Tribomechadynamics

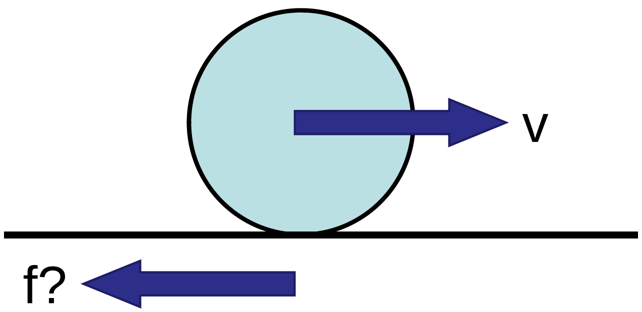
The Emergence of a New Field at the Confluence of Tribology, Contact Mechanics, and Structural Dynamics

Matthew Brake
Rice University
brake@rice.edu

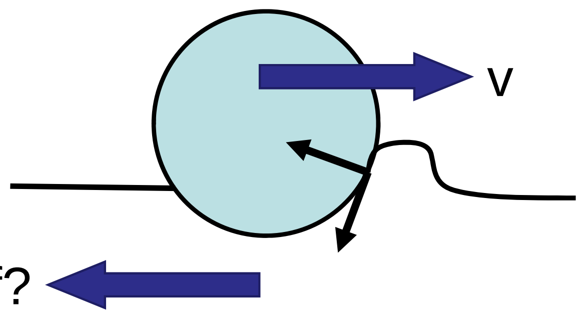
- What is Tribomechadynamics?
  - Fundamental relationship between Tribomechadynamics and interfacial mechanics
- Case study: the Brake-Reuß beam
  - Application of contact mechanics to structural dynamics design; parameter studies; role of wear
- Research in Tribomechadynamics
  - Surrogate System Hypothesis
  - Experimental insights

Some Context

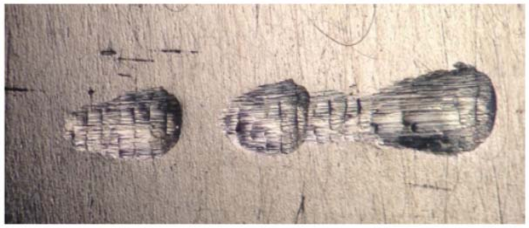
- What is friction?
  - The sliding resistance between two surfaces in contact with relative tangential motion
- Consider case of frictionless contact (e.g. lubrication):

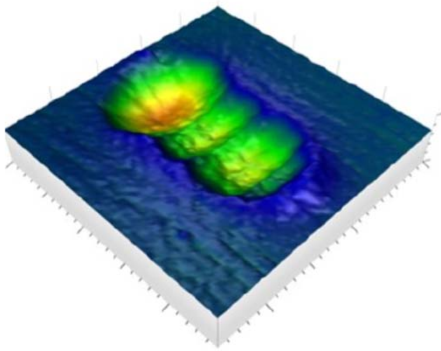


macroscale



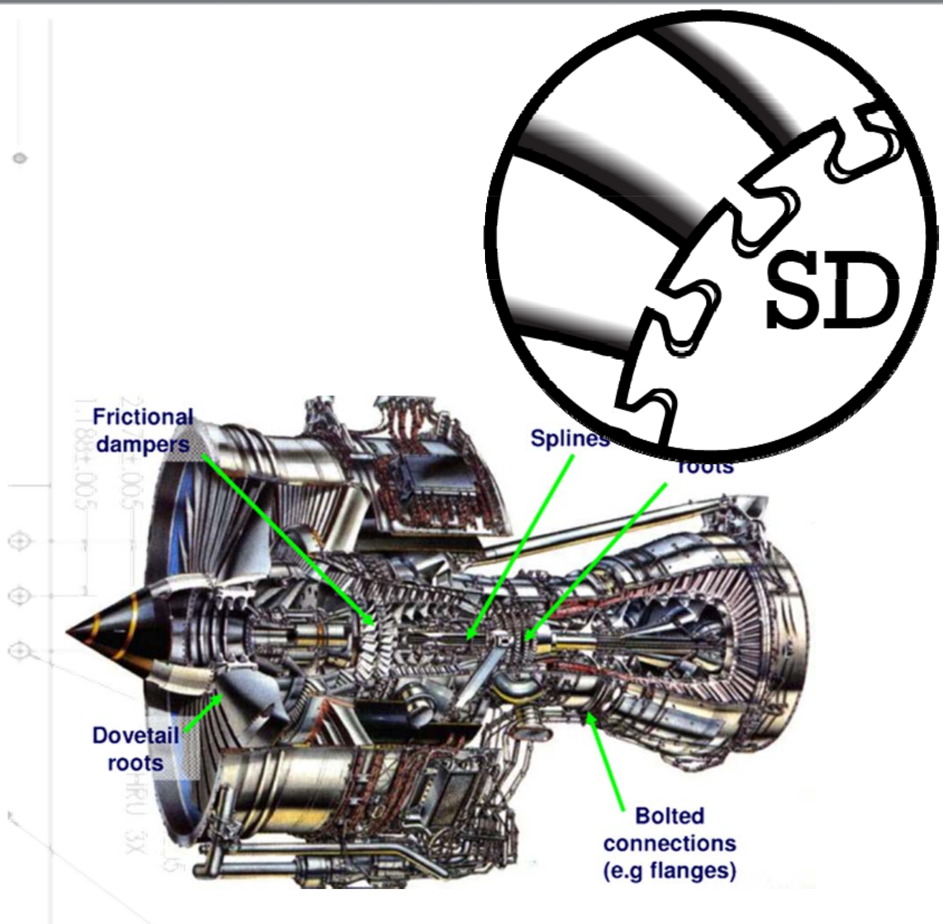
microscale





Result: even in a lubricated joint, you still have frictional forces for high contact loads…

