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Joint Challenge 11: Implementation of Predictive Joint Models in Finite Element Codes

M.R. Brake (Sandia),

D. Brown (AWE),

H.G.D. Goyder (Cranfield),

And E.P. Petrov (Sussex)

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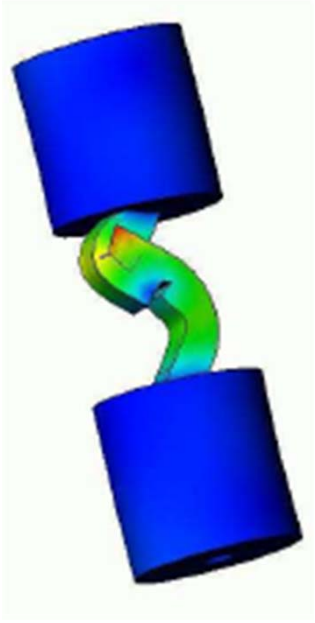

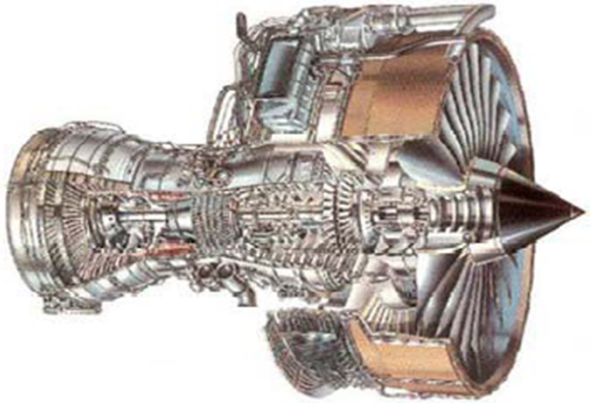

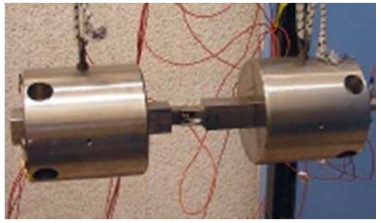

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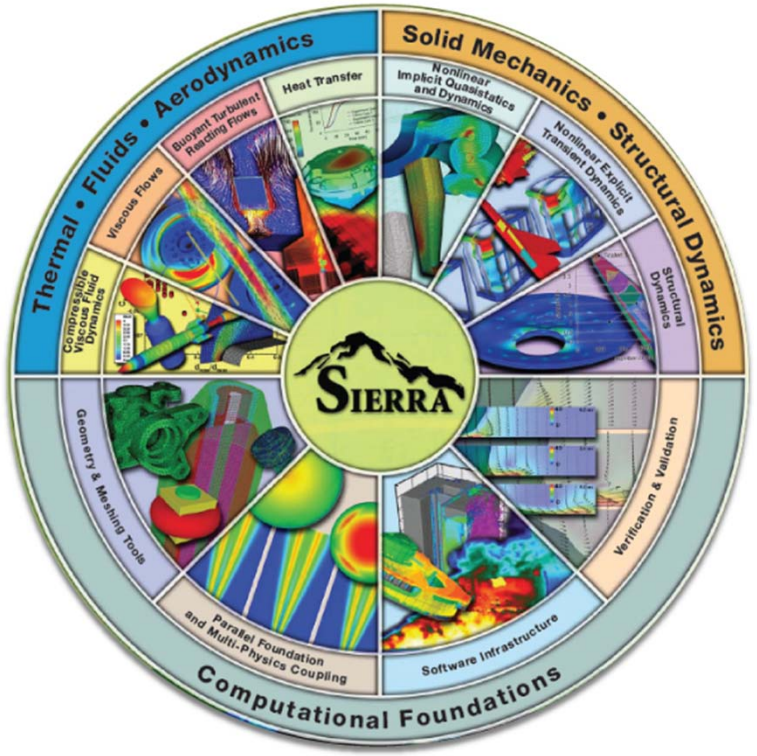
Case Study: Sierra

- In house code developed at Sandia
- Designed to be massively parallel
- Several dedicated development teams
- Iwan models incorporated into it
- Issue: the joint models aren't used by analysts
  - Too computationally expensive



