# Smart Vehicle Concepts Center (SVC) Projects

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**National Science Foundation (NSF)**
**Industry-University Collaborative Research Center (IUCRC)**

**Smart Vehicle Concepts (SVC)**


**Center Director:**
**Marcelo Dapino**
**<dapino.1@osu.edu>**

**Department of Mechanical and Aerospace Engineering**
**The Ohio State University**


**www.SmartVehicleCenter.org**

**https://svc.osu.edu/**

| *SVC Companies* | |
|---|---|
| American Axle and Manufacturing | Former Member |
| Advanced Numerical Solutions | Former Member |
| Army Research Laboratory | Former Member |
| Battelle Memorial Institute | Current Member |
| BorgWarner | Former Affiliate |
| Bridgestone Americas Tire Operations, LLC | Former Member |
| Eaton Innovation Center | Former Member |
| Edison Welding Institute | Former Member |
| Ford Motor Company | Current Member |
| F.tech R&D* | Former Member |
| Goodyear Tire & Rubber | Former Member |
| Honda R&D Americas Inc.* | Current Member |
| Hyundai-Kia Motors* | Former Member |
| LMS Software | Invited Observer |
| MIT Lincoln Laboratory | Former Member |
| Moog Inc. | Current Member |
| MSC Software | Invited Observer |
| NASA Glenn Research Center | Current Member |
| Owens Corning | Former Member |
| Parker Hannifin | Current Member |
| REL, Inc. | Former Member |
| Romax | Invited Observer |
| Solidica | Former Member |
| Tenneco, Inc. | Former Member |
| The Boeing Corporation | Former Member |
| Tokai Rubber | Former Member |
| Toyota Research Institute, N.A.* | Current Member |
| Transportation Research Center, Inc.* | Current Member |
| YUSA | Former Affiliate |

Key: * Multiple Memberships

# Smart Vehicle Concepts Center

## National Science Foundation Industry-University Cooperative Research Center (IUCRC)

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### Cooperative Center Concept - IUCRC

- Encourages collaborative research
- Focuses on pre-competitive research
- Projects driven and mentored by Industry
- Evaluator appointed by NSF to ensure quality control

### SVC Mission

- Conduct basic and applied research, with application to ground and aerospace vehicle components and systems
- Build an unmatched base of research, engineering education, and technology transfer
- Develop well-trained engineers and researchers (at the undergraduate, MS, and PhD levels)

### Industrial Advisory Board

- IAB consists of one representative from each member company.
- The board is responsible for evaluating current research thrusts, suggesting new opportunities, evaluating center operations, and matching center capabilities with unfilled research needs.
- IAB holds two meetings each year during the SVC review meetings.

### Membership Fee Structure

***The Ohio State University***

- $40K/year - Full Membership (One vote per full membership; access to all Center projects)
- $14K/year - Affiliates (Access to one ongoing project only; no voting or intellectual property rights)

*Leveraging: Membership fee, when combined with cost-sharing and NSF money, gives members access to over $750K per year of research*

### Additional Project Fee Schedule to Ensure a Guaranteed (Solo) Project

| Center Year (for Phase III) | 2017 | 2018 | 2019 | 2020 | 2021-22 |
|---|---|---|---|---|---|
| Membership Fee (a) | $40K | $40K | $40K | $40K | $40K |
| Project Fee (b) | $12K | $14K | $16K | $18K | $20K |
| Admin Fee (c) | $5.2K | $5.4K | $5.6K | $5.8K | $6K |
| **Cost of Solo Membership (a + b + c)** | **$57.2K** | **$59.4K** | **$61.6K** | **$63.8K** | **$66K** |

### SVC Core Faculty

**Prof. Marcelo Dapino**
Expertise: Smart materials; nonlinear coupled systems, design, control

**Prof. Jen-Ping Chen**
Expertise: : Computational fluid dynamics simulation and coding; turbulence modeling; turbomachinery

**Prof. Hanna Cho**
Expertise: Nonlinear NEMS/MEMS; AFM cantilever dynamics; multi-functional ferroelectric material energy systems; nano- and bio-science

**Prof. Vicky Doan-Nguyen**
Expertise: Synthesis; in-situ structural characterization; smart materials; advanced materials for energy storage/conversion

**Prof. Ryan Harne**
Expertise: Vibration/noise damping, energy harvesting/transfer, sensing

**Prof. David Hoelzle**
Expertise: Learning/adaptive control systems; additive manufacturing processes; microsystems for mechanobiology research; dynamics systems analysis

**Prof. Rajendra Singh**
Expertise: Noise & vibration control, geared systems, nonlinear dynamics, DSP

**Prof. Vishnu Sundaresan**
Expertise: Piezoelectric materials, active polymers, bio-derived materials

### SVC Affiliated Faculty and Research Staff

**Dr. Siva Chillara**
**Dr. Luke Fredette**
**M. Bryant Gingerich**
**Dr. Leon Headings**
**Dr. Nicholas Mastricola**
**Prof. Scott Noll**
**Prof. Soheil Soghrati**
**Dr. Prasant Vijayaraghavan**

www.SmartVehicleCenter.org

For further details: https://svc.engineering.osu.edu/membership

# New Research Matrix for Phase III

| Thrust | Interfacial Mechanisms | Safety, Comfort, and Health Monitoring | Adaptive Noise, Vibration, and Harshness (NVH) | Emerging Vehicle Technologies |
|---|---|---|---|---|
| | Characterization, constitutive modeling, system integration (sensors, actuators, dynamic simulation) | Machine and material diagnostics, human-machine interface, strain energy management | Active noise and vibration control, adaptable structures, system integration | Vehicle electrification, autonomous vehicles, lightweighting |
| **Relevant Projects** | 40A, 40E, 40F, 55 | 44, 46, 49, 53, 58 | 45, 47A, 52, 57 | 47B, 51A, 51B, 54, 56 |
| **Typical Sponsors** | Honda R&D, TRC, R&D, Tenneco, Ford, NASA Glenn, Owens Corning | Bridgestone, Honda R&D, Moog, Eaton** | Honda R&D, TRC, Tenneco, NASA Glenn, Toyota, Parker Hannifin, CVG** | NASA Glenn, Honda R&D, Battelle, TRC |

** Pending proposals

# Project # 1: Electro-Hydrostatic Actuation and Sensing (E-HAS)

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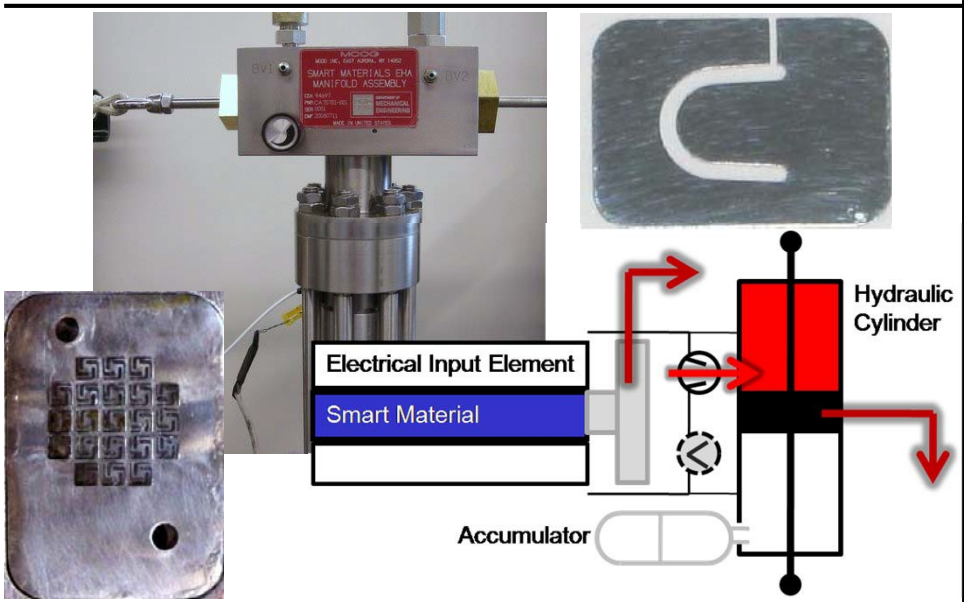
## Technology Summary

- Smart materials produce high force, high frequency, low displacement motion
- Hydraulic fluid is used to rectify motion to create large displacement and high force
- Frequency response of existing mechanical one-way fluid valves is a limiting factor

## Applications/Benefits

Advantages over traditional linear actuators:

- No need for separate pump/fluid lines
- Few moving parts
- Fast response
- High power-to-weight ratio




## Plan

- Investigate valve designs to improve high frequency operation:
  - Reed-type mechanical valves
  - Micro-machined valve array
  - Active valve concepts
- Design, model, and test progressively miniaturized actuator designs to reduce system compliance and inertance


Project leader: Marcelo Dapino (dapino.1@osu.edu)

Project Initiated by Moog Inc.

# Project # 20: Development of an Interfacial Force Sensing System (Sub-Project # 20C: Characterization of Pump Bearing Surfaces)

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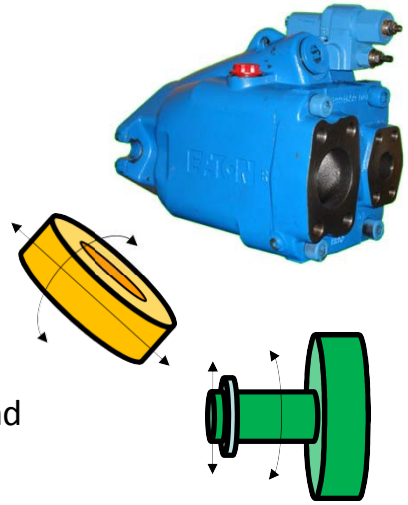
## Motivation

- Pump hydrostatic and boundary lubricated surfaces are poorly understood
- Knowledge of multidimensional force transmissibility through a pump's bearings interface is vital for dynamic modeling and vibration reduction

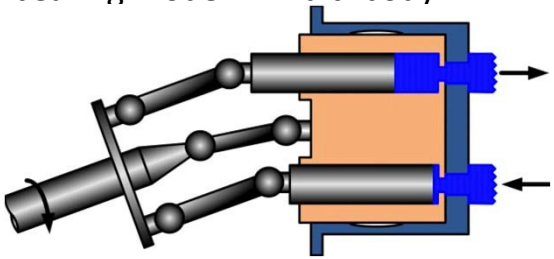


## Goals and Expected Benefits

- Static and dynamic measurements will improve system level modeling
- Understanding the lubrication regimes will be helpful in developing better math models
- Estimation of interfacial forces will lead to better efficiency and durability and reduced NVH concerns
- Characterization of the lubrication regimes will be helpful in developing math models

## Problem Formulation

- Determine the nature of the lubrication regimes
- Conduct dynamic characterization experiments
- Model bearing interfaces using first principles
- Develop an improved bearing model in multi-body dynamic software
- Compare prediction with measurements



