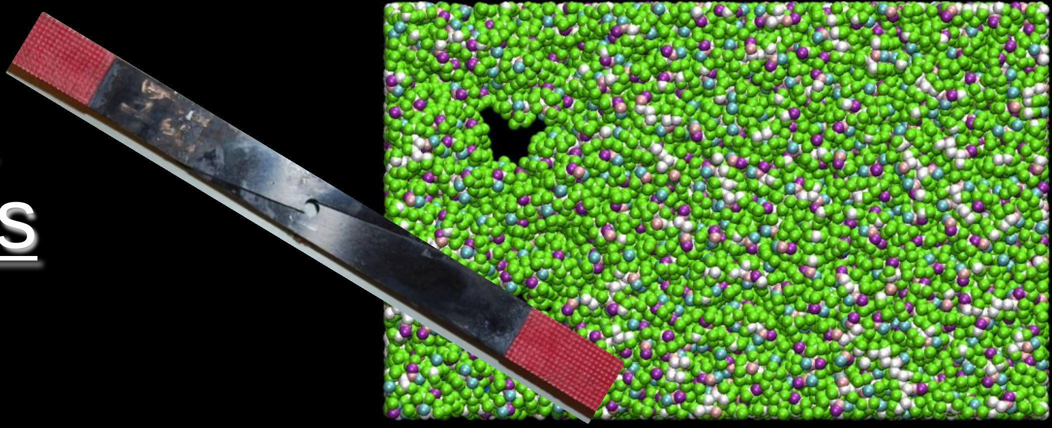
NASA Technology Road Map: Materials and Structures

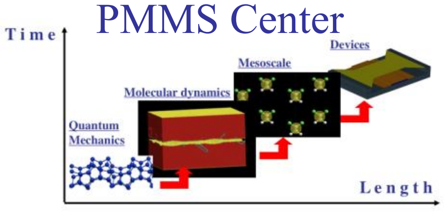


R. Byron Pipes

John L. Bray Distinguished Professor of Engineering

School of Materials Engineering, Purdue University

bpipes@purdue.edu



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R. Byron Pipes, NAE

Purdue: John L. Bray Distinguished Professor of Engineering; Director of Defense Programs

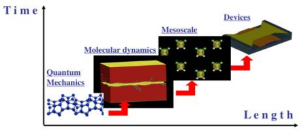
U. Akron: Goodyear Professor of Polymer Engineering

NASA Langley: Visiting Distinguished Scientist

Rensselaer: President

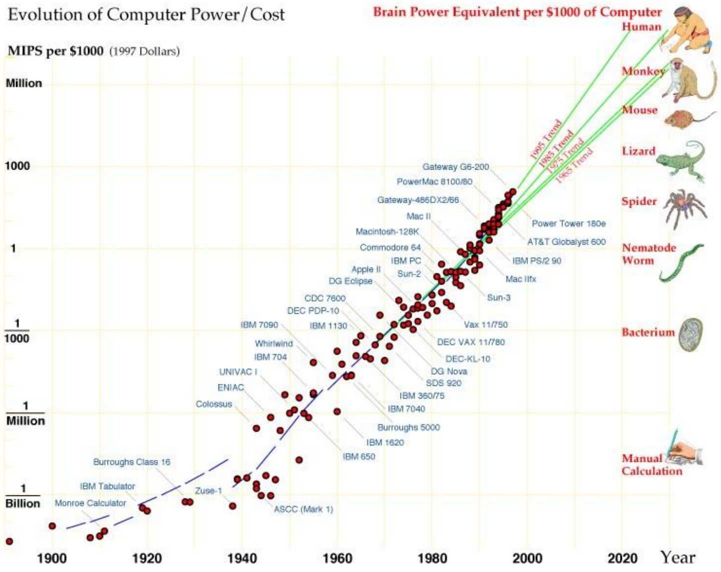
University of Delaware: Director of the NSF ERC Center for Composite Manufacturing Science and Engineering; Provost, Dean of Engineering

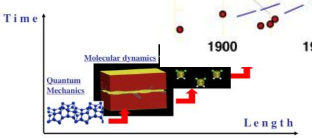
General Dynamics FW: Senior Structures Engineer



Aerospace Ages

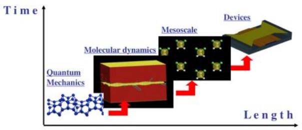
- Age of Flight
- Jet Age
- Space Age
- Information Age



