Quantification of Margins and Uncertainties (QMU): Turning Models and Test Data into Mission Confidence

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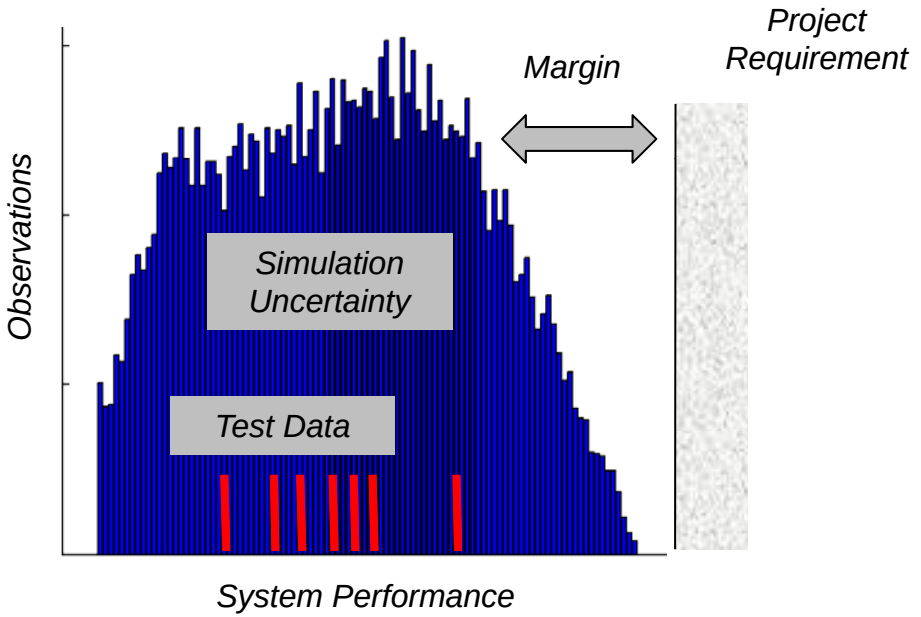

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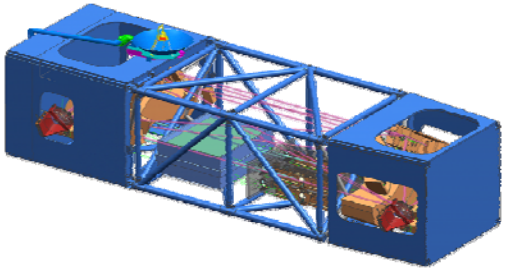
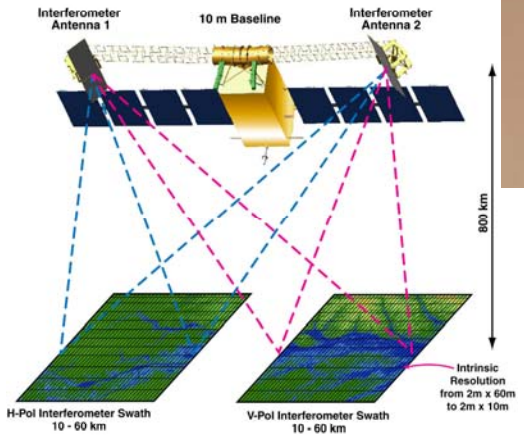
Presentation Overview

- QMU background and methodology
- Tools for high fidelity multiphysics models and simulations
    - Piloted use of Sandia (DOE) developed tools for space application
- Future applications and directions





JPL is developing QMU technology to enable rigorous certification of models and simulations for extrapolation to poorly-testable flight conditions

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"All models are wrong, but some are useful."

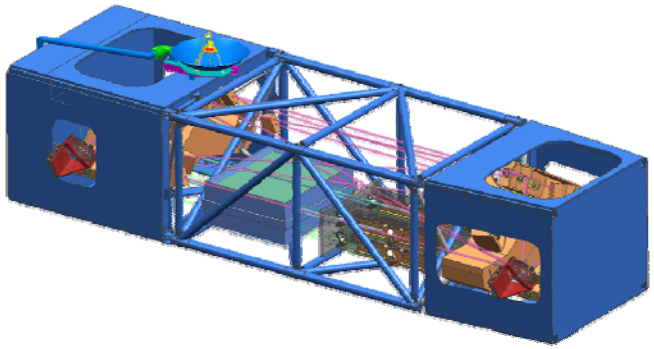
Prof. George E.P. Box,
U. of Wisconsin

"Models answer questions to support decisions."

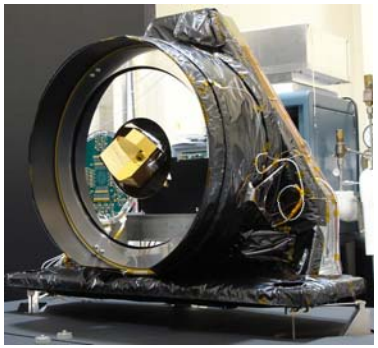
Dr. Greg Agnes,
NASA JPL

Models and simulations have an increasing role in qualifying flight system performance and risk

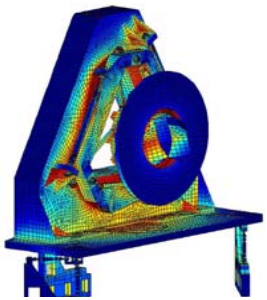
Need to model system level interactions with sufficient fidelity to extrapolate from ground test to flight



Component or Subsystem Test



Component or Subsystem Model



Validated, Integrated System Model
- Structures/Thermal/Optics/Control
- Sub-nanometer resolution
- Gravity effects (damping, hysteresis)

Extrapolated 0-g performance
- Closed-loop robustness
- Validated error budget
- System validation by analysis

Such models need to have high fidelity and quantified uncertainty

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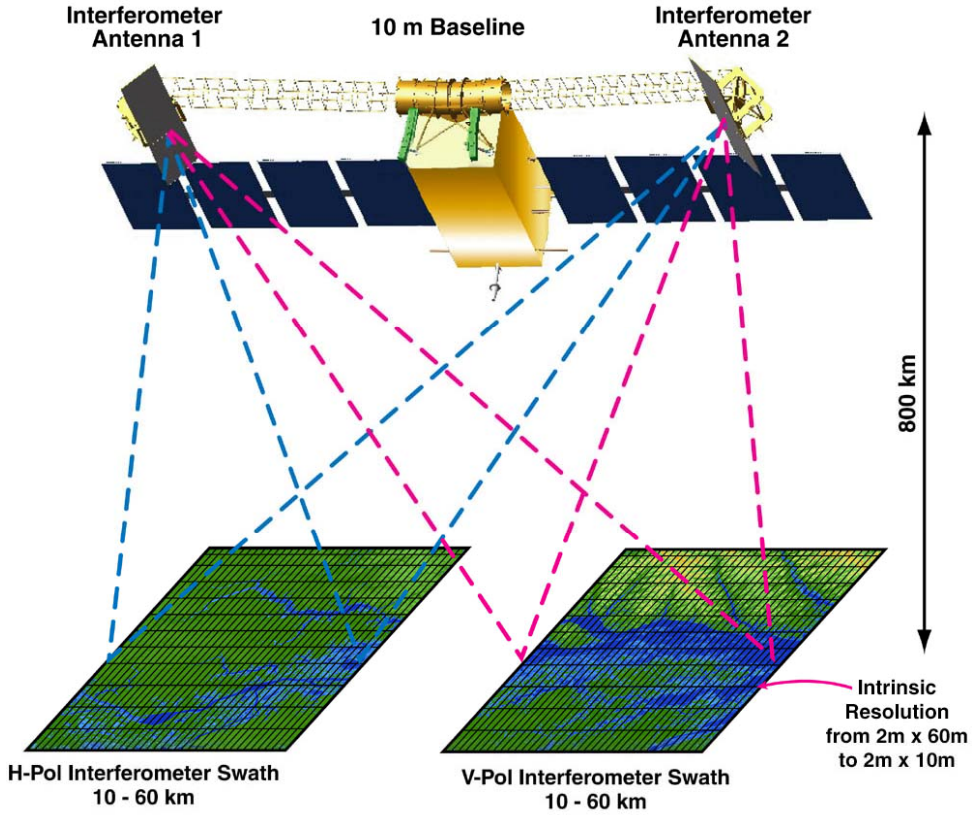
SWOT is an example of how high credibility modeling is key to establishing error budgets

