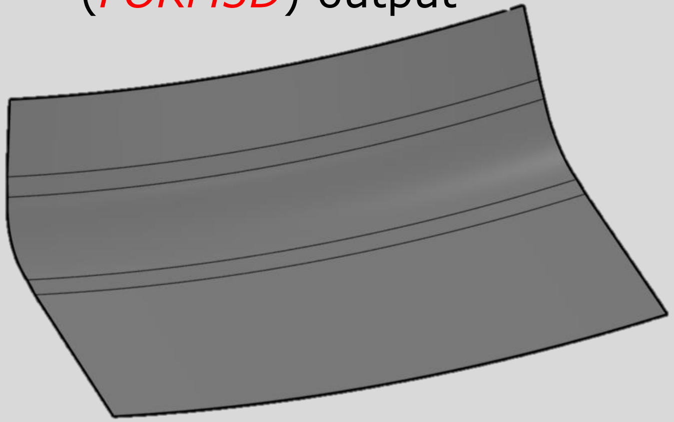
- Virtual Twin
  - Captures each of the important phenomena that occur in physical part production process
  - Digital thread is maintained from beginning to end of part fabrication
  - Can reside within larger software environments (e.g. Dassault 3DX)
  - Assisting the transition to industry 4.0
- "First-time-right" tooling & part production
  - Predict part shape evolution through the process cycle
  - Run case-studies and select "optimal" process settings
  - Predict location of wrinkle defects
  - Predict the tool shape required to make the correct part shape
    - Tool shape compensation

FORM3D ™ Part Shape Prediction - Validation

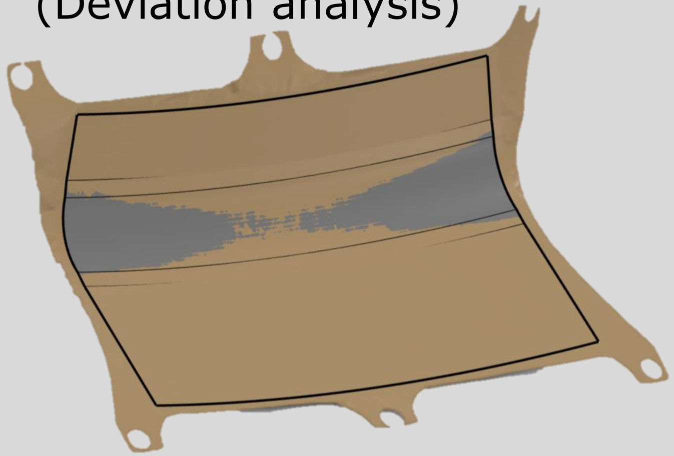
Laser Scan (Experimental)



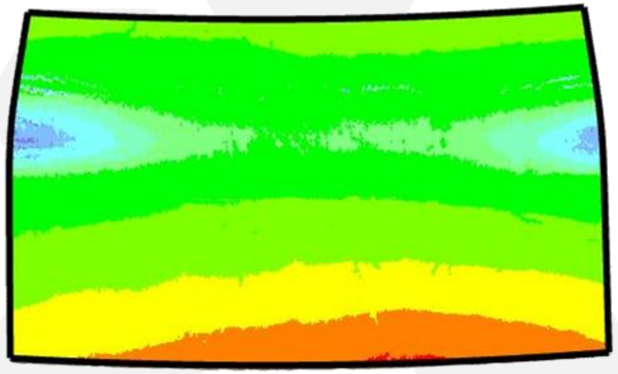
CAD or Simulation (*FORM3D*) output

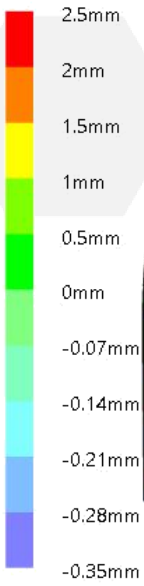


Overlay & compare (Deviation analysis)

