Tribomechadynamics

The Emergence of a New Field at the Confluence of Tribology, Contact Mechanics, and Structural Dynamics

Matthew Brake

Rice University

brake@rice.edu

Goal of Tribomechadynamics

- Given an assembly,
  - Predict response during design stage
  - Predict performance degradation over time
  - Use models to optimize joint designs (weight/properties/wear/etc)

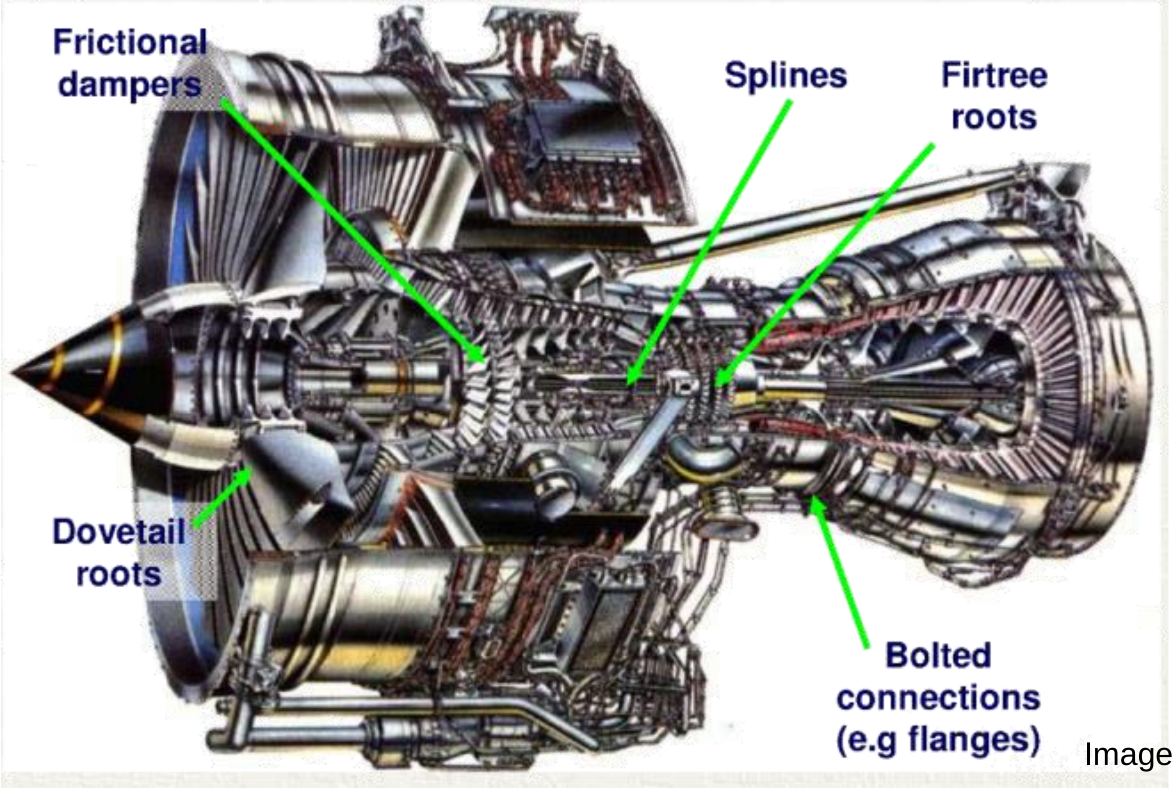


Image courtesy of Rolls Royce

Composition of Tribomechadynamics

Tribology

- Wear
- Surface Evolution Over Time
- Micro- and Nano-Scale Features

Solid Mechanics

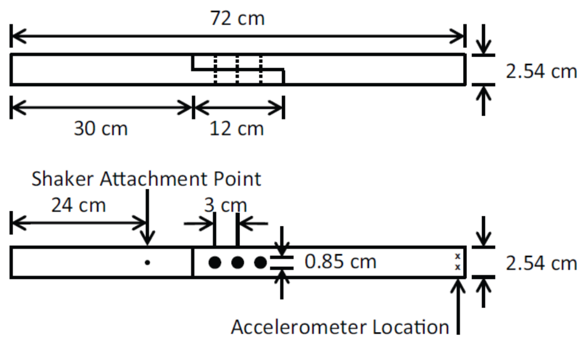
- Elasticity and Plasticity Solutions
- Static Stress Analysis
- Contact Patch Focus

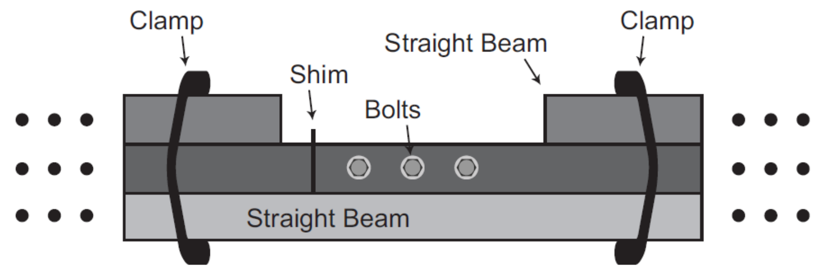
Structural Dynamics

- Vibration and Nonlinear Dynamics
- Reduced Order Modeling
- System Level Analysis