## Analytical and Experimental Methods

- Determine lubrication regime on bearing surfaces via pressure and acceleration measurements conditions
- Analytical models will be used to understand the physics and identify the system
- Use commercial multi-body dynamics software to model the bearing system and tune its parameters

http://www.auto-bearings.cn

Project Leaders: Raj Singh (singh.3@osu.edu) and Jason Dreyer (dreyer.24@osu.edu)
Project Initiated by Eaton Corporation

# Project # 31A: Ultrasonic Friction Control

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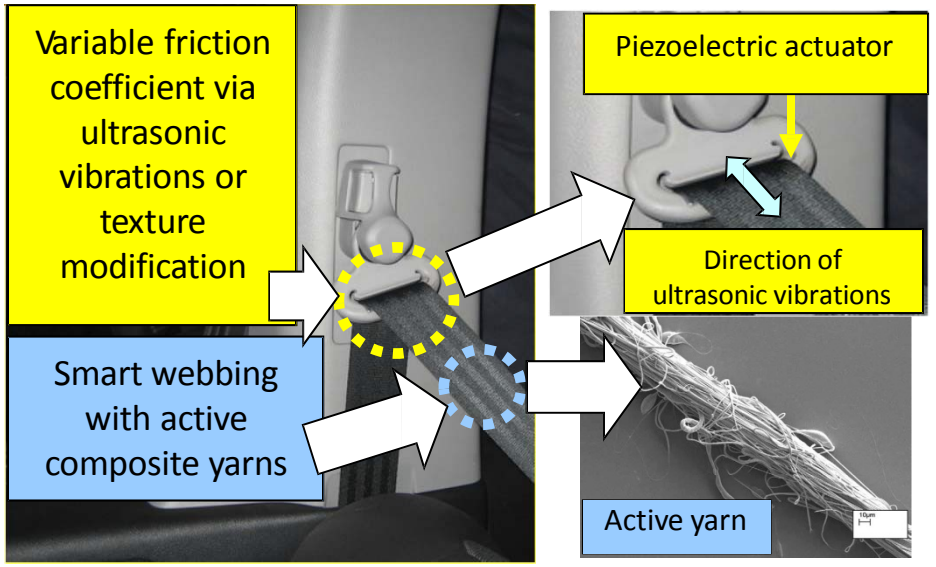
## Technology Summary

- **Ultrasonic lubrication:** the coefficient of dynamic friction between two surfaces decreases when ultrasonic vibrations are superimposed to the sliding velocity
- This form of friction reduction is "solid state" and **requires no greases or oils**
- **Piezoelectric actuators** can be used to create ultrasonic vibrations
- The objective is to modulate the friction coefficient between "high friction" (**off state**) and "low friction" (**on state**) by driving the actuator at different voltages




## Application/Benefits

- Adaptive seat belt system capable of providing **superior safety and comfort, reduced mass, simpler operation and more flexible design**
- Using smart materials to continuously measure and control the loading force can help design **active systems with feedback control**
- The friction control concept is applicable to a wide range of traditional problems **where lubricants are not feasible** and future applications with **active friction control as an enabling technology**

## Plan

- Create a **proof-of-concept experiment** to fundamentally analyze and demonstrate ultrasonic lubrication at high speeds and high normal forces
- Demonstrate the principle of active friction control on a **tabletop seat belt system**
- Analyze and understand the dependence of friction on **system** parameters
- **Analytical modeling** of friction behavior in the presence of ultrasonic vibrations


Project leader: Marcelo Dapino (dapino.1@osu.edu)

Project Initiated by Honda R&D Americas and NASA Glenn

# Project # 31B: Non-Contact Measurement, Visualization, and Analysis of Smart Dynamic Systems

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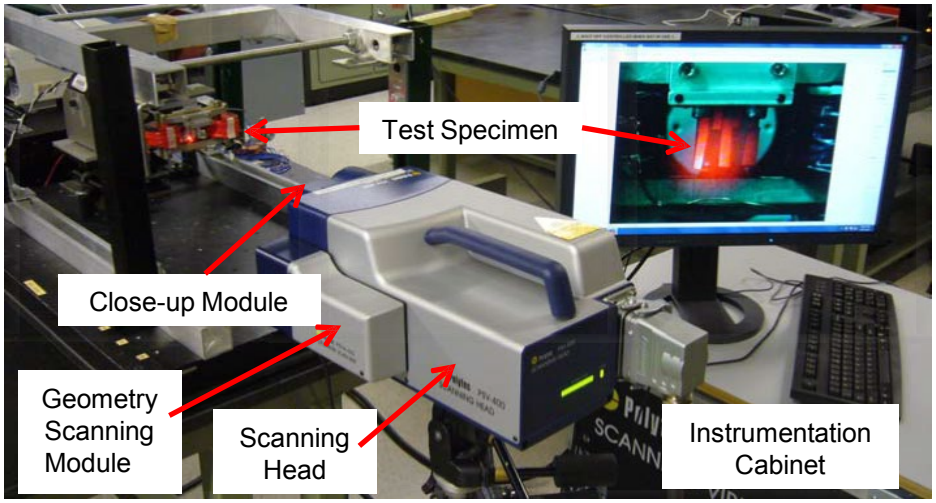
## Laser Vibrometer

Features:

- **Non-contact out-of-plane velocity measurement**
- Scans to **measure vibration of entire structure**
- **"Small" and "large" structures** ($mm^2$ to $m^2$ scale)
- Measurements on complex shapes, ultrasonic devices, red-hot components
- **Geometry scan unit** to acquire 3D geometry and output to CAD software
- 4 analog inputs
- **Bandwidth: up to 1 MHz**
- **Velocity: 1 cm/s to 20 m/s**

## Measurement System




## Dynamic Testing of UAM Al-Galfenol Composites

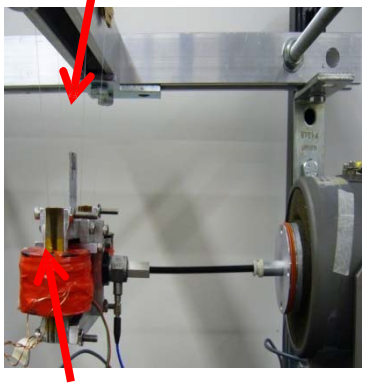
**Experimental setup**

- UAM composite of Al containing Galfenol (a magnetostrictive material)
- Composite cantilevered within a magnetic circuit
- **Modal analysis conducted on active cantilever beam under multiple bias magnetic fields**

**Challenges**

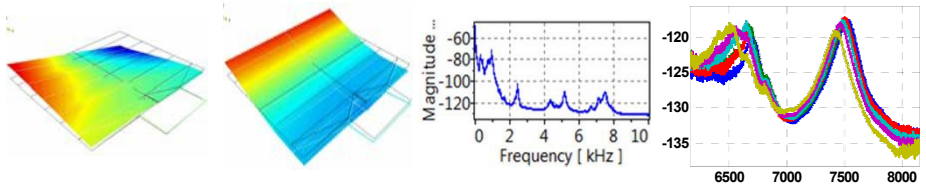
- Composite response expected to be nonlinear; **complex models required to extract full beam response from single point measurement**
- Ability of fixture to produce cantilever condition unknown
- **Many single point measurements required**

Circuit hung as pendulum with fishing wire



magnetic circuit with cantilevered composite

## Typical Data




Composite mode identification

In-depth data processing

| Bias Field at 0 Stress (kA/m) | Mode 1 (1st Bending) | | Mode 2 (1st Torsion) | | Mode 3 (2nd Bending) | | Mode 4 (2nd Torsion) | |
|---|---|---|---|---|---|---|---|---|
| | Frequency (Hz) | Percent Difference (%) | Frequency (Hz) | Percent Difference (%) | Frequency (Hz) | Percent Difference (%) | Frequency (Hz) | Percent Difference (%) |
| 0 | 949.22 | ------ | 2456.3 | ------ | 5166.4 | ------ | 7515.6 | ------ |
| 1.13 | 948.44 | 0.08 | 2448.4 | 0.32 | 5160.2 | 0.12 | 7506.3 | 0.12 |
| 4.51 | 946.88 | 0.25 | 2451.6 | 0.19 | 5149.2 | 0.33 | 7501.6 | 0.19 |
| 8.95 | 950 | 0.08 | 2441.4 | 0.61 | 5118.8 | 0.93 | 7474.2 | 0.55 |
| 13.5 | 946.09 | 0.33 | 2434.4 | 0.90 | 5108.6 | 1.13 | 7463.3 | 0.70 |
| 17.8 | 946.09 | 0.33 | 2422.7 | 1.38 | 5096.1 | 1.37 | 7410.2 | 1.41 |

**Change in modal frequencies due to applied magnetic field (constant current to coils)**


Project Leader: Marcelo Dapino (dapino.1@osu.edu)


Project Initiated by Honda R&D

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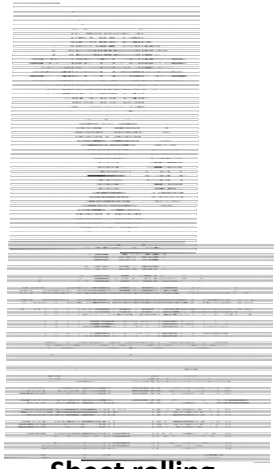
# Project # 31C: Ultrasonically-Assisted Metal Forming

## Background and Objective

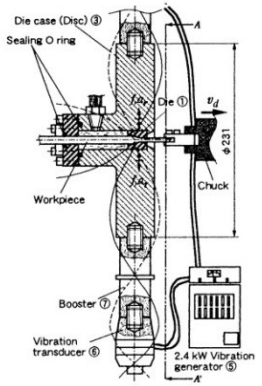
**Objective:** Develop 3D model for ultrasonic lubrication under speed and stress conditions found in metal forming processes

- **Ultrasonic lubrication**: coefficient of dynamic friction between two surfaces decreases when **ultrasonic vibrations** are superimposed to the macroscopic sliding velocity
- This form of friction reduction is "**solid state**" and requires no greases or oils
- We use a **piezoelectric actuator** to create ultrasonic vibrations.
- Modulate the friction coefficient between "high friction" (off state) and "low friction" (on state) by driving the actuator at different voltages

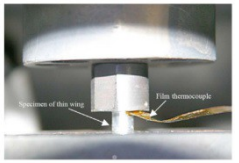
## Examples of Ultrasonic Metal Forming



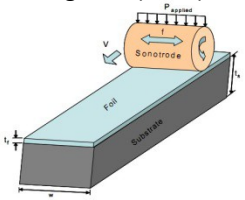
**Sheet rolling**
Severdenko et al. (1974)