- Self-shadowing in LEO on a large, flexible structure
- Micron-scale dimensional error budget allocations
- Comparable magnitude for effects neglected by conventional tools
  - Nonlinearity, thermal snap
- Ground test validation will need models to extrapolate to flight



Error budgets comparable to routinely neglected physics means model uncertainty can drive system design.

(ref: SWOT_ThreeSlides 10/9/08)

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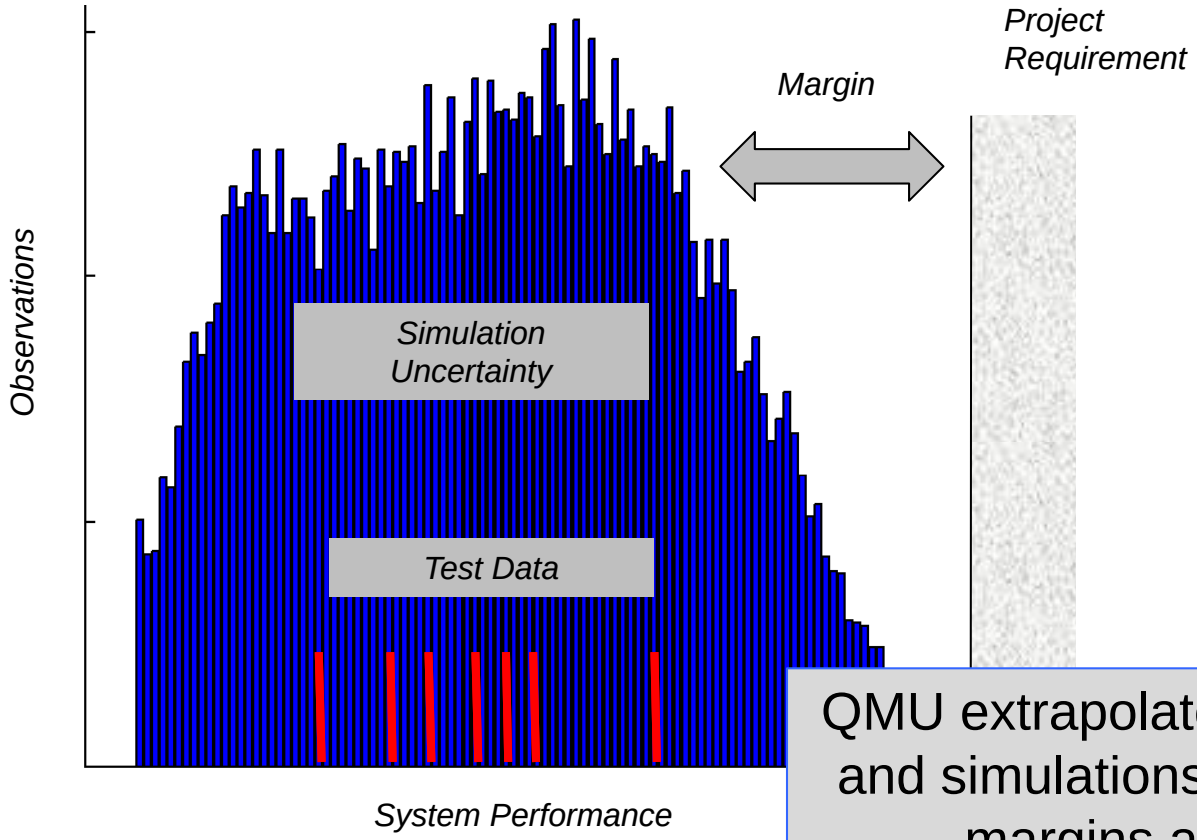
QMU seeks to provide quantitative measurements of margins and uncertainty to decision makers



