National Renewable Energy Laboratory
Innovation for Our Energy Future

Thermal Stress and Reliability for Advanced Power Electronics and Electric Machines

U.S. Department of Energy Annual Merit Review

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presented by

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APE017

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Overview

Timeline

- Project start date: FY08
- Project end date: FY11
- Percent complete: 60%

Barriers

- Validated life models are not available in the open literature for technologies of interest in advanced inverter design

Budget

- Total project funding
  - DOE share: $1.3M
  - Contractor share: $0
- FY08 Funding: $280k
- FY09 Funding: $375k
- FY10 Funding: $650k

Partners

- Interactions & Collaborations
  - FreedomCAR Electrical & Electronics Technical Team, General Motors, Delphi, UQM, NIST, University of Maryland, Oak Ridge National Laboratory, Advanced Engineering Solutions
- Project lead: NREL

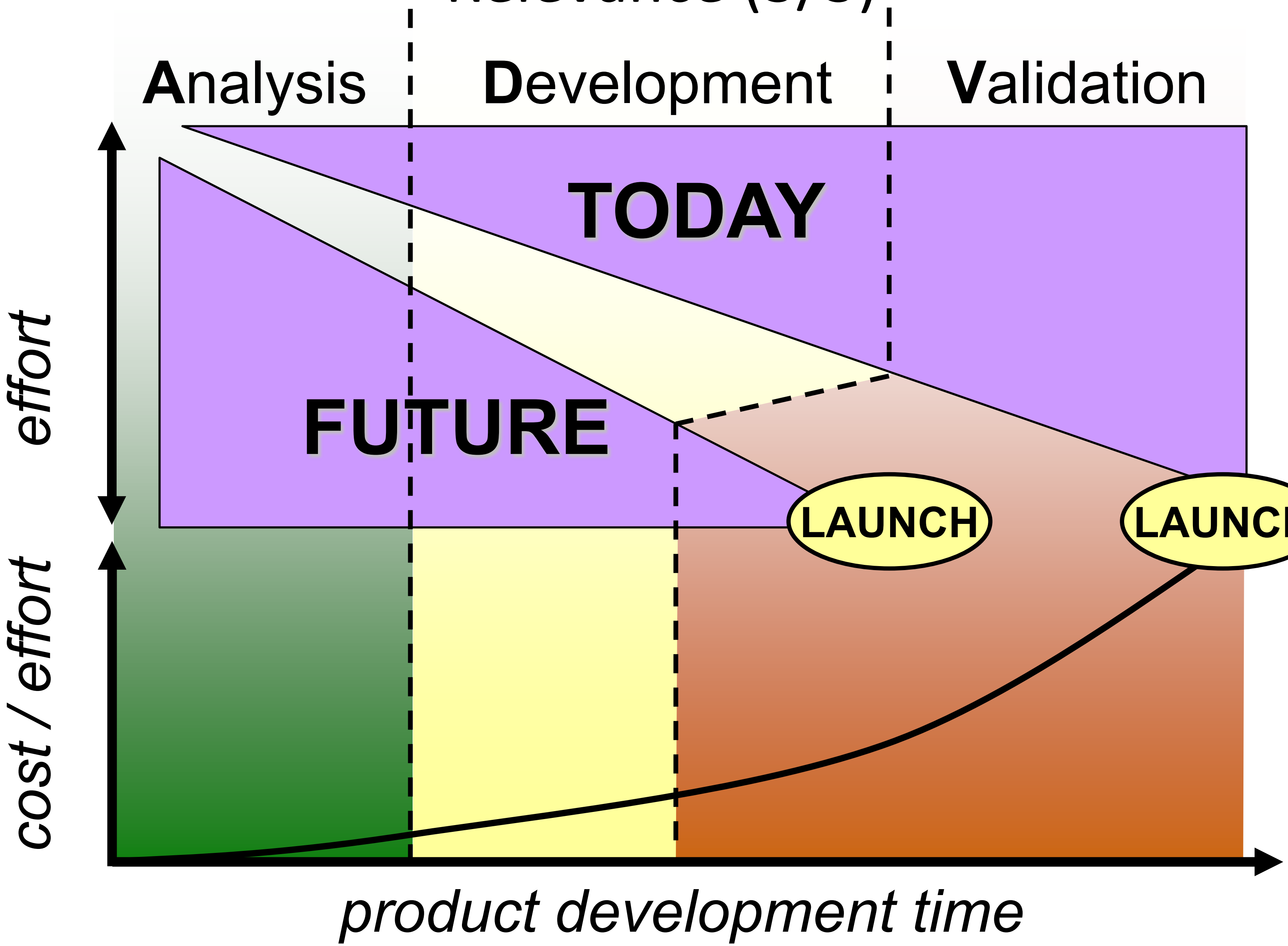
Relevance (1/3)

- Overall Objective
  - ***Develop*** bonded interface model(s) using commercial CAE tools and ***validate*** coefficients for physics-of-failure damage models to be used in or with the tools
  - Use models to ***characterize*** the ability of power module concepts to meet the 15 year program life requirement
  - Use models to ***synthesize*** new design concepts by conducting design space exploration, optimization, and robust design

Relevance (2/3)