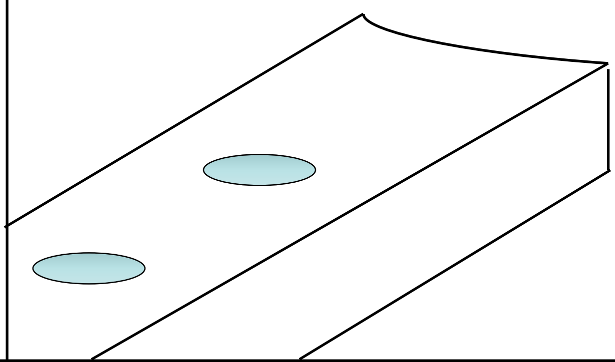
Taxonomy of Issues

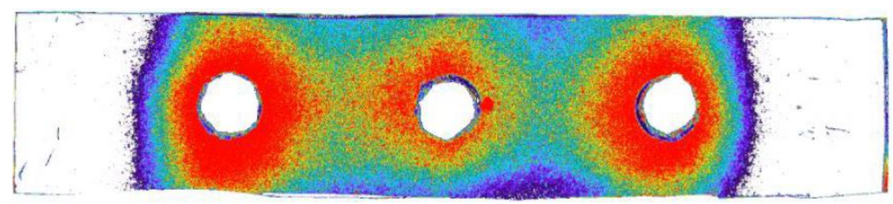
Macroscale



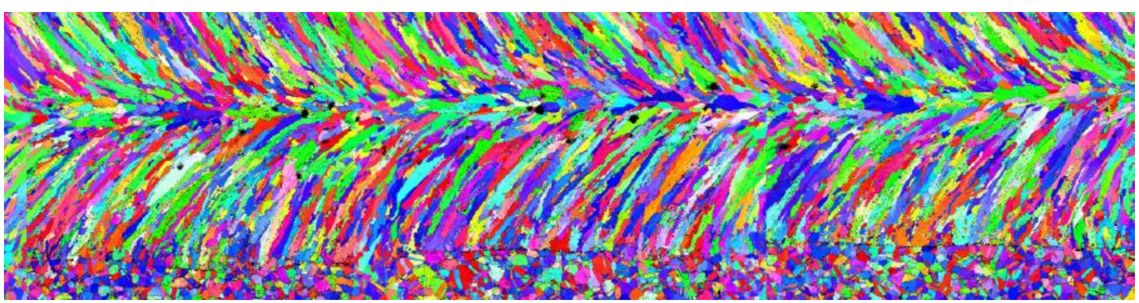


Meso- and Microscale





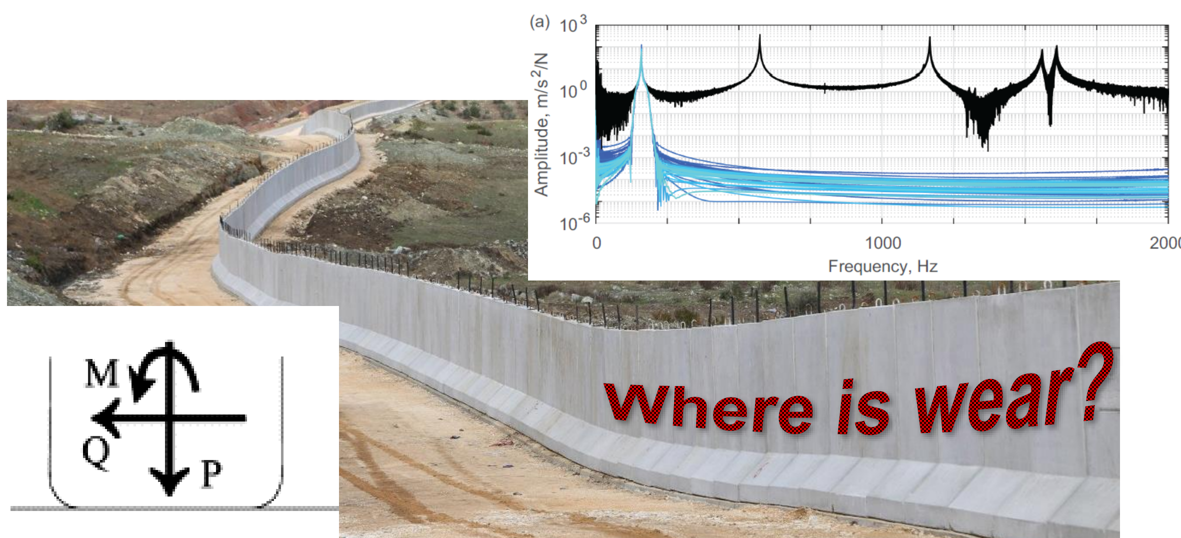
Nanoscale



How Do We Design Joints?

- Industry standards
  - Purely based on solid mechanics, how a load is carried, etc.
  - No consideration for dynamic effects
  - Indirect consideration for tribological issues (regarding wear)

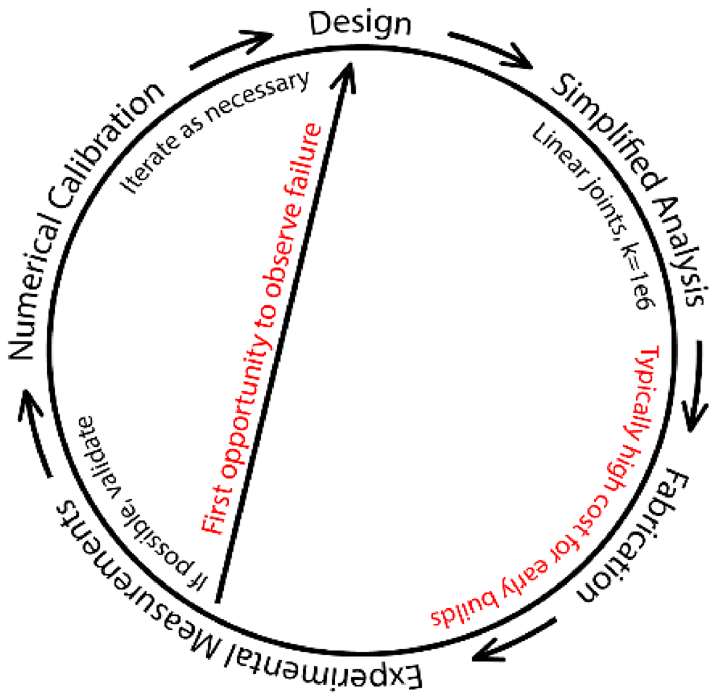
- Research perspective
  - Academic communities, though inter-related, have not traditionally collaborated here.