QMU extrapolates from tests and simulations to estimate margins and risk

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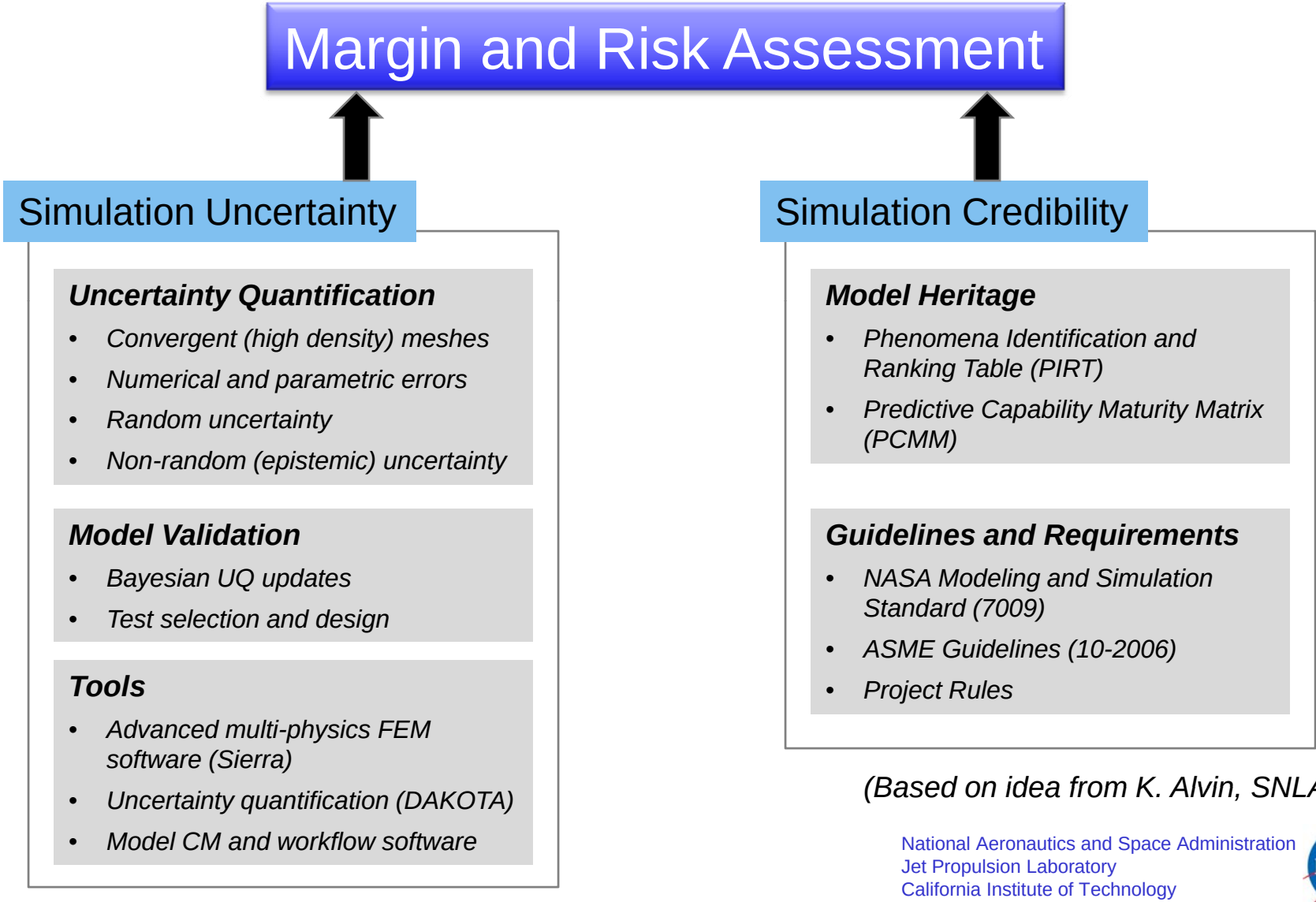
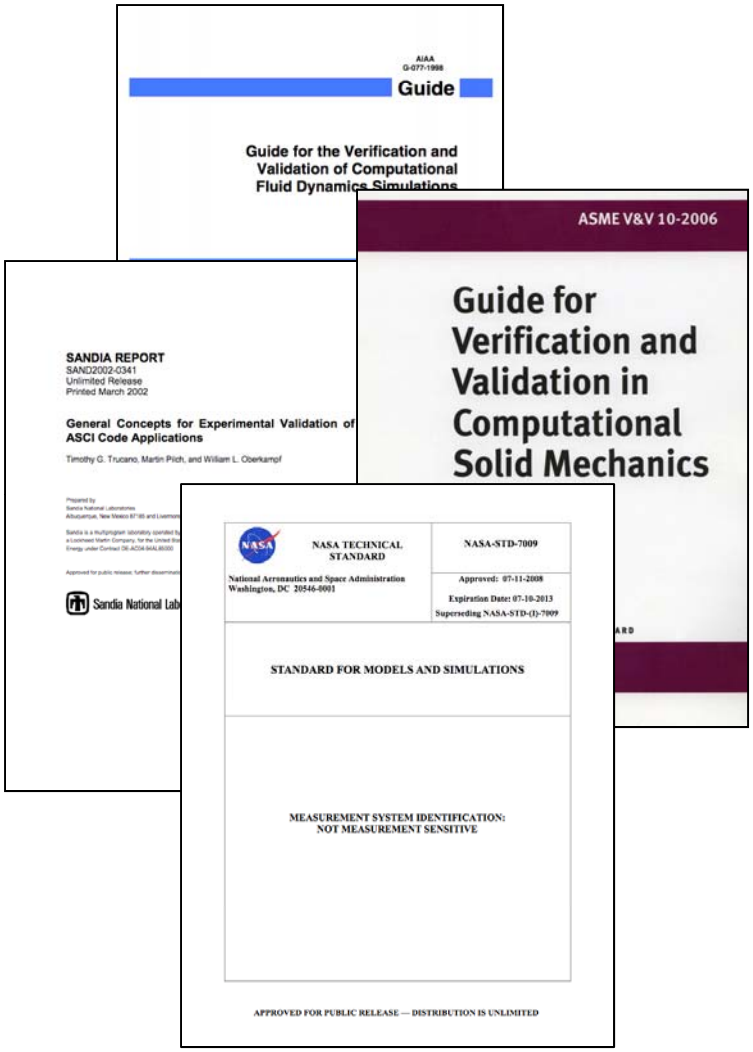
Analysis and practice are both key to establishing a QMU modeling, simulation and test campaign



(Based on idea from K. Alvin, SNLA)

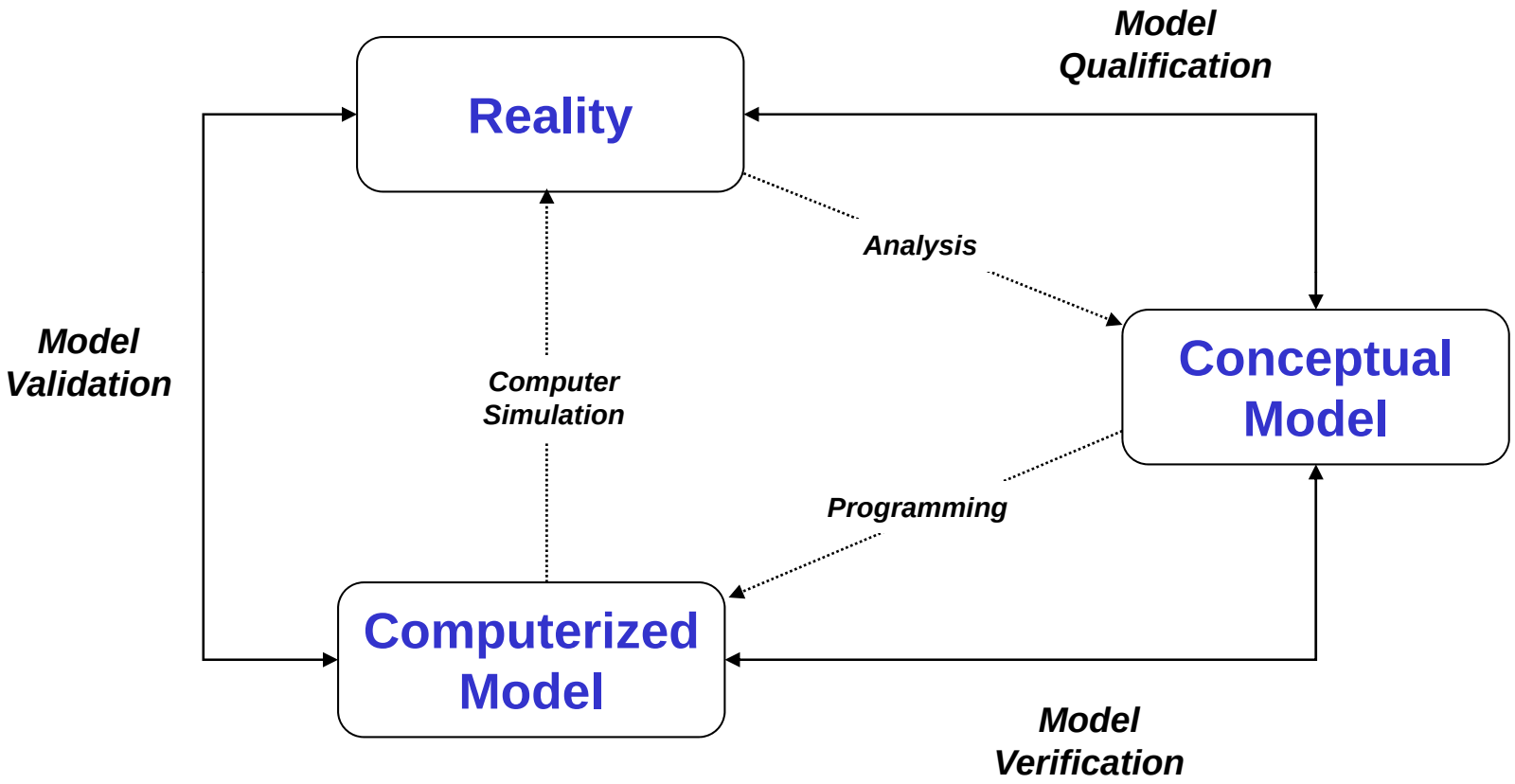
Rigorous Model Verification and Validation is the backbone of QMU