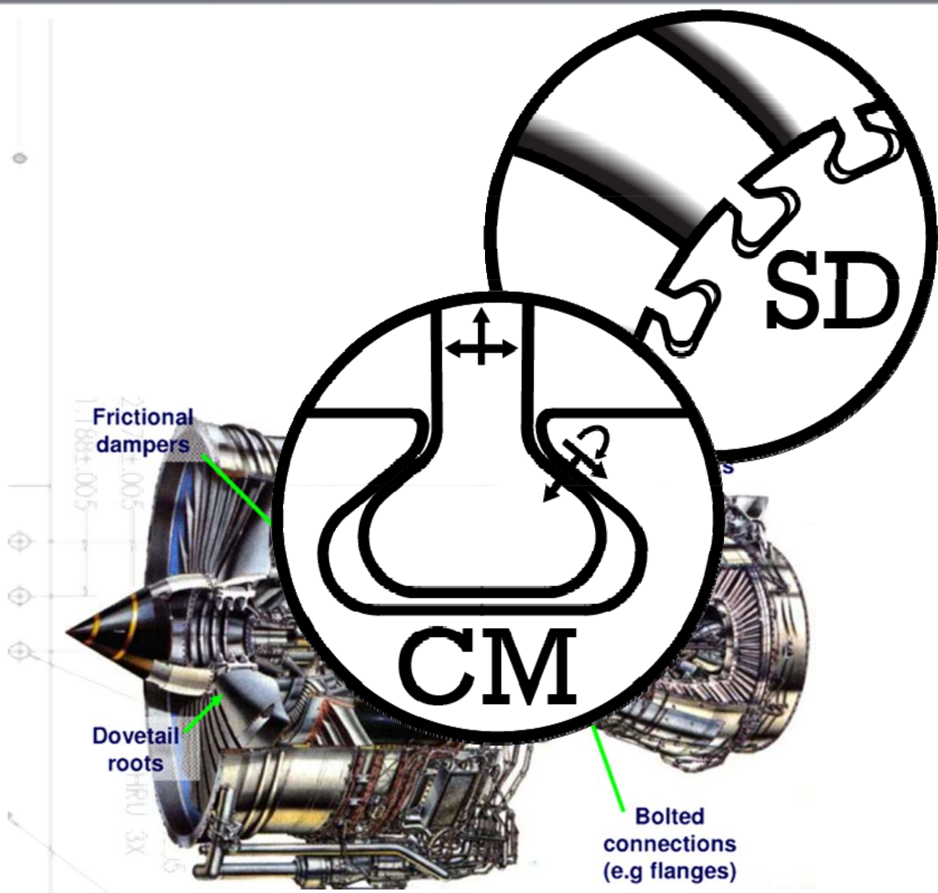
Tribomechadynamics Constituent Research Areas



Structural Dynamics

- Vibration and nonlinear dynamics
- Reduced order modeling
- System level analysis (macroscale)
- Simple, pointwise contact models; usually heuristic in nature
- Typical experiments use shakers, impact hammers, accelerometers
- Typical models are dynamic, finite element or reduced order models

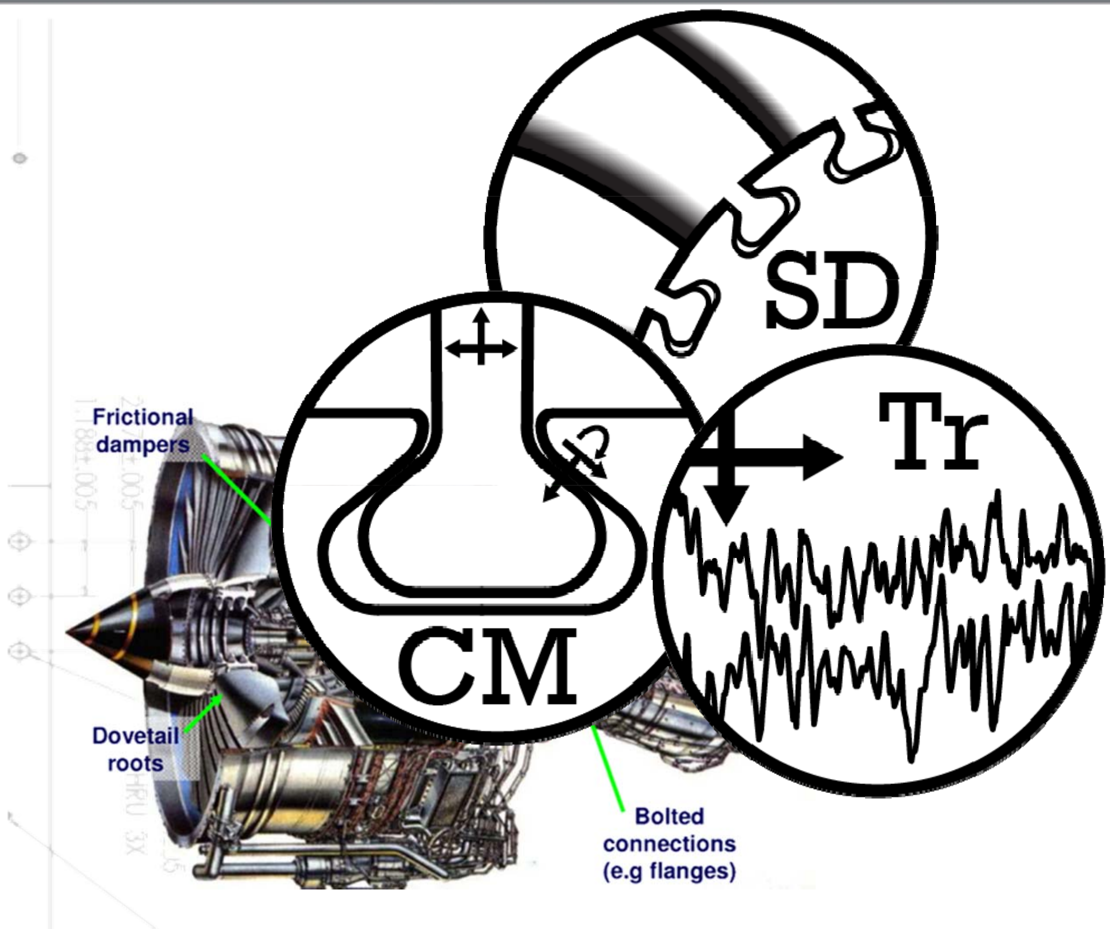
Tribomechadynamics Constituent Research Areas



Contact Mechanics

- Elasticity and plasticity solutions
- Static stress analysis
- Focus on the contact patches (spans meso- and macroscale)
- Contact models usually are large, spatially distributed, and based on Coulomb.
- Typical experiments use MTS machines or fretting rigs
- Typical models are static, high fidelity finite element