Primary Issues

- Efficiency
  - Without an efficient implementation, joint models are unlikely to be adopted by analysts
- Accuracy
  - The Iwan model, or its future successors, is an improvement over existing techniques (linear springs)
- Usability
  - In order to be widely adopted, the model must require parameters that are easily found (contrast a Prony series with a Kelvin-Voigt model)

Existing Research on Efficiency

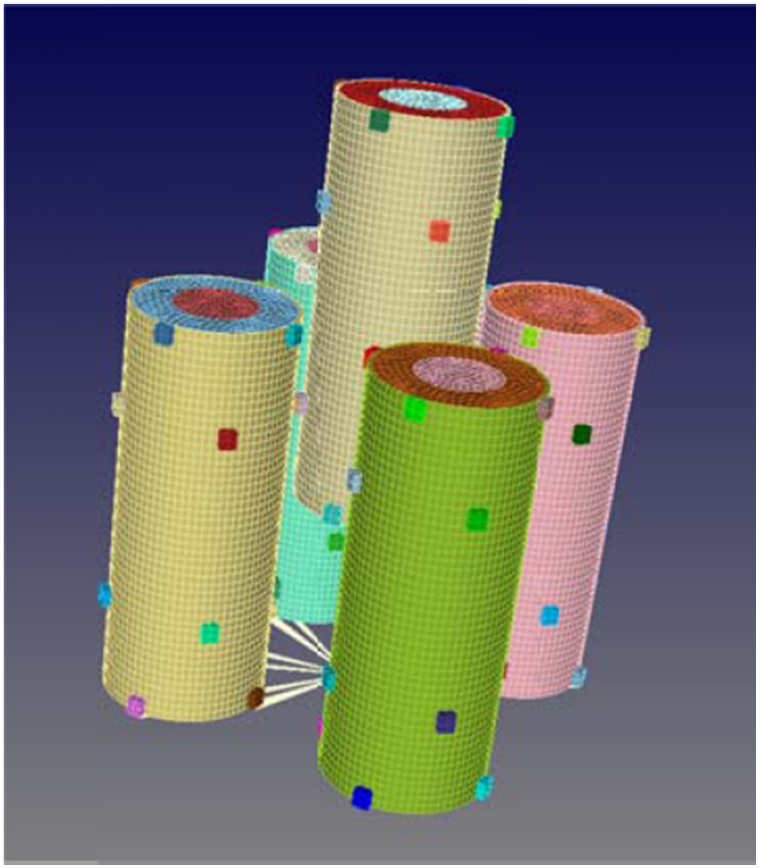
- Model reduction techniques incorporating nonlinearities (a non-exhaustive list)
  - Frequency based substructuring (Reuss et al., 2012; de Klerk et al., 2008)
  - FRF based model reduction (Petrov, 2010; Popp and Maagnus, 2002)
  - Other harmonic balance methods (Firrone et al., 2011; Tangpong et al., 2008)
  - Non-smooth basis functions (Brake and Segalman, in press; Milman and Chu, 1994)