- Objective for FY09 – FY10:
  - Plan experimental element to validate model results
  - Contact other groups to collaborate on validation
  - Use modeling tools to demonstrate design for reliability optimization of an APEEM concept
- Relevance to the Vehicle Technologies Program:
  - The ability to use modeling early in the design process to investigate reliability decreases time, cost, and risk in commercializing new technology
  - Allows program to assess ability to meet the 15 year life requirement

Relevance (3/3)



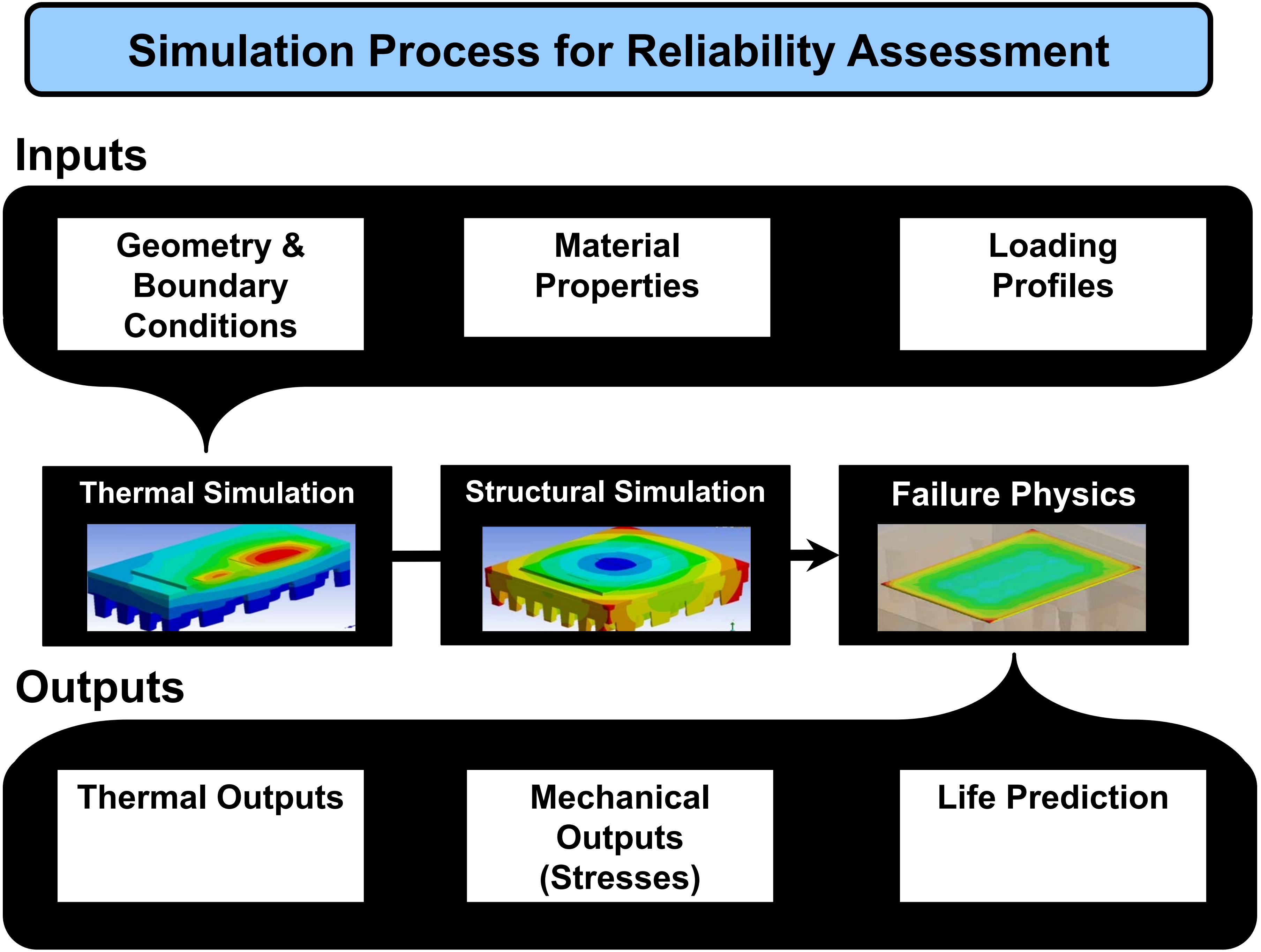
Assertion: Validated design for reliability modeling tools, applied early in the development process, can reduce the risk, time tomarket, and cost of commercialization.