Tribomechadynamics Constituent Research Areas

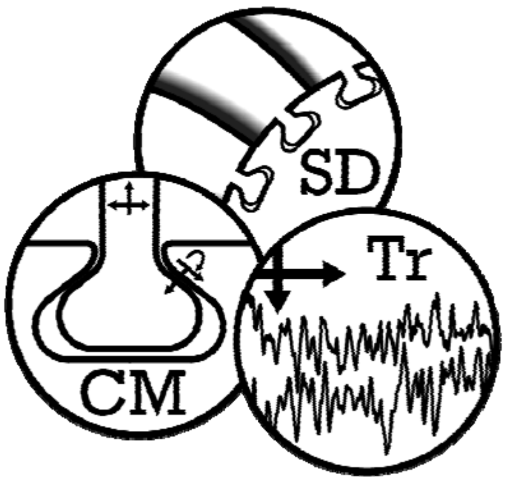


Tribology

- Wear
- Surface evolution over time
- Focus on micro- and nano-scale features
- Contact models usually are for asperity on asperity contact
- Typical experiments use tribometers or other wear rigs in addition to profilometers
- No such thing as typical models (tribology spans many disciplines…from solids to fluids to chemistry)

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)



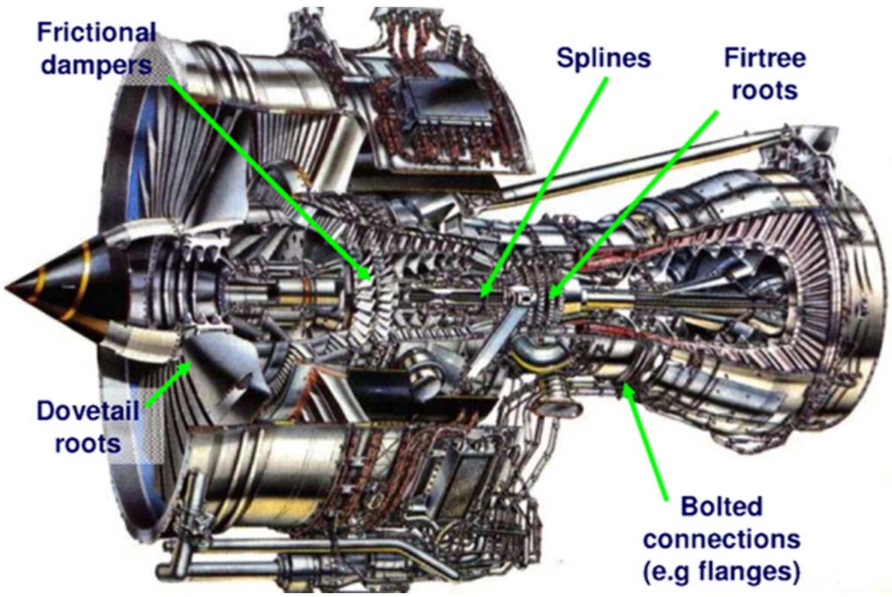


Image courtesy of Rolls Royce

Taxonomy of Issues – Multiscale Interface Dynamics!

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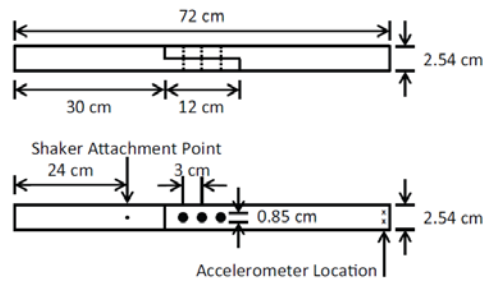
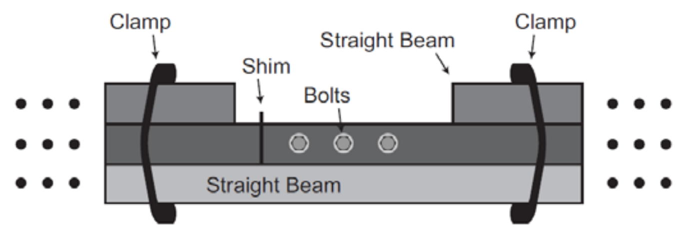
<td>Macroscale</td>
<td>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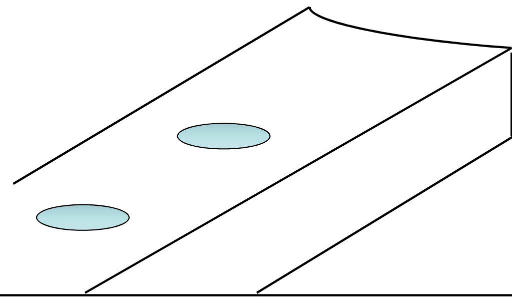
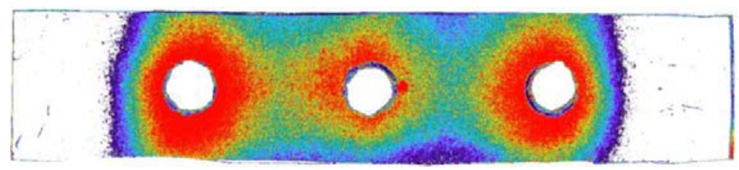
<td>Meso- and Microscale</td>
<td>
</td>
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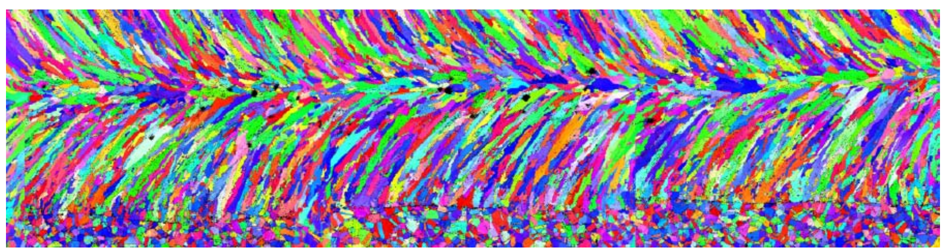
<td>Nanoscale</td>
<td></td>
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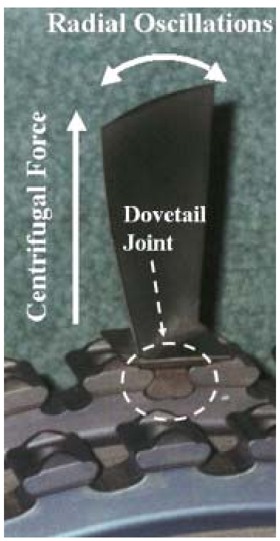
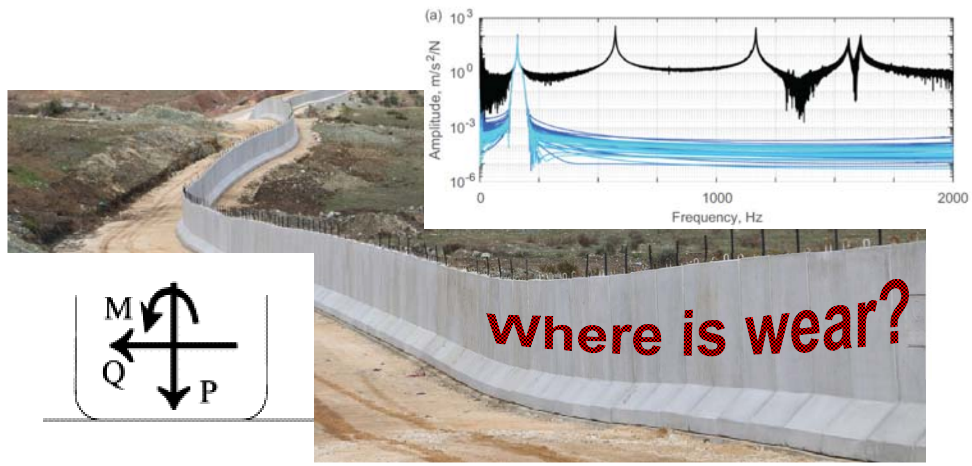
How Do We Design Joints?