- Large activities over the past 10-15 years (especially in DOE labs)
- Recent NASA *Standard for Models and Simulation* (NASA-STD-7009, released July 2008)
  - In response to the Columbia Accident Investigation Board (CAIB) report
  - Embodies much of the modern model V&V language



NASA, AIAA, ASME, DOE and DOD Guidelines and Recommended Practices

Model “verification” is not model “validation”



[AIAA, 1999]

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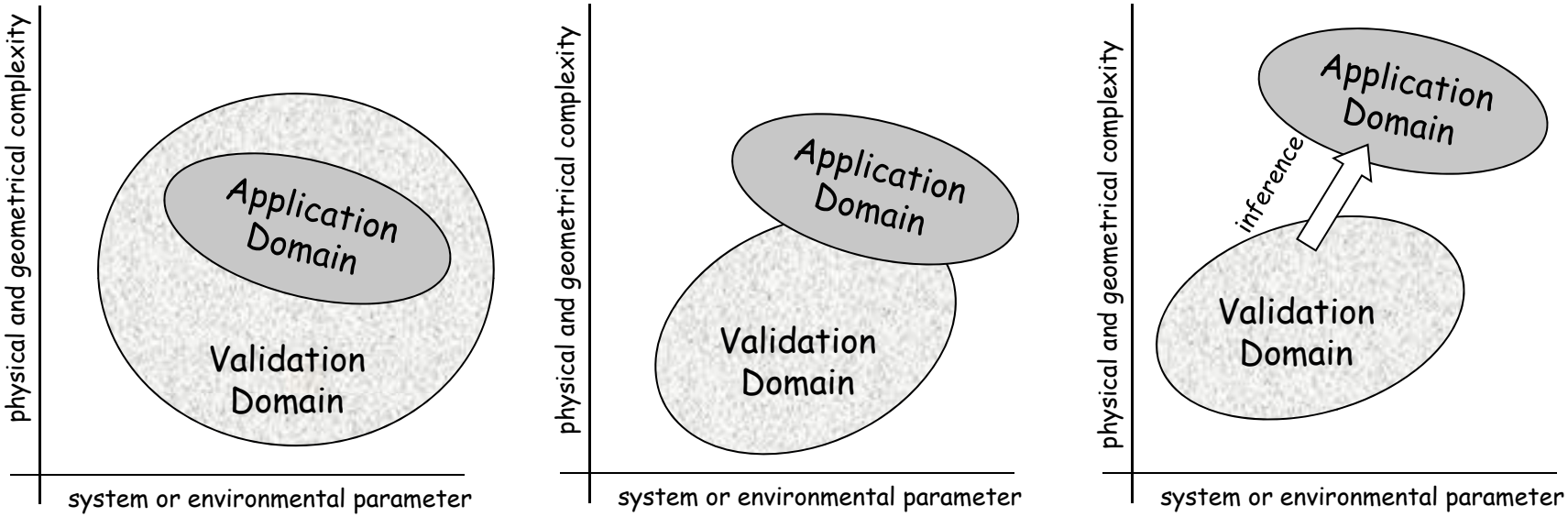
A validated model can be credible for extrapolation.



[Oberkampf et al, 2004]

Extrapolation depends on whether the model gets the right answer … for the right reasons.

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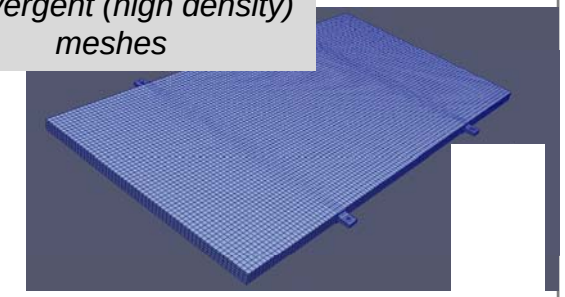
What are key technologies for QMU of space systems?

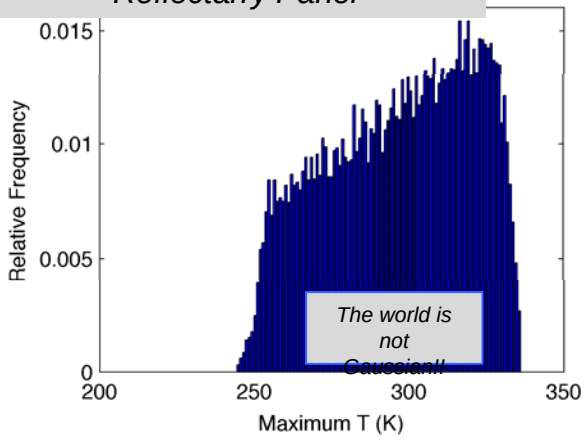
- Realism
  - *CAD-like meshes*
  - *Nonlinearities*
  - *Imperfections*
  - *Randomness*
  - *Couplings & interactions*
- Credibility
  - *Rigorous model V&V*
  - *Design-CAD-Simulation traceability*
  - *Model parameterization and sensitivity*
- Speed
  - *High performance computing*
  - *Efficient model iteration and sampling algorithms*
  - *Templated model construction and CM*

Examples

Convergent (high density) meshes



UQ Results from SWOT Reflectarry Panel



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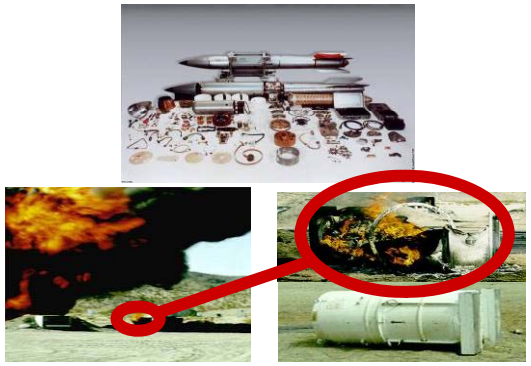
DOE labs faced similar challenges in their quest for model-based qualification without full system test