Flat pad approximation

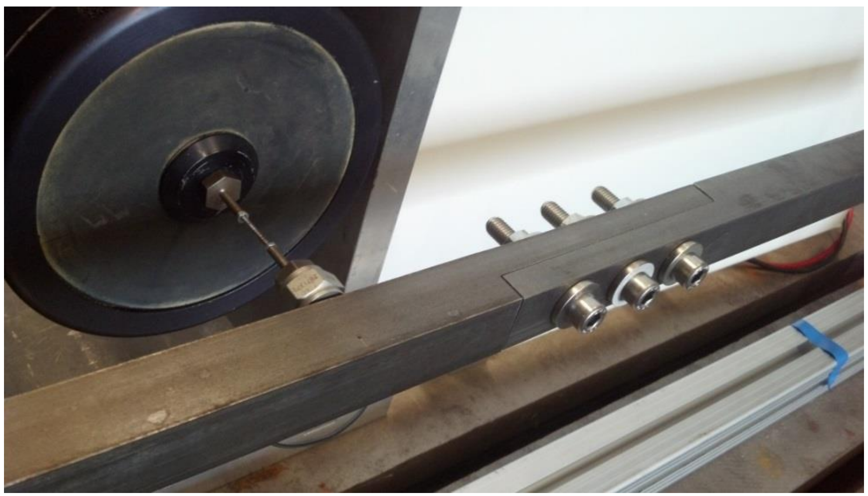
Ramifications

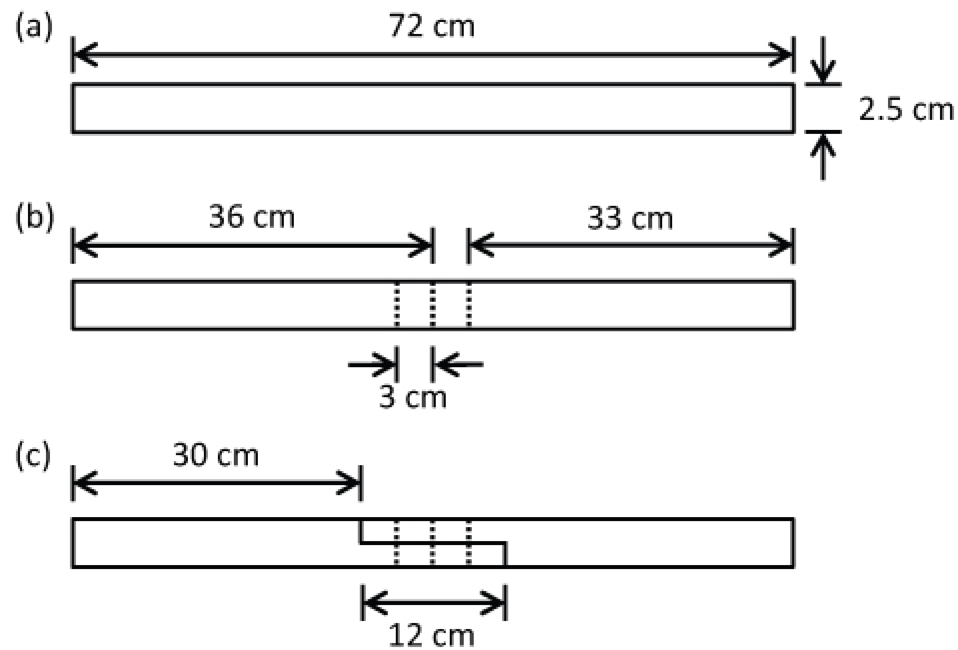
- Dynamic designs are "the worst possible designs from a solid mechanics perspective."
- Solid mechanics designs have no consideration for dynamic effects, resulting in massive over designs.
- Wear often addressed after a design is fabricated (not a priori)



Case Study: Benchmark System

- The Brake-Reuß beam is a structural dynamics benchmark adopted by approximately 20 institutions

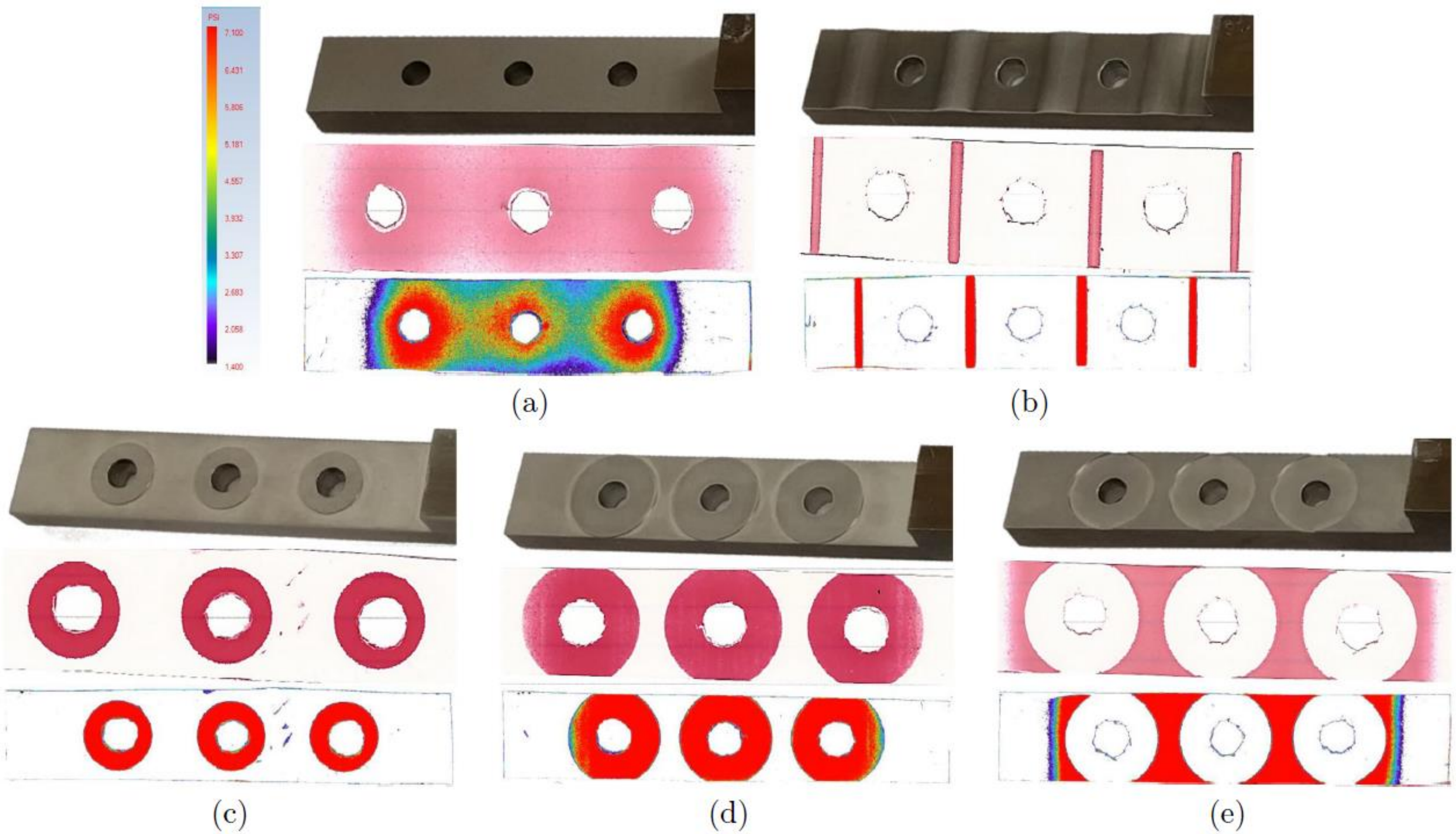




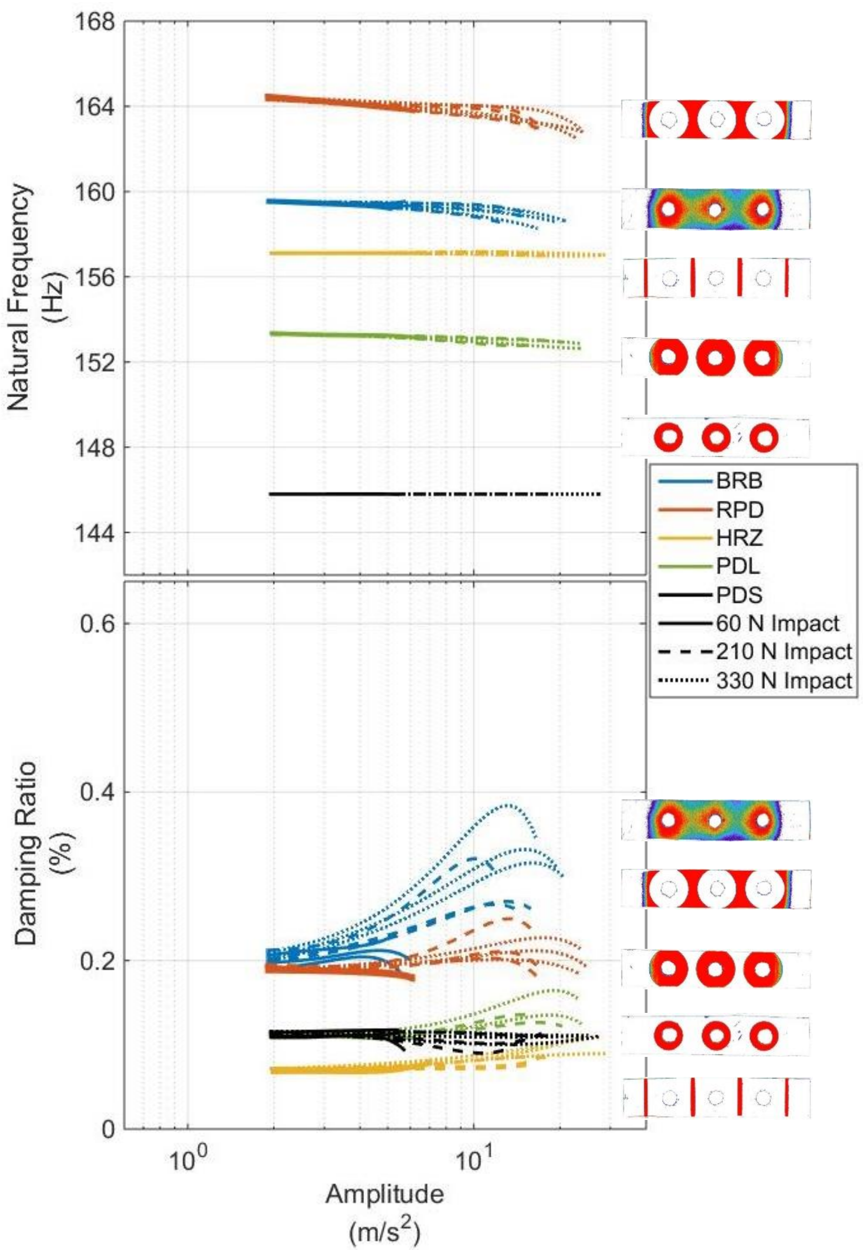
- Multiple version exist to assess the effects of interface design, and influence of the structure on joint properties