Approach / Strategy (1/2)

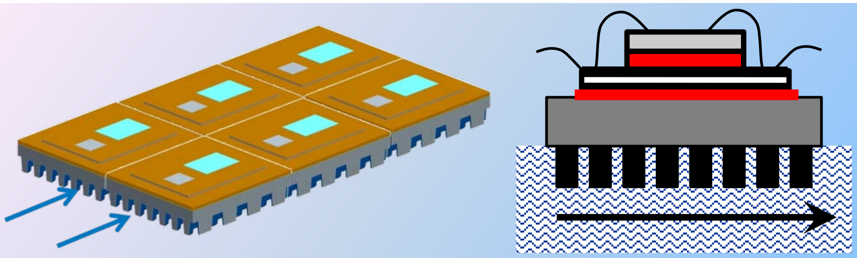
- Focus on one failure mechanism at a time
  - Initial focus: die and DBC attach failure
- Identify the appropriate failure model for each mechanism
- Validate model prediction against test data
  - Focus on die attach and DBC attach
  - Use test data from in-house and collaborations
- Demonstrate the use of CAE tools for design for reliability
- Publish validated model parameters

Approach / Strategy (2/2)

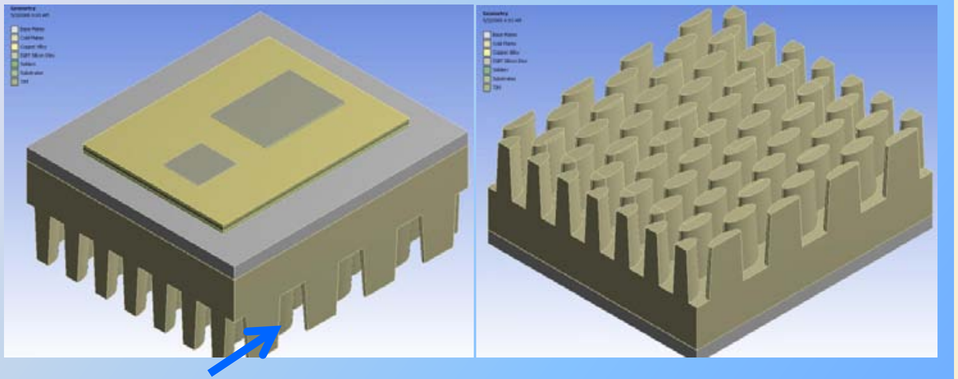
Month/ Year	Milestone or Go/ No-Go Decision Point
Jul 2008	Reliability Effort Multi-Year Project Plan
Sep 2008	Annual Milestone Report
Jun 2009	Report on Reliability Modeling for Advanced Power Electronics
Sep 2009	• Annual Milestone Report • O'Keefe, M. and Vlahinos, A. (2009). "Reliability Impacts of Cooling Strategies for Power Modules in Electric Traction Drive Vehicles." 5th IEEE Vehicle Power and Propulsion Conference, Dearborn, Michigan. September 7-11, 2009.
Oct 2009	Vlahinos, A. and O'Keefe, M. (2009). "Designing Six Sigma Quality into Electric Traction Drive Vehicles Power Electronics", Technical Presentation given at the Accelerated Stress Testing and Reliability Workshop, Jersey City, New Jersey. October 7-9, 2009.
Nov 2009	Vlahinos, A. and O'Keefe, M. (2009). "Sensitivity of Bonded Joint Fatigue to Sources of Variation in Advanced Vehicular Power Electronics Cooling." ASME International Mechanical Engineering Congress, Lake Buena Vista, Florida. November 13-19, 2009.
Sep 2010	**Milestone:** Report on status and results of reliability model applied to inverter packages using different thermal control technologies

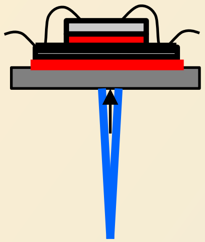

Simulation Process for Reliability Assessment
Inputs
Geometry & Boundary Conditions
Material Properties
Loading Profiles
Thermal Simulation
Structural Simulation
Failure Physics
Outputs
Thermal Outputs
Mechanical Outputs (Stresses)
Life Prediction