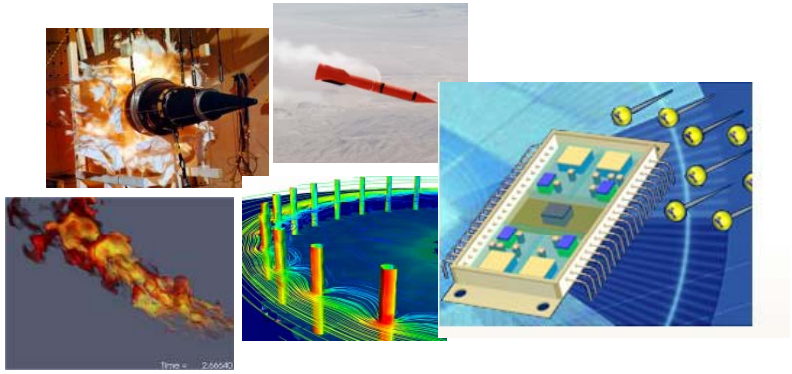
- DOE advanced modeling, simulation and model V&V technology over two decades
  - Multi-$B investment in hardware, software and test methodologies
  - Pervasive use of multiple physical domains, nonlinearity

    Specialized to DOE weapon performance
  - Rigorous model V&V practices

JPL has been collaborating with Sandia to pilot the application of their tools and methods for spacecraft QMU.



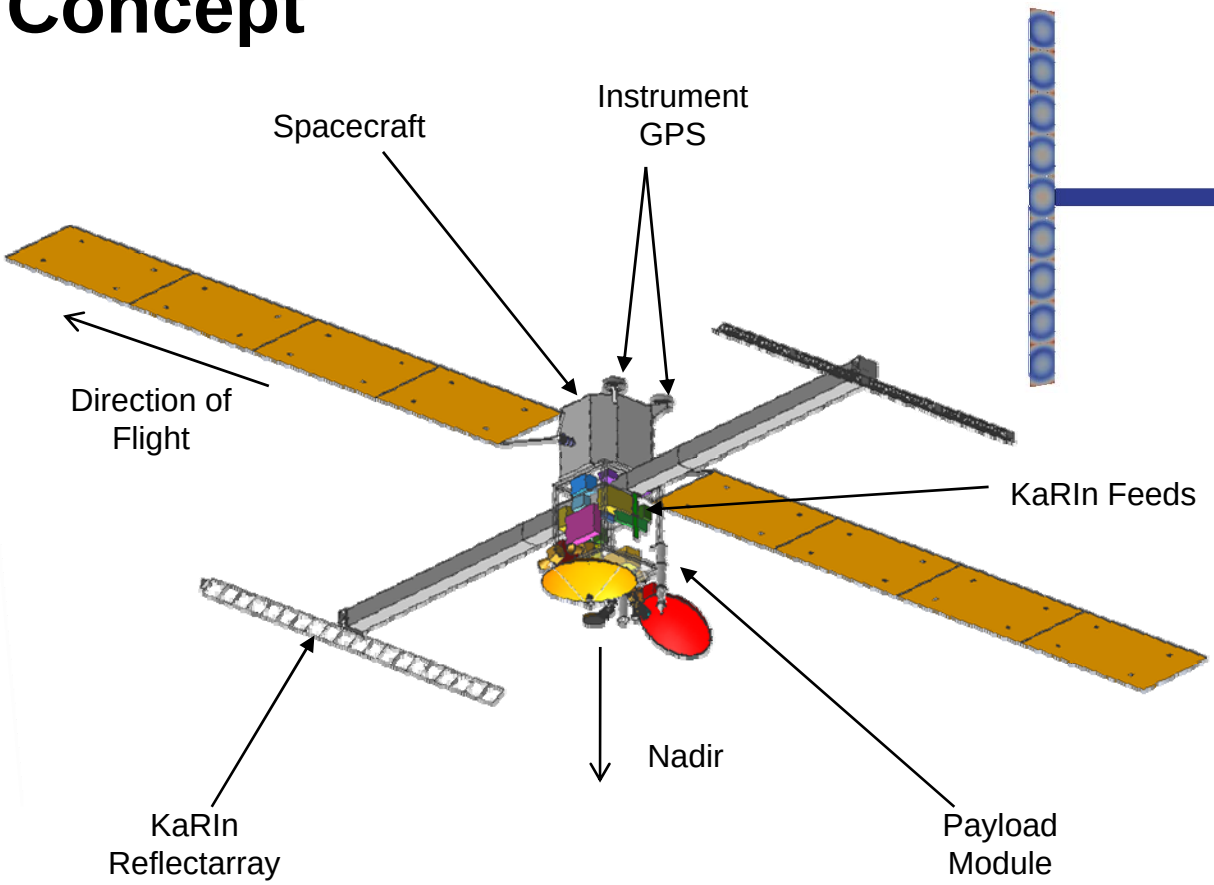
Complex Systems, Components, and Physics

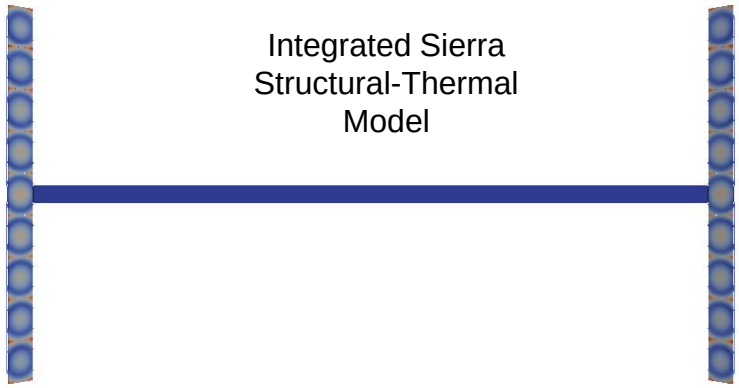


Diverse Applications

(ref: A. Ratzel, SNL, 5/19/09)

