Winds of change in automotive composites

BMW's Klaus Draeger says the i3 and larger i8 (pictured) will change the car making game forever

Juxtaposition of the Boeing 787 and carbon fiber automotive prototype

The next decade according to Poursartip

- After more than 40 years of promise, the next decade will see an explosion in the use of composite materials as the major aerospace players, namely Boeing, Airbus and general aviation, have finally fully committed to this technology:

  - **The point of no-return has been crossed for aerospace**

- This commitment means that composites design and manufacturing technology will change dramatically, first in aerospace and then in all sectors as the technology permeates throughout the industry

  - **Automotive and alternative energy markets will follow**

- In ten years, no manufacturing company or material supplier will be untouched:

  - if in composites, they must stay competitive
  - if not in composites, they must ask whether another company can make their product in composites

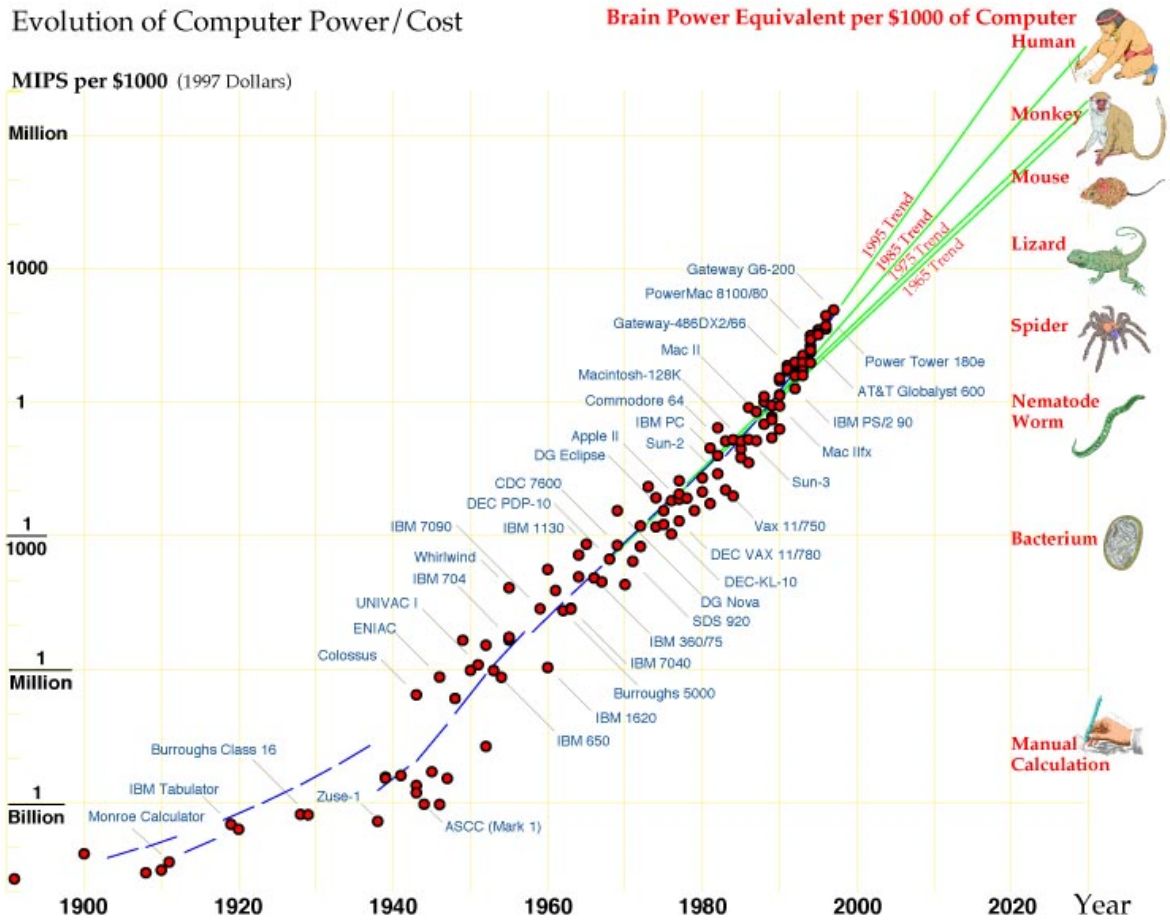
Why has it taken so long?