Technical Accomplishments & Progress (2/8):
Work to Date

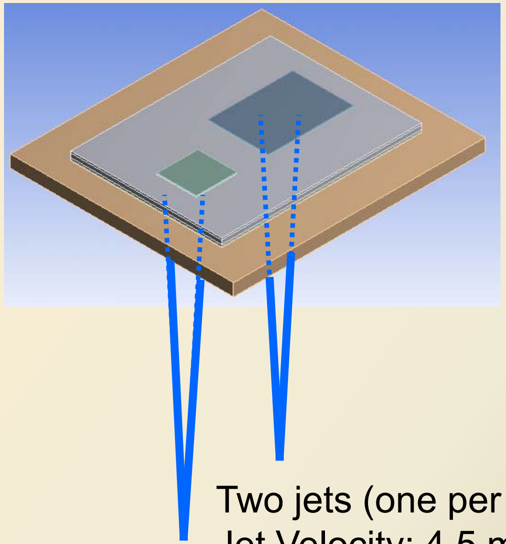


Topology 1
Baseline Pin-Fin





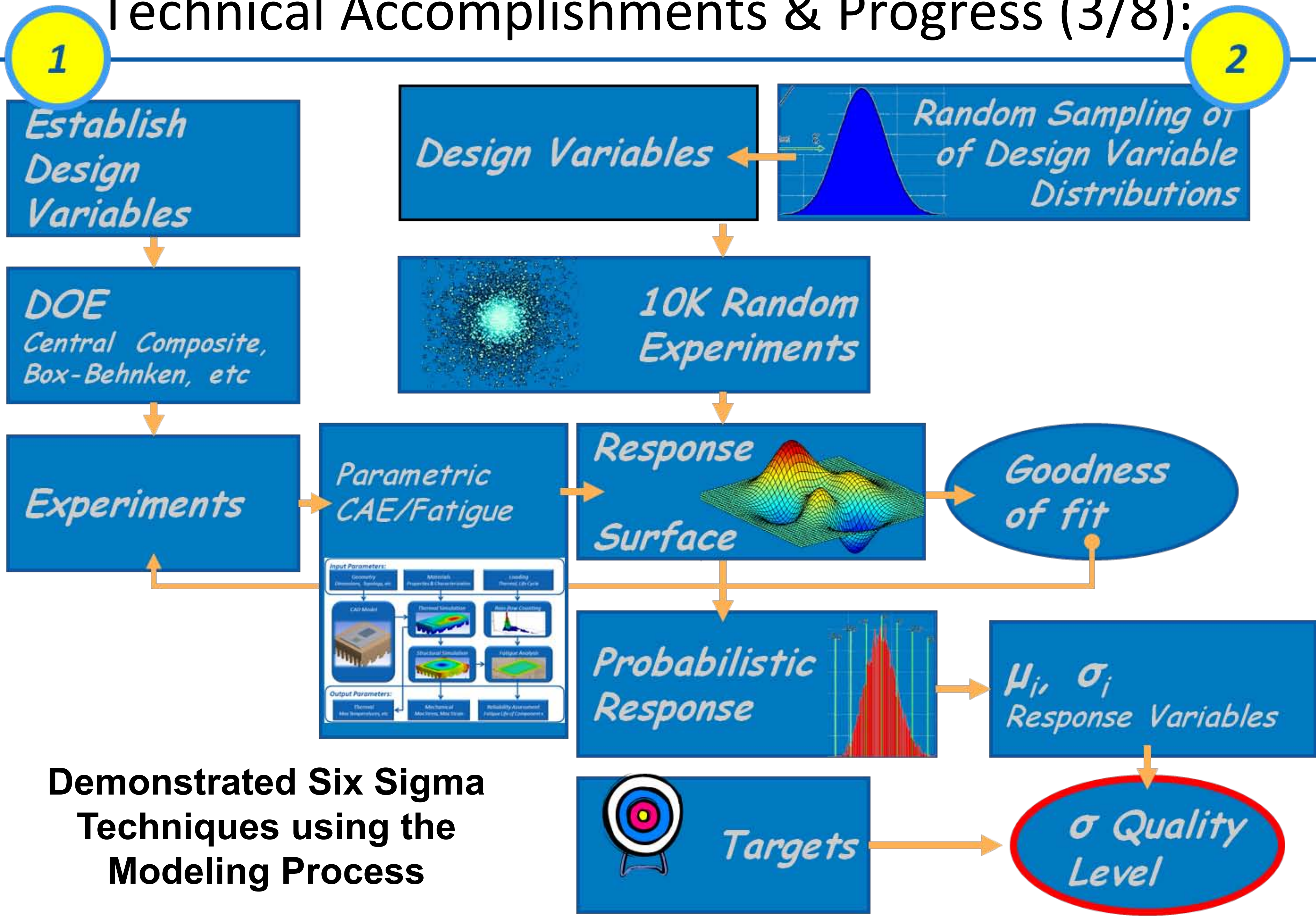
Topology 2
Jets on Baseplate



Two jets (one per chip)
Jet Velocity: 4.5 m/s
Nozzle diameter: 1.4 mm

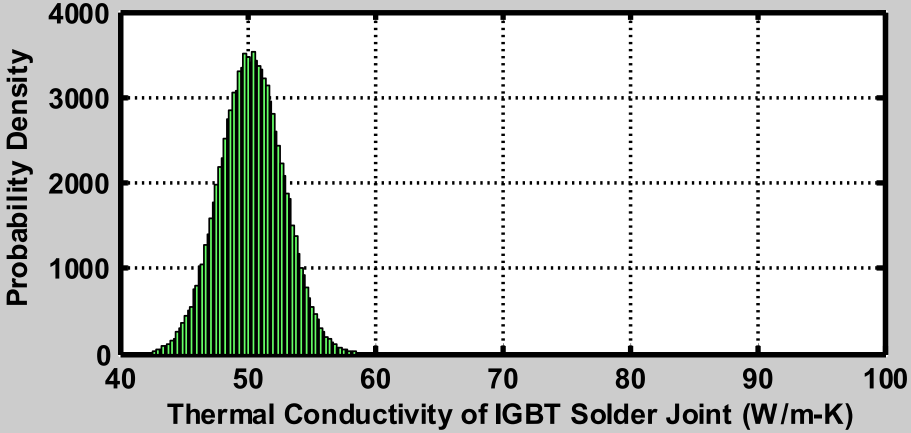
DBC Solder Cycles to Crack Initiation	**17**	**163**