- 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.

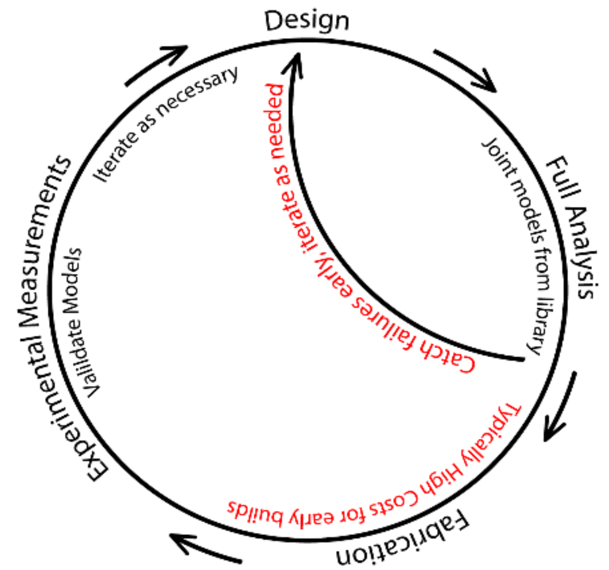




Flat pad approximation

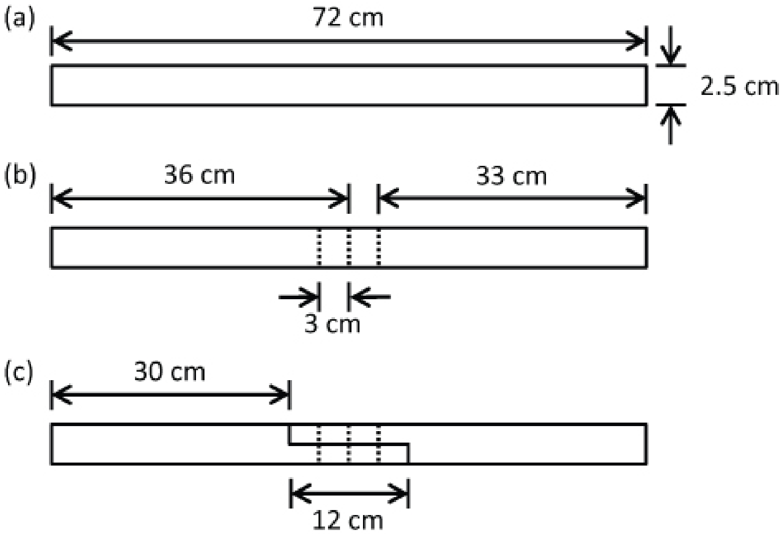
Ramifications

- 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*)