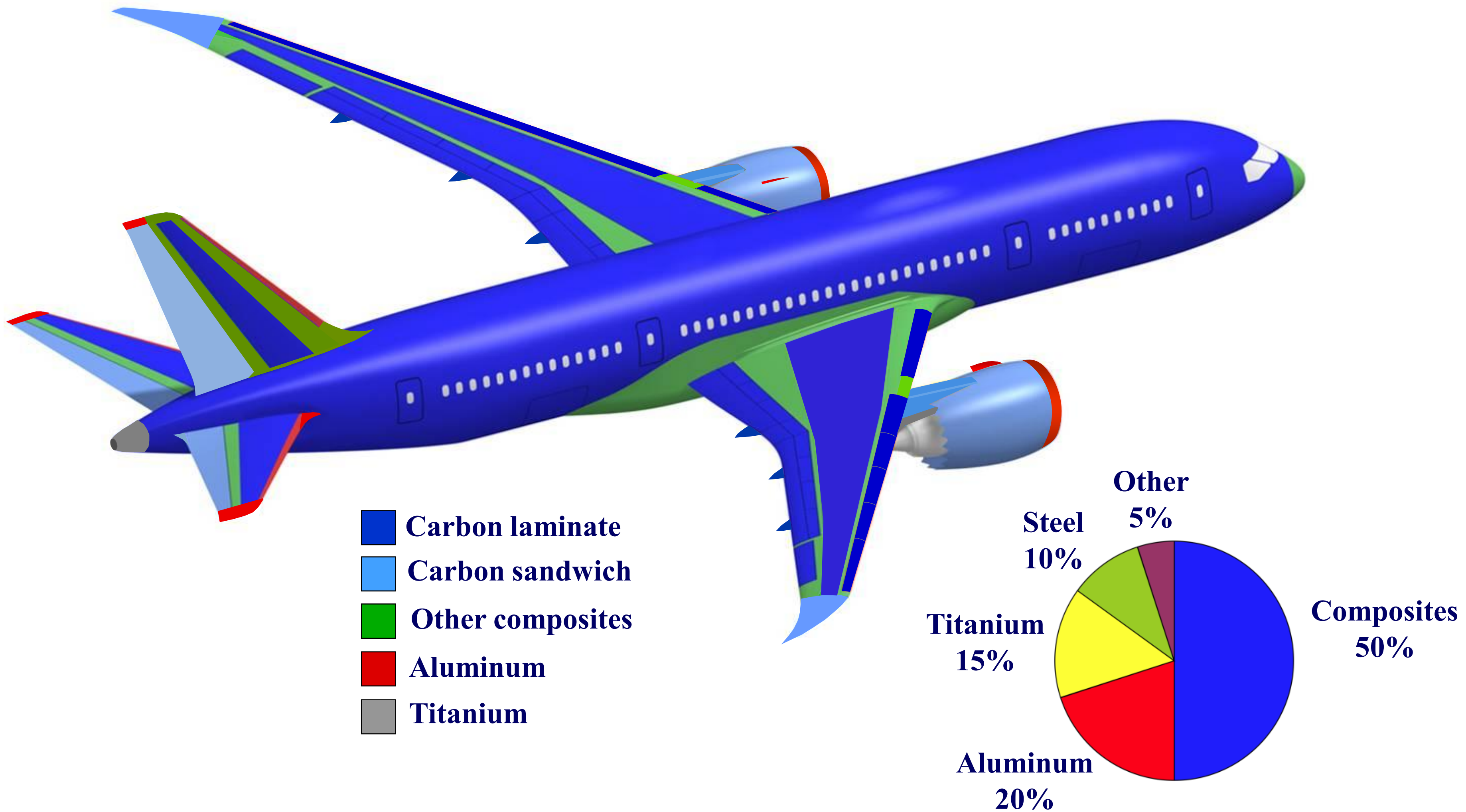


After 40 years of progress in composites research

- Commercial aircraft are a reality
- Defense aerospace composites are pervasive
- The world-wide failure analysis proved to no comprehensive failure model has been developed to date
- Yet we design successfully
- We do so with significantly conservative approaches based on experimental tests

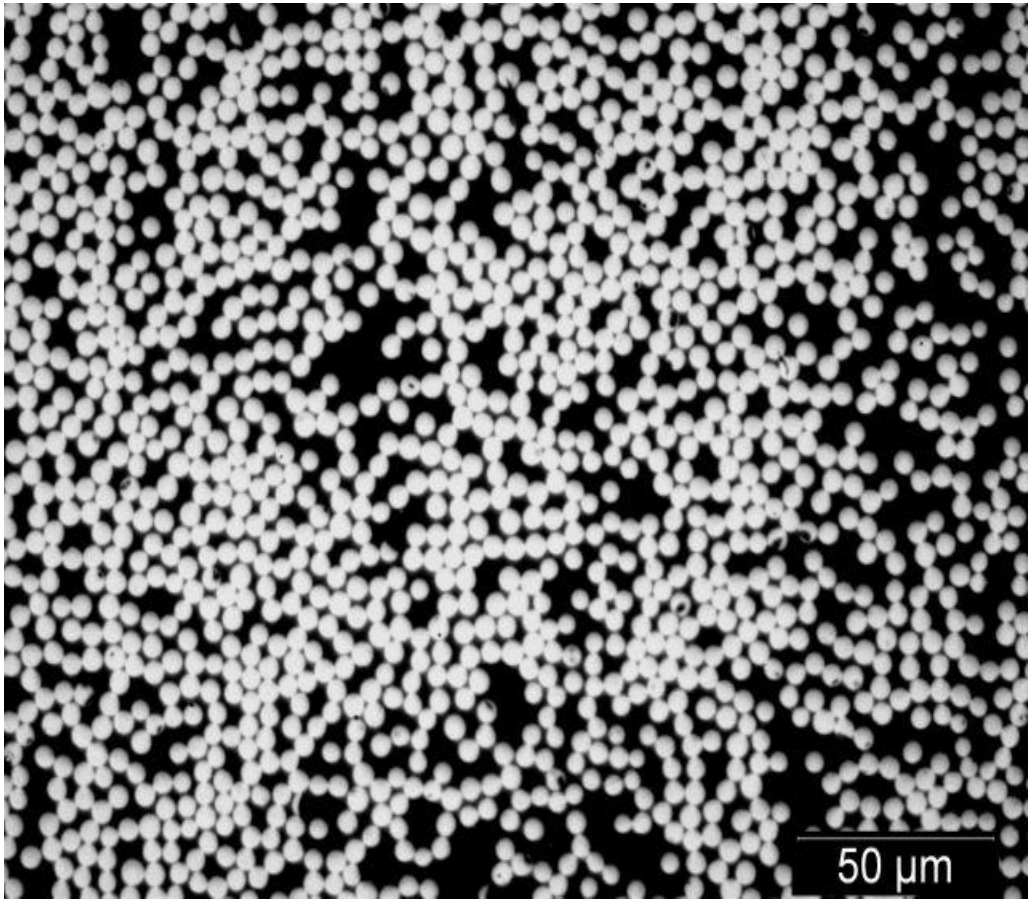


Boeing 787 Composite Structure



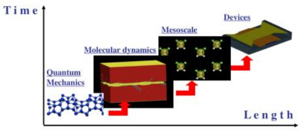
787 Program and Technology Integration

Hexcel IM7-8552 Prepreg Microstructure, V_f=0.57



What has Changed in 40 years?

- Computational power has increased by a factor of 10,000,000,000 since 1970, the year of the first flight of composite structure – F-111 horizontal stabilizer
- Certification of composite materials and structures is dominated by experiments aided by analysis
- Once certified, materials changes are economically impossible
- We have the computational power to change the paradigm



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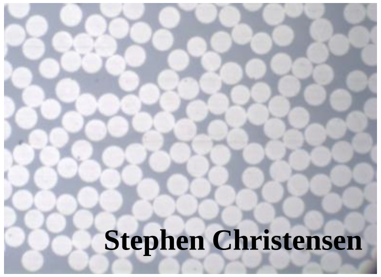
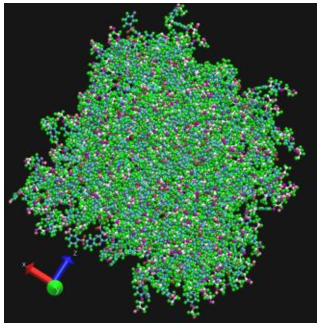
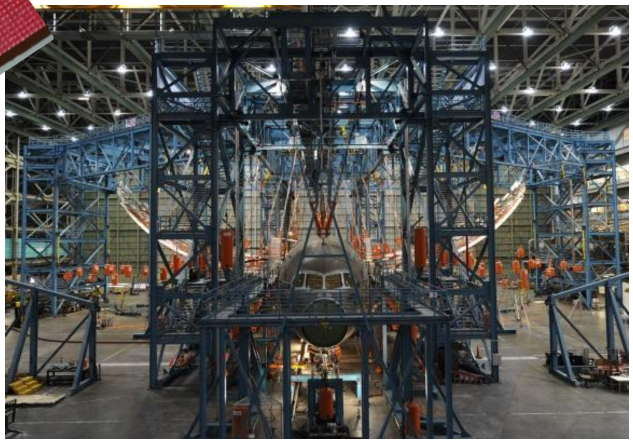
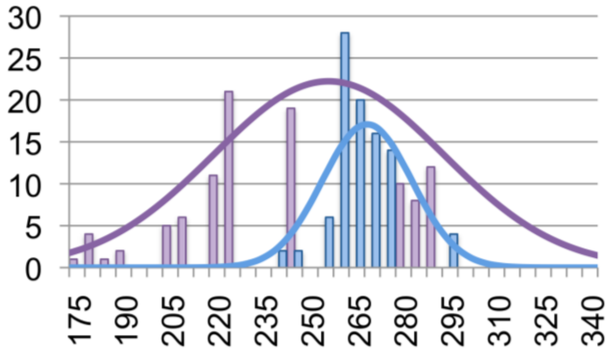
PMMS overall goals