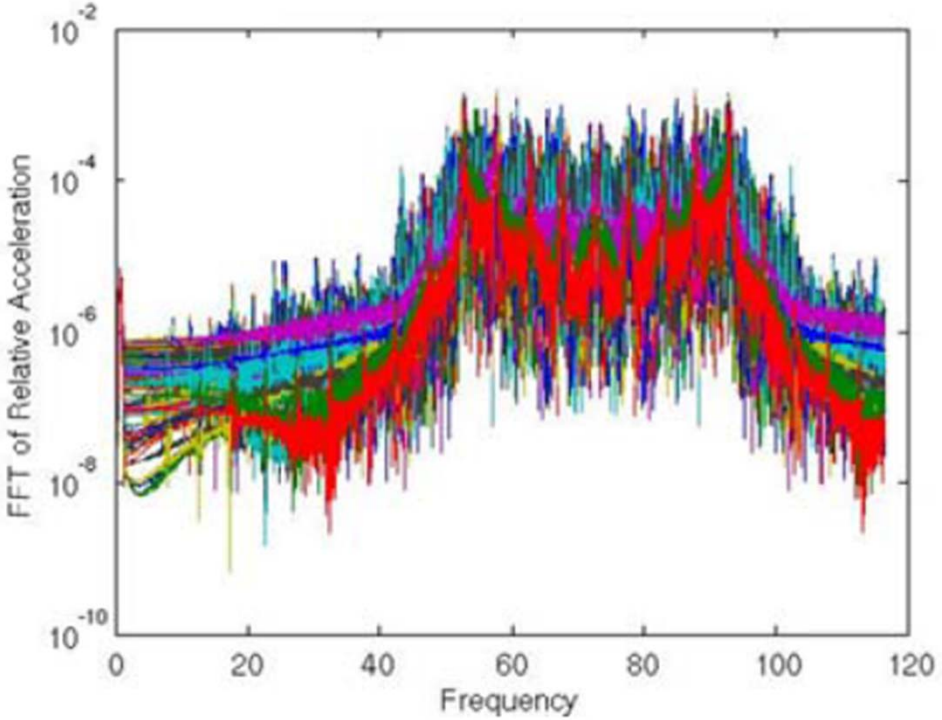
- Many approaches, but little consensus

- Collaborations directly comparing methodologies are necessary
  - **Outcome of last workshop** – collaboration between Sandia and Stuttgart to assess frequency based substructuring and non-smooth basis function methods

Model Reduction of Nonlinear Systems

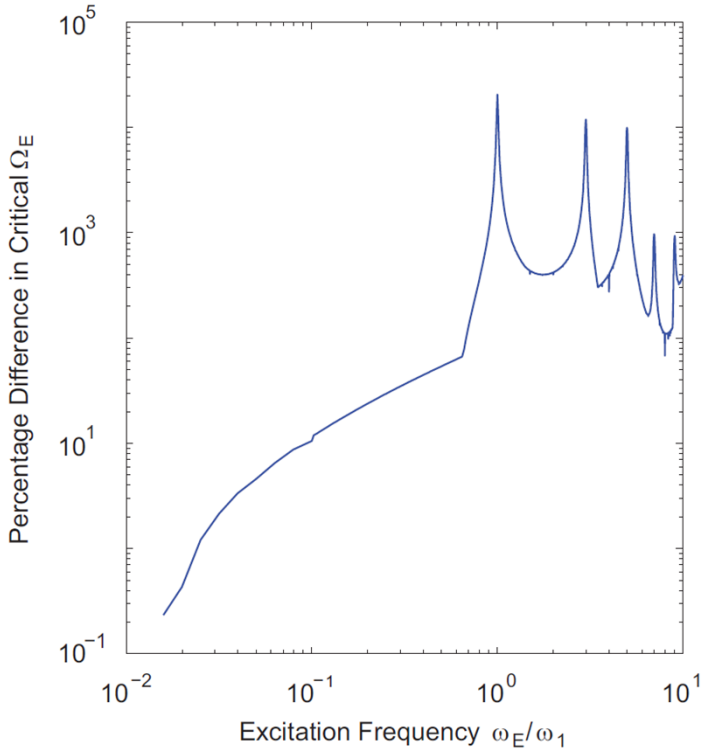
- In progress collaboration between Sandia and Stuttgart (Reuss et al., IDETC2013, Brake et al., WTC2013)