- New materials and processes present significant risks
- Uncertainty is at the heart of the matter
  - Ultra-conservative designs have been pervasive
  - Building block certification approach is very expensive
  - Certification is testing based ($millions/material)
  - Manufacturing is empirical, not science-based
  - Large scale integration of subassemblies to monocoque structures (too large to fail!)
  - Repair and joining technologies not robust

Barriers to growth

- **Isotropic** knowledge and education: black metal
- Cost of **certification**: $100 million/material
- Empirical based **manufacturing**: codification and simulation in their infancy
- Engineering **workforce**: small fraction of engineers are composites competent

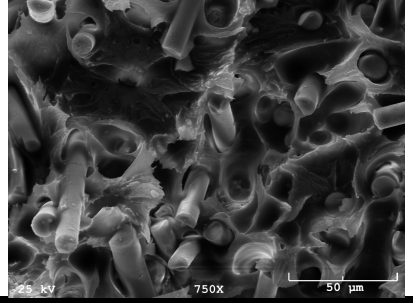
Computing power has grown since 1970 by a factor of 10,000,000,000



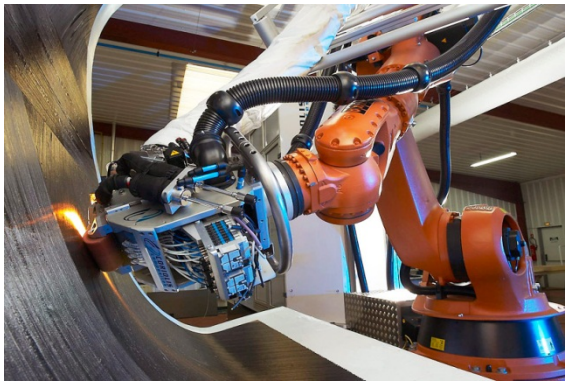
What is the answer?

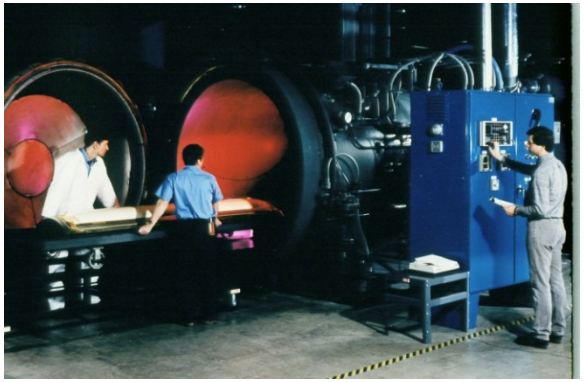
- Paradigm shift in simulation comprehensiveness: design for manufacturing and performance
  - replace the building block approach with simulation and **test for validation**
  - certify products in a manner that allows for composition and processing to be adjustable **without recertification**
- Build the **simulation base in design and manufacturing**
- Understand the **origins of uncertainty** and control them
- Simulation tools can guide understanding of **propagation of uncertainty in design and manufacturing**
- Make **simulation tools broadly available** for designers, materials suppliers and manufacturers

The state of composites manufacturing simulation



The process for developing new manufacturing simulation tools remains in its infancy. Unlike design simulation software, the manufacturing of polymer composite materials and structures involves multi-physics phenomena such as the curing reactions of thermoset polymers, melting and solidification of thermoplastic polymers, flow and impregnation of viscous polymers in fibrous preforms and tows, consolidation of fiber preforms, conduction and convective heat transfer, geometric conformation of fiber preforms to curvilinear surfaces, residual deformations due to anisotropy in thermal expansion and tooling-composite thermal interactions. These phenomena span the disciplines of polymer science, rheology, reaction kinetics, fluid mechanics of non-Newtonian liquids, heat and mass transfer, mathematical topology, anisotropic thermoelasticity and viscoelasticity. While multi-physics analysis tools have recently been introduced, their use in composites manufacturing simulation is still quite early.