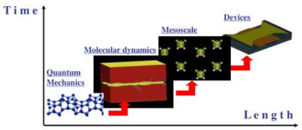


Computational materials design aided by experiments

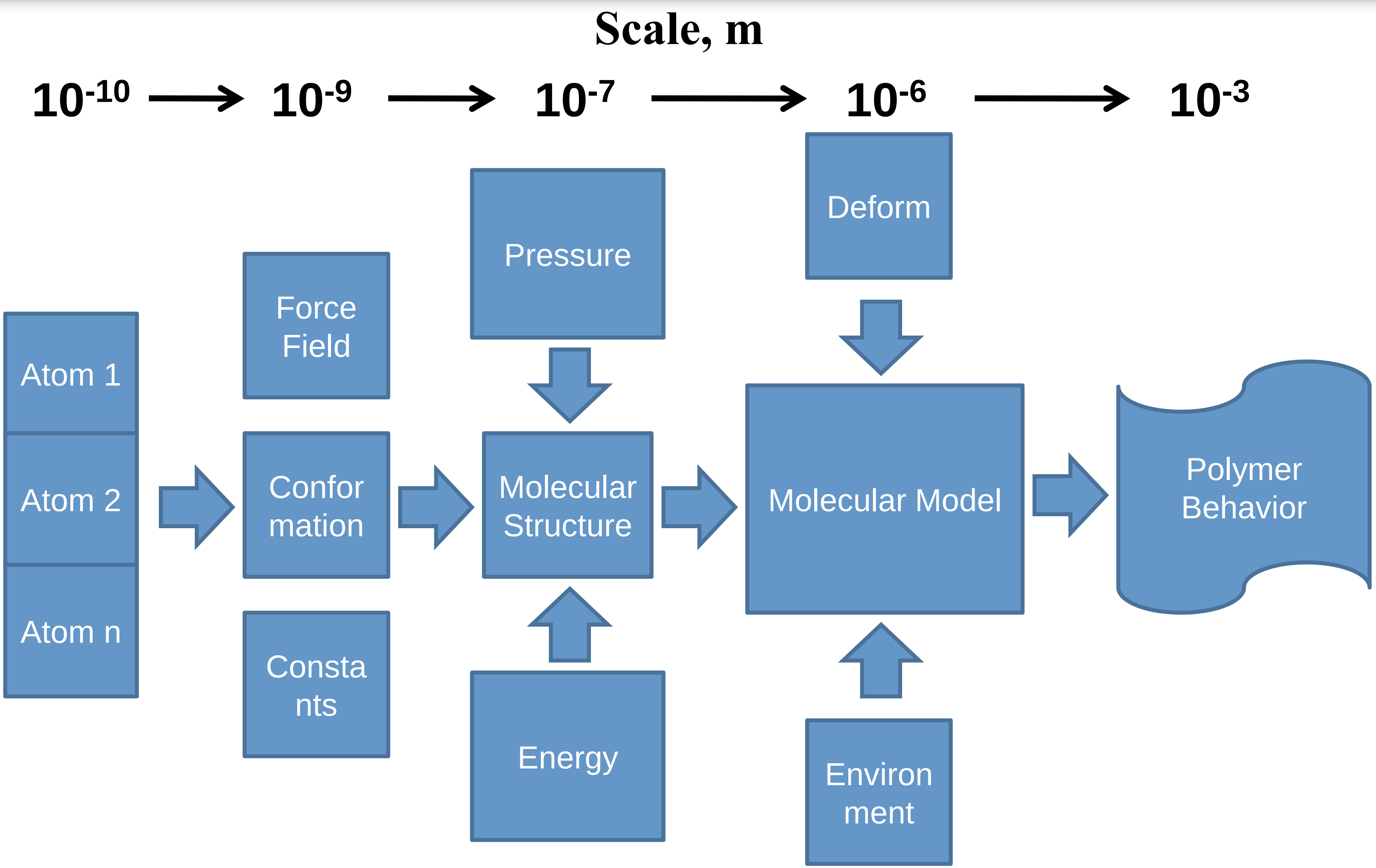




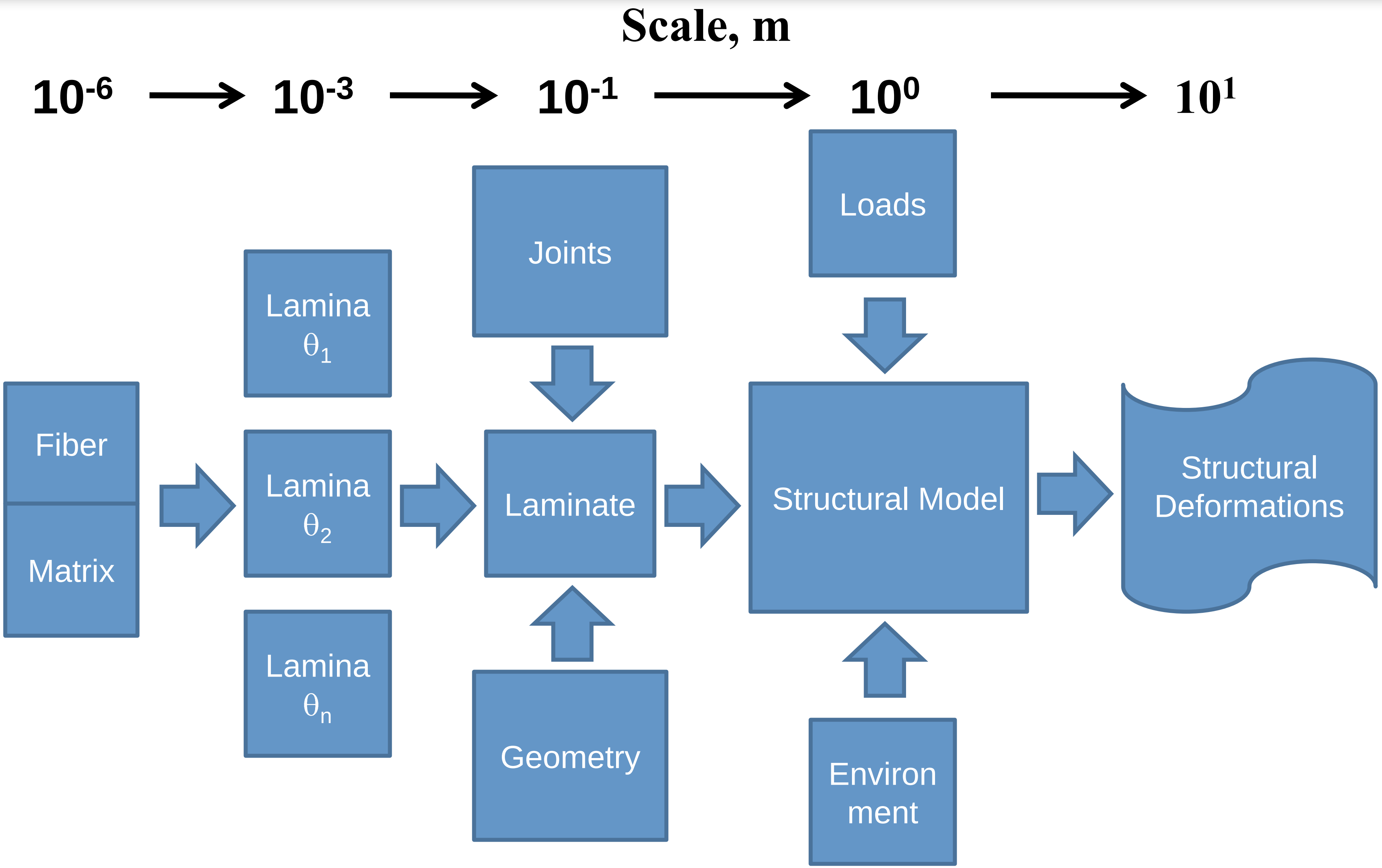