Initial Piloted Application of Sierra to SWOT Concept





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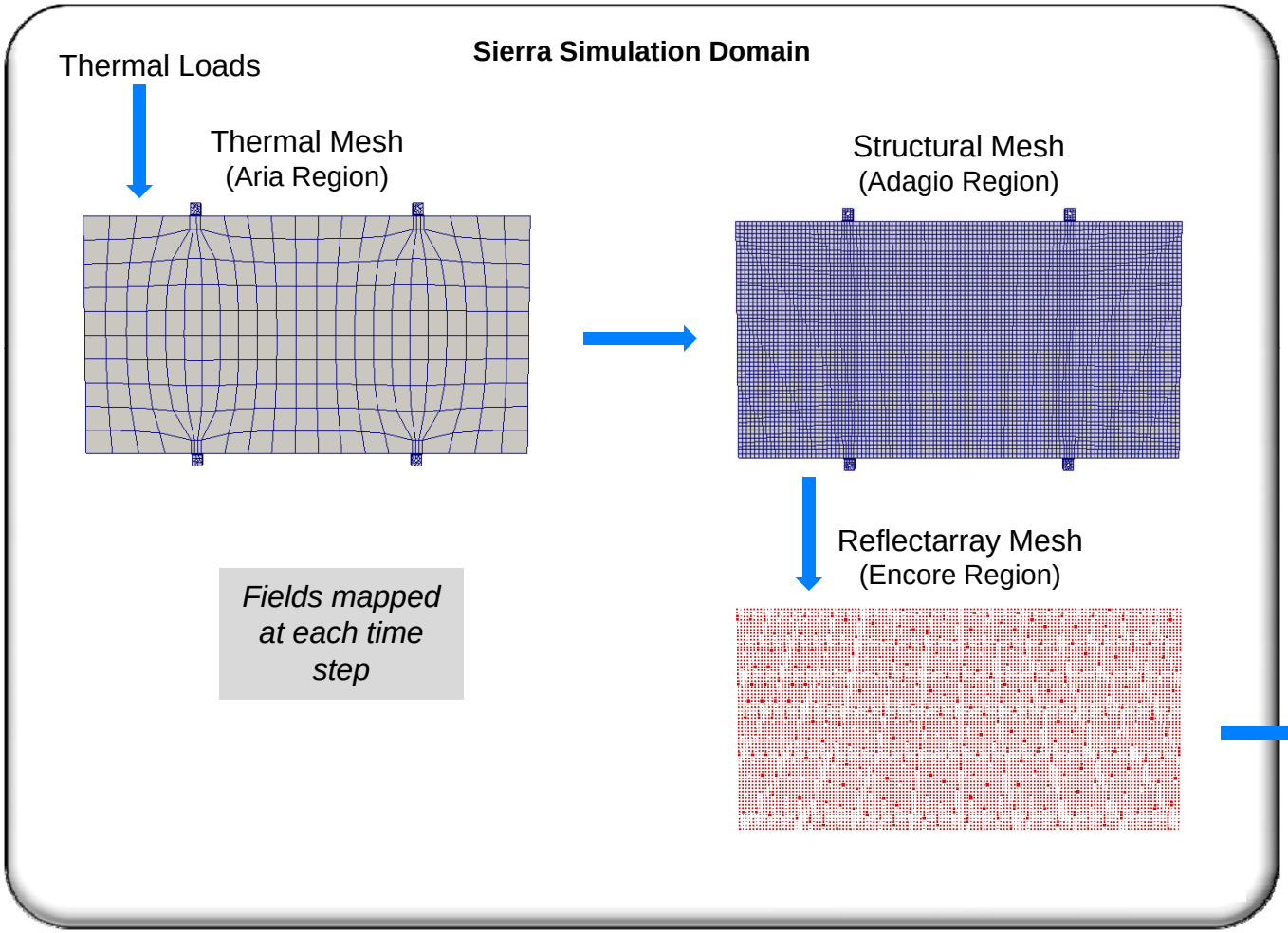
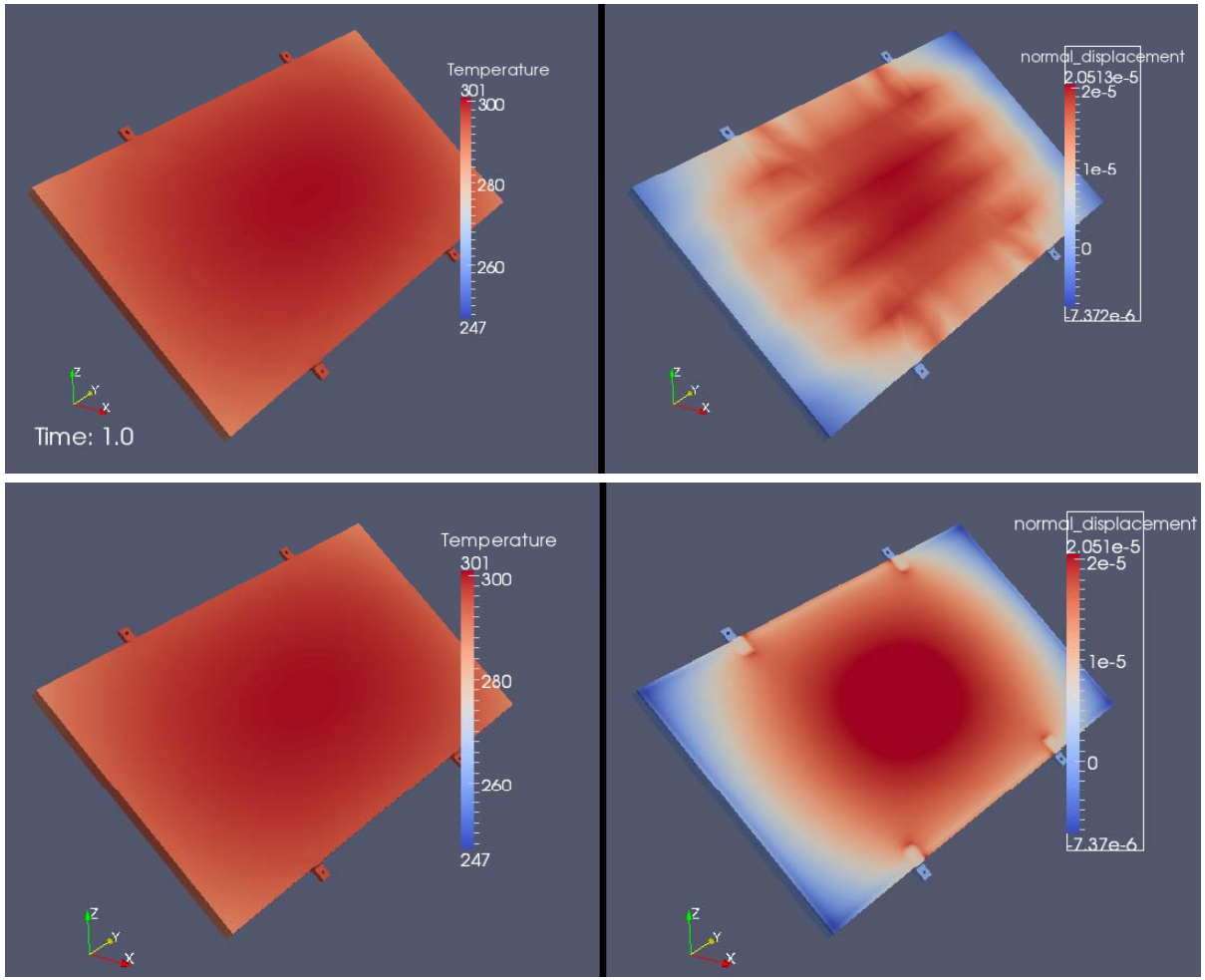
SWOT KaRIn Array Panel Multiphysics Model



Is the peculiar steady-state displacement pattern real or numerical?



