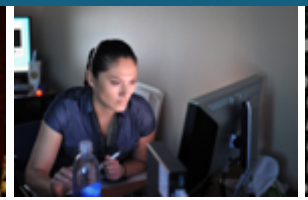
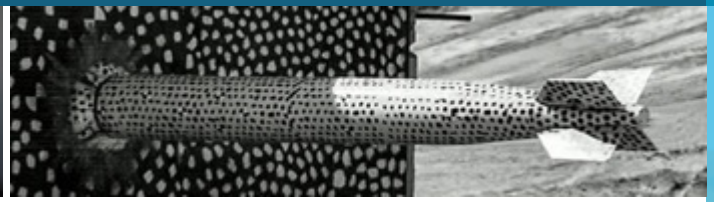
SAND2021-10510PE

LDRD Ending Project Review
Multi-fidelity thermal modeling of laser powder bed additive manufacturing 224003





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Team Members: Daniel Moser

FY21, $95K

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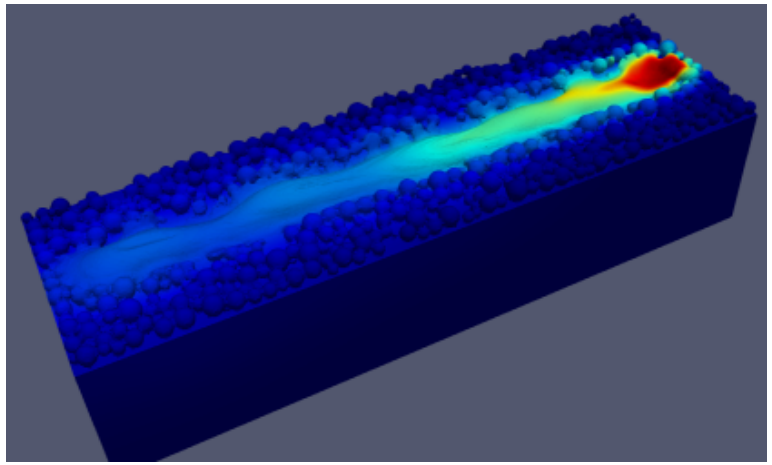
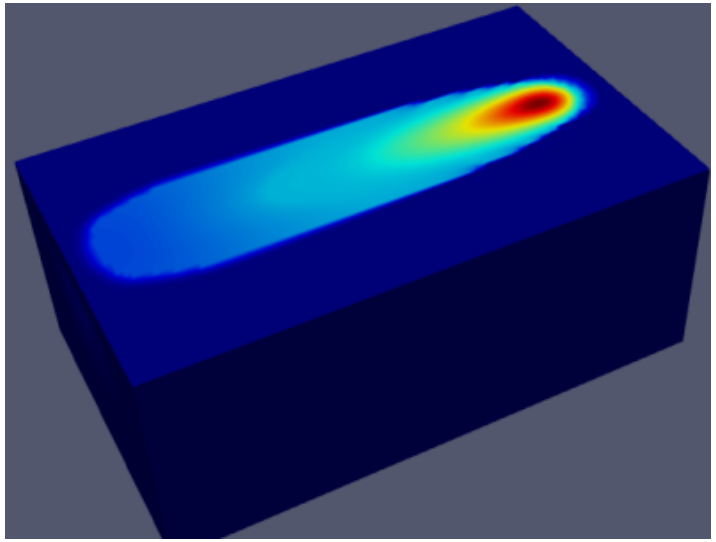
PURPOSE, GOALS AND APPROACH

- **Key ST&E question: Can the outcomes and variabilities of high fidelity thermal-fluid laser powder bed fusion (LPBF) models be captured using reduced-fidelity conduction models with uncertainty quantification?**
- Efficient and credible methods for predicting LPBF process outcomes are needed to guide design and qualification
- Large differences in scale between process phenomena necessitate credible multi-scale modeling techniques
- This project introduces novel focus on uncertainty quantification in calibrating low fidelity LBPF models from high fidelity results
  - Bayesian inference
  - Adjoint-based error estimation