Computational materials certification aided by experiments



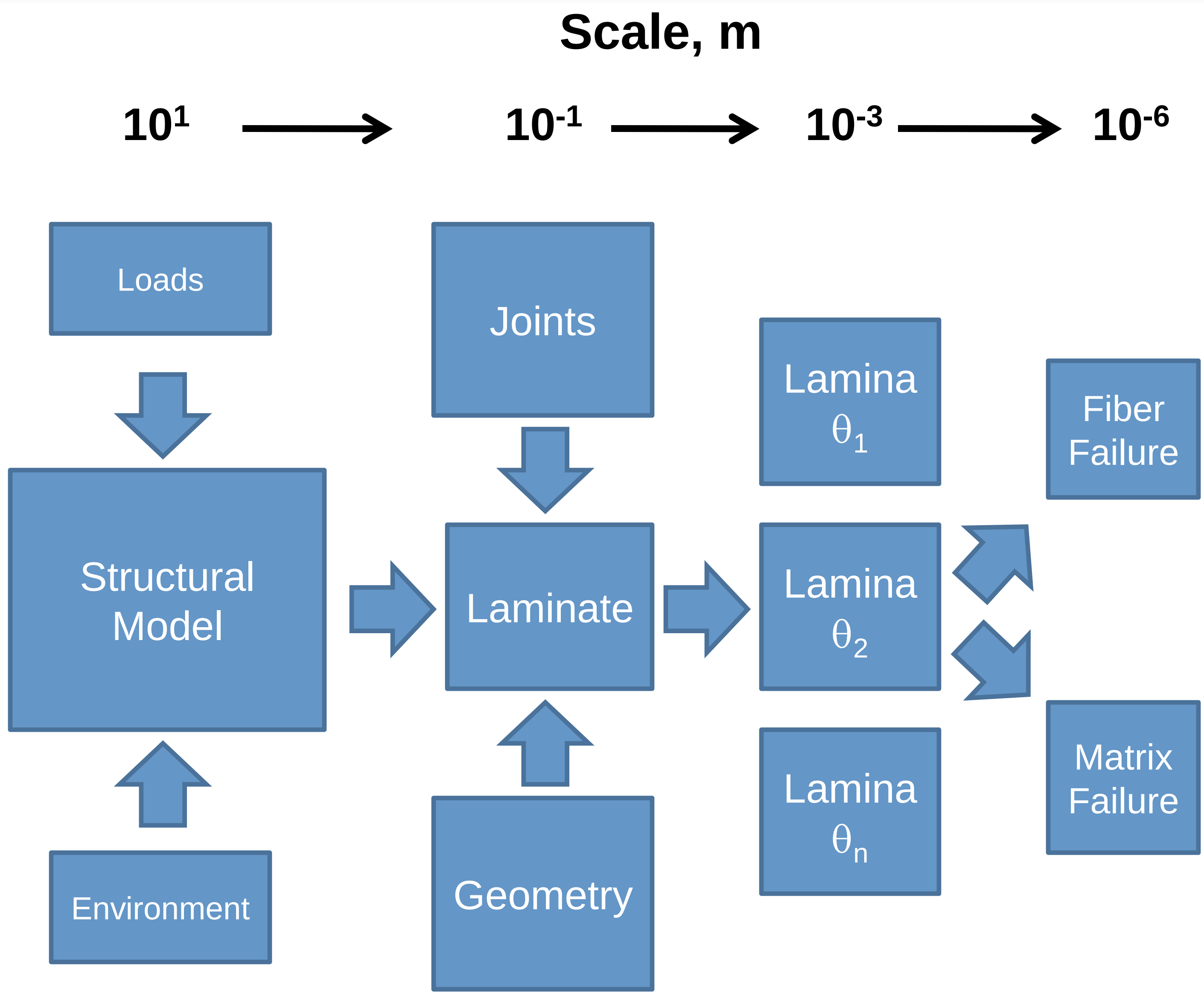
Molecular Modeling for Polymer Matrix Structure