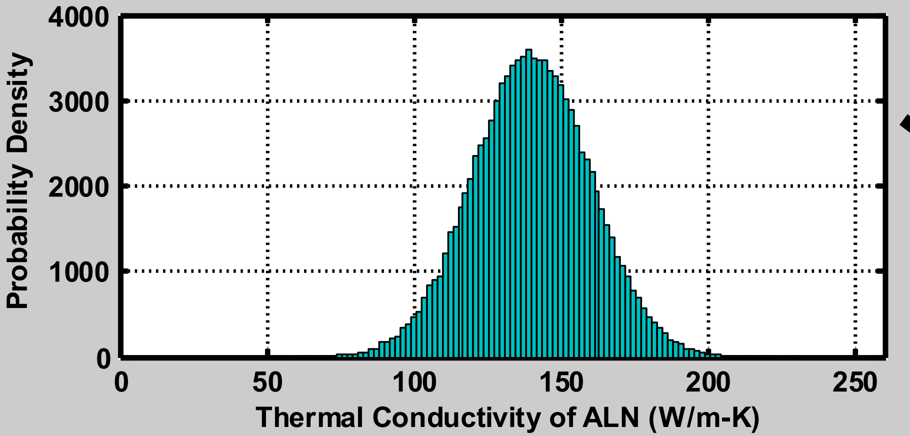
Technical Accomplishments & Progress (3/8):

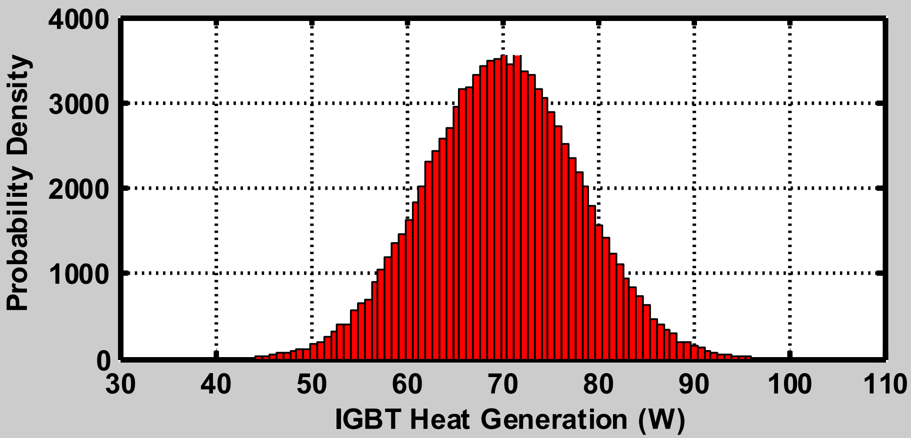


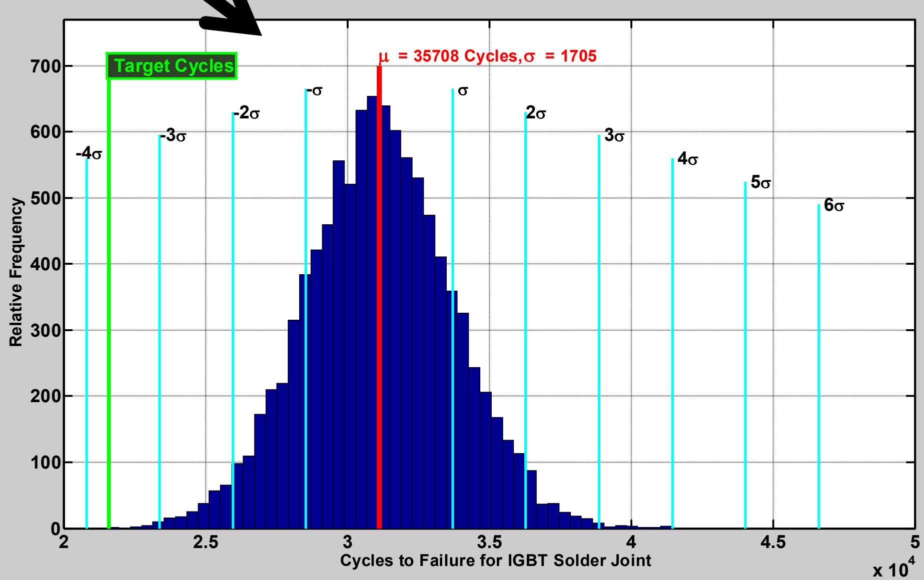
Demonstrated Six Sigma Techniques using the Modeling Process

We demonstrated how stochastic input parameters can be used to predict stochastic output metrics.