Case Study: Interface Designs

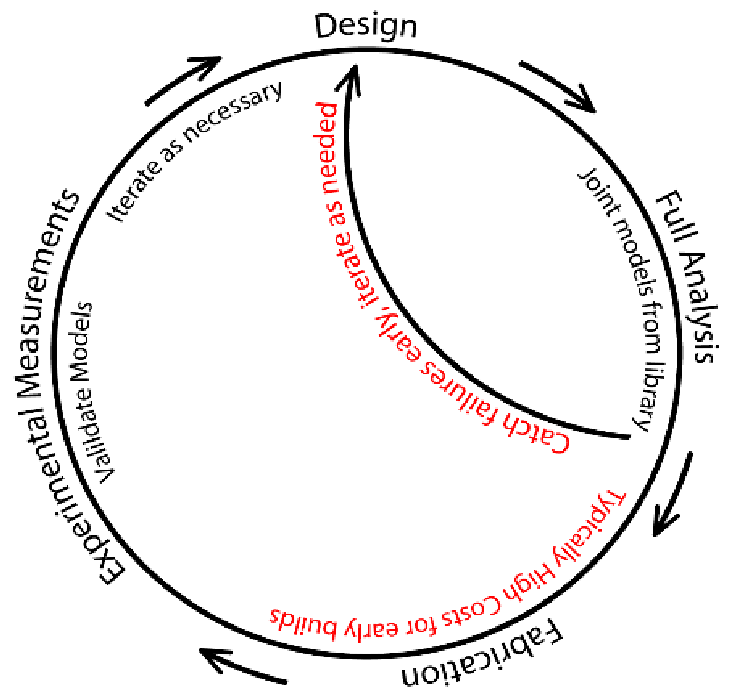
- Modified interfaces to investigate role of geometry on system properties



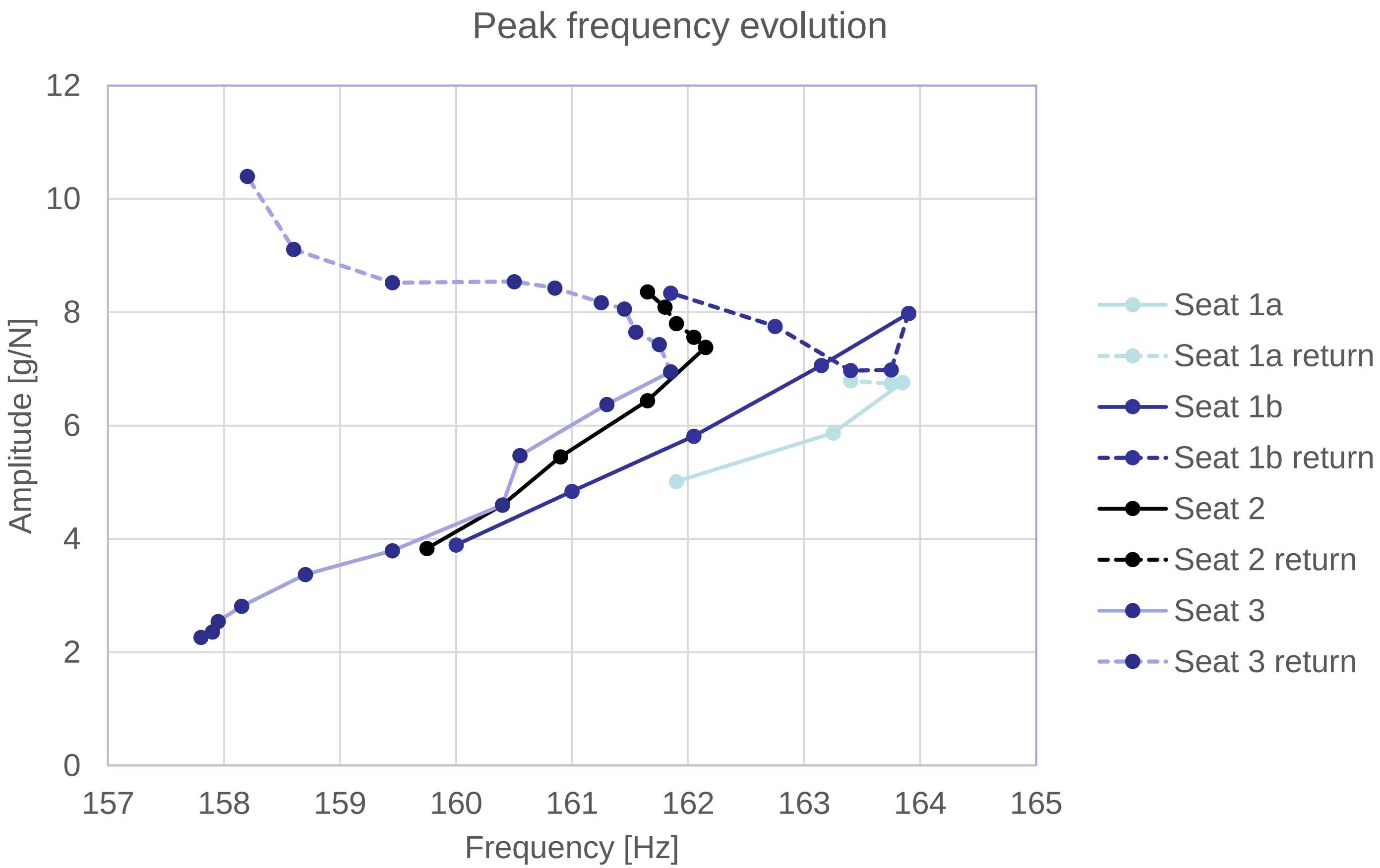
Case Study: Dynamic Responses



- Lessons from solid mechanics led to a linearized dynamic system
- Linearized systems are much more conducive to design
- Ultimate goal: design tools…



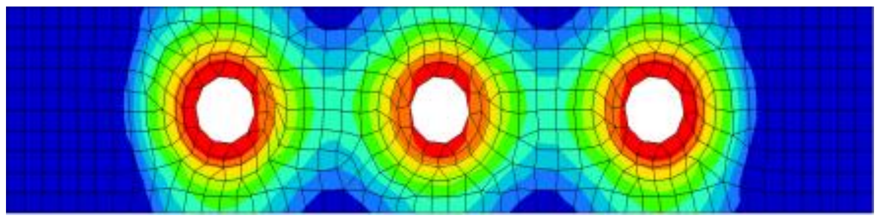
Case Study: Still Missing Tribology...