Homogenization in Modeling Composite Structure

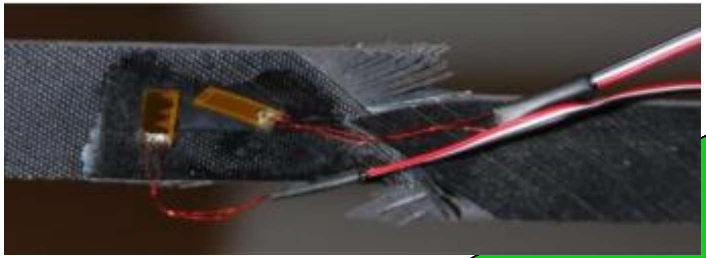


Dehomogenization in Modeling Failure

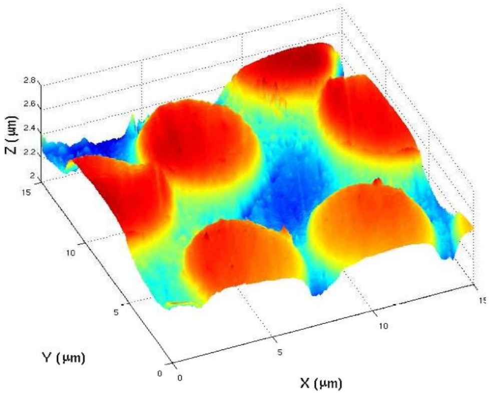


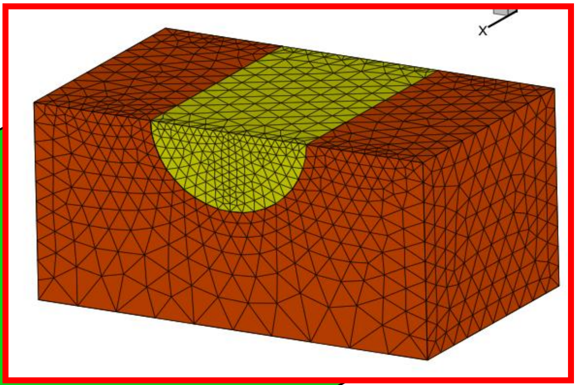
PMMS Center Approach

Characterization



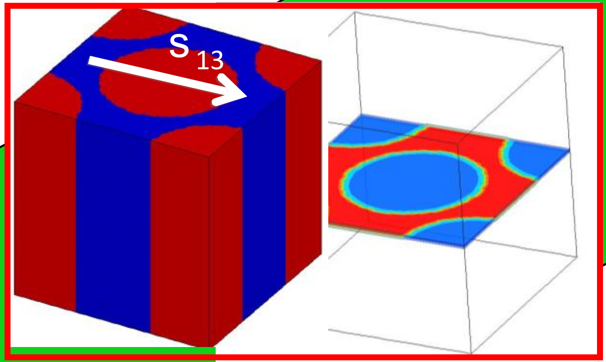
Nanometrology



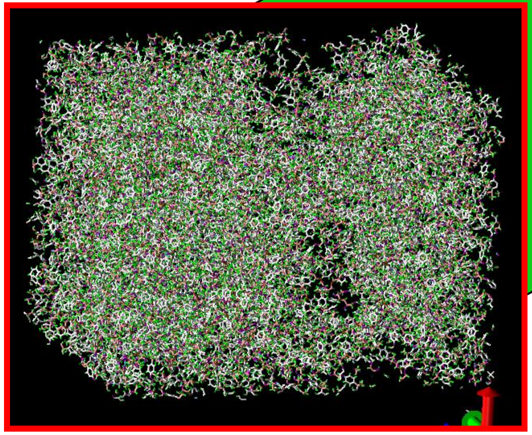


Finite Elements

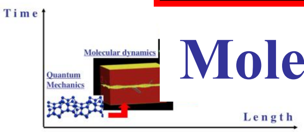
Viscoelastic models



Phase field micromechanics



Viscoelastic models

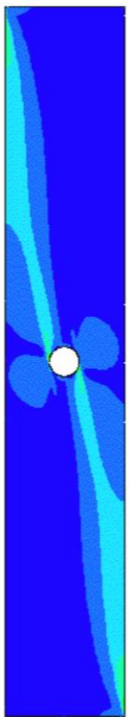


Molecular Dynamics

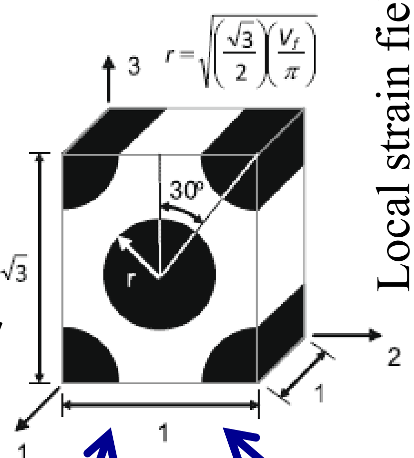
Vision: predictive, validated models can help design and certify new materials