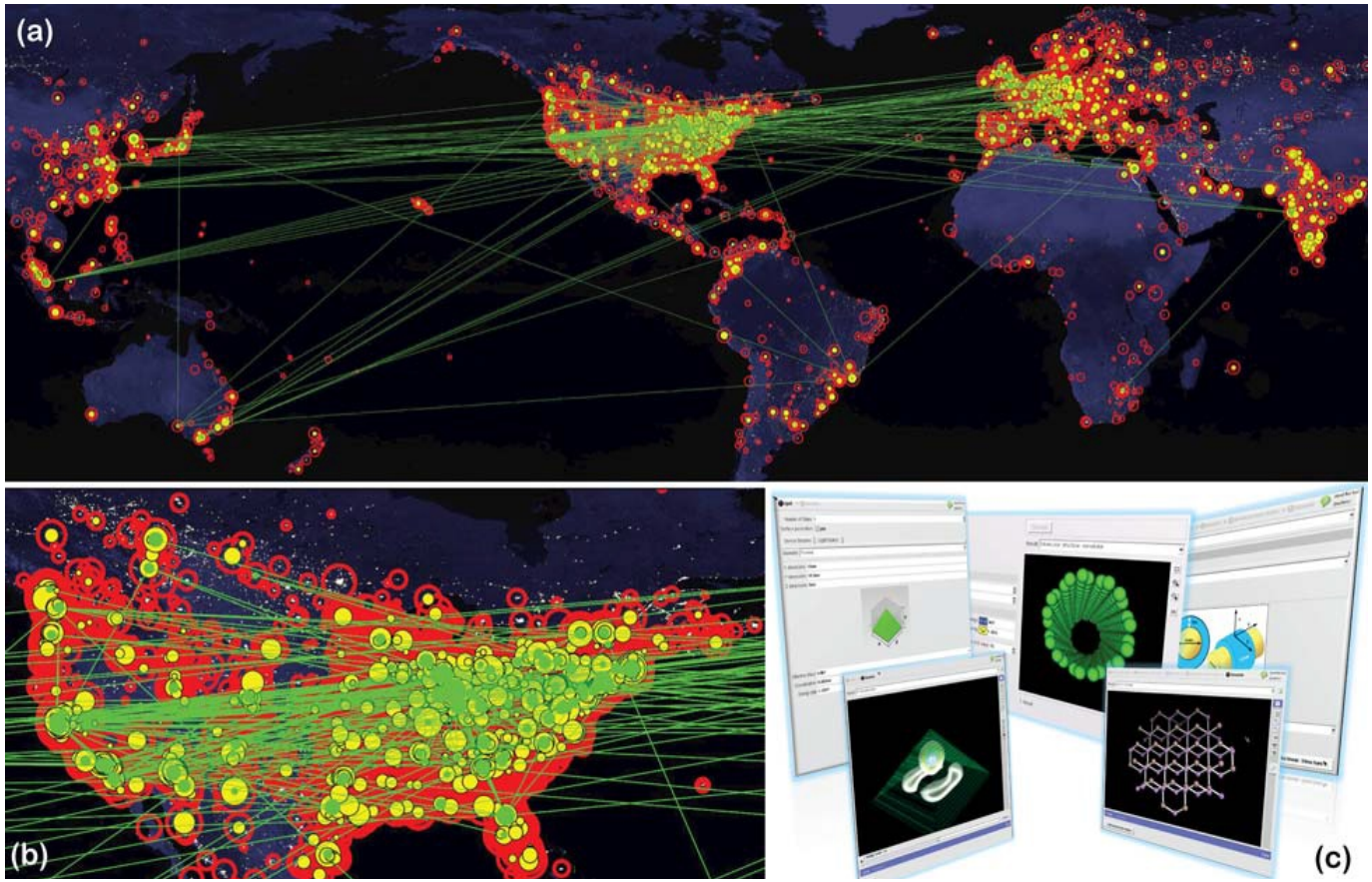




Certification by Analysis

- Conventional certification of product manufacture and performance is an expensive experiment-based process.
- Simulation can be the paradigm for change and accelerate product development.
- Simulation can significantly reduce the cost of product development.