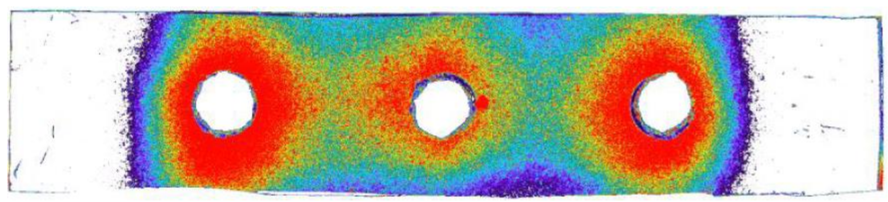


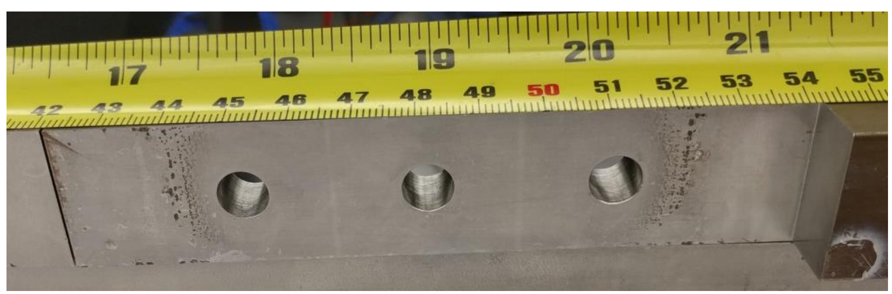
Solid line: high amplitude excitation
Dashed line: low amplitude return

Case Study: Low Cycle Fretting

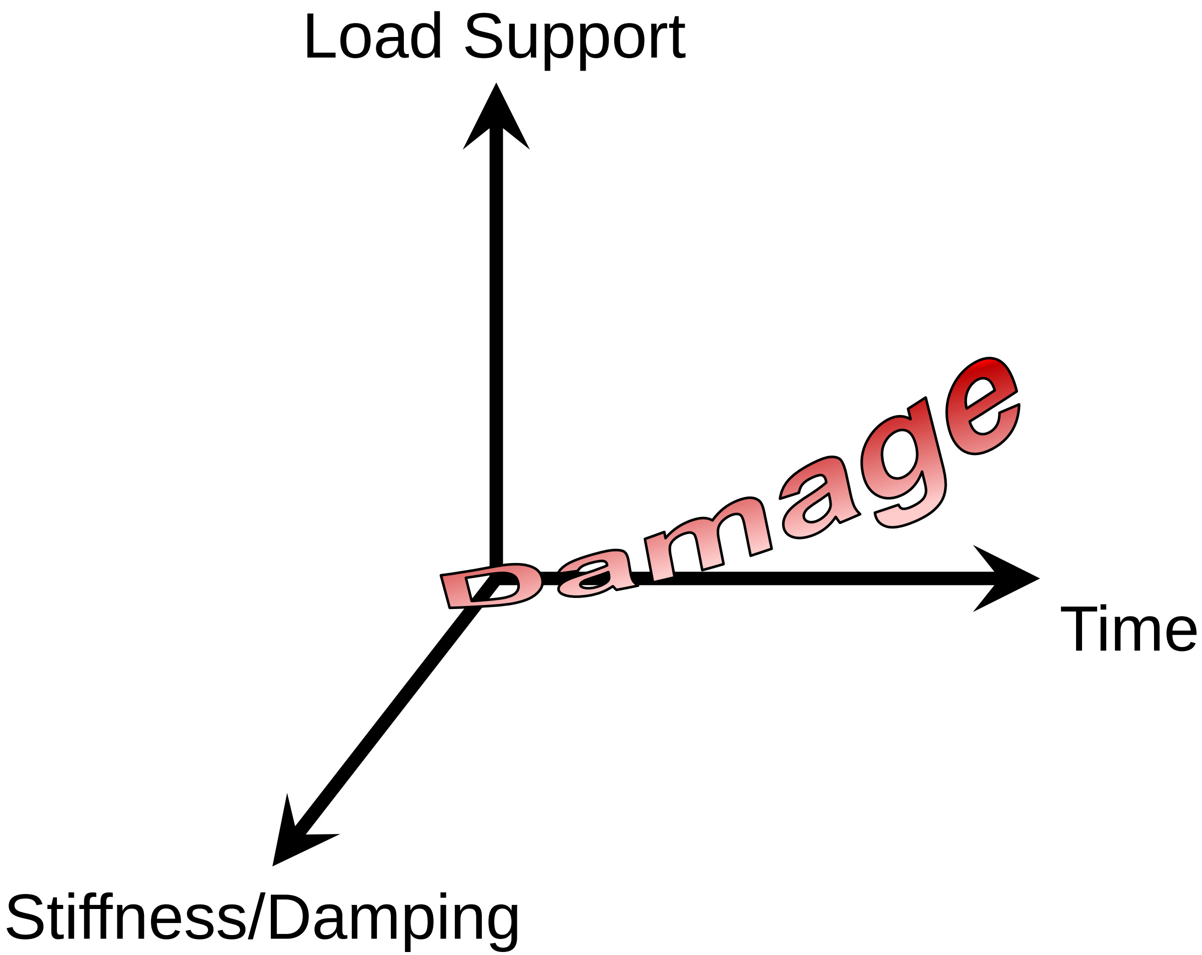
- Direct observation of wear where we expected it:







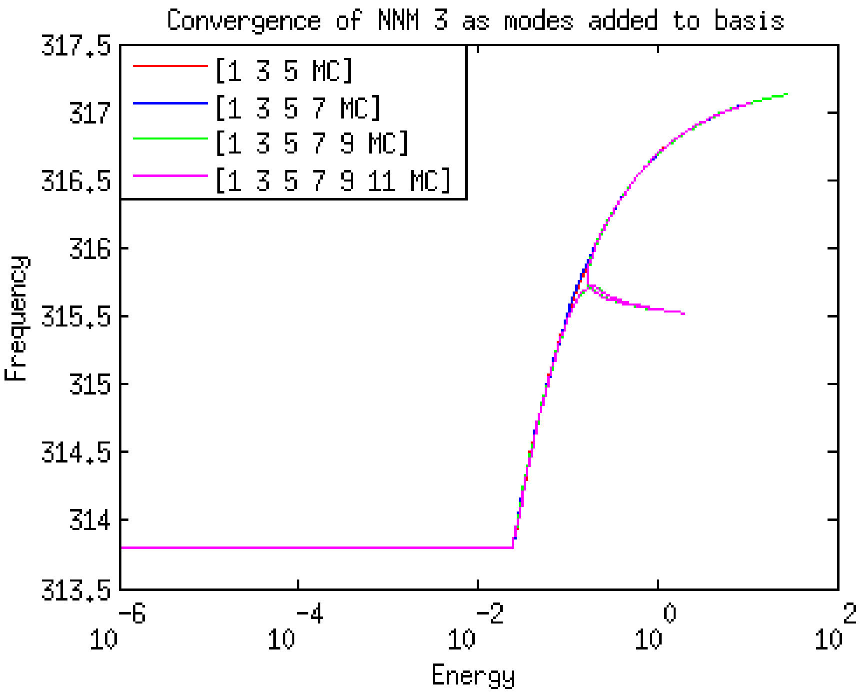
Why Tribomechadynamics, Why now?