Baseline Mesh

6x Mesh

QMU enables systematic assessments off models for numerical error

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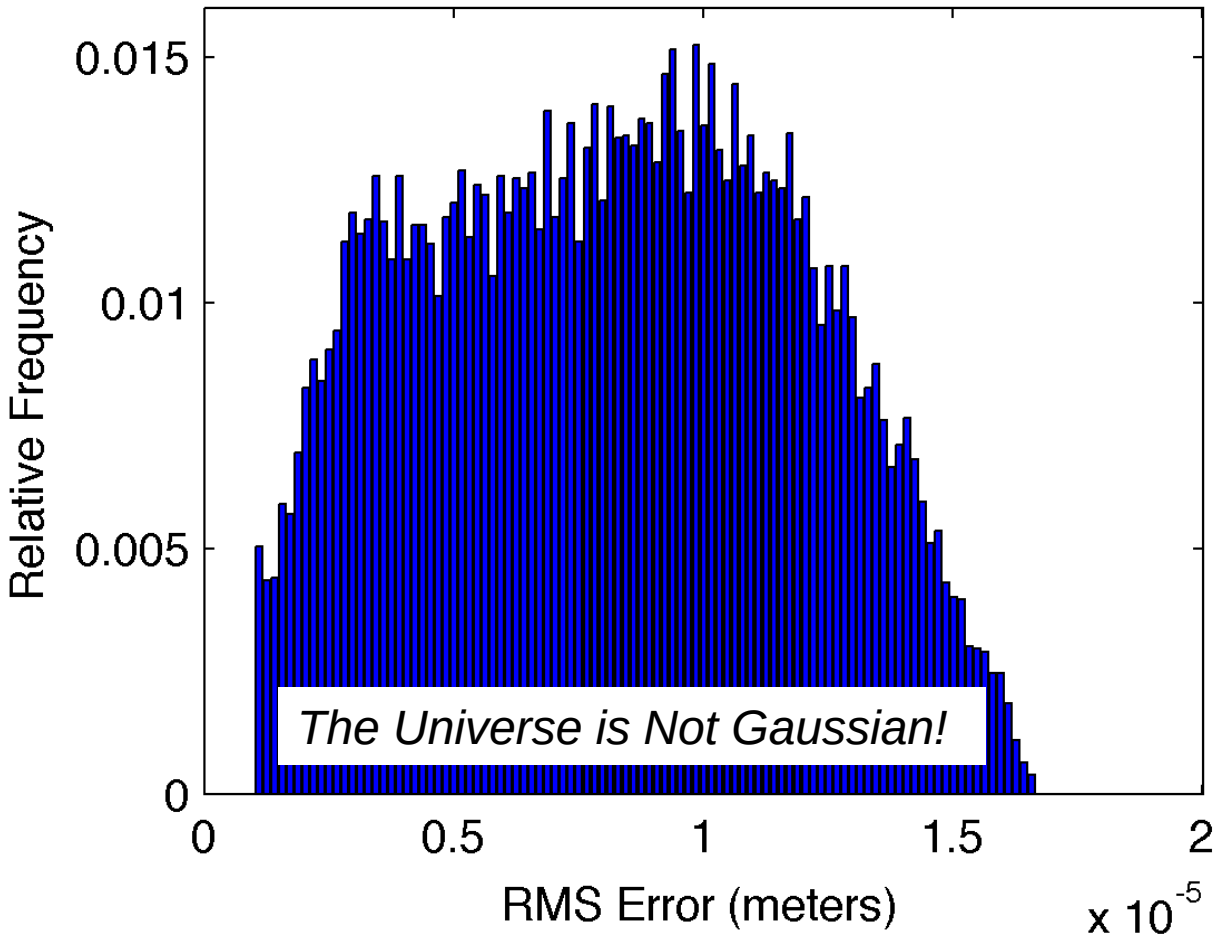
Illustrative SWOT Panel UQ Study Results



QMU enables systematic assessments off parametric uncertainty

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But there is more to QMU than just “uncertainty quantification”

- Need to establish “simulation credibility” via application of rigorous process

  A routine model with simple UQ may be adequate for a given application

  A complex model with complex UQ may not be any more credible than a simple model

- Model Credibility Assessment and Planning Tools
  - Phenomena Identification and Ranking Table (PIRT)
  - Predictive Capability Maturity Matrix (PCMM)

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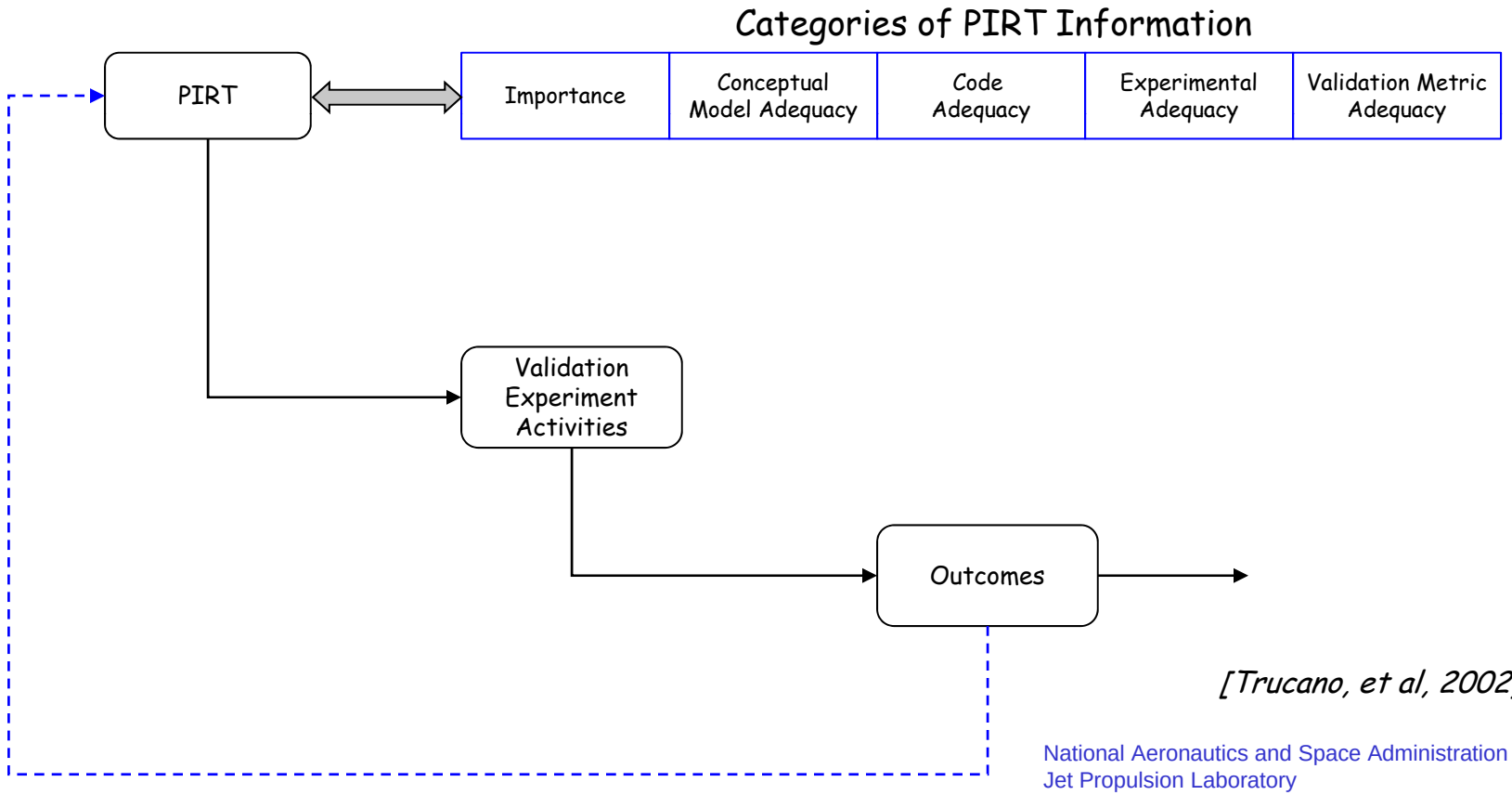
PIRT analysis forms the basis for simulation credibility by identifying key phenomena