nanoHUB.org founded 2002

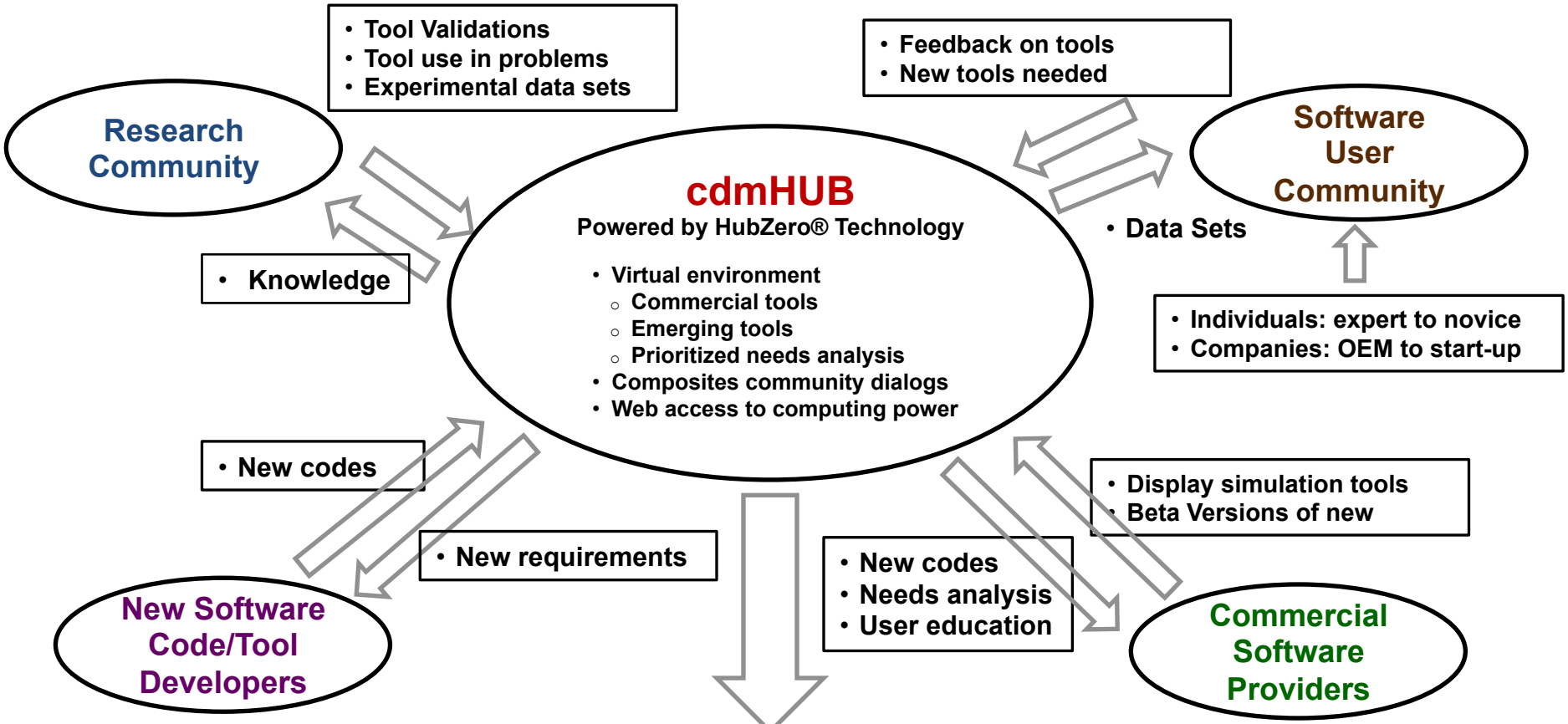


a) **nanoHUB** user map in the year 2011 superposed on NASA's world at night. Red circles designate users viewing lectures, tutorials, or homework assignments. Yellow dots are users of simulation. Green dots indicate authors of over 720 scientific publications citing nanoHUB. Dot size corresponds to the number of users, and lines show author-to-author connections proving intense research collaboration networks.
(b) U.S. enlarged. (c) a collage of typical nanoHUB interactive tool sessions and 3D-rendered interactively explorable results (quantum dots, carbon nanotubes, nanowires).