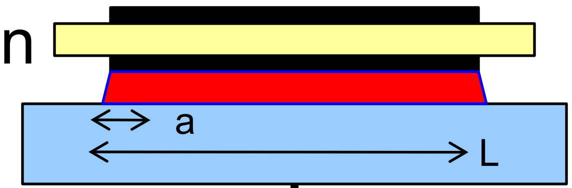


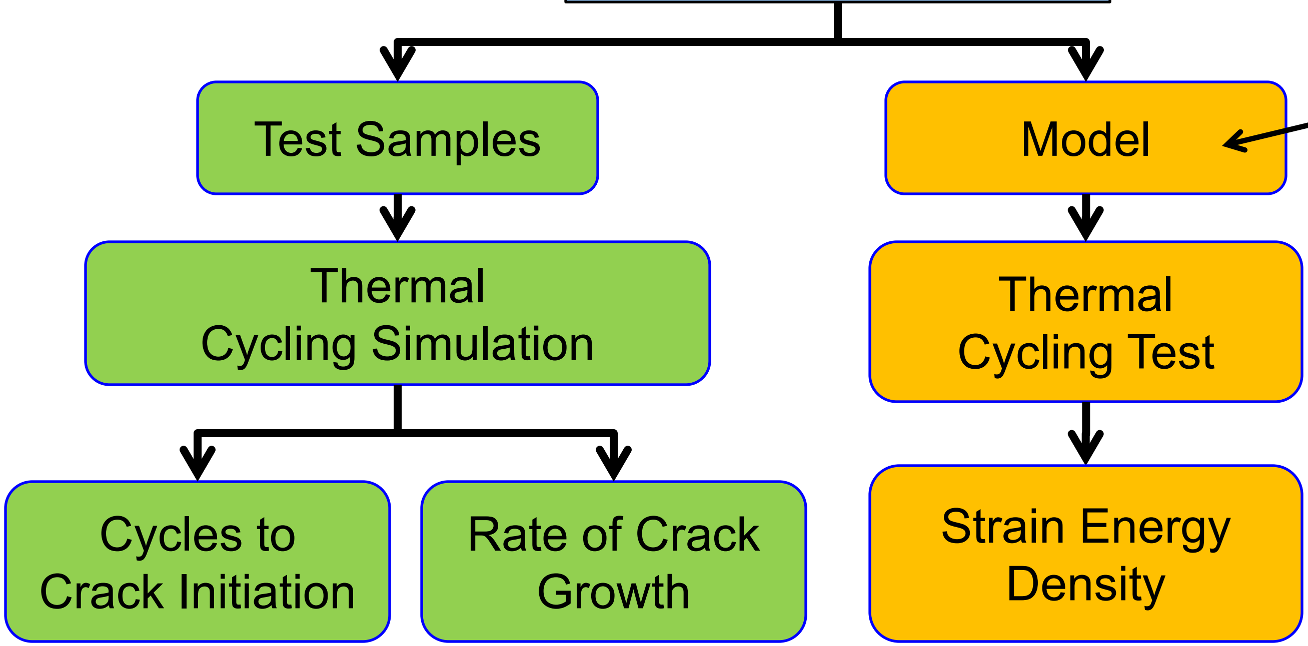




Technical Accomplishments & Progress (5/8)

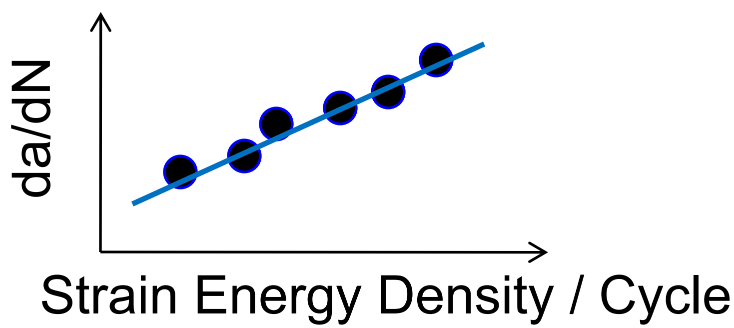
Planned Validation Technique

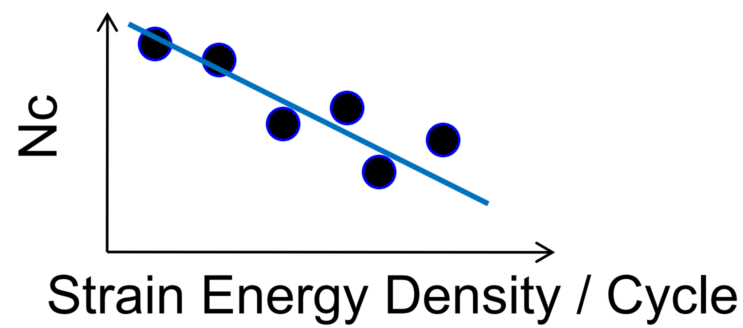




Where available, use model parameters from literature

$$N_f = N_c + \frac{L}{\frac{da}{dN}}$$





Test Procedure Overview

START:
Bonded Interface Samples

Initial
Hi-Pot, Dimensions, &
R_{th} Measurements

Thermal Shock
for 300 Cycles

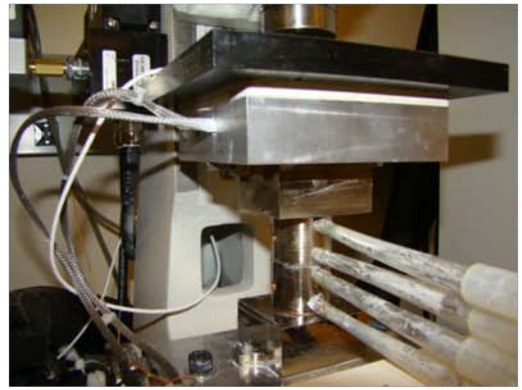
Hi-Pot & R_{th}
Measurements

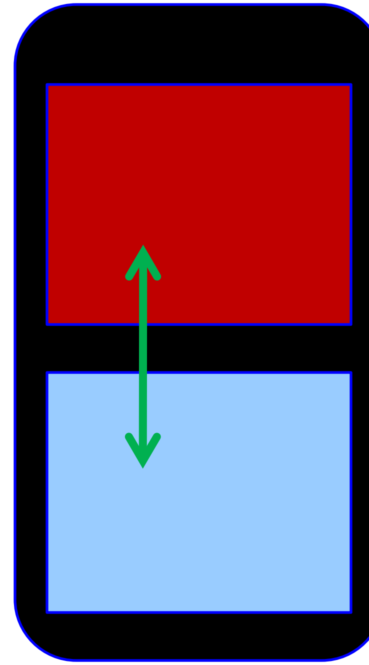
Total Cycles > 1,800?