**Wire drawing**
Murakawa et al. (2001)

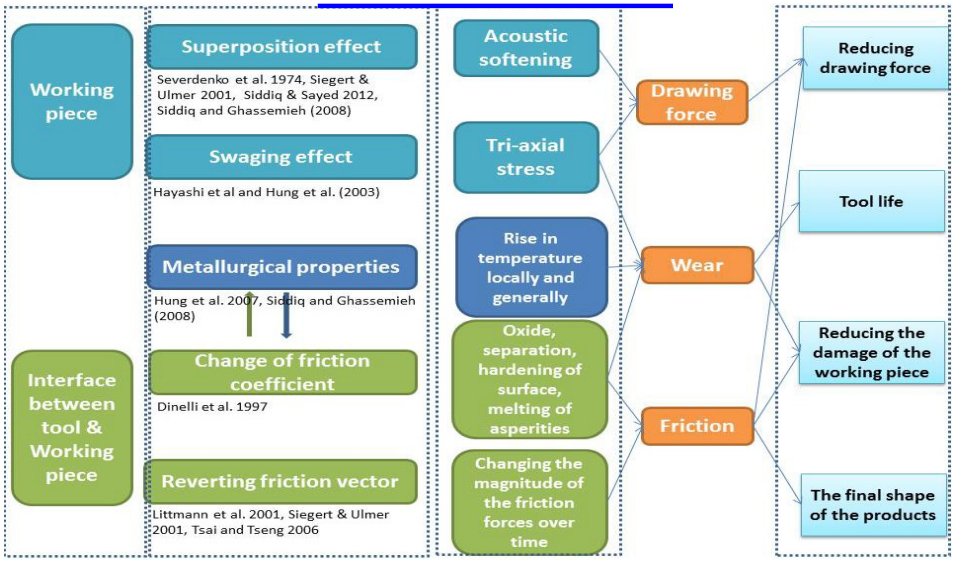


Hung et al (2007)

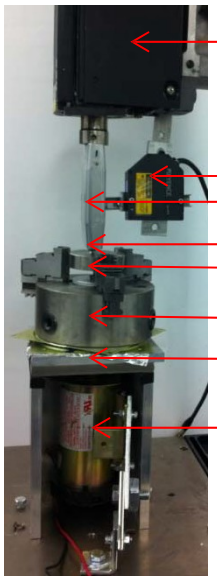



**Compressing**
Siddiq and Ghassemieh (2008)

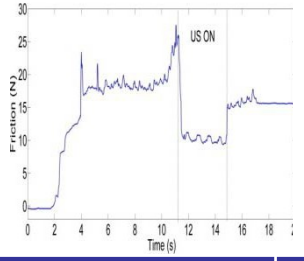
## Literature Review

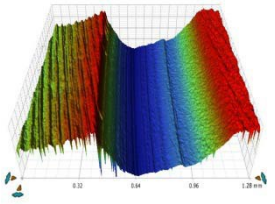



## Experiments




Ultrasonic lubrication was tested between stainless steel pin and stainless steel disc under **stress** (31-35 MPa) and **speed** (266 mm/s) conditions found in metal forming



| | |
|---|---|
| **Friction without US** | **22.88 - 27.52 N** |
| **Friction with US** | 9.93 - 10.71 N |
| **Friction reduction** | 56.8 - 61.1% |


Project Leader: Marcelo Dapino (dapino.1@osu.edu)

Project Initiated by Honda R&D

# Project # 40:
# Modeling & Characterization of Passive & Adaptive Bushings & Mounts
# (Sub-Project # 40A: Rubber Bushings)

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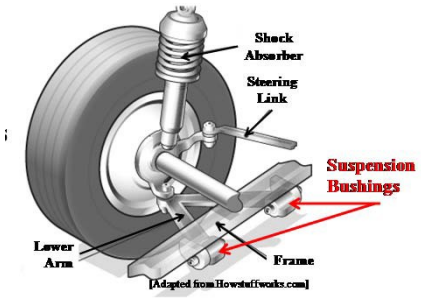
## Motivation

➢ **Complexity in Modeling Bushing Properties**

- Geometry
- Static and Dynamic Loadings
- Multi-axis coupling
- Transient / Steady State
- Static Pre-loading
- Material / Manufacturing
- Assembly issues

- Hysteresis
- Strain-rate Dependence
- Dynamic Amplitude / Frequency Dependence

***Provide some analytical insight into an empirical world***

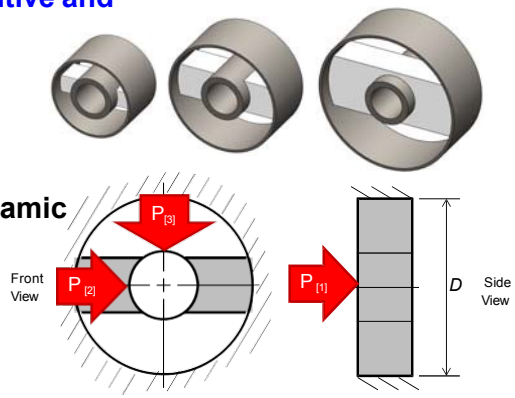



## Experimental Component Study

**Both frequency and time domain characterization of bushings, including amplitude-sensitive and frequency- dependent properties**

✓ Static load-deflection
✓ Harmonic input (1 – 50 Hz)
✓ Step-up and step-down inputs
✓ Different controlled mean and dynamic displacements (strains)

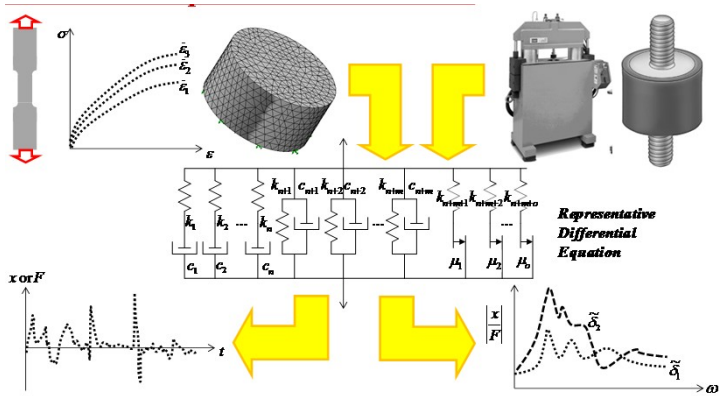
✓ 3 Different size specimens
✓ 9 Material compositions
✓ 3 Loading directions




## Objectives

- Develop improved multi-dimensional linear and nonlinear dynamic models for elastomeric bushings (in both frequency and time domains)
- Develop and conduct systematic experimental characterization procedures to extract bushing parameters and validate dynamic models
- Examine the preloads effects and coupling between axial, radial and torsional stiffness elements
- Use models to examine geometric scaling and material considerations in bushing design
- Understand and quantify testing error
- Investigate feature / shape effects within components

## Alternate Component-Level Models




- Multiple linear and nonlinear models have been developed and evaluated
- Multiple dimensional properties and coupling effects have been investigated analytically, computational, and experimentally


Project Leaders: Raj Singh (singh.3@osu.edu), Jason Dreyer (dreyer.24@osu.edu); and Scott Noll (noll.34@osu.edu)


Project Initiated by Honda R&D, TRC, F.tech R&D, Tenneco, & Ford

# Project # 40:
# Modeling & Characterization of Passive & Adaptive Bushings & Mounts
# (Sub-Project # 40B: Hydraulic Bushings)

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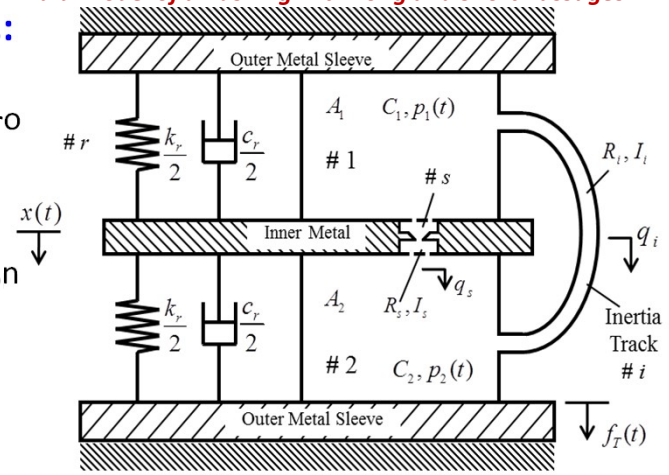
## Motivation:

- Passive or adaptive hydro bushing can satisfy both motion control and vibration isolation requirements
- Many features of hydro bushings are described in patents but no analytical justifications are provided
- Very few scholarly articles on this topic are available
- Most hydro bushing designs are based on linear system principles, though their dynamic properties are highly frequency dependent and amplitude sensitive
- Apply expertise gained from recent SVC research on hydraulic mounts (SVC # 3 and #20A)

## Project Goals:

- Develop new models of hydro bushings
- Propose improved characterization methods
- Develop new adaptive concepts

*Fluid Model of a Bushing with Long and Short Passages*




## Research Plans:

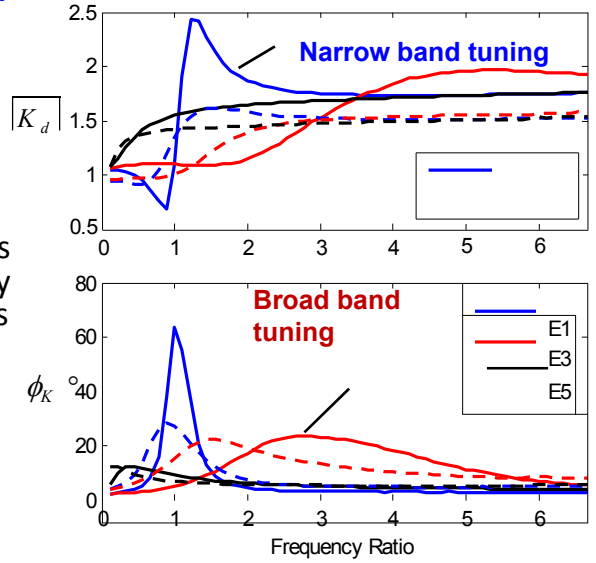
- Develop linear models of hydro bushings with two flow passages
- Investigate static and dynamic properties of production bushings
- Conduct experimental studies on a new prototype and validate linear models in frequency domain
- Conduct time domain experiments and analysis
  - Develop quasi-linear (spectrally-variant properties) and nonlinear models (stopper and flow passage nonlinearities)
  - Explore adaptive bushing design concepts

*New prototype device*

## Recent Results:

- Significant frequency and amplitude dependence are observed from measured dynamic stiffness and examined by analytical models
- Narrow/broad band tuning can be achieved by adjusting the combinations of flow passages

*Dynamic Stiffness Measurements of the prototype*





Project Leaders: Raj Singh (singh.3@osu.edu), Jason Dreyer (dreyer.24@osu.edu); and Scott Noll (noll.34@osu.edu)



Project Initiated by Honda R&D, TRC, F.tech R&D, Tenneco, & Ford

# Project # 40:
# Modeling & Characterization of Passive & Adaptive Bushings & Mounts
# (Sub-Project # 40C – Subframe Dynamics)

THE OHIO STATE UNIVERSITY

## Motivation:

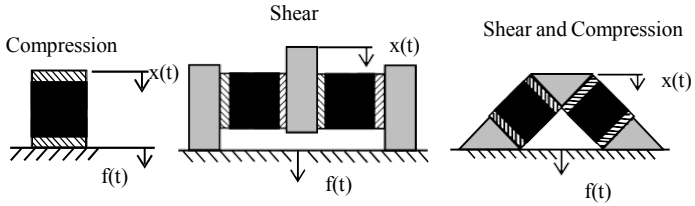
Automotive elastomeric joints are used extensively to accommodate relative movement between metal parts and absorb shocks. Subframes are formed in complicated shapes that must be lightweight, high strength and compact. Subsystem designs must balance the competing needs for:

- Noise, Vibration, and Harshness
- Ride and Handling
- Durability

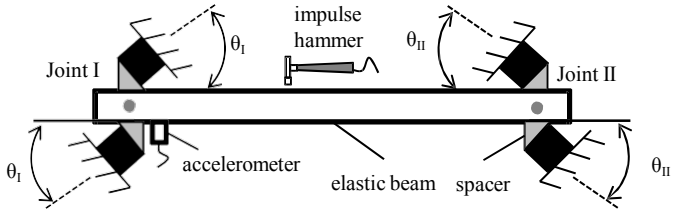
www.hondanews.com

## Benchmark Stiffness Coupling Experiments:

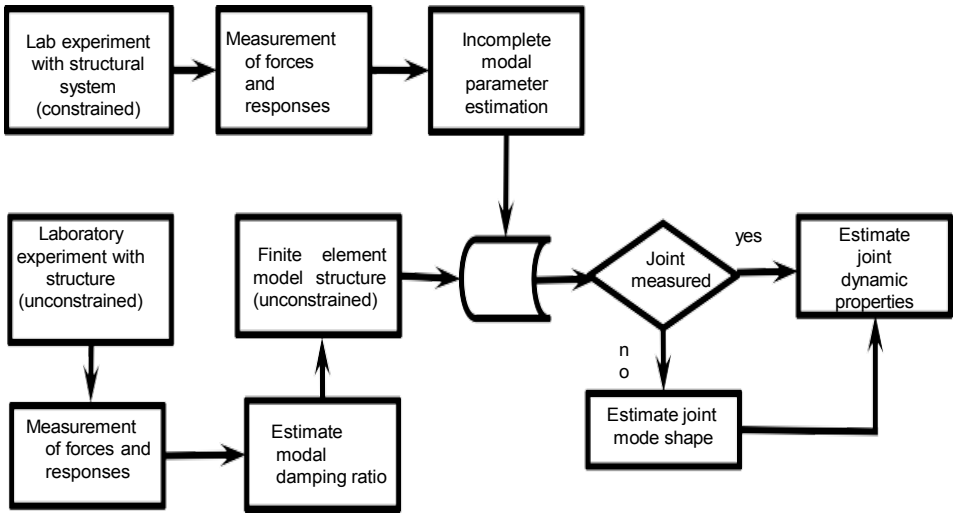
Direct Joint Measurements



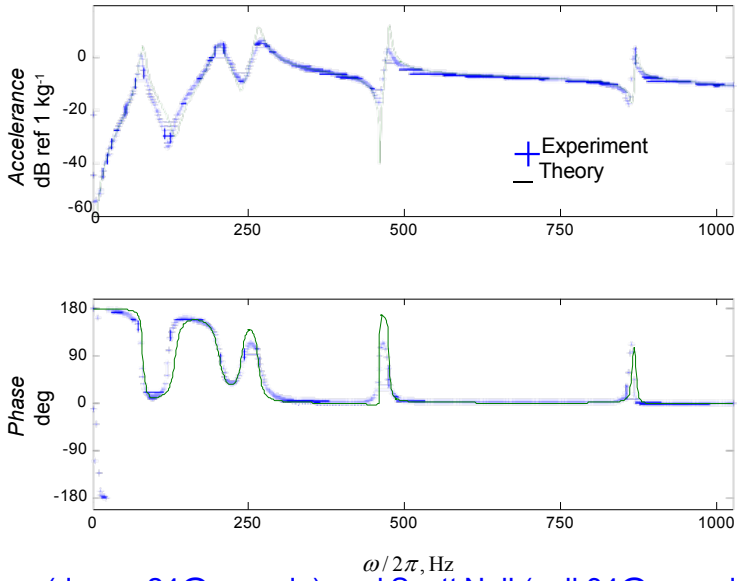

Joint Identification Using Inverse Method




## Joint Identification Using Inverse Method:




## Recent Results: Elastic Beam with Viscoelastic Supports





Project Leaders: Raj Singh (singh.3@osu.edu), Jason Dreyer (dreyer.24@osu.edu); and Scott Noll (noll.34@osu.edu)



Project Initiated by Honda R&D, TRC, F.tech R&D, Tenneco, & Ford


www.SmartVehicleCenter.org

# Project # 40:
# Modeling & Characterization of Passive & Adaptive Bushings & Mounts
# (Sub-Project # 40D: Hybrid Modeling Methods)

THE OHIO STATE UNIVERSITY

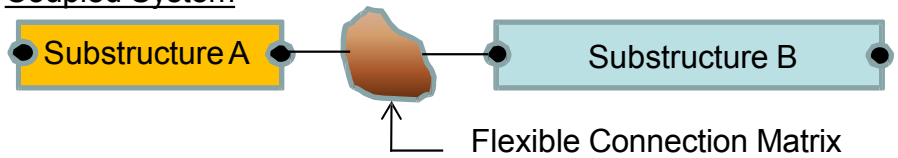
## Motivation:

- Seeking to understand the sensitivity between rear subframe (including its modifications and end supports) and the sound pressure from within the vehicle compartment.
  - Potential Benefits:
    - Improve target setting for NVH.
    - Improve subframe design and performance.
    - Minimize prototype iterations.
    - Improve modeling capability.

## FRF Based Substructuring:

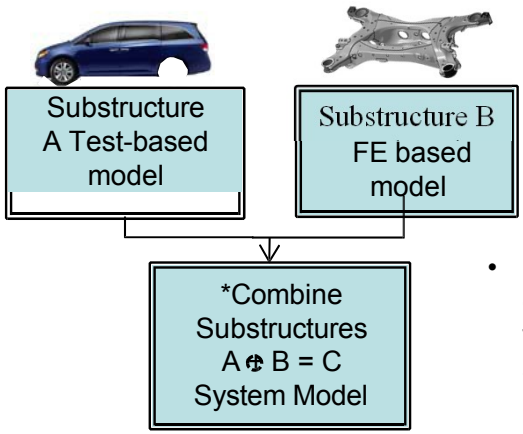
Uncoupled System

Coupled System



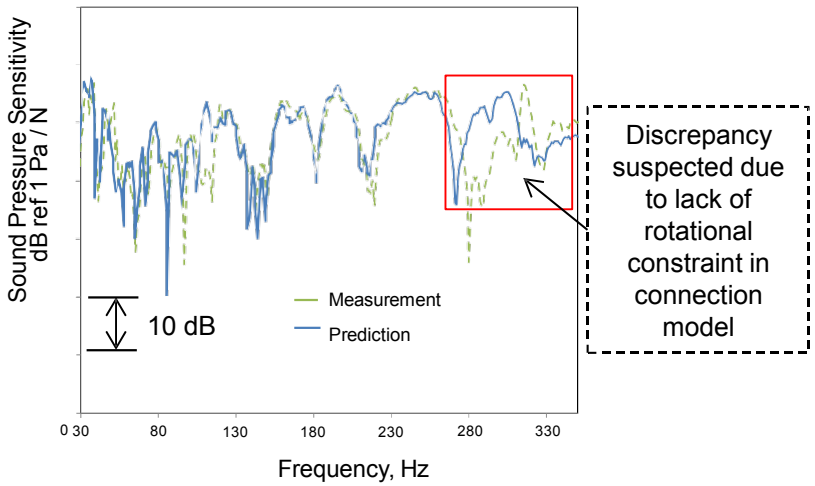

$$\begin{bmatrix} \mathbf{H}_{C_{rr}} & \mathbf{H}_{C_{rs}} & \mathbf{H}_{C_{rt}} \\ \mathbf{H}_{C_{sr}} & \mathbf{H}_{C_{ss}} & \mathbf{H}_{C_{st}} \\ \mathbf{H}_{C_{tr}} & \mathbf{H}_{C_{ts}} & \mathbf{H}_{C_{tt}} \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{A_{rr}} & \mathbf{H}_{A_{rs}} & 0 \\ \mathbf{H}_{A_{sr}} & \mathbf{H}_{A_{ss}} & 0 \\ 0 & 0 & \mathbf{H}_{B_{tt}} \end{bmatrix} - \begin{bmatrix} \mathbf{H}_{A_{rs}} \\ \mathbf{H}_{A_{ss}} \\ -\mathbf{H}_{B_{ts}} \end{bmatrix} \left[ \mathbf{H}_{A_{ss}} + \mathbf{H}_{B_{ss}} + [K_s]^{-1} \right] \begin{bmatrix} \mathbf{H}_{A_{rs}} \\ \mathbf{H}_{A_{ss}} \\ -\mathbf{H}_{B_{ts}} \end{bmatrix}^T$$

## Problem Formulation:




- Particular components may be too difficult to model analytically with the required precision.

## Recent Results:





Project Leaders: Raj Singh (singh.3@osu.edu), Jason Dreyer (dreyer.24@osu.edu); and Scott Noll (noll.34@osu.edu)



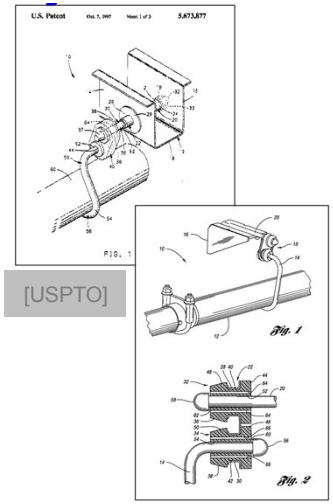
Project Initiated by Honda R&D, TRC, F.tech R&D, Tenneco, & Ford

# Project # 40:
# Modeling & Characterization of Passive & Adaptive Bushings & Mounts
# (Sub-Project # 40E: Automotive System Isolation)

THE OHIO STATE UNIVERSITY

## Motivation:

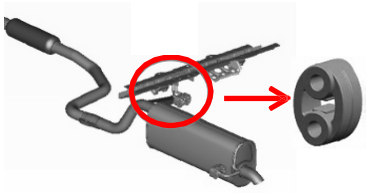
- Exhaust hangers are widely used to isolate exhaust structure and powertrain vibration
- Many features of exhaust hanger and isolation systems are described in 5500+ patents but no analytical or scientific justifications are provided
- Very few scholarly articles on this topic are available



[USPTO]