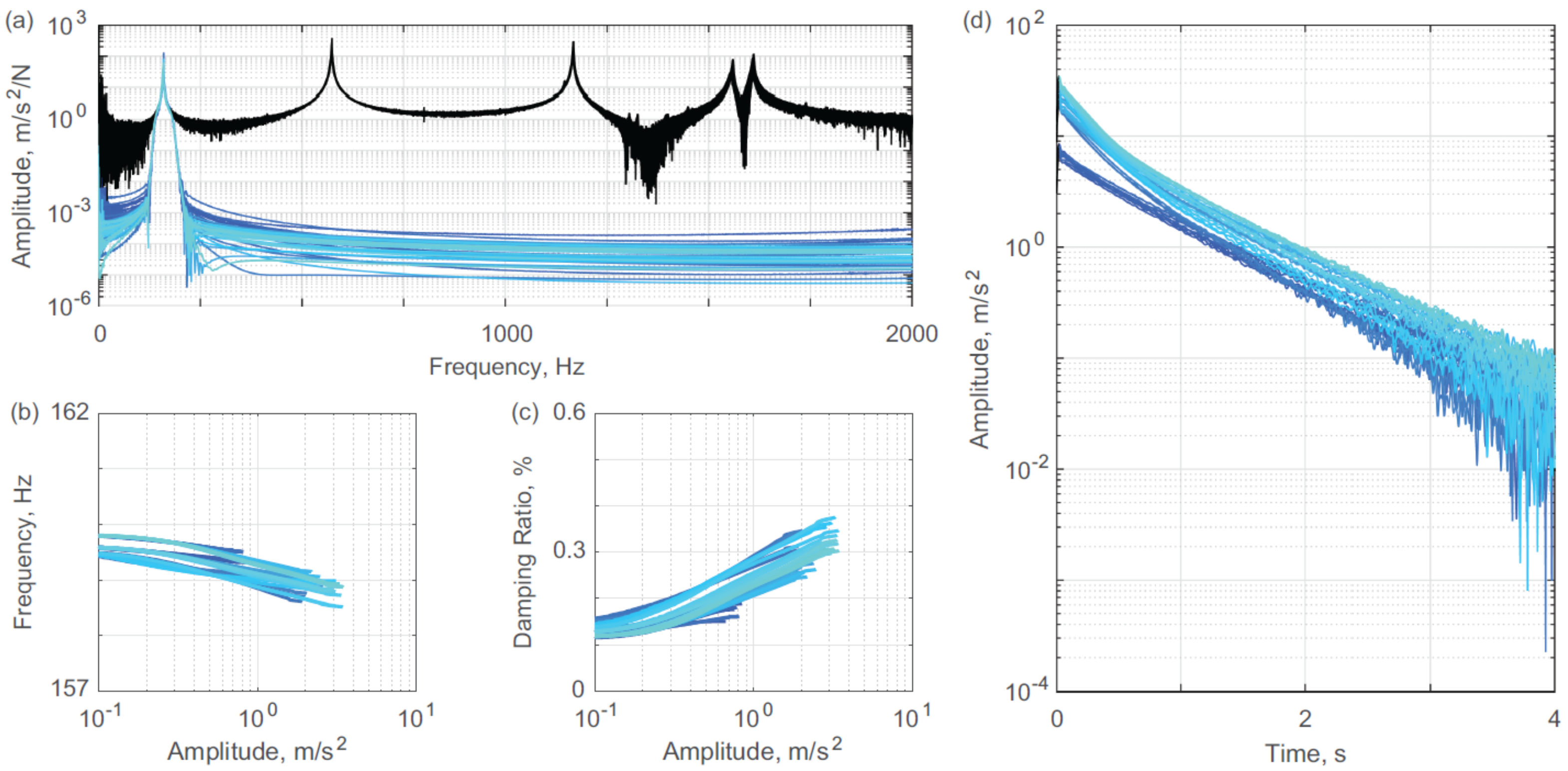
Case Study: Benchmark System

- 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

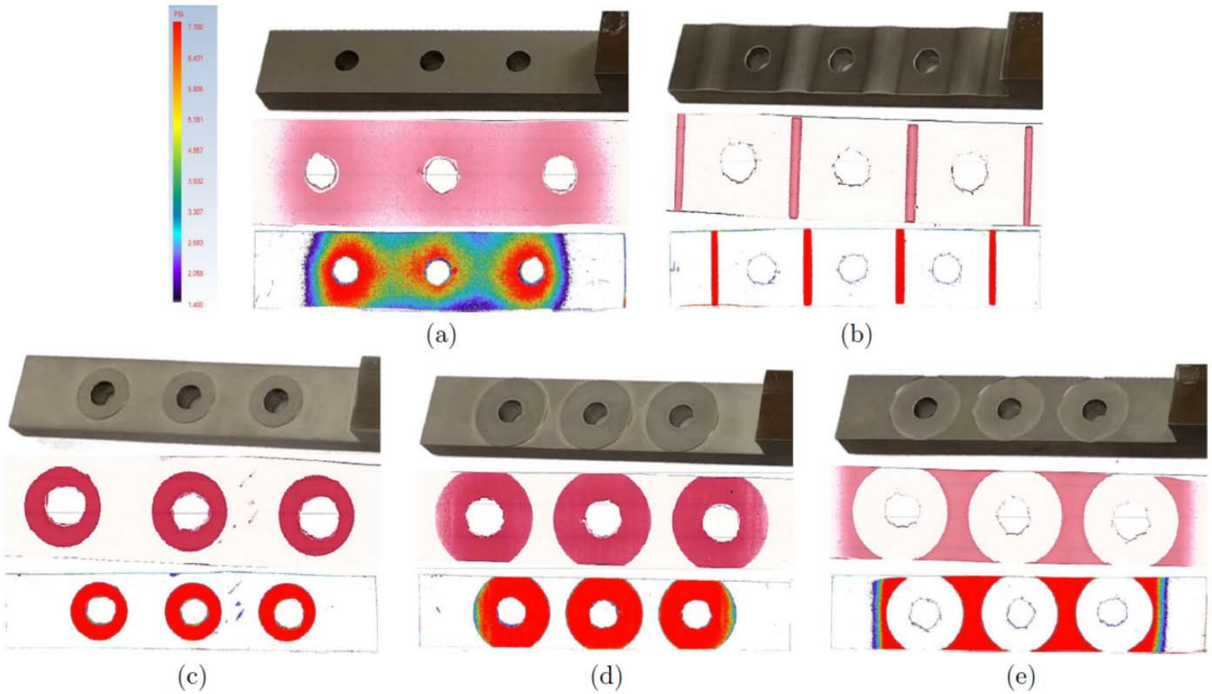
Dynamic Response



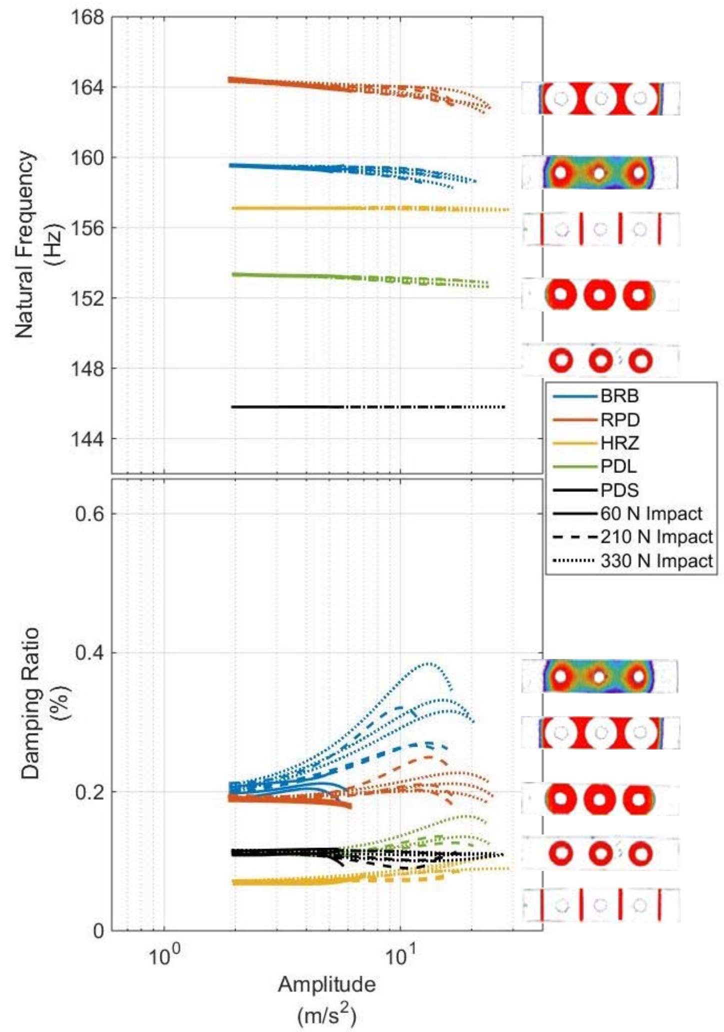
- Typical characterization: Ring Down Response -> Modal Filter -> Hilbert Transform -> Polynomial Fit -> Extraction of Amplitude Dependent Frequency and Damping