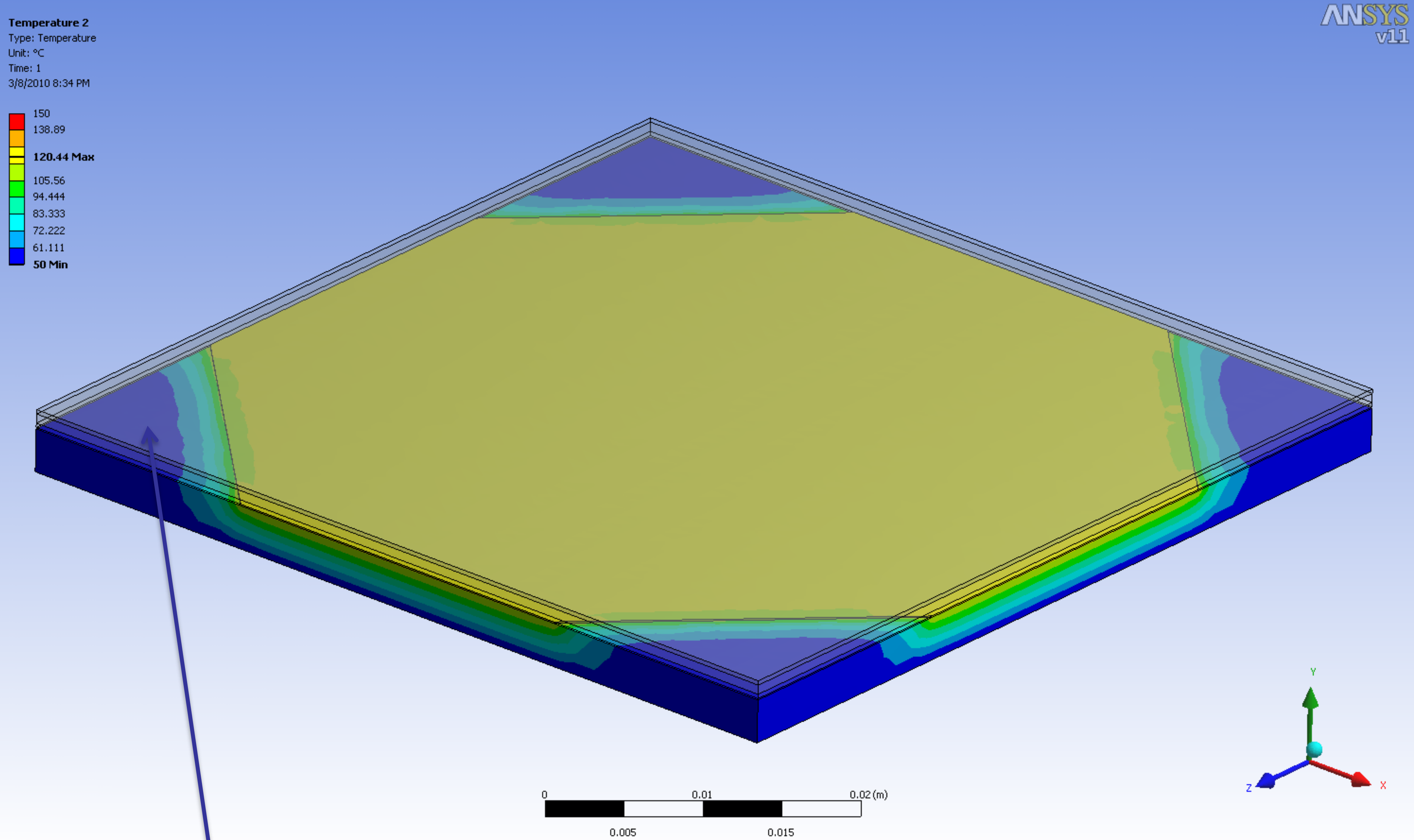
No

Yes

STOP

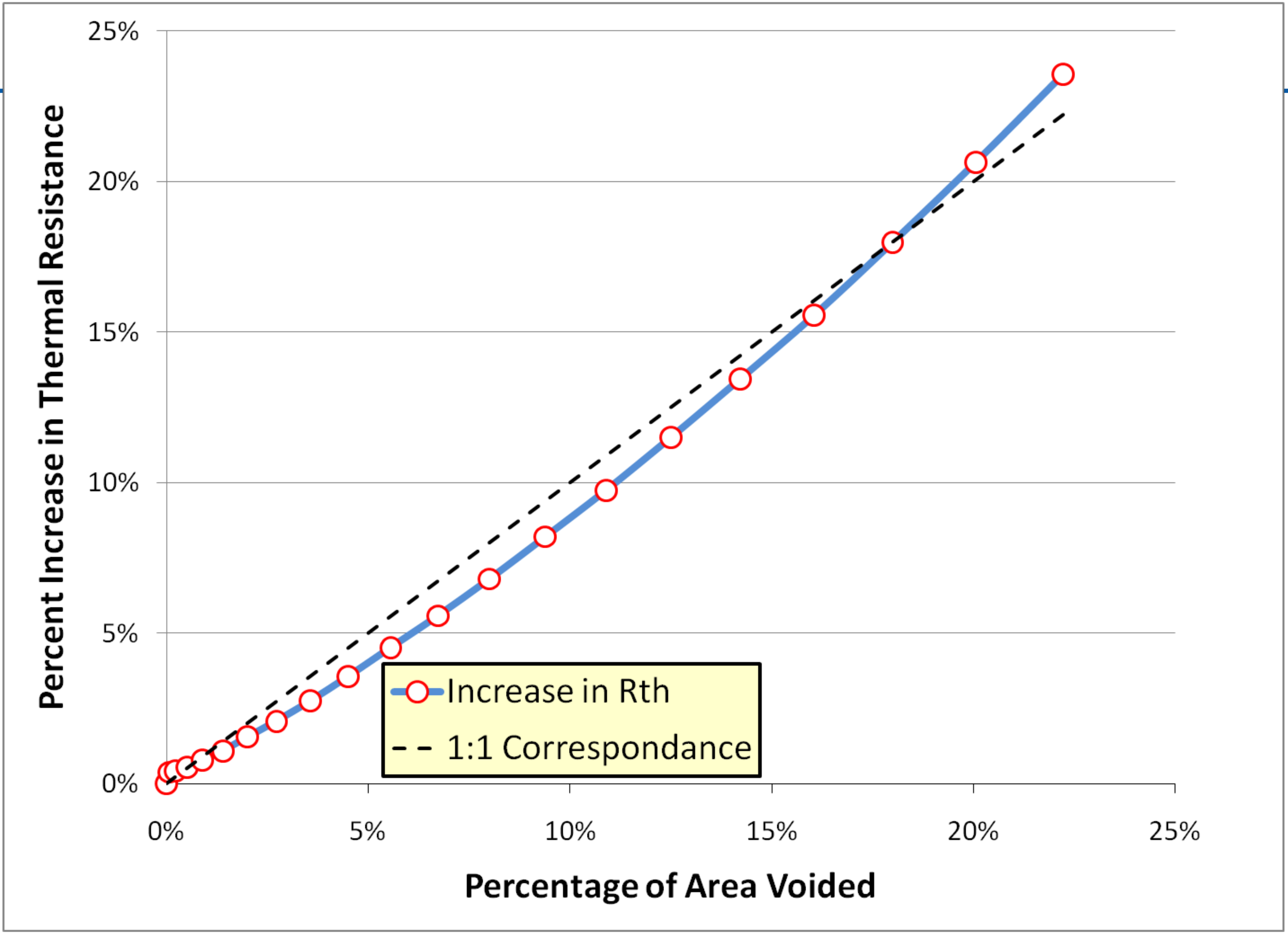






Simulated Voiding

as sample will be measured in Thermal Interface Material Test Stand



25%
20%
15%
10%
5%
0%
Percent Increase in Thermal Resistance
0%
5%
10%
15%
20%
25%
Percentage of Area Voided
Increase in Rth
1:1 Correspondance

Collaboration / Coordination with Other Institutions (1/2)

- Industry
  - General Motors, Partner, validation data, input on plans
  - Delphi, Partner, input on plans
  - Electrical & Electronics Tech Team, Partner, input on plans

- Universities
  - University of Maryland, under subcontract
    - add mechanical degradation to electrothermal models (ETMs)
    - develop accelerated degradation tests for ETMs
    - identify in-situ metrics to track and monitor package degradation
  - Virginia Tech, subcontract, bonded interface tech

Collaboration / Coordination with Other Institutions (2/2)

- Other Government Laboratories
  - Oak Ridge National Laboratory, Partner
    - Collaboration with the Transportation Materials Group
    - Collaboration with PEEMRC Packaging Group
  - National Institute of Standards and Technology, Partner
    - NREL to assist with heat transfer technology for electrothermal model development

Proposed Future Work

- Use test specimens to calibrate fatigue damage models for life of new bonded interface materials
- Validate model prediction against tests of joints in various configurations and loadings
- Initiate modeling & testing effort to look at electrical interconnects (wire bonds, ribbon bonds, planar packaging, etc.)

Summary (1/2)

- Relevance
  - Validated life models for use with commercial CAE tools can guide R&D decisions, reduce deployment time, identify barriers to meeting life/reliability goals, increase R&D robustness
- Approach/ Strategy
  - Focus on validating reliability of bonded interface through in-house experiment and collaboration with other groups. Use commercial tools where possible.
- Technical Accomplishments
  - Developed experimental validation test plan
  - Demonstrated Six Sigma robust design techniques in existing model framework

Summary (2/2)

- Collaborations & Coordination
  - Collaborations established with leading industry partners, universities, and R&D labs
  - Coordinating testing efforts with other DOE labs

- Proposed Future Work
  - Validate model against test data (begin this FY)
  - Evaluate new interface materials and build reliability models (solder, sinter, brazing, thermoplastics)
  - Expand efforts to electrical interconnects