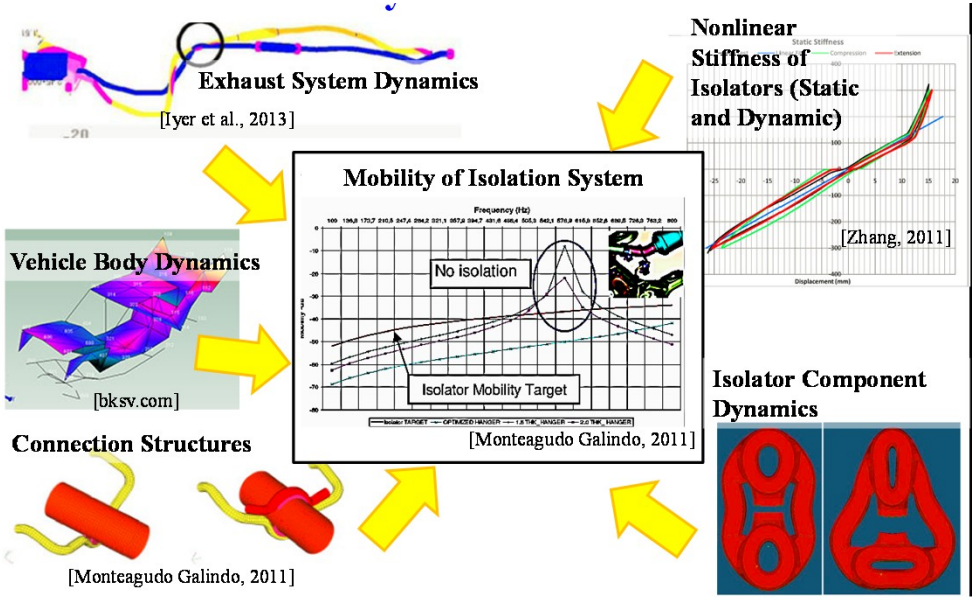
## Project Goals:

- Improve modeling tools (including feature-based models)
- Refine dynamic characterization procedures
- Gain insight into contributions various components to system performance
- Understand component and system design targets
- Resolve associated scholarly issues



[Figure adapted from Monteagudo Galindo, 2011 and tenneco.com]

## Elements of Dynamic Performance:




## Technical Issues:

- ❑ **Dynamic behavior of elastomeric or plastic materials**
  - Environment (temperature, humidity, chemical, age)
  - Loading conditions (mean load, dynamic amplitude, frequency)
- ❑ **Nonlinear features within component**
  - Shape effects of isolators and brackets (geometric nonlinearities)
  - Stoppers; friction and clearances within joints
- ❑ **Modeling issues**
  - Different models for time and frequency domains
  - Only linear models are used in spite of many nonlinearities
- ❑ **Representation of connection dynamics in models**
  - Multi-dimensional coupling; multiple structural paths
  - Local stiffness vs. global stiffness


www.SmartVehicleCenter.org

Project Leaders: Raj Singh (singh.3@osu.edu), Jason Dreyer (dreyer.24@osu.edu); and Scott Noll (noll.34@osu.edu)



Project Initiated by Honda R&D, TRC, F.tech R&D, Tenneco, & Ford

# Project #40: Modeling and Characterization of Passive and Adaptive Bushings and Mounts

## Sub-Project #40F: Inverse Identification Method for Radiator Mounts

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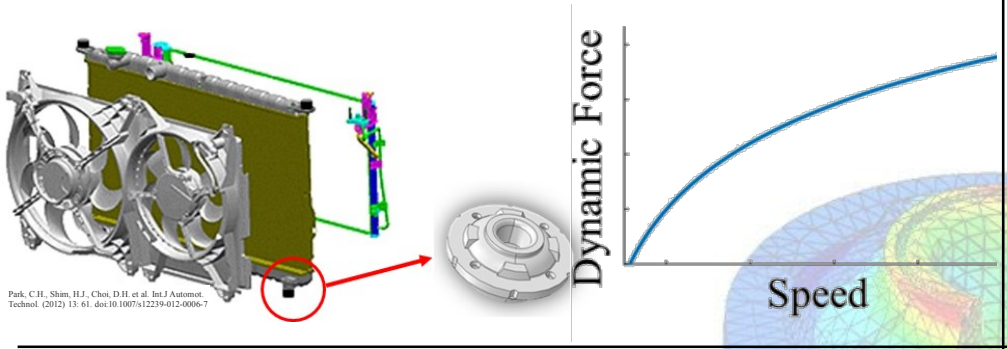
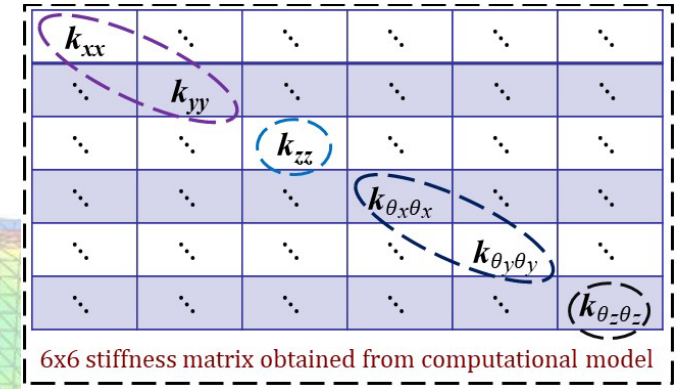
## Industry Need, Context, and Relevance

- Improved understanding should strengthen isolator design methodology and specifications for higher speed cooling fans




## Goals

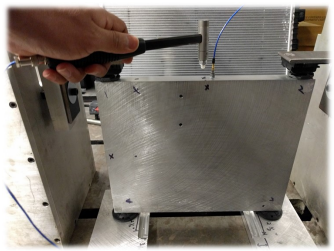
1. **Characterize the multi-dimensional stiffness matrix of elastomeric isolators using the inverse identification method**
2. **Develop refined computational models for the dynamic analysis of a radiator-fan mounting system**




6x6 stiffness matrix obtained from computational model

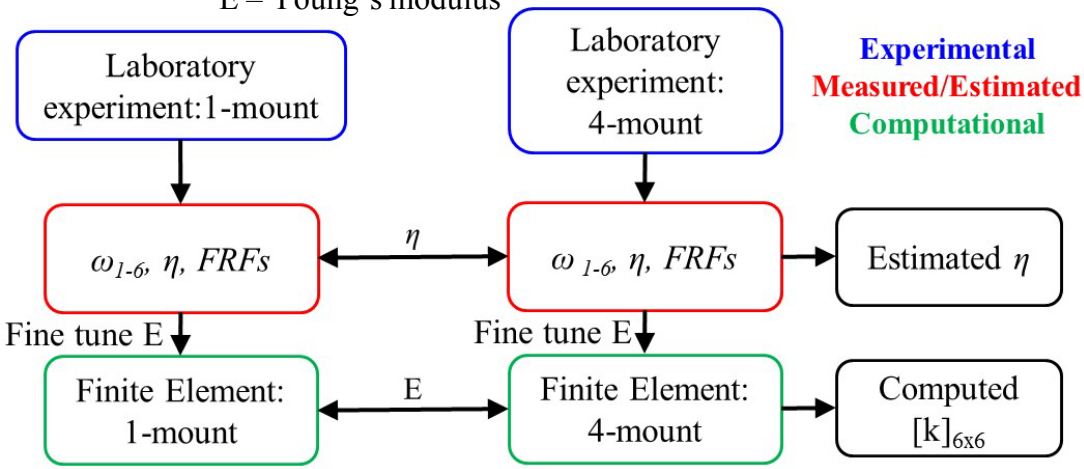
## Scope and Assumptions

- Focus on 6 rigid body modes
- Linear system theory (small displacements) for noise and vibration studies
- Dynamic force excitation
- Frequency-independent stiffness (with structural damping)



## Approach (Research Methods)

Key: $\omega$ – Natural frequency; $\eta$ – Loss factor; E – Young's modulus; *FRFs* – Frequency response functions; $[k]_{6x6}$ – Stiffness matrix of dimension 6





**Project Leader: R. Singh (OSU)**

**Project Mentor: Yi Zhang (Ford Motor Company)**

# Project # 42A: Enhanced Methods for Reducing Powertrain Vibration Transmitted through the Mounts

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## Motivation

➢ The move towards lighter weight vehicle components (say in the transmission) creates significant high frequency structure-borne noise and vibration

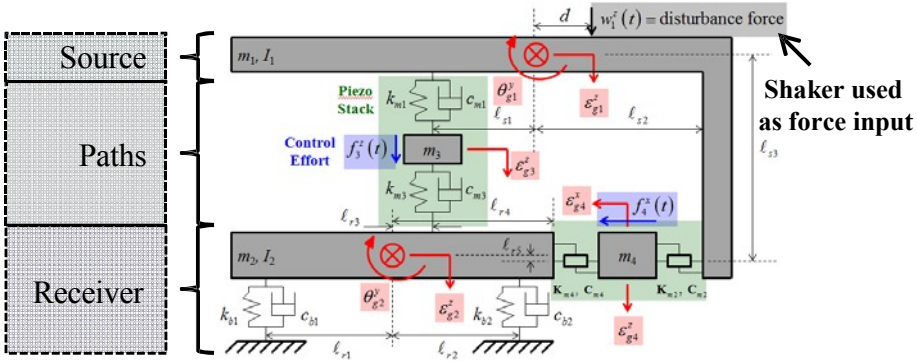
| Source(s) (Powertrain, Transmission) | ↔ | Path(s) (Mounts) | ↔ | Receiver(s) (Sub-frame, chassis) |
|---|---|---|---|---|
| Design likely fixed | | Flexibility in design | | Design likely fixed |

**Motivation to enhance mount designs for NVH control.**

**Remark**

1. The path(s) may interact with the source(s), receiver(s), and each other. Care must be taken to sort out and properly account for these possible interactions.

## Problem Formulation



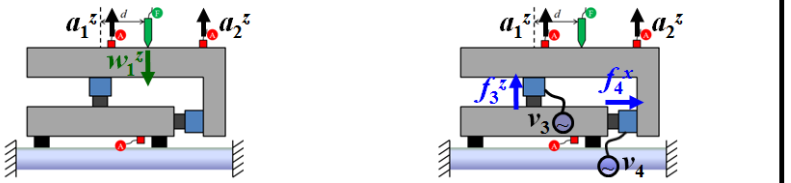

1. Conceptual experiment constructed for feasibility study of active mounts.
2. Active mounts are piezoelectric stacks, modeled with discrete masses.