Boeing-Purdue Atoms to Aircraft

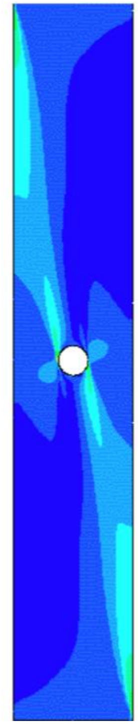
Homogenized strain fields



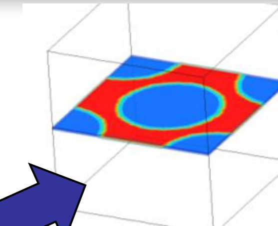
Micromechanics enhancement



Local strain fields

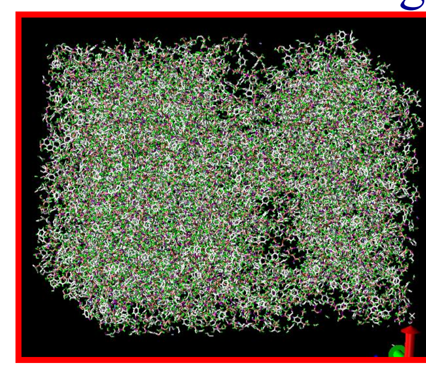


Onset criteria

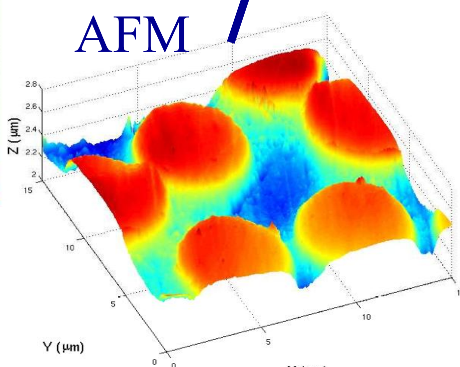


Propagatio

Molecular modeling

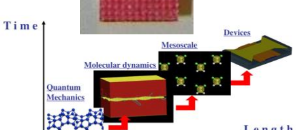


AFM



Non-linear viscoelastic model

Physics-based – no fitting parameters



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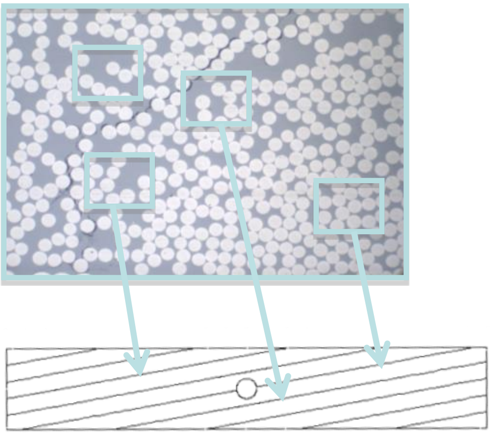
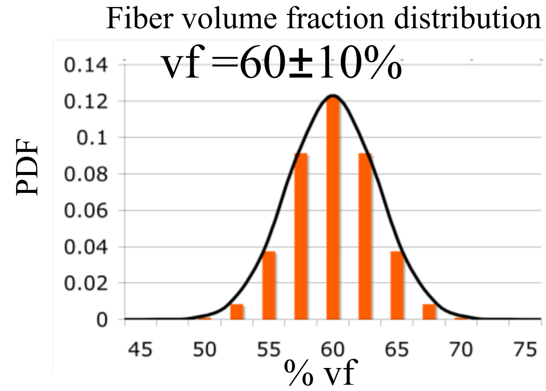
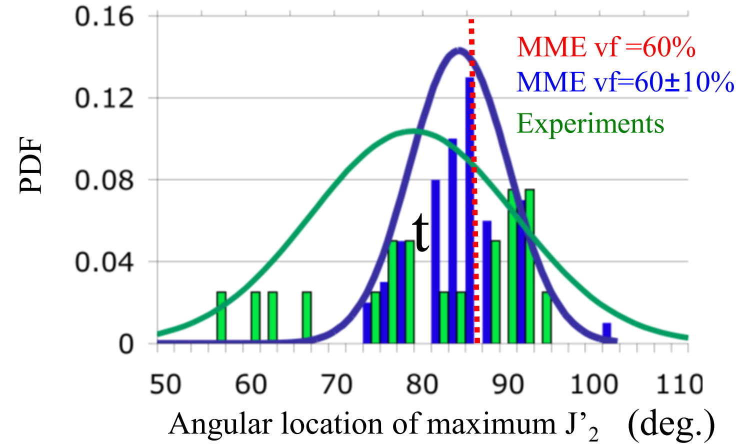
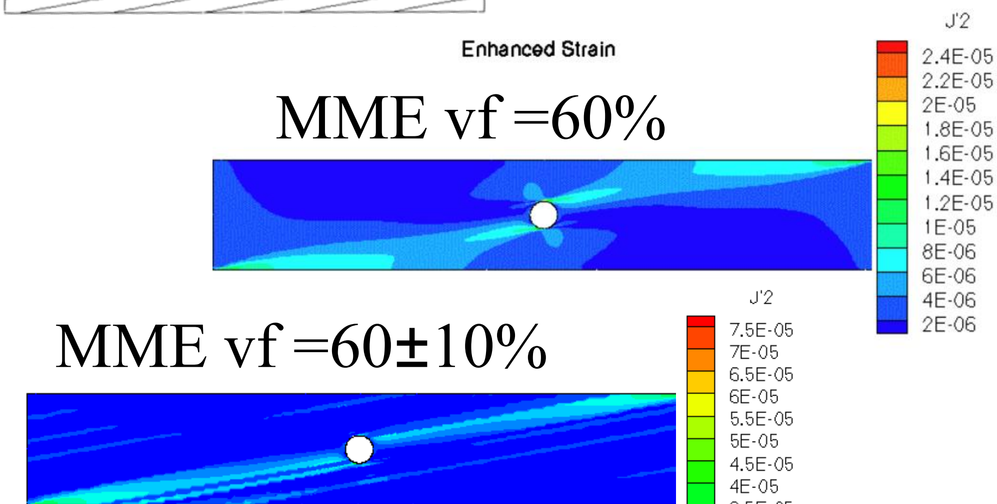
Uncertainty quantification in model validation

Local variations in fiber volume fraction explains experimental variations in fracture angle