Phenomena Identification and Ranking Table (PIRT)



[Trucano, et al, 2002]

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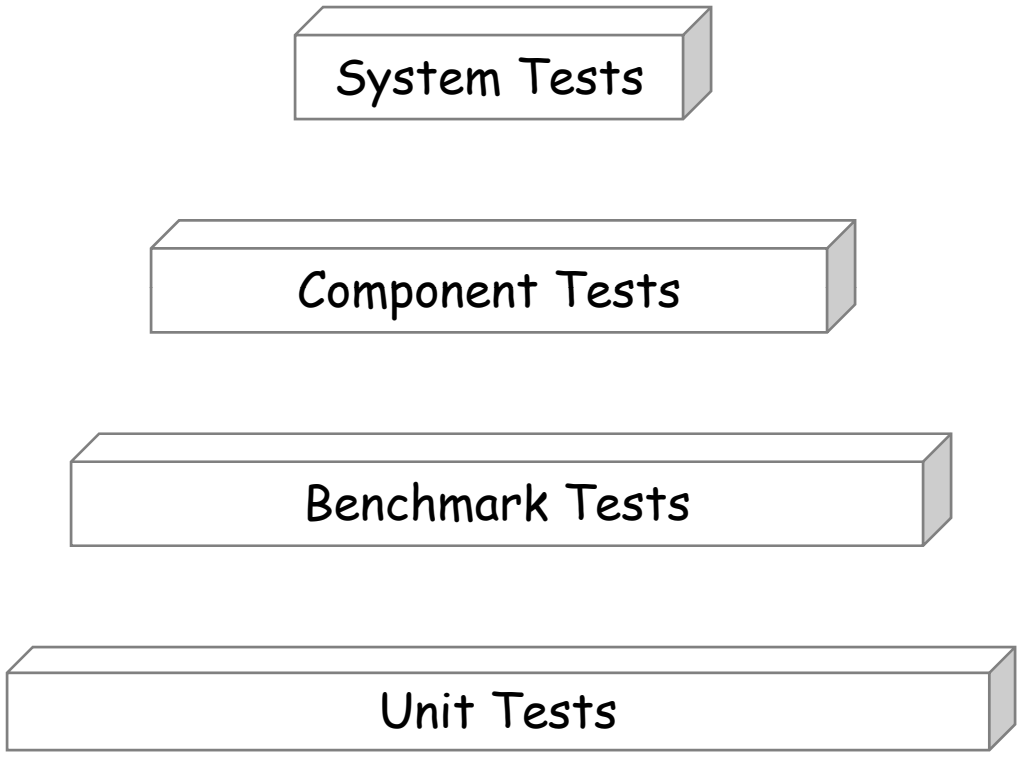
PIRT analysis leads to a desired hierarchy of model validation tests.



Moderate to high uncertainty in test conditions.
Not used for empiricism.
Predictive evaluation only.

More difficult to isolate single error source.
Undesired for empiricism.

Predictive evaluation of benchmark tests.

Two or more basic physics
Ideal boundary conditions
Predictive evaluation of unit tests.

Basic physics and empiricisms.
Tightly controlled test conditions.

Very low test uncertainty.

Lower level validation test results can be reused in multiple projects.

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How this Might be Applied for xTerraMechanics Modeling

- PIRT can be used to identify the key simulation, model validation, and basic physical experiments requiring further development
  - Which phenomena are most important?
  - Which code components are least reliable?
  - Where is test data most lacking?

PIRT can help establish a solid story for future research and development needs

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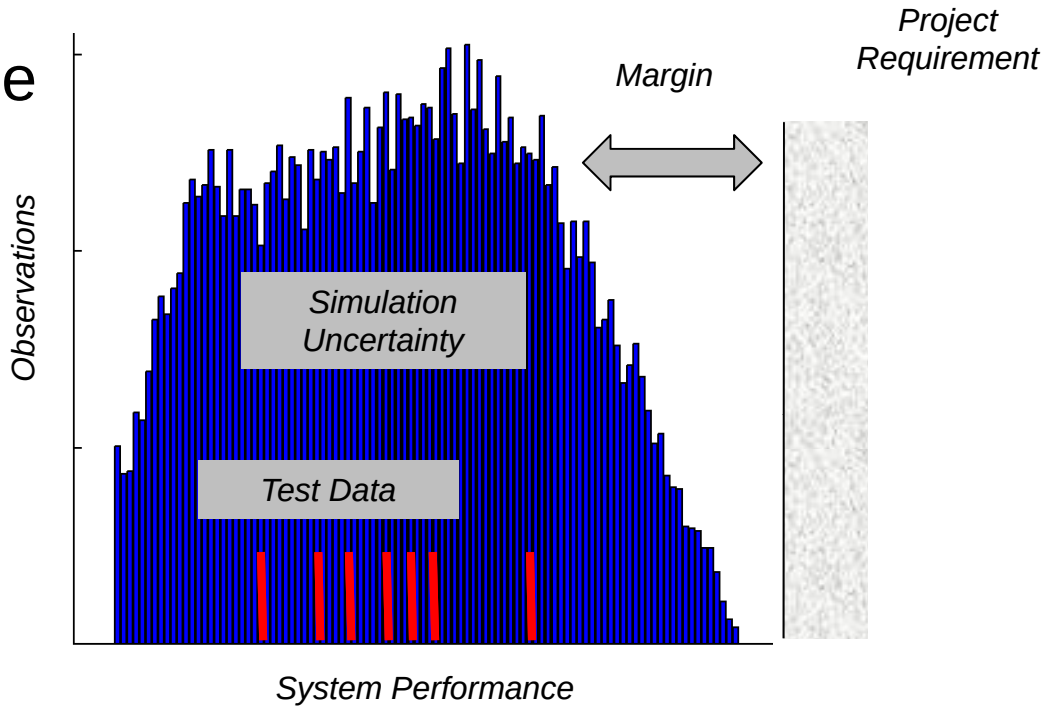
Summary

- JPL has been piloting the use of DOE developed pedagogy, tools and practices for QMU of space systems
- Key new technologies, tools and practices specific to spacecraft applications
- QMU pedagogy might help plan future KISS xTerraMechanics investments



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