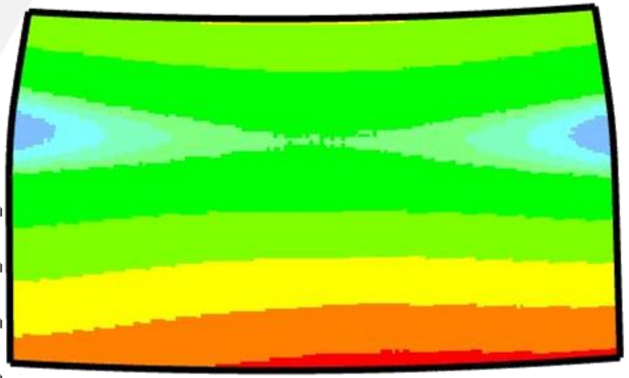


Experimental vs. nominal

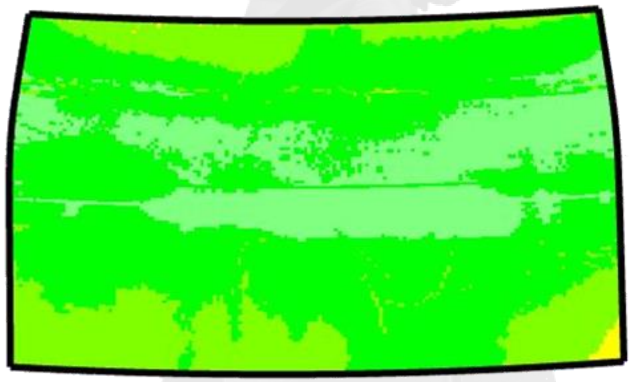


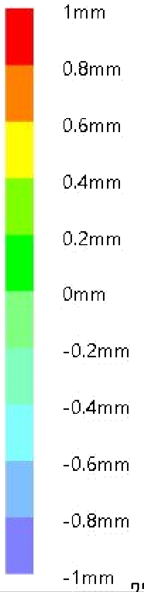


FORM3D prediction vs. nominal



FORM3D vs. Experimental

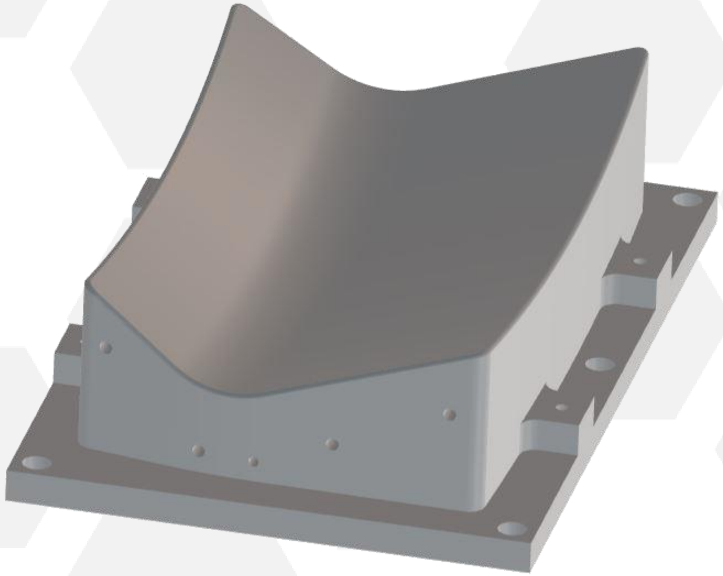


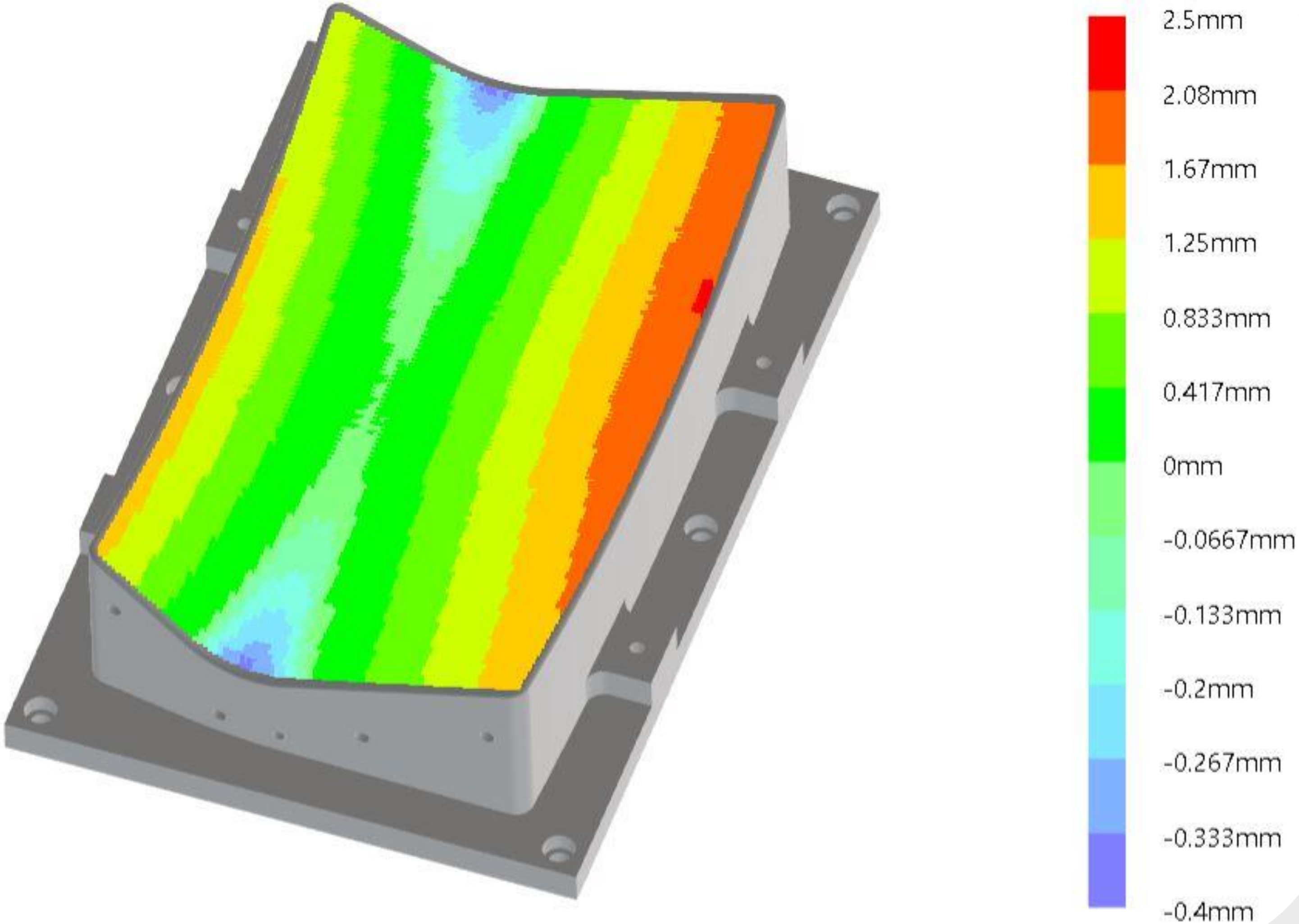


Typically predicts ±0.2mm
Maximum deviation ~0.5mm

Tool Compensation: Result

Nominal

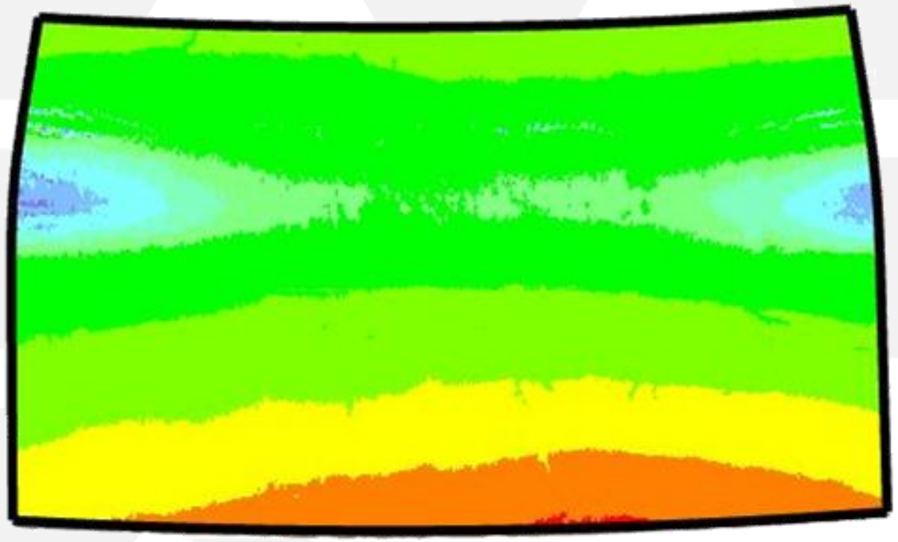




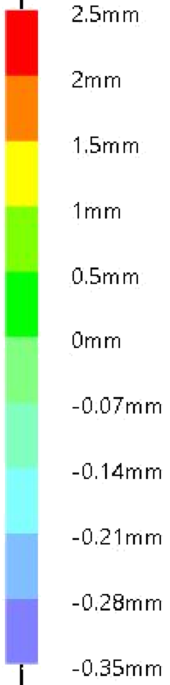
Tool Compensation: Influence on final part shape

Experimental part vs. CAD "designed" part