Case Study: Interface Designs

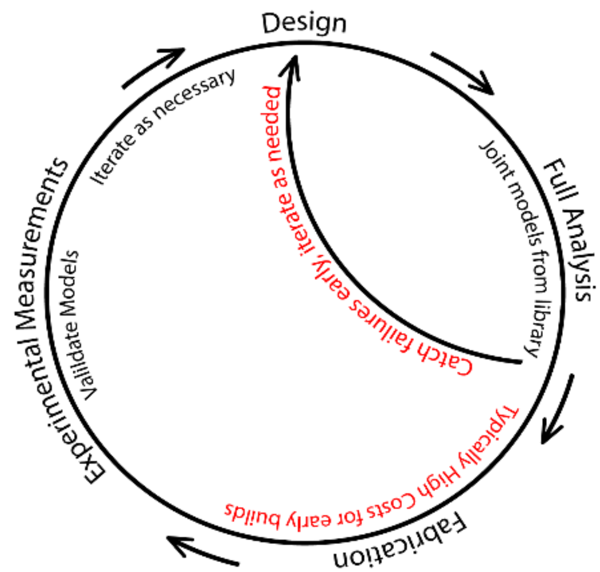
- Modified interfaces to investigate role of geometry on system properties


(a) (b) (c) (d) (e)

Case Study: Interface Design Dynamic Responses

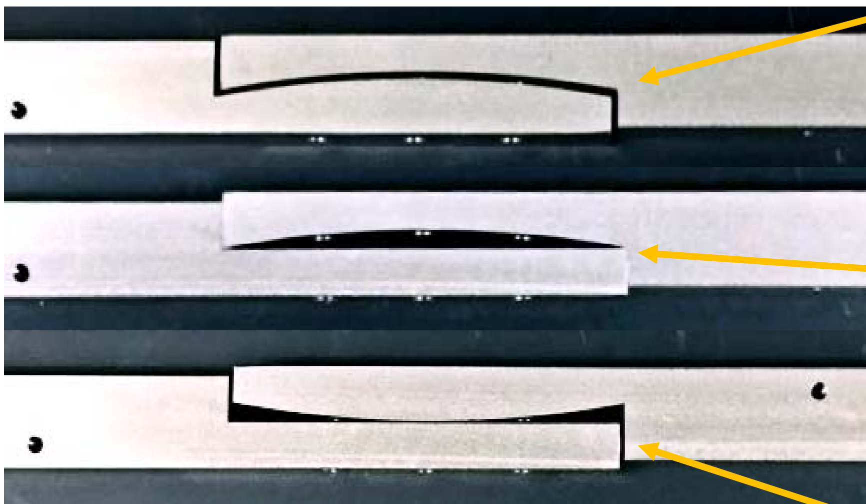


- Lessons from solid mechanics led to a linearized dynamic system
- Linearized systems are much more conducive to design
- Ultimate goal: design tools…



Case Study: Interface Curvature

- Second set of interface modification experiments studied the effect of curvature.



conformal
50 – 50
250 – 250
1000 – 1000
5000 – 5000

baseline
0 – 0
(three slides back)

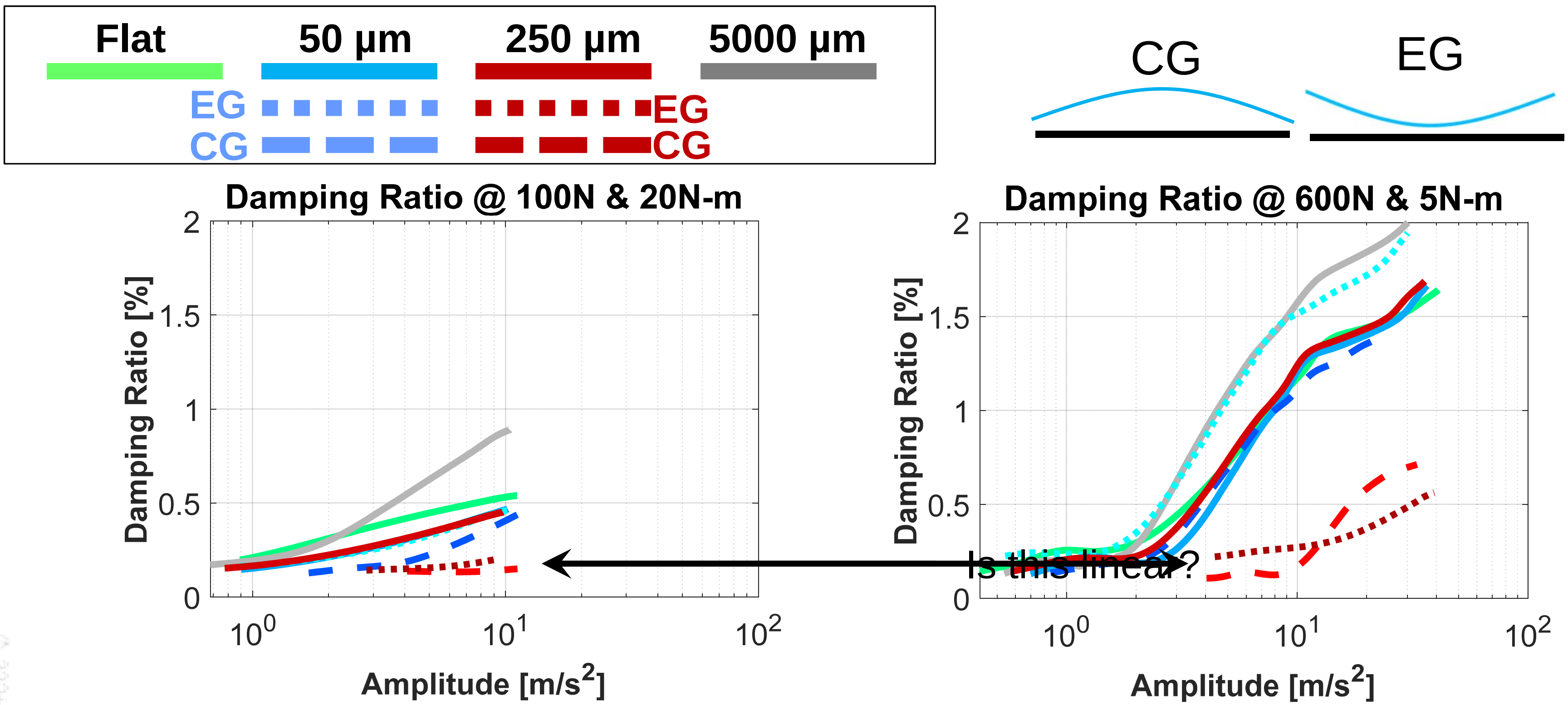
non-conformal (convex)
50 – 0
250 – 0
1000 – 0
5000 – 0