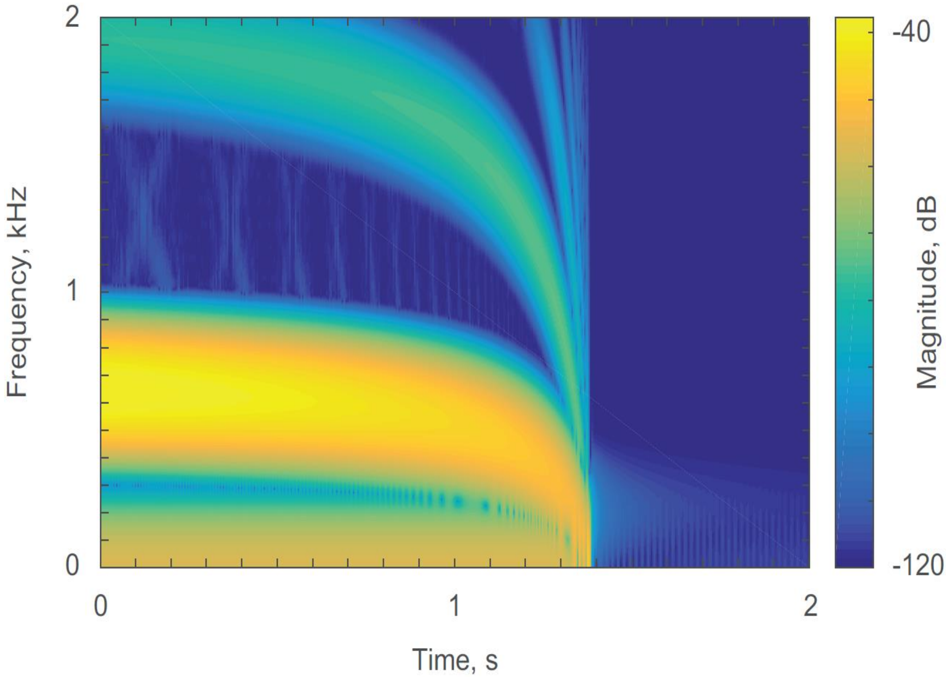


- The evolution of the system properties over time is a phenomenon tied to the nonlinear energy transfer between length scales
- Numerical methods advanced enough for us to incorporate more sophisticated, evolving models

Evidence of Mechanical Turbulence

- Nonlinear Normal Modes – internal resonances between modes/mode coupling
- Low frequency excitations can lead to high frequency response and vice versa



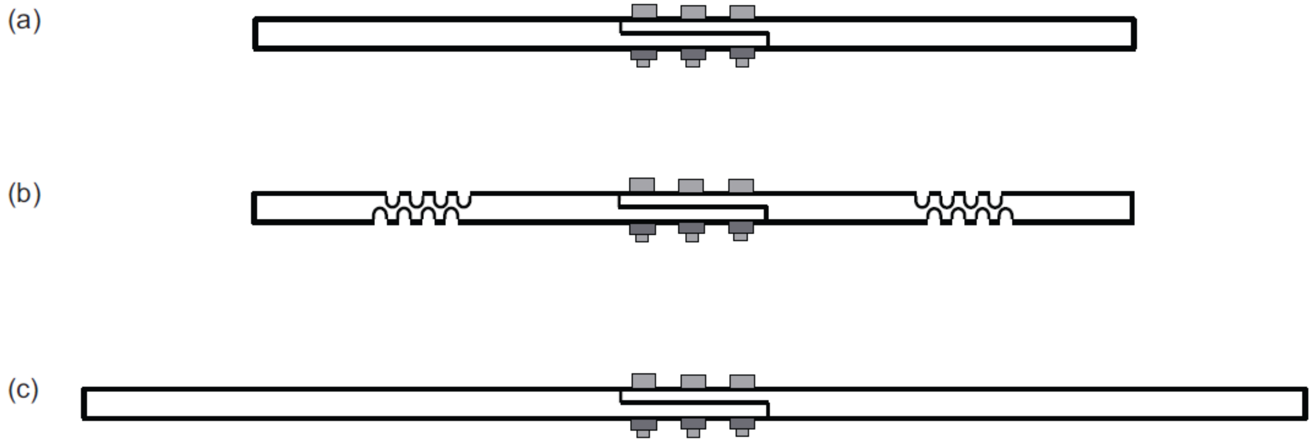


Research in Tribomechadynamics

- System-scale: how do we *predict* the dynamic properties of a system?
  - Surrogate system hypothesis
- Multi-scale: how does the surface evolution affect the system behavior?
- Multi-scale: how can we incorporate the effect of evolving surfaces into a system-level simulation?
- Micro-/nano-scale: how can we *predict* the wear performance for an arbitrary joint?
- Numerical methods: need for efficient, nonlinear interface reduction techniques
- Uncertainty quantification: need for methods to propagate uncertainties through models *efficiently*
- Nonlinear system identification: how do we characterize a system? Need for advanced metrics