The Vision

- The *Composites Design and Manufacturing HUB (**cdmHUB**)* becomes the platform to build a new array of simulation tools and the human talent to support composites design and manufacturing simulation
- Browser-based platform format is exercised to test its robustness
- Commercial simulation tools are showcased
- Engineers and scientists interact with composites community colleagues continuously and securely
- New simulation tools are available as they are developed and deployed on the ***cdmHUB***
- 24/7 interaction in user and developer chat groups
- Synergism yields more and unexpected results (business)
- Increase in the rate of development and deployment of simulation tools and the composite simulation tools user community **by an order of magnitude**

Composites Design and Manufacturing Hub Overview



Objectives

1) Engage user, developer, research communities
2) Provide a platform to use and develop tools needed for composite materials in manufactured products
3) Provide a pathway to commercialization for new design and manufacturing software for composites

Key Outputs

- Integrated User/Developer/ Provider Community
- New simulation software
- Increase in number of simulation tools
- More capable manufacturers
- User feedback loop on needs and performance of new tools
- Integrated software tools

- Organize Hub by:
  - Complexity of tool
  - Process
  - Function
  - Material system

- Sponsored by:
  - Consortium memberships
  - Government Agencies
  - User fees
  - Royalties returned to Hub

Opportunities

- The simulation tools for design and performance of composite materials and structures is a rapidly evolving business
- Many tools have been developed and are being integrated to give the designer the ability to consider many issues not previously possible in the design stage
- Significant new opportunities in developing a portfolio to meet the same needs in composites manufacturing
- The human talent needed for this enterprise is in short supply
- The virtual environment is a welcome home for use and learning of integrated composites design tools
- The ***cdmHUB*** is a virtual environment that can bring the composites community together in 24/7 interactions with simulation tools and learning
- The composites community is composed of large OEMs, Tier 1 and Tier 2 suppliers, government laboratories, universities, experts, individuals and students
- The opportunity is to derive benefits from the organization of the composites community to develop new businesses, identify and educate personnel, watch the use characteristics of a large user group and identify opportunities for the future accordingly.

Primary Functions of the *cdmHUB*

- Convene the global composites simulation community
- Host commercial simulation codes for learning and assessment
- Introduce and mature emerging simulation tools
- Provide for verification and validation of simulation codes
- Provide standard data for simulation
- Provide for education in tool use
- Provide forum for user community discussions
- Identify human talent pool for composites simulation

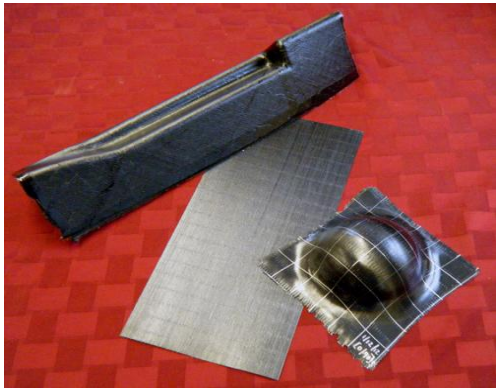
By the numbers

If ***cdmHUB*** is as successful as the ***nanoHUB***, we could expect the development of simulation tools and the user community to grow substantially.

***cdmHUB*:** 10,000 composites simulation users worldwide, 600,000 simulations and 250 new and existing simulation tools

Phenomena based tool development

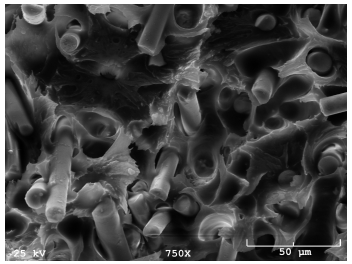
- An integrated simulation tool suite can consist of the assembly of modules that treat specific phenomena
- These phenomena are central to all composites manufacturing and performance characteristics
- By assembling the modular elements, all the important issues in design and manufacturing can be inter-related in order to provide optimum solutions



Important phenomena in performance and manufacturing

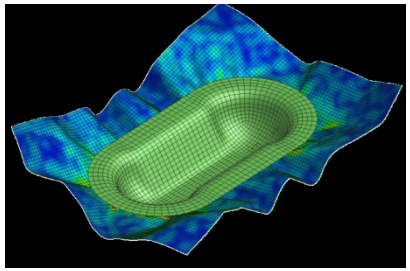
Phenomena in Performance:

Anisotropic elastic constants
Anisotropic fracture strength
Damage propagation
Fatigue life
Acoustic properties
Creep and relaxation
Creep rupture
Moisture absorption/de-absorption
Anisotropic thermal expansion
Solvent resistance
Impact damage
Electronic shielding
Anisotropic thermal conductivity
Surface finish
Polymer aging and thermal degradation
Crack initiation