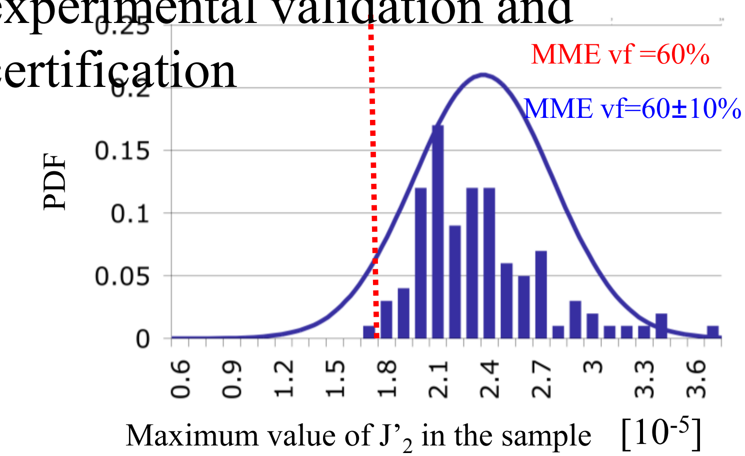


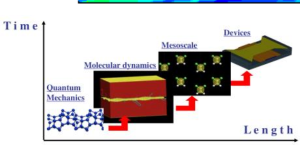






Variability in local strains key to experimental validation and certification





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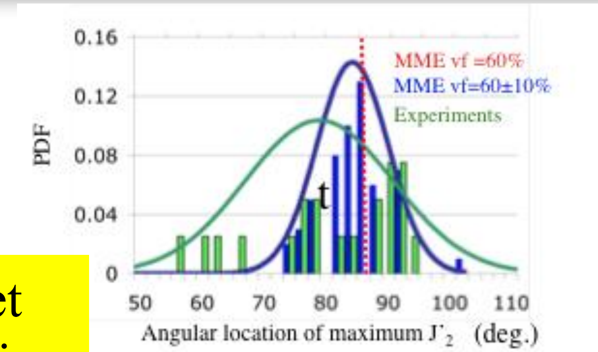
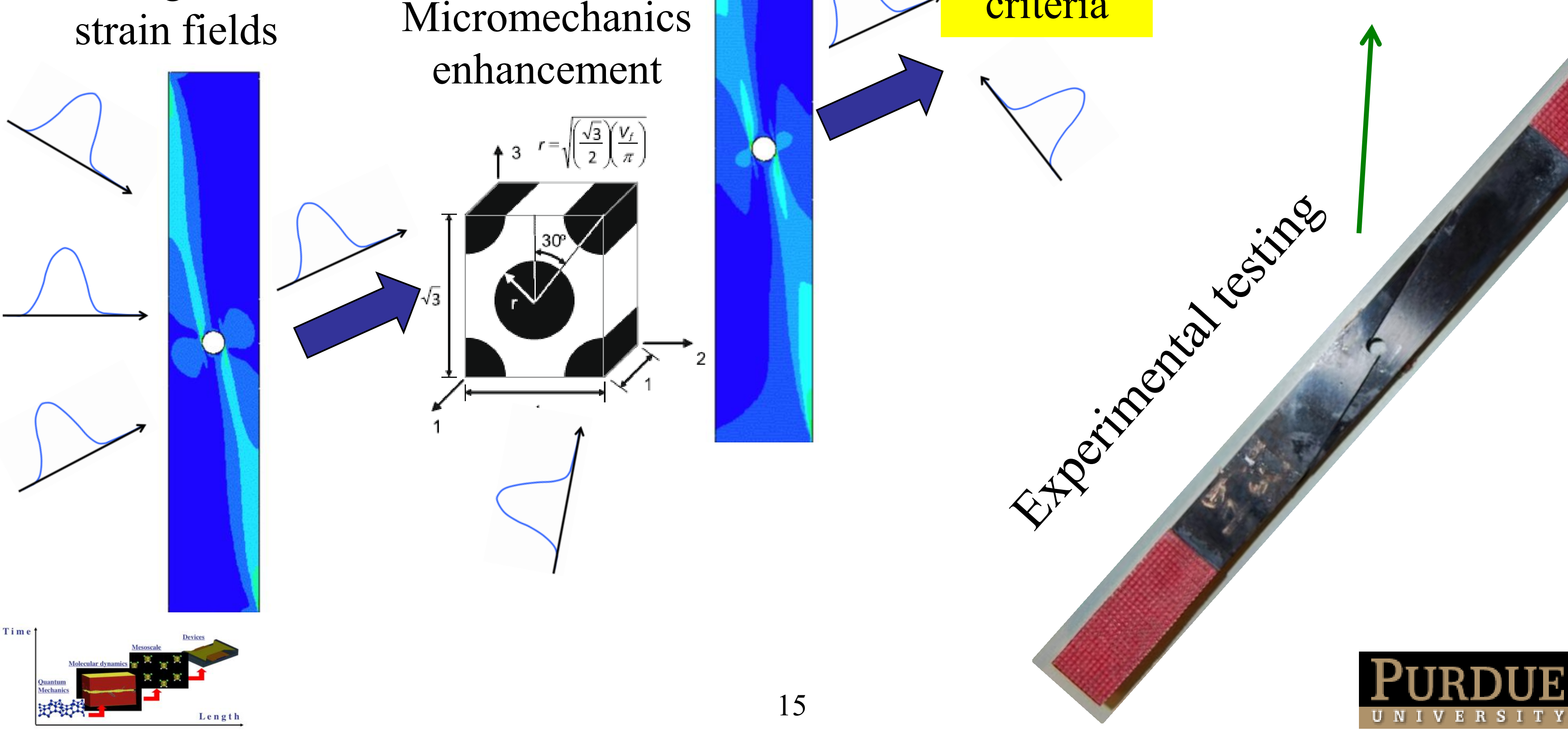
Quantification of margins and uncertainties

QMU key for validation and certification





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Materials Modeling and simulation vision

A computational/experimental approach to:

Simulation driven materials and structures certification

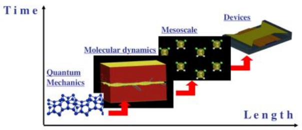
Demonstrate a significant reduction in the number of experiments needed for certification via simulations with rigorous uncertainty quantification and validation

Simulation driven materials and structures design

Enhance the predictive capabilities of our modeling effort driven by two goals:

i)Improve accuracy certification models (narrower margins),

ii)Design of new materials and structures with improved performance



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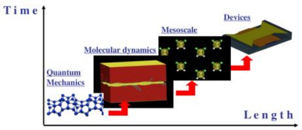
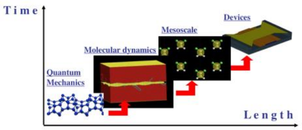
What are the benefits?

- Significant reduction in the cost of materials development
- Rapid certification of new materials innovations
- Significant reduction in the cost of new materials certification
- Insertion of new materials innovations in existing aerospace structures once barred by certification costs
- $100 million shift in certification costs
- More platforms certified to meet specific needs



Pervasive composites knowledge and learning

- Anisotropy and heterogeneity are the norm
- Robust prediction capability
- Manufacturing science simulation
- Active models and data in archival publications
- Virtual laboratories: “Connect, click and control”
- Internet based learning
- Composites communities of learning



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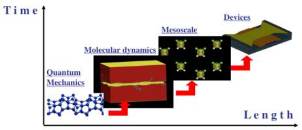
NASA Perspectives

NASA serves two masters: Space and Aeronautics

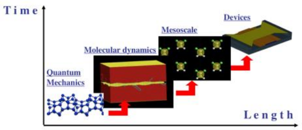
- The technology issues are not the same for both:
  - Space missions require unique solutions and missions involve “special environments.”
  - Aeronautics is pervasive: 28,600 new aircraft will be needed in the next 20 years at $2.84 billion.
  - Human safety is a central issue for both.
- The economics and technology drivers are different, but:
  - The engineering technology is common to both.
  - The materials systems and structural configurations are drawn from the same industrial base.



Criteria

Would the technology provide game-changing, transformational capabilities in the timeframe of the study?

What other enhancements to existing capabilities could result from development of this technology?