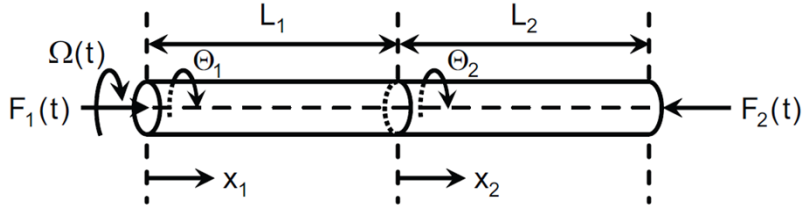




Assessment of Accuracy

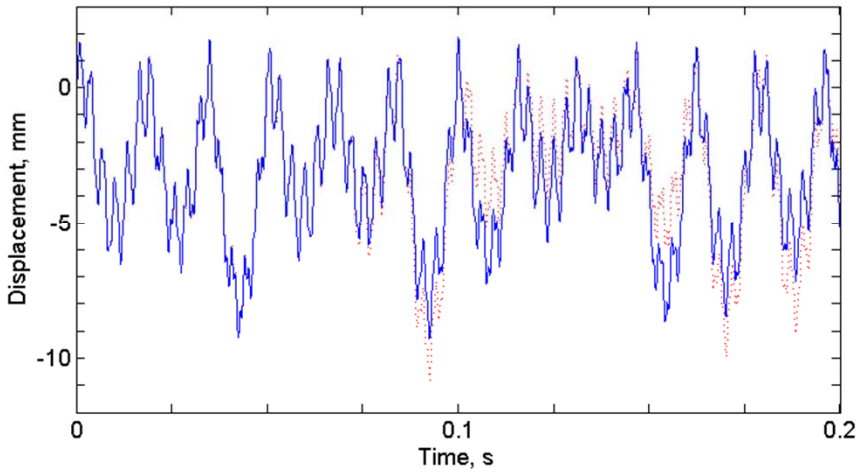
- Validity of model techniques
  - **Outcome of last workshop** – collaboration between Sandia and Oxford (Brake and Hills, under review in Tribology International)
  - Quasi-static v. Dynamic modeling techniques
- Determining convergence for nonlinear systems
  - **Outcome of last workshop** – collaboration between Sandia and Wisconsin (Kuether, Brake, and Allen, IMAC2014)
- Accuracy of joint models…

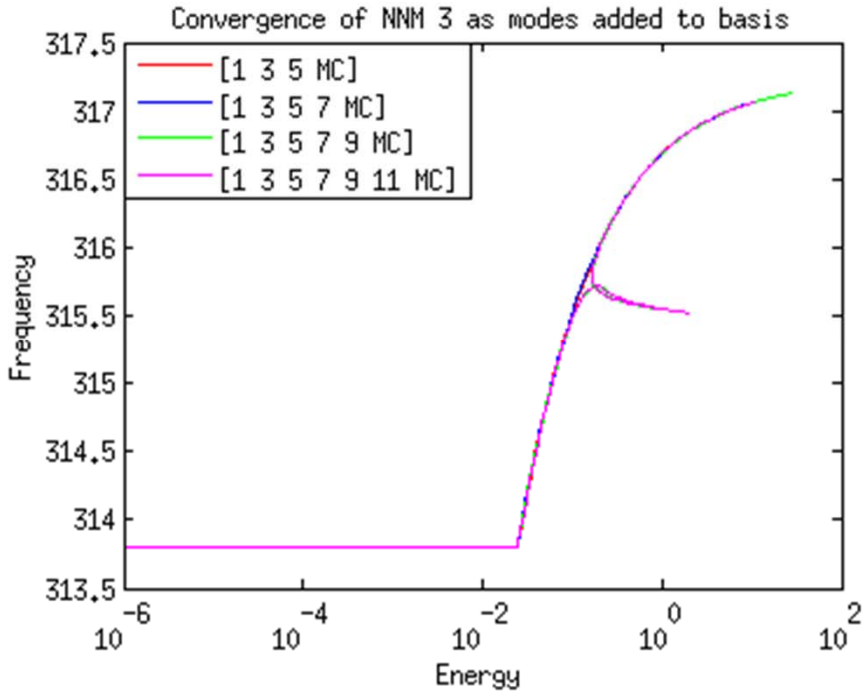




Comparison of Nonlinear Systems

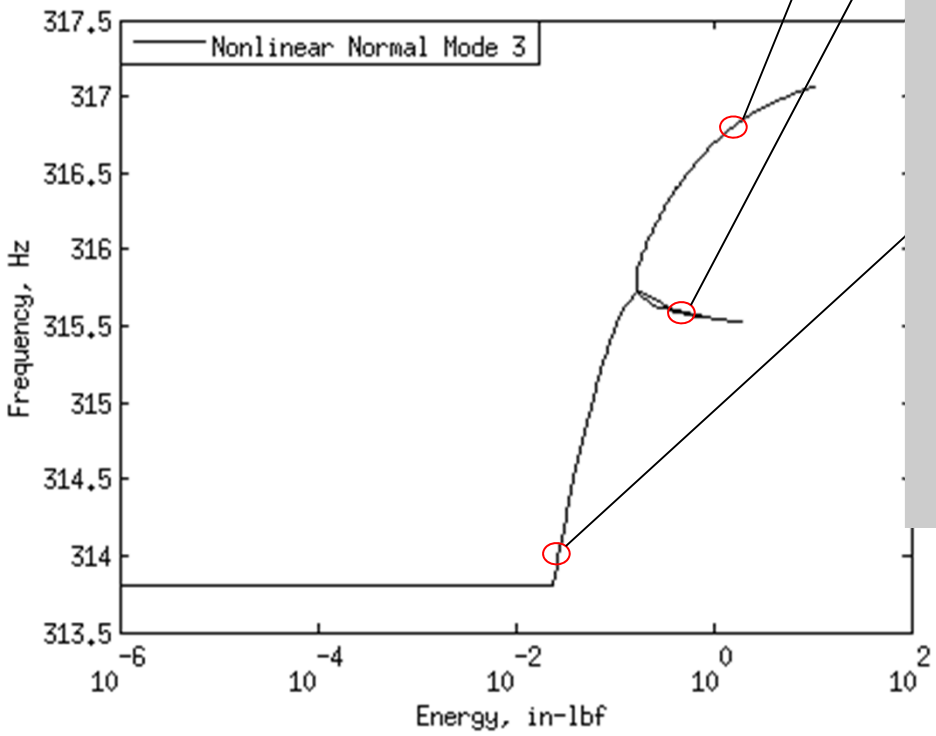
- How do you compare two different models of the same nonlinear system?
  - Time histories, dissipation, strain energy, L_2 norm, etc.
  - Use of nonlinear normal modes to measure convergence