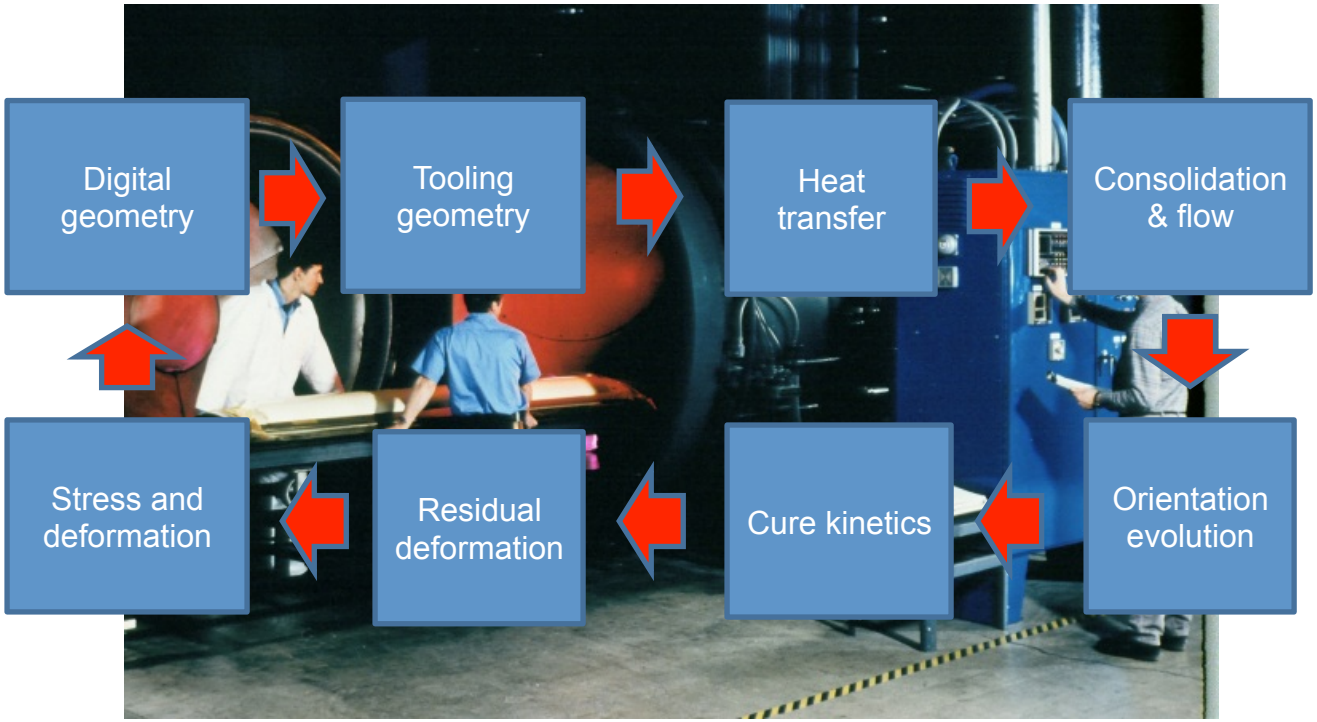
Phenomena in Manufacturing:

Anisotropic heat transfer
Multi-scale infusion flows
Consolidation flows
Cure kinetics
Melt/solidification/crystallization
Adhesion and wetting
Orientation evolution
Chemo/thermo deformation
Shrinkage deformation
Material deposition
Material removal
Digital geometry
Stress and deformation
Tooling issues for desired requirements
Void formation



End-to-end simulation for a specific manufacturing process such as out-of-autoclave processing

Assemble the models of various phenomena in out-of-autoclave processing:



Certify product manufacture and performance through simulation

- The overall goal is to establish protocols to certify product manufacture and performance through simulation.
- Certification by simulation requires that simulation codes be verified and validated (V&V).
- Simulation codes vary by degree of maturity.
- There is a need to develop processes and procedures to establish simulation code V&V level.