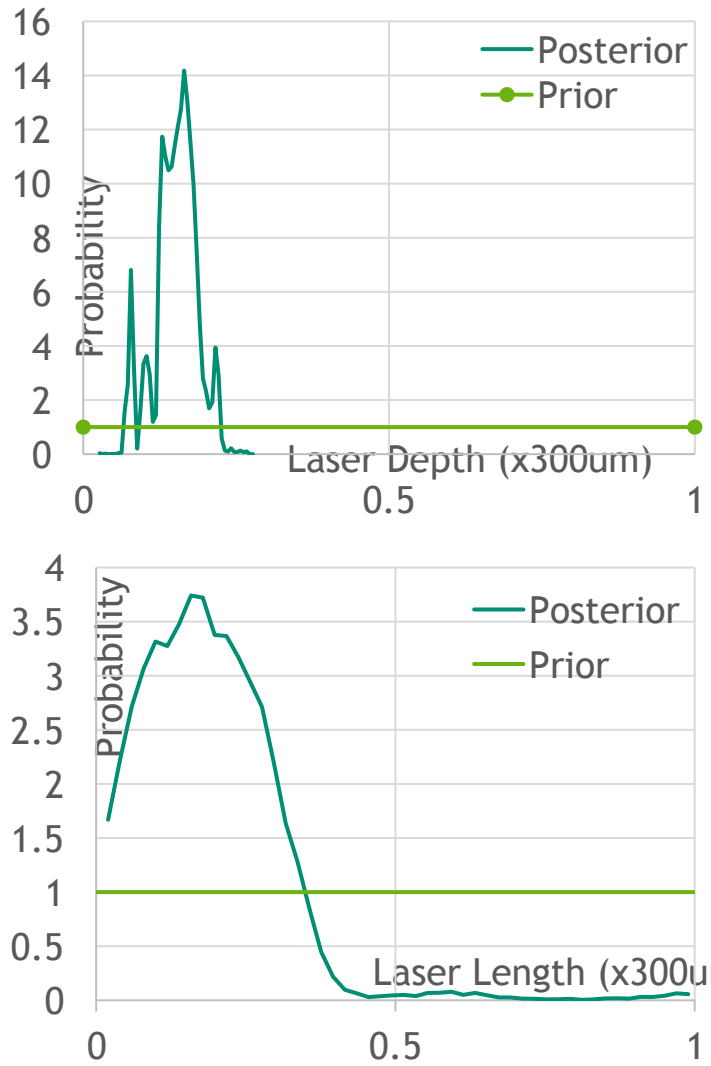




PI's PROJECT LEGACY

Technical Accomplishments

- Developed technique for doing Bayesian calibration of laser heat source parameters from high fidelity model results
  - Automated sampling methods and surrogate model construction
  - High fidelity model evaluation and data extraction
  - Rapid calibration with surrogate-based MCMC
- Adjoint-based error estimation to bound uncertainties between linear and nonlinear models
- Parametric uncertainty quantification of reduced-fidelity model
  - Volume averaging of thermal quantities
  - Comparison to high-fidelity results



PI's PROJECT LEGACY

Lessons Learned

- Heat source calibration may not provide adequate parameterization to fully capture variability seen in high fidelity model
  - Next Steps: Investigate material parameter and model deficiency calibration
- Adjoint-based error estimation bounds may be overly conservative
  - Next Steps: Investigate additional parametric UQ for going from nonlinear to linear models

Impacts

- Leveraged by funded FY22 ESRF LDRD Project: "Model-based quantification of margins and uncertainties in metal additive manufacturing for process design and qualification"
- ND 3.0 Exemplar: "Modeling and simulation of additively manufactured metal components for process qualification"
- In conjunction with FY22 LDRD, projected impact to NNSA mission priority of improved deterrent responsiveness by reducing barriers to insertion of metal AM in 5 year timeframe

PROJECT OUTPUTS

- Presentations
  - AM Working Group Meeting, July 2021
  - Innovation Incubator, July 2021

CAPABILITIES DEVELOPMENT

- Capabilities expected to impact future work
  - Automated surrogate model construction for LPBF models
  - Scripts for performing Bayesian calibration of LPBF models
  - Lessons learned on need model parameterizations for capturing variability in LPBF process
- Gained experience as early career PI

TEAM BUILDING AND PARTNERSHIPS

- Formation of 1500/1800 research team to pursue FY22 LDRD, including support from KCNSC
- SNL re-engagement with SHAP3D AM industry consortium

IA/PM PROJECT LEGACY

How did this project contribute to IA strategic goals and objectives?

- Potential impact to NNSA mission priority of improved deterrent responsiveness by reducing barriers to insertion of metal AM in 5 year timeframe
- Early career PI development
- Lessons learned on model parameterization to be leveraged in FY22 LDRD

What are the key results from this research that will be useful to other current and future projects?

- Development of multi-fidelity UQ capabilities
- Alignment to ND Mission Foundation “Development Agility” strategic focus area
- Impact on ND 3.0 exemplar

Technology insertion and follow-on funding for potential and realized ROI

- Funded FY22 ESRF LDRD: “Model-based quantification of margins and uncertainties in metal additive manufacturing for process design and qualification”
- Ongoing reduced fidelity modeling efforts in ASC PE&M advanced manufacturing portfolio