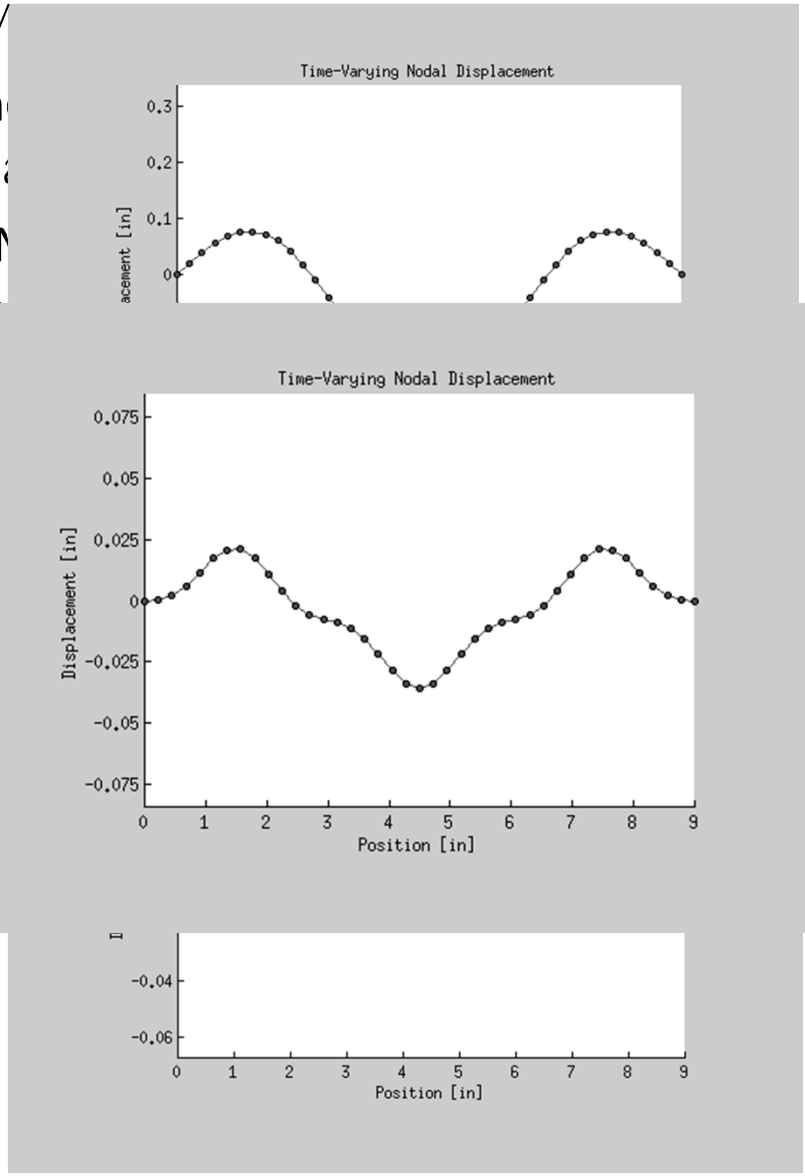




What Are Nonlinear Normal Modes?