**Focus is on motion control of the source mass**

## Methods

**STEP #1:** Apply a shaker force (400 Hz cosine wave) and measure the amplitude

**STEP #2:** Calculate needed control effort(s) to counteract the disturbance

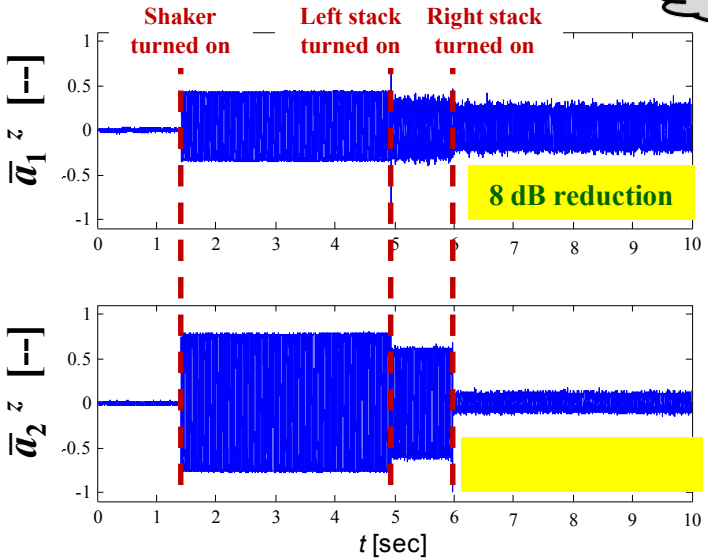


**STEP #3:** Apply the calculated control effort(s) using the piezo stack(s)

**STEP #4:** Adjust the phase(s) and magnitude(s) for best results

**Control effort(s) calculated using model**

## Experimental Results




**Remarks**

**Feasibility for motion control of source mass using piezo stacks is demonstrated.**

**Experimental results are similar to simulated results**


Project Leaders: Raj Singh (singh.3@osu.edu) and Jason Dreyer (dreyer.24@osu.edu)


Project initiated by Hyundai Motor Company (R&D Division)

# Project # 42B: Enhanced Methods for Reducing Powertrain Surface Radiated Noise

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## Motivation

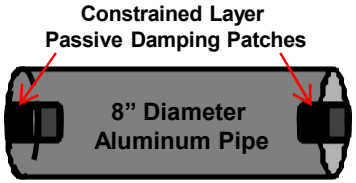
- **New noise sources seen in hybrid and electric vehicles**
- **Characteristics of motor noise**
  - Modulated sounds (with multiple sidebands)
  - Strong directivity
- **May excite structural resonances at high frequencies**
- **Psycho-acoustic perception issues**

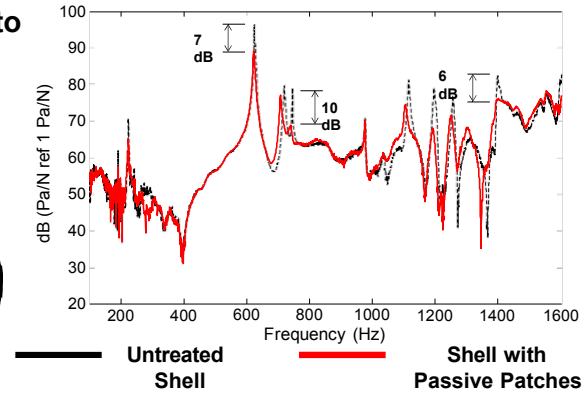
## Objectives

- **Reduce surface radiated noise from surfaces through passive, active, or hybrid patches**
  - Maximize the reductions in radiated noise using minimal patch material
- **Use passive patches to determine optimal patch locations and capabilities of patch placement**
- **Develop control algorithm for use with active patches**

## Passive Patch Investigations

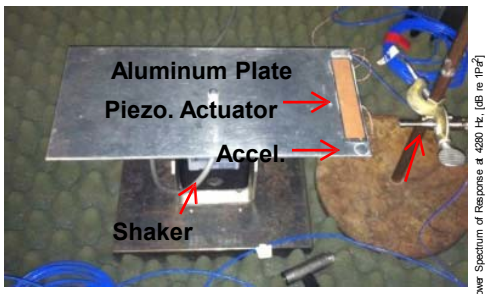
- **Passive damping patches placed on structural anti-nodes of hollow aluminum shell (2% of surface area covered)**
- **Comparative studies showed anti-nodes to be optimal patch placement**
- **Same method applied to circular annular plates with similar reductions**

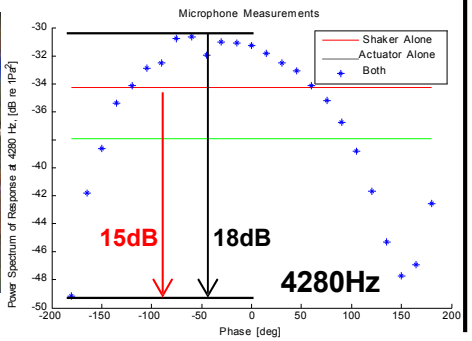



## Active Patch Investigations

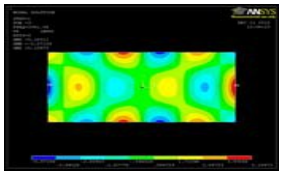
- **Representative experimental setup**
  - Aluminum plate, disturbance from shaker
  - Piezoelectric patch to attenuate noise by destructive interference
- **Significant reduction observed in sound pressure and accel.**
  - Phase between disturbance and control signals varied
  - Reduction observed at different frequencies & for different patches

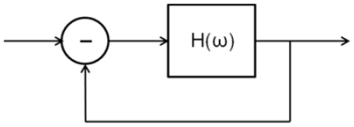



## Future Work

- **Mode Shape Characterization**
  - Use roving-hammer-type test
  - Correlate with FEA, use to optimize patch placement (antinodes)
- **Control Algorithm Development**
  - Unknown disturbance frequency determined from measurement
  - Phase is control variable to minimize sound
- **More complex geometry**
  - Curvature, features like ribs
  - True in-situ geometry →electric motor housing





From http://www.123rf.com


Project Leaders: Raj Singh (singh.3@osu.edu) and Jason Dreyer (dreyer.24@osu.edu)


Project initiated by Hyundai Motor Company (R&D Division)

# Project # 43: Thermally Invariant Smart Composites

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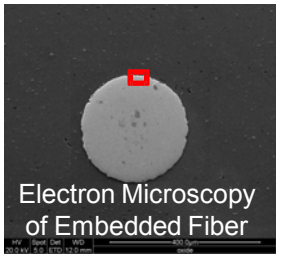
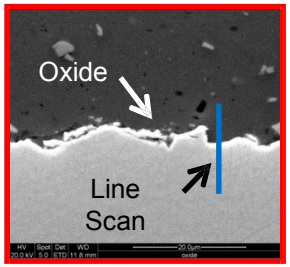
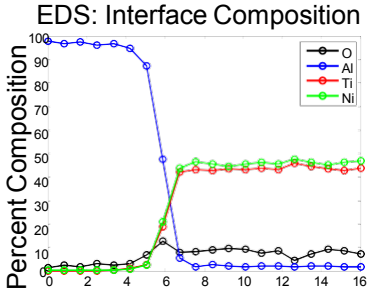
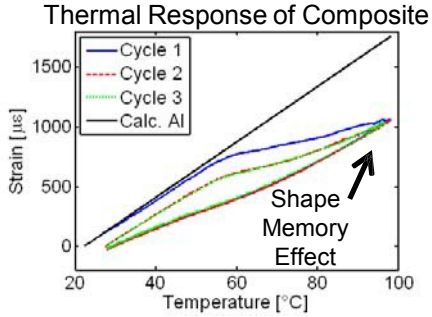
## Technology Summary

- NiTi-Al composites are a light weight alternative to iron based thermally invariant materials like Invar
- Tight part tolerance is required in aerospace components which undergo large temperature fluctuations
  - Ultrasonic Additive Manufacturing (UAM) enables the manufacture of gapless NiTi-Al composites below the melting temperature of the constituent materials



Composite: 15.2% NiTi, Fully Detwinned

## Applications/Benefits

- Low fiber volume fraction is possible, which reduces cost and weight
  - NiTi-Al composites can be mounted with standard fasteners, are tough, and require no power to function
  - Composite is multifunctional:
    - Slows composite thermal response
    - Provides stiffening with heating
    - Can be activated passively or actively

## Plan

- Develop high fidelity models for composite design and analysis
  - Improve and understand interfacial coupling between NiTi fibers and Al matrix
  - Scale up technology with mechanized UAM process:
    - Automated tape feed
    - CNC subtractive stage and laser etching
    - Fixtures for laying out of fibers

Project Leader: Marcelo Dapino (dapino.1@osu.edu)
Project initiated by MIT Lincoln Laboratory

# Project # 44: Smart Condition Detection and Monitoring

THE OHIO STATE UNIVERSITY

## Problem Statement

- The objective of this Smart Vehicle Concepts Center project is to develop flexible, self-powered, multi-functional tire sensors
- We are interested in measuring tire physical properties, log tire history, and generate real-time information on tire condition and tire-road interactions
- Research focus is PVDF (polyvinylidene fluoride) sensors and energy harvesters
- As a first step we developed a tire revolution counter
- We propose electrode patterning to measure various tire properties (revolutions, temperature, load, wear) with the same PVDF sensor

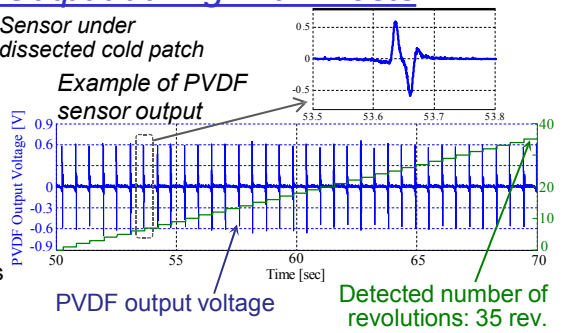
## Background

- Smart sensors and devices can add significant value to tires
  - Safety: Real-time notification of tire condition and tire-road interactions can improve safety by providing accurate parameter estimation to the vehicle electronic stability control (ECS) system
  - Performance: Historical monitoring of tire data can be used to improve tire design, modeling, and fabrication
  - Operating costs: Tire condition monitoring is important in commercial vehicles where tires are the single largest maintenance cost item and may be retreaded multiple times

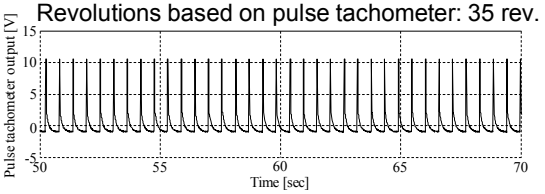
## PVDF Sensor Output during Drum Tests

Truck tire

Sensor under dissected cold patch




- Drum tests:
  - PVDF sensors bonded to a truck/bus tire innerliner
  - Tested various bonding methods
  - Tested under typical vehicle speeds and loaded tire radius conditions
- Drum test results:
  - Sensor successfully demonstrated without failure
  - Revolutions counted by sensor and algorithm matched data from a pulse tachometer



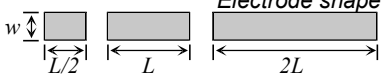

## Prediction of Measured PVDF Voltage

➢ Rectangular shape (Length: L/2, L, 2L)