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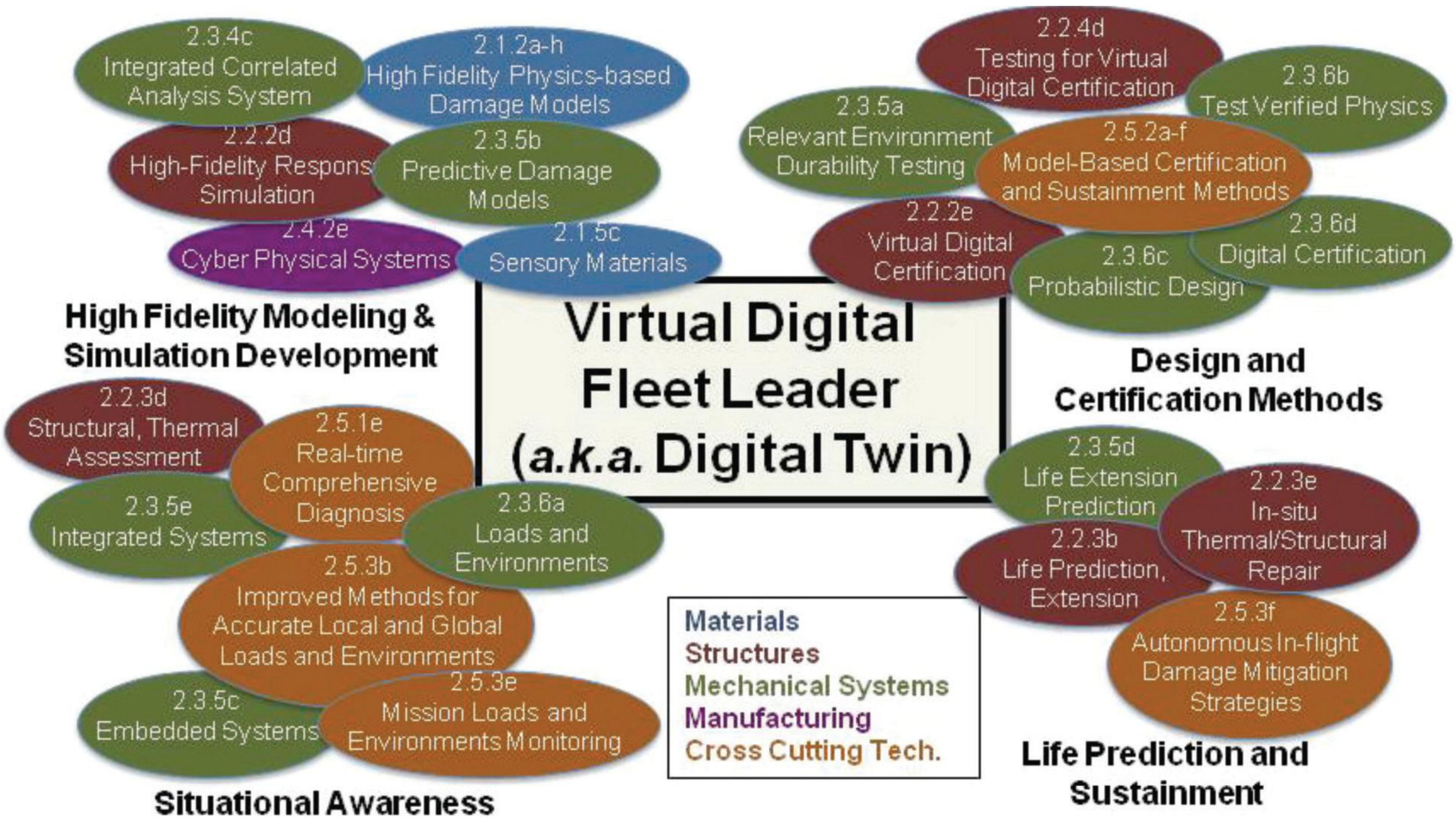
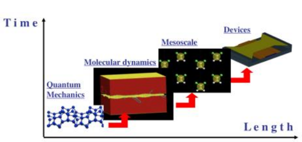
Total Program





Inter-related fields

Materials:

- Lightweight structures
- **Computational design materials**
- Flexible material systems
- Environment
- Special materials

Structures:

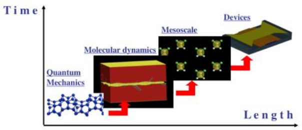
- Lightweight concepts
- **Design and certification**
- Reliability and sustainment
- Test tools and methods
- Innovative multifunctional concepts

Cross-cutting:

- NDE and sensors
- **Model-based certification**
- Loads and environments

Manufacturing

- **Manfg. processes**
- Intelligent integrated Mfg. and cyber physical syst.
- Electronics and Optics
- Sustainable Mfg.

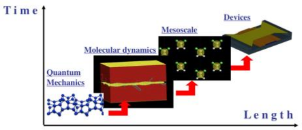


Micro Design Models

Develop first-of-kind life prediction methods for thin metallic materials and PMC damage progression models. Lightweight Composite Overwrapped Pressure Vessel with thin metallic liners.

Understanding PMC microcracking, fiber failure and their influence on damage progression. Needed to design composites that retard permeability. **Human and Science Exploration**.

TRL 3-4; No fracture mechanics methods for life assessment of thin metallic liners. Little understanding of PMC microcracking and progression in extremely constrained configurations. Microcracking currently a constraint on composite tanks. **Thin liner model by 2013 and robust modeling by 2015. Microcracking damage progression model by 2015**



Modeling and Simulation Advancements

PHYSICS BASED LAMINA MODELS

Lamina materials models. Design of complex multifunctional or hybrid composites.

All Missions

TRL 3-5; Design practices are ad-hoc and rely on extensive testing of specific configurations. **Develop analyses of critical interfaces by 2015**

MOLECULAR DESIGN MODELS

Design and produce PMC resin with predicted enhanced constitutive properties.

Proof of concept for computational design of structural PMCs**. All Missions**

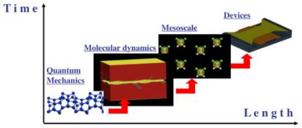
TRL 2-3; Predictive capabilities for PMC properties in early stage. **Capabilities maturing 2020 to 2025.**

ATOMISTIC DESIGN MODELS

Design and produce simply alloy with predicted enhanced constitutive properties. Proof of concept for computational design of structural alloy**. All Missions**

TRL 2-3; Predictive capabilities for alloy properties are in very early stage.

Capabilities maturing 2020 to 2025



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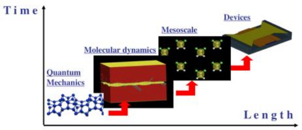
Design and Certification Methods

Virtual Digital Certification

Systematic validation and verification (V&V) of models of pristine and degraded structure at all scales in the building block development pyramid with Test Tools and Methods (2.2.4d). Reduction of costly physical testing, improved confidence for combined environments that cannot be simulated in test. **All Missions**

TRL 2; Ongoing efforts to incorporate realistic physics to improve reliability and ease of structural analysis techniques at NASA and elsewhere. Test validation of large scale response and damage progression predictions. Development of relevant criteria for certification.



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Model-Based Certification and Sustainment

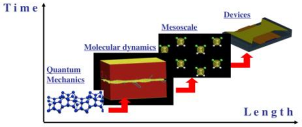
PHYSICS BASED DESIGN MODELS

Physics-based multiscale modeling that are validated (coupled) with macro / micromechanical scale test measurements and NDE.

Significant weight savings for primary structure and lower building-block test costs. **All Missions**

TRL2-4, Linear models are standard practice, nonlinear response models used in special cases, a variety of failure models (both empirical and theoretical) exist but no comprehensive multi-scale architecture exists.

Varies with application (e.g., predictive design allowables, shell collapse predictions.



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Manufacturing Processes

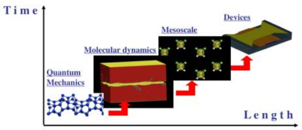
Smart Materials Production

Development/creation of new manufacturing methods.

Adaptability of structures, **health monitoring** and self-healing.

TRL 3 Limited NASA activity, generally led by industry and academia

Significant long-term effort for realization of production ready processes



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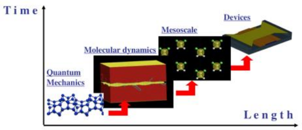

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