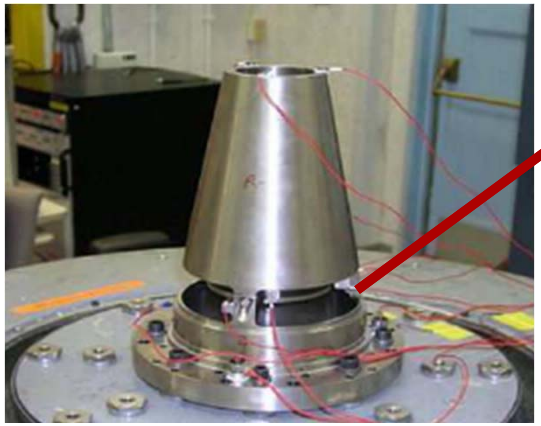
- A nonlinear normal mode is defined as a n
  periodic response to the conservative equa
- For a nonlinear conservative system with N
  NNM branches that initiate from each lin





The Iwan Model

- Long history of development: Baushinger, 1886; Masing, 1926; Prandtl, 1928; Ishlinskii, 1944; and Iwan, 1966 and 1967
- Four parameter Iwan model: Segalman, 2005
  - **Usability issue**: determining those four parameters (β, χ, K_T, F_S)
  - Still not predictive…



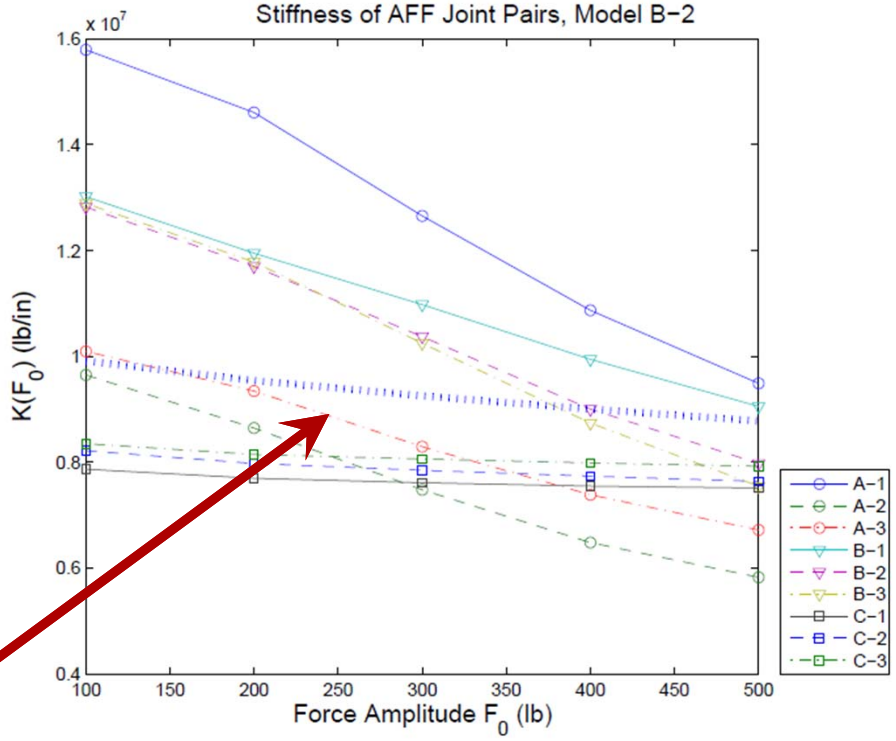


Figure 12.15. Stiffness of AOS Joint Pairs.

The thick dotted line is the stiffness of the four-parameter Iwan model, calibrated to reproduce the dissipation curve with fidelity and to match the stiffness of a load of 400 lb.

From the joint handbook (SAND2009-4164)

Concluding Thoughts

- Not yet ready to involve commercial code developers
  - We could potentially involve research code developers once we address several questions…
- Three major issues to be addressed first: efficiency, accuracy, and usability
- Clear that we must simultaneously develop higher accuracy models with modeling techniques
- Several collaborations have been developed since the last workshop between Sandia and Oxford, Stuttgart, and Wisconsin
  - This research focuses on developing efficient ROMs for nonlinear problems, assessing the validity of ROMs, and assessing the validity of modeling techniques

Some Points for Discussion

- Are there other promising model reduction techniques?
- How can we proceed forward on developing a higher accuracy joint model?
- At what point will it be right to involve research code developers?
- At what point will it be right to involve commercial code developers?
- How should we involve code developers?