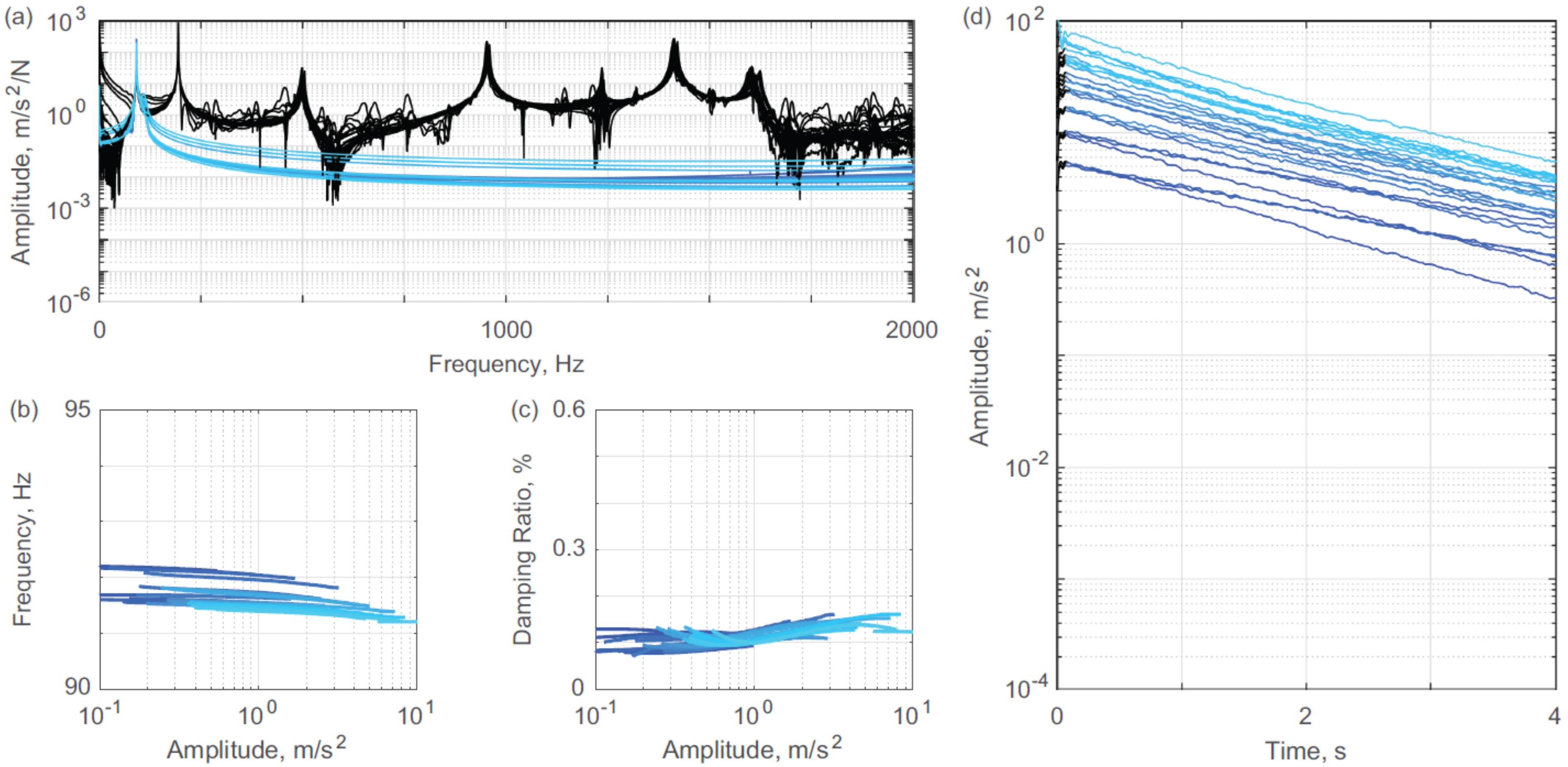
Surrogate System Hypothesis Background

- What role does the structure play in observed properties?
- Question: if the same joint is used in two vastly different structures, will it have the same properties?
- My interpretation of the Ferri Hypothesis: the far-field structure will result in the joint being loaded differently, yielding *seemingly* different joint properties…



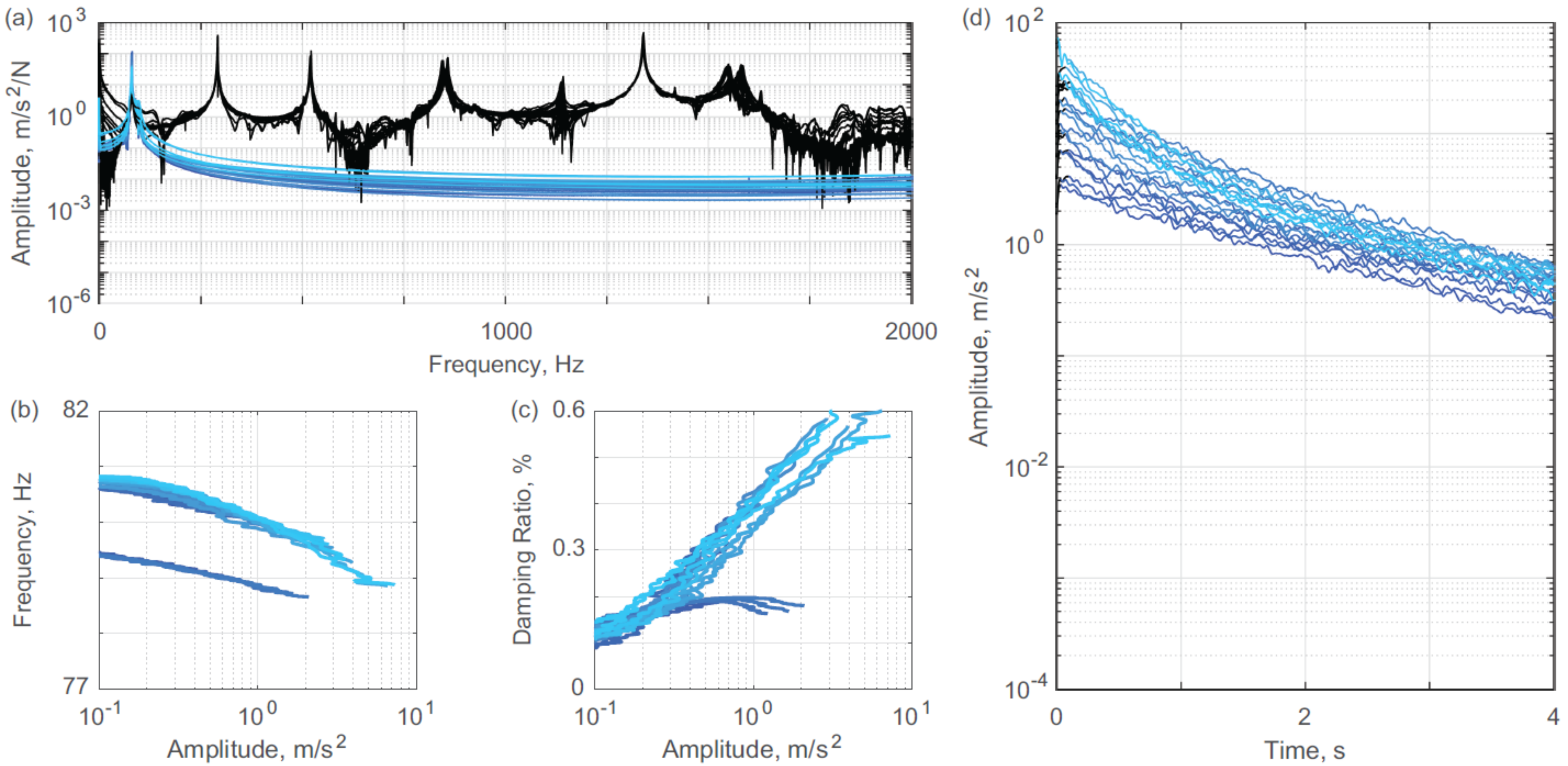
Effect of the Far-Field Structure

- Stiffness modified beam:



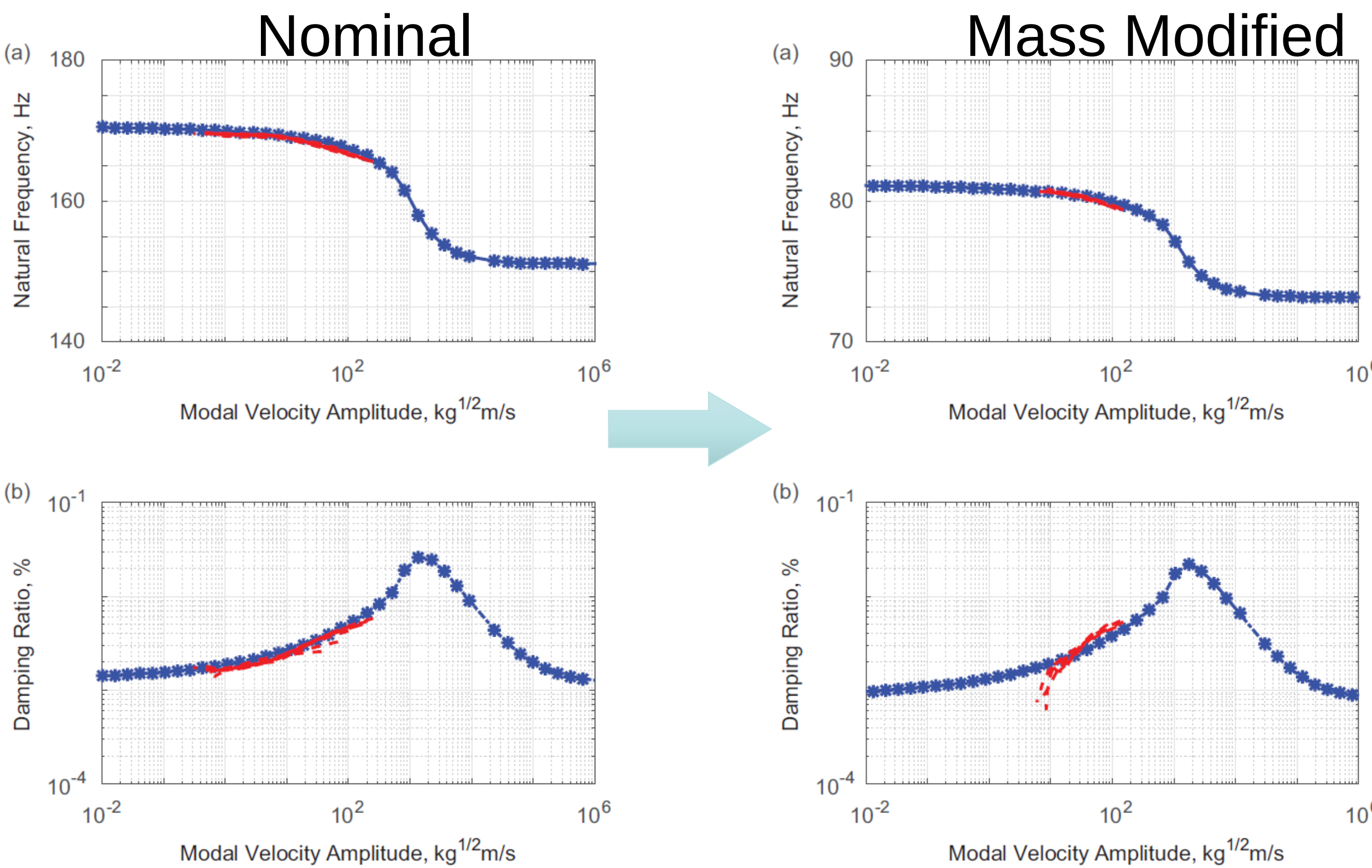
Effect of the Far-Field Structure

- Mass modified beam:



- Very different damping and nonlinear characteristics for *geometrically identical* joints

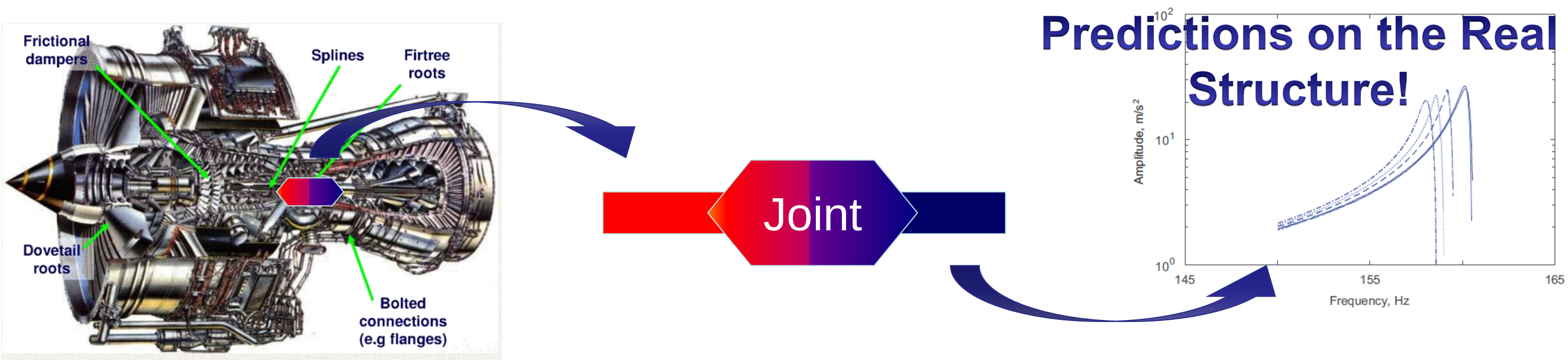
Numerical Insights



- Numerical model calibrated to data for nominal system, then used to make <u>blind predictions</u> of the response of the modified systems!
- Prior state-of-art: 25% accuracy for stiffness, within two orders of magnitude for damping

Surrogate System Hypothesis

- **The Surrogate System Hypothesis** states that a surrogate structure, i.e. one that is easy to model and machine, that contains the same joint as the system of interest can be used to deduce the properties of the joint. These properties, once accounting for the properties of the surrogate structure, can then be substituted directly into the system of interest as a spatially discrete joint model (as opposed to a modal model).



Outlook and Discussion Points

- Tribomechadynamics – confluence of nonlinear mechanics, nonlinear dynamics, and tribology is a rich research field
- Concept of mechanical turbulence still evolving – nonlinear energy transfer between scales
- Major open question 1 – how does the system response evolve over time with wear/damage?
- Major open question 2 – if we struggle to predict system response without wear, how can we predict it with wear? UQ methods?
- Major open question 3 – how can tribological interactions be integrated into system level models?

ND-CSI 2017

- The Institute for Nonlinear Dynamics of Coupled Structures and Interfaces (NDCSI)
- Six week long research collaboration
- Hosted by Rice University in Houston, TX
- June 26th to August 4th, 2017
- Directed by a four person steering committee: Matthew Brake (Rice University), Christoph Schwingshackl (Imperial College London), Matt Allen (University of Wisconsin), and Malte Krack (University of Stuttgart)
- Four projects for the 2017 Institute:
  - Interfacial Contact Pressure – In Situ Measurements and Numerical Modeling
  - Nonlinear System Identification for Joints Including Modal Interactions
  - The Effect of Non-Flat Interfaces on System Dynamics
  - Comparison of Nonlinear Modal Testing Methods for Jointed Structures
- Email brake@rice.edu for more information, or visit: http://brake.rice.edu/nd-csi
- Applications due March 1st.
- Travel support is available for all participants