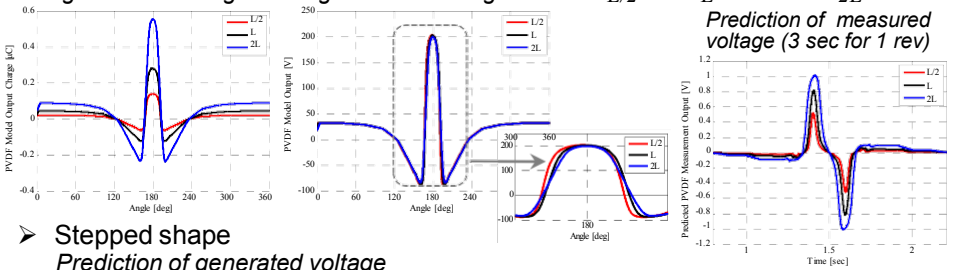
*Prediction of generated charge*

*Prediction of generated voltage*

*Electrode shape*



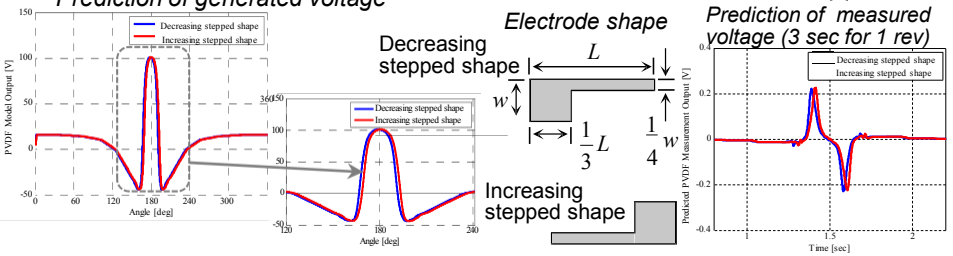

*Prediction of measured voltage (3 sec for 1 rev)*




➢ Stepped shape

*Prediction of generated voltage*

*Electrode shape*




*Prediction of measured voltage (3 sec for 1 rev)*

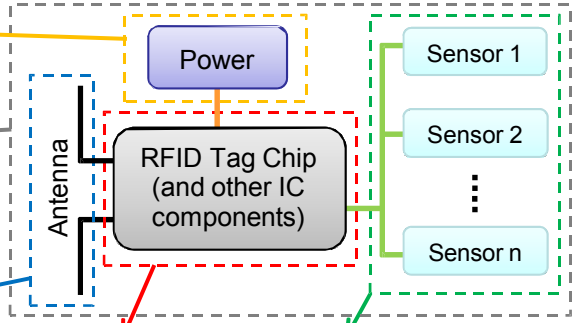
## Flexible, Self-Powered, RFID Based Sensors

Objective: Develop autonomous, self-powered, radio frequency identification (RFID)-based smart tire sensors (STS) that log the tire history within the tire and generate real-time information on tire condition and tire-road interactions

*Energy Harvester*
- Energy harvesting to power data processing and writing to memory

*System Architecture*
- Compatibility and optimization of components for system performance
- Multifunctional elements that reduce cost and weight by using fewer components

*Tag Antenna*
- Reliable reading regardless of tire construction and condition
- Robust structure to withstand rubber curing, retreading, vehicle running/stopping




*RFID Tag Chip*
- Receiving sensor input from multiple sensors
- Processing of sensor data
- Memory to store data
- Energy harvesting circuitry

*Sensors*
- Reliable sensing of different tire phenomena
- Reliable algorithms to interpret sensor data
- Robust structure and mounting to withstand operating conditions


Project Leader: Marcelo Dapino (dapino.1@osu.edu) and Leon Headings (headings.4@osu.edu)



Project initiated by Bridgestone

# Project # 45: Morphing Panels for Aerodynamic Performance

THE OHIO STATE UNIVERSITY

## Problem Statement

- Objective: Investigate morphing panels for improved aerodynamic performance at high vehicle speeds (150+ mph)
- Methodology:
  - Identify vehicle body shapes for aerodynamic drag reduction and examine smart material technologies to create appropriate shape changes
  - Propose shape morphing body concepts to reduce overall aerodynamic drag
  - Develop models and laboratory demonstrations to test the selected approaches and provide a basis for future development

## Background

- There is growing interest in the use of morphing materials in both land and air vehicle applications to enhance aerodynamic performance
- Morphing vehicle structures must be lightweight and durable over a wide range of operating conditions
- Morphing panels can be used to improve aerodynamic performance by reducing drag and generating downforce at high speeds
- A variety of smart materials, composites, and devices can be used to create morphing structures for different applications

## Actuator Technologies and Morphing Panel Concepts

- Actuator technologies
  - Short-term: Torsional SMAs
    Objective: Develop welding methods for joining NiTi alloys to common structural materials and enhance thermal dynamic response
  - Mid-term: Electro-hydraulic actuators driven by smart materials
    Objective: Develop lightweight and small scale electro-hydraulic actuators driven by smart materials such as magnetostrictive or piezoelectric materials in order to actuate UAM panels
  - Long-term: Shape memory polymer composites
    Objective: Develop morphing shape memory polymer (SMP) composites with shape fixity and shape recovery
- Morphing panel concepts
  - UAM panels and hinges
    Objective: Develop morphing panels and hinges by joining dissimilar materials, smart materials, polymers, or electronics
  - UAM origami structure
    Objective: Develop morphing structure by joining multiple UAM panels with integral smart hinges

## UAM Active Hinge with SMA Ribbons

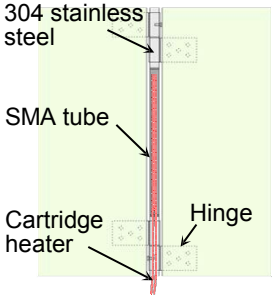
- UAM active hinge concept using SMA ribbons
  - SMAs embedded in Al matrix are trained in a 180 degree folded shape for shape memory effect by heating shape set temperature of around 500 ºC for 25 min and quenching in cold water

  - By applying electrical current through the two Al plates, SMAs actuate to fold the plate when heated above the transformation temperature
- 2.25"x4.5" active hinge panels with nine embedded SMA ribbons

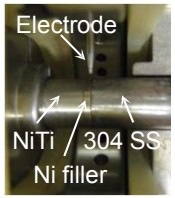
The panels are activated by ~23 A drawn from the battery. If the SMA wires are electrically isolated and connected in series, activation current will be reduced to less than 1 A.

## Active Hinge with SMA Torque Tube

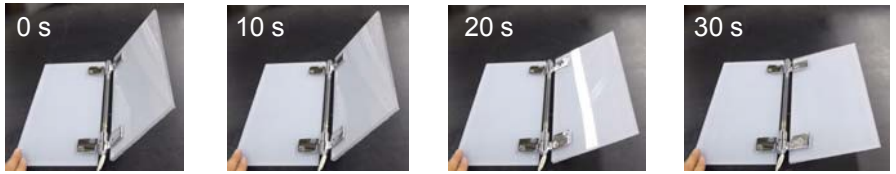
- Shape memory alloy torque tube hinge concept




Both ends of 6" SMA tube are welded to 2.5" 304 stainless steel (with Ni filler) by orbital TIG welding




Applied 222 in-lb torque
(Critical finish torque of TIG weld: 201 in-lb)




Thermal dynamic response can be enhanced by using a cartridge heater with larger diameter and filling the tube with a highly conductive material


Project Leader: Marcelo Dapino (dapino.1@osu.edu)

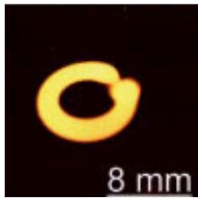
Project initiated by Toyota Technical Center

# Project # 46: Mechanoluminescent Paintable Light Sources for Automotive Applications

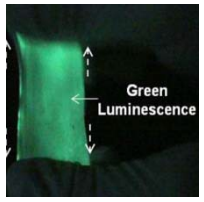
THE OHIO STATE UNIVERSITY

## Motivation

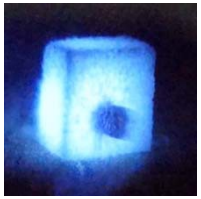
- Need for a paint-on light source that can be used for aesthetic purposes in automotive applications
- Paint-on light to be coated on outer body surface of automobiles
- Mechanoluminescence (ML) of inorganic phosphors prime candidate




*Yellow light from ZnS:Mn phosphor*
*Appl. Phy. Lett.* 74, 1236 (1999)

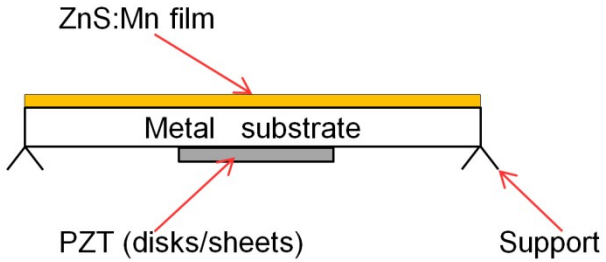



*Green light from ZnS:Cu in PDMS*
*Appl. Phy. Lett. 102, 051110, (2013)*



*Blue light from a sugar cube on collision with bullet*

## Problem Formulation



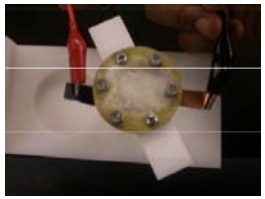

- ML - light emission induced by mechanical action
- ZnS:Mn film - ZnS:Mn particles in a matrix (epoxy binder)
- ZnS:Mn particles-micro and nano-sized particles
- Binder – Transparent, efficient in stress transfer, adhesive

## Methods

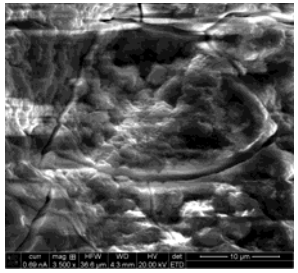
Wet chemical method – ZnS:Mn nanoparticles

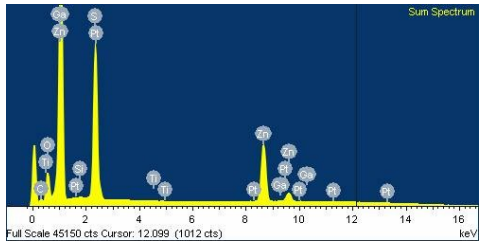
$Zn(C_2H_3O_2)_2 + Na_2S + PVP \rightarrow PVP\text{-}ZnS + NaC_2H_3O_2$

- Easy control over dopant concentration.
- Particles synthesized are in nanoscale.
- Control over particle size achieved
- PVP found to increase PL emission



## Experimental Results






- Chemical composition of ZnS nanocrystals has been confirmed.
- ML has not been observed yet from the nanocrystals
- Micro-particles are to be considered in the future

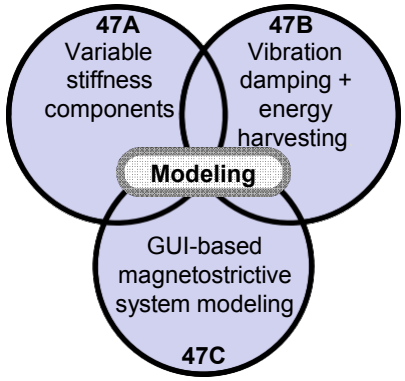

Project Leader: Vishnu Baba Sundaresan (sundaresan.19@osu.edu)

Project initiated by Honda R&D

# Project # 47: Multifunctional Magnetostrictive Systems – Experiments and Computer Simulation

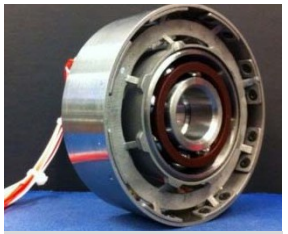
## Project Overview

- Motivation: reduce driveline/gear vibration
- Objective: study magnetostrictive systems in relation to stiffness tuning, vibration damping, and energy harvesting
- Expected Outcomes:
  - Better understanding of multifunctionality
  - User-friendly FE module for 3D simulation