CG

non-conformal (concave)
0 – 50
0 – 250
0 – 1000
0 – 5000

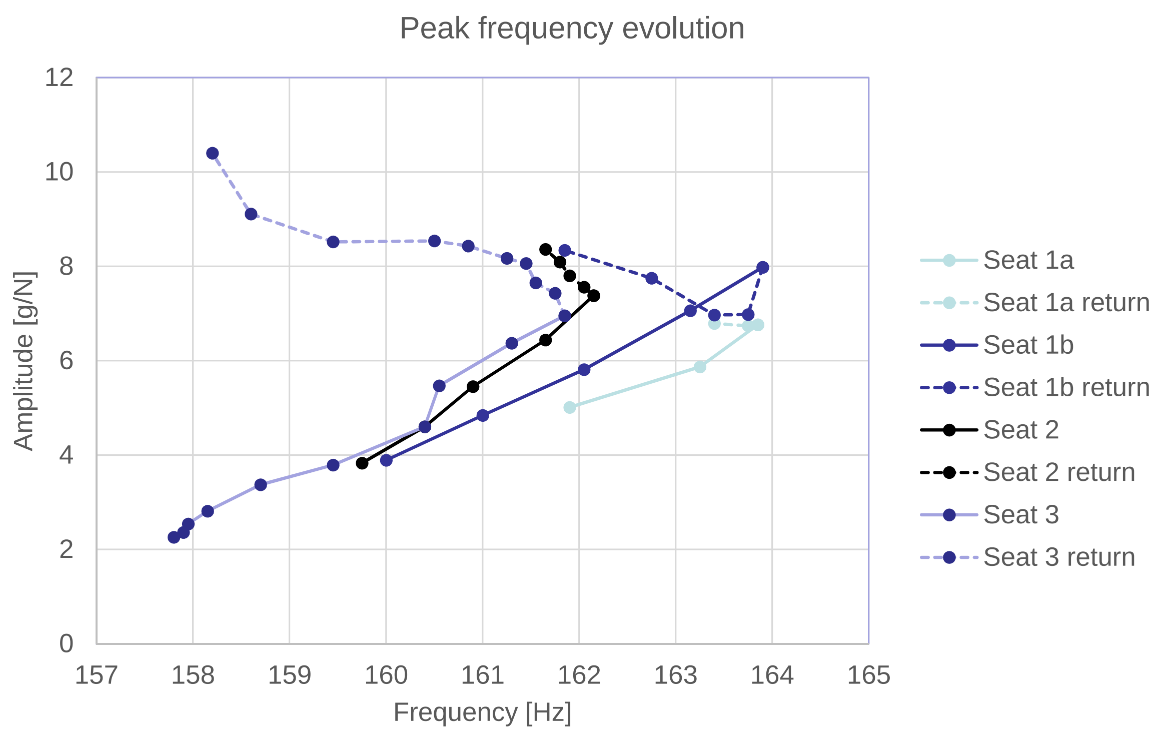
EG

Case Study: Interface Curvature; What Is Linear?



- Perceived linearity depends on contact patch and excitation amplitude

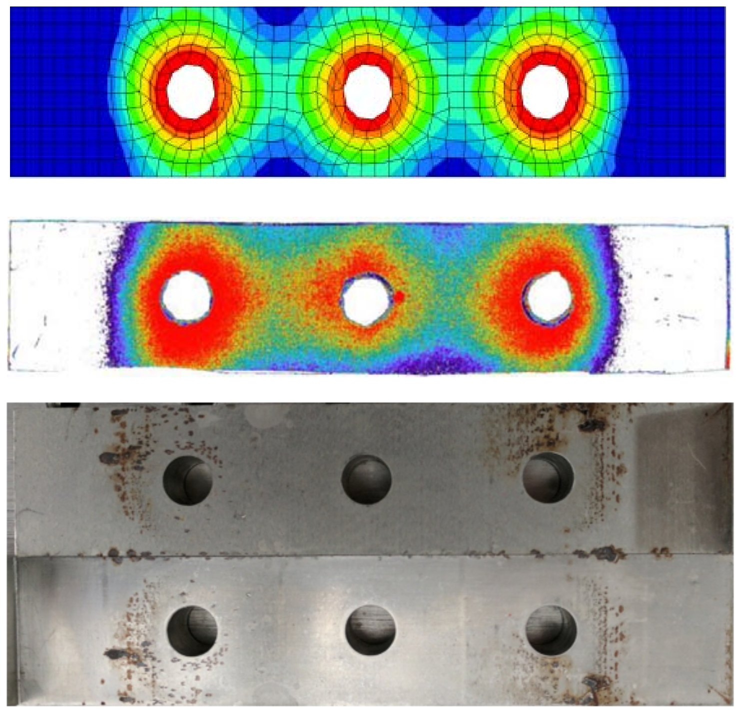
Case Study: Still Missing Tribology...



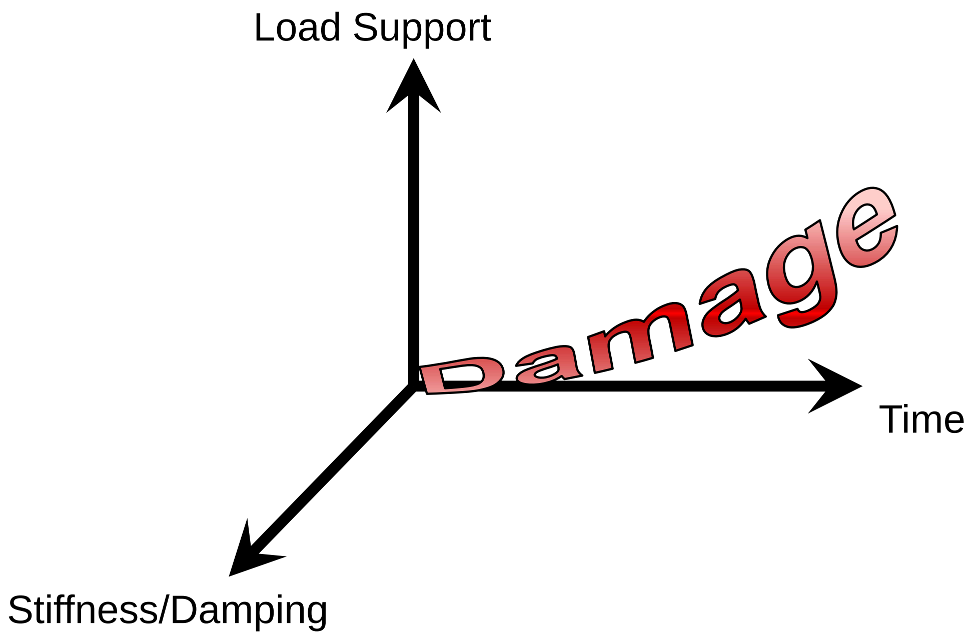
Solid line: high amplitude excitation
Dashed line: low amplitude return