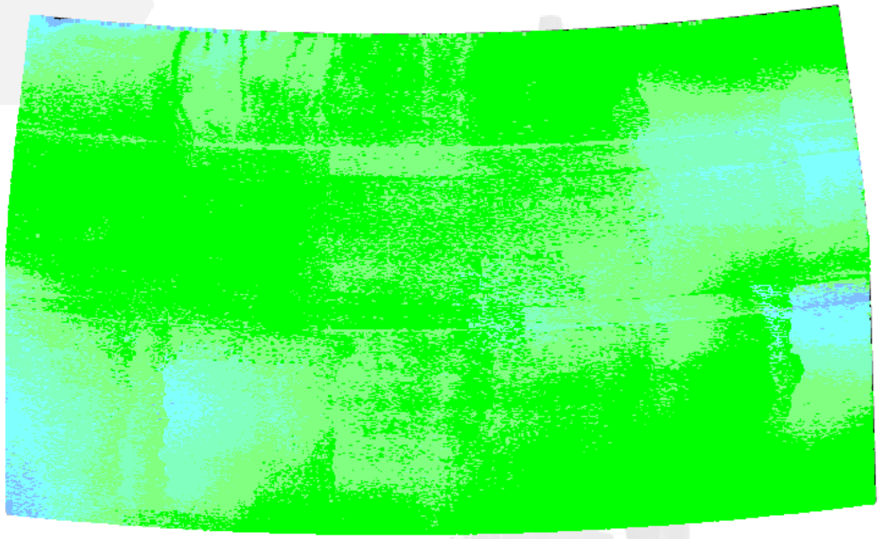
Before tool compensation



Part deviation: difference from desired shape
+2.5mm, -0.35mm



After tool compensation



Part deviation: difference from desired shape
±0.25mm

The Digital Transformation in Composites Manufacturing

- Document based engineering is the past
- Integrated digital models will replace documents
- Future engineering decisions will be digitally based
- Virtual twins of manufacturing processes can accelerate product development
- Multi-physics based virtual twins in manufacturing:
  - Extrusion deposition additive manufacturing – **ADDITIVE3D ™**
  - Workflow for thermoplastic composites sheet stamping –**FORM3D ™**
- Growing portfolio of composites manufacturing Virtual Twins
  - Continuous fiber EDAM **CFADDITIVE3D TM**
  - Prepreg platelet molding– upcycling **PPMC3D ™**
  - Flow of anisotropic media **FLOW3D ™**
  - Life cycle analysis **LCA3D ™**
- Model-based systems engineering in manufacturing can drive product development acceleration
- Integration of physics-based virtual twins and artificial intelligence is the future