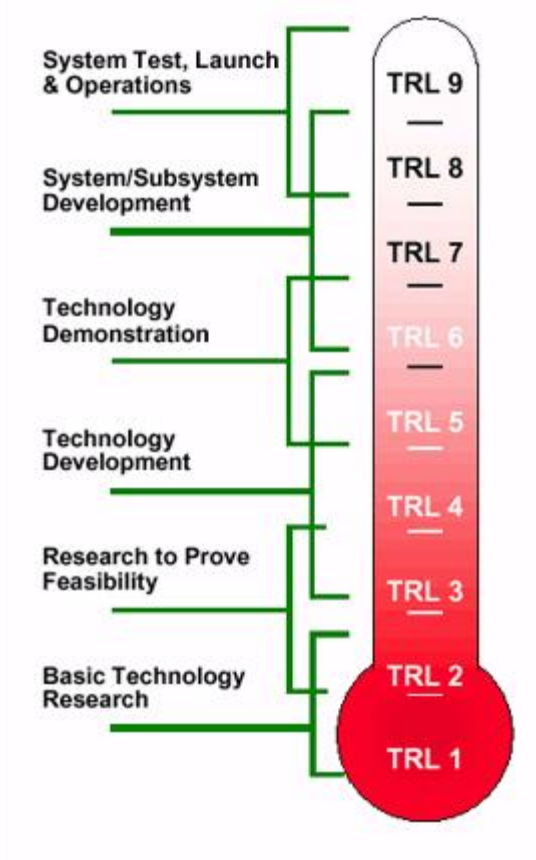
BASF thermoplastic molding cell

Validation and verification

- Simulation tools can be verified for science foundation
- Simulation tools can be validated with data
- Data bounds establish tool utility and breadth of applicability
- Few tool standards have been developed
- Available tools are at various levels of V&V
- The *cdmHUB* can be the platform for user community evaluation
- Think composites simulation tool “Consumers Reports”

Analogy to TRL Technology Readiness Level

TRL	Maturity Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in relevant environment
7	System prototype demonstration in an operational environment
8	Actual system completed and qualified through test and demonstration
9	Actual system proven through successful mission operations



Tool maturity description (TML)

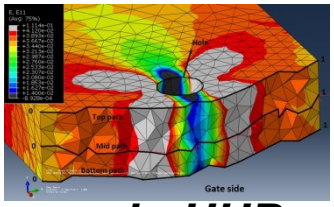
Tool Maturity Level (TML)	Simulation Tool Maturity Description* emerging tools / commercial tools
1	Analytical process is exploratory in nature. Fidelity of predictions is largely unproven. Provides some physical insight, but cannot reduce development testing
2	Proven capability for comparative assessment, ranking or trending. Experimental validation is still necessary. Can drive development or assessment plan and test matrix
3	Material or process can be developed or assessed with significantly reduced testing. Expectation that development iterations will be reduced or eliminated. Accuracy and uncertainty effects must be quantified. Range of applicability well defined.
4	Material or process performance and impact on system or application are understood. Accuracy and uncertainty effects must be verified. Additional data may be required when applied to new materials or processes, or to extend range of application
5	All material and process performance and system interaction effects are understood within defined range of application. Analytical process can be applied without testing.
6	All material and process performance variability and system interaction effects are understood within defined range of application.**
7	Analytical process can be applied to predict performance variability distribution without testing.**

*Cowles, B., Backman, D. and Dutton, R., "Verification and validation of ICME methods and models for aerospace applications," Integrating Materials and Manufacturing Innovation, (2012), 1:2, http://www.immijournal.com/11/2.
**Pipes, R.B., "Lightweighting through Composites Simulations - the Composites Design and Manufacturing HUB" , SPE ACCE Conference, Novi, MI, September 11, 2013.

cdmHUB provides the platform for growth of composites simulation

- Provides a single site for review of all composites simulation tools
- Convenes composites experts to establish simulation tool maturity level (TML)
- Identifies opportunities and mechanisms for tool integration
- Identifies needs for new tool innovations
- Supports the growth and maturity of new simulation tools
- Supports data bases necessary of verification and validation of simulation tools
- Supports the development of intellectual talent in simulation tool use and development

Join the *cdmHUB* Team



cdmHUB

- *cdmHUB* launched in 2013
- Industry as a primary partner
  - Global access for multi-national companies
  - OEMs: End-to-end simulation
  - Tier I Suppliers: Product and/or process Simulation
  - Materials suppliers: Validation and data
  - Tier II and small businesses:
    - Access to simulation tools by browser
    - Access to learning