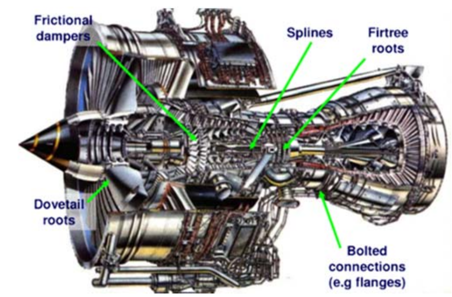
Case Study: Low Cycle Fretting

- Direct observation of wear where we expected it:



Tribomechadynamics in Action





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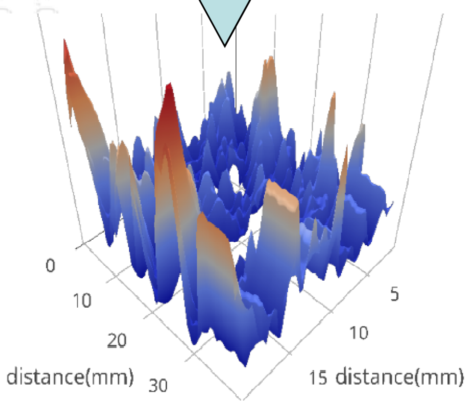
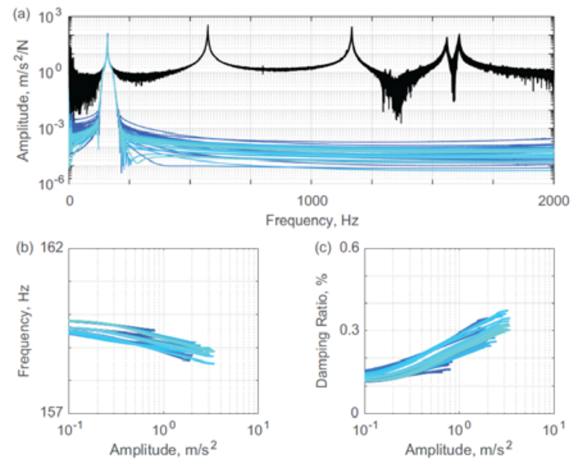
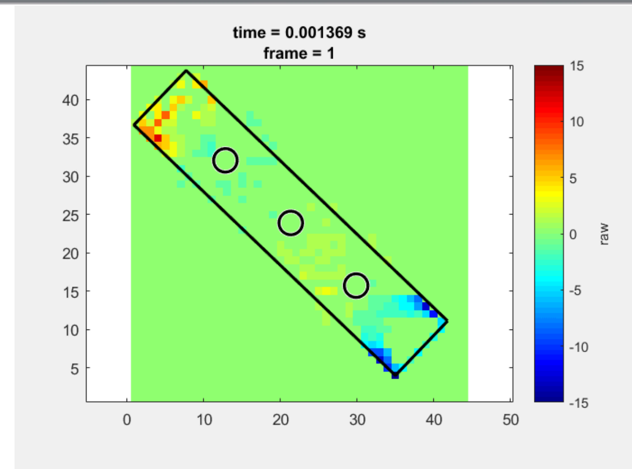


Measure the interface geometry

Experimental Validation





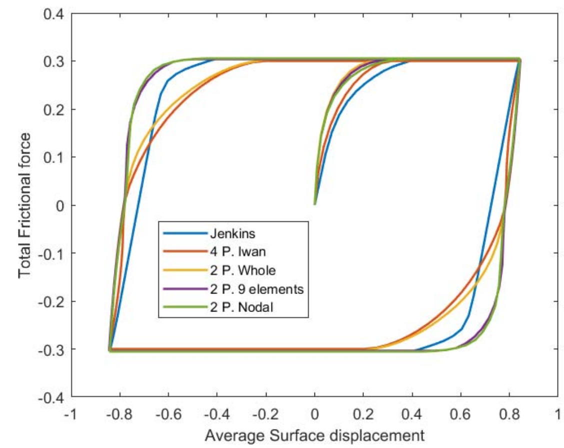
Numerical Modeling

Next gen joint models

- Preserve local kinematics
- Parameters all physical

- Rough contact Iwan model
- 2 parameter friction model

$$\rho(\phi) = \frac{\underline{\mu}\,\underline{p}\,\underline{A}}{\underline{\phi_I}\phi} = \frac{\underline{K_T}}{\underline{\phi}}$$



Research in Tribomechadynamics

- System-scale: how do we *predict* the dynamic properties of a system?
  - Surrogate System Hypothesis
  - A Priori Metrics Hypothesis
- Multi-scale: how can we incorporate the effect of evolving surfaces into a system-level simulation to assess its effect on system dynamics?
- Multi-scale: investigation of the nonlinear transfer of energy between scales, aka “Mechanical Turbulence”
- Meso-/nano-scale: how can we *predict* wear performance for an arbitrary joint?
- Numerical methods: need for efficient, nonlinear interface reduction methods
- Uncertainty quantification: need for methods to propagate uncertainties through models *efficiently*
- Nonlinear system identification: need for methods to characterize mode coupling

Acknowledgements

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ND-CSI Summer Program 2018

- The Institute for Nonlinear Dynamics of Coupled Structures and Interfaces (NDCSI) is now accepting applications.
- Six week long research collaboration
- Hosted by Imperial College London, in London, UK
- July 4th to August 10th, 2018
- Directed by a three person steering committee: Matthew Brake (Rice University), Christoph Schwingshackl (Imperial College London), and Malte Krack (University of Stuttgart)
- Four projects for the 2018 Institute:
  - Evolution of Wear and Joint Behavior
  - Suitability of Asymptotic Numerical Method for Friction Damping
  - High Speed Camera DIC to Monitor Joint Behavior
  - Continuation Method for Bladed-Disk Vibration with Contact and Friction
- Email brake@rice.edu or c.schwingshackl@imperial.ac.uk for more information, or visit: http://brake.rice.edu/nd-csi
- Applications due March 2nd.
- Some travel support is available.

Questions?