## Background

- NASA is investigating piezoelectric-based solutions
- Available magnetostriction models are for expert users and have computational issues
- Galfenol and Terfenol-D offer the potential for
  - Improved energy harvesting and damping
  - Robust and reliable stiffness tuning


NASA's vibration ring

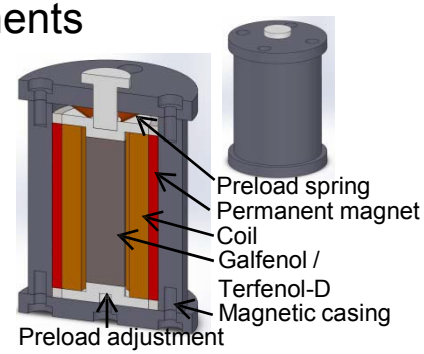
## Plan

Sub-project 47A:

- Model stiffness switching (0 – 1 kHz)
- Design, build, and test magnetostrictive variable-stiffness components
  - Benchmark against NASA's variable spring

Sub-project 47B:

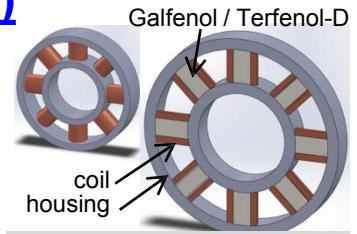
- Model 2D/3D electro-magneto-mechanical behavior of harvester/damper



Variable spring concept

## Plan (cont.)

- Design and build vibration ring and circuitry
- Test prototypes up to 2.8 kHz



Vibration ring concept

Sub-project 47C:

- Improve material model solution procedure and numerical inversion for
  - Elimination of singularities
  - Faster and more robust convergence
- Integrate system models directly into commercial FE software


Project Leader: Marcelo Dapino (dapino.1@osu.edu)

Project initiated by NASA Glenn and Honda R&D

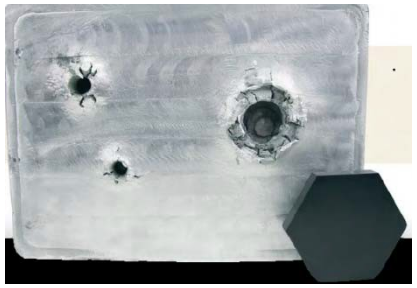
# Project # 48: Stress Field Development During Load Transfer in Functionally Graded Metal Matrix Composite Macro Interfaces

THE OHIO STATE UNIVERSITY

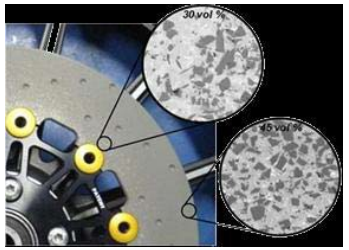
## Technology Summary

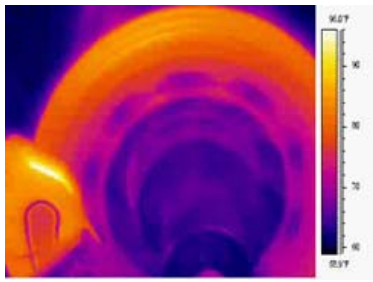
- Metal matrix composites (MMCs) consisting of matrix and reinforcing material
  - Matrix: Al or Mg
  - Reinforcement: $Al_2O_3$, carbon fiber, or SiC
- Functional grading can be manufactured using ceramic preforms and squeeze casting under high force and low velocity
- A need exists for understanding mechanical and thermal properties along the gradient

**Ceramic preforms**



**Armor application**



**Brake rotor application**

## Applications / Benefits

- MMCs can be tailored to achieve low density, high stiffness, improved wear characteristics, and enhanced high-temperature strength

•Functionally graded composites offer tunable properties through selective reinforcement
  - Withstand specified thermomechanical loading conditions in specific areas

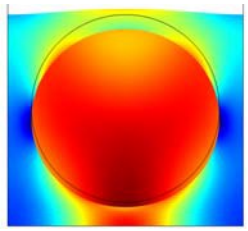
•Applications include brake rotors and armor

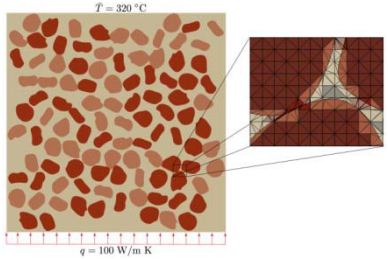
## Approach

- Micro and Macro characterization on coupon specimens to determine microstructure and mechanical properties

•Multi-scale modeling of coupon specimens using RVE approach in Comsol

•Development of structural level model using hierarchical finite element approach





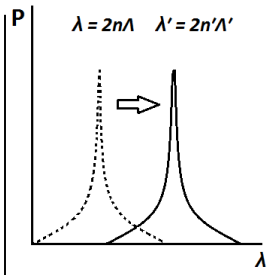

Project Leaders: Marcelo Dapino (dapino.1@osu.edu) and Soheil Soghrati (soghrati.1@osu.edu)
Project initiated by REL Inc.

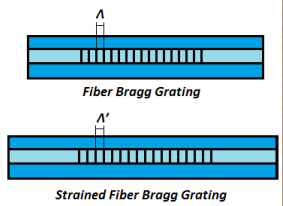
# Project # 49:
# Embedded Fiber Optic Sensors for Structural Health Monitoring

THE OHIO STATE UNIVERSITY

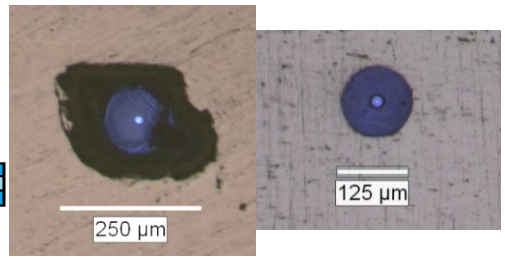
## Technology Summary

- Fiber Bragg Grating (FBG) sensors can be used for real-time strain sensing
- Sensors are needed to monitor internal strains of metallic structures
- Ultrasonic Additive Manufacturing (UAM)
  - ➢ Low temperature process for rapid prototyping of 3D metallic structures
  - ➢ Gapless joining of dissimilar metals
  - ➢ Sensing fibers can be seamlessly embedded into metals (e.g., Al 6061) with UAM

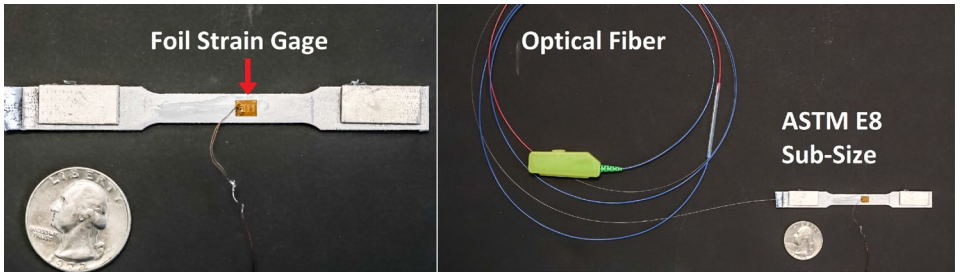



Strain Measurement




Embedded Fiber Optics




Comparative Tensile Testing

## Applications / Benefits

- FBG sensors are small, noninvasive, immune to electromagnetic interference, and can be multiplexed
- •UAM process does not alter FBGs
  - ➢ No thermal loading
  - ➢ No deformation of the glass core
  - ➢ Embedded with commercial coatings
- •In-situ embedded sensing
  - ➢ Smart maintenance
  - ➢ Minimize downtime
  - ➢ Monitoring in harsh environments

## Results

- Process developed for embedding FBGs
- Accurate and repeatable strain tracking from embedded FBGs
  - ➢ Measurements during both tensile and cantilever bending testing
  - ➢ No slip between acrylate coating and matrix
  - ➢ Strain tracking at elevated temperatures
  - ➢ Dynamic response
- Improvements to temperature threshold of sensor coating as a result of embedment

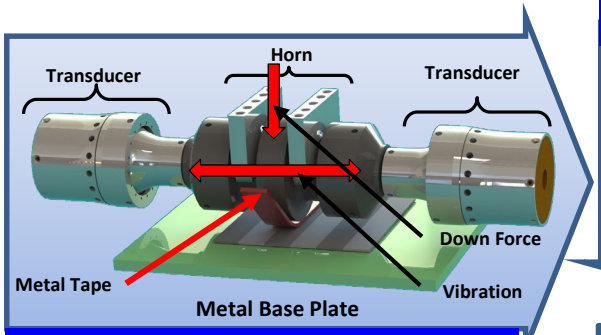

www.SmartVehicleCenter.org

Project Leaders: Marcelo Dapino (dapino.1@osu.edu)
Project Initiated by Moog Inc.

# Project #51:
# Ultrasonic Additive Manufacturing for Automotive Structures

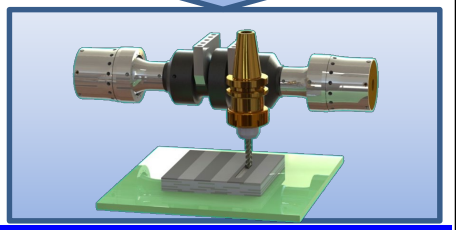
THE OHIO STATE UNIVERSITY

## Ultrasonic Additive Manufacturing:




Ultrasonic welding system with rolling horn welds metal tape to base plate

Successive application of metal tape builds part



Periodic machining shapes part and maintains uniform welding surface

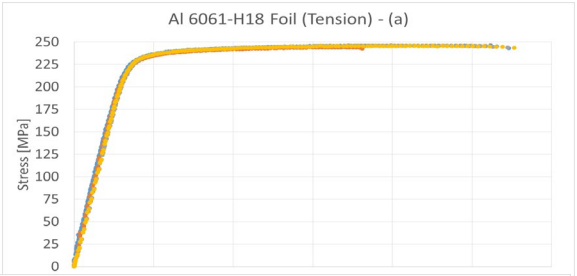
- 3D printing technology based on ultrasonic metal welding
- Low-temperature process
- Dissimilar metal parts and integrated structures

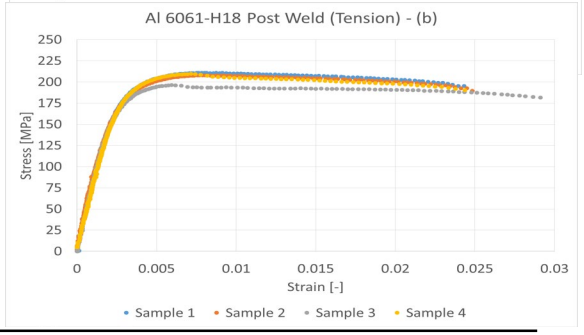
## Purpose:

Enable lightweight vehicle structures via UAM

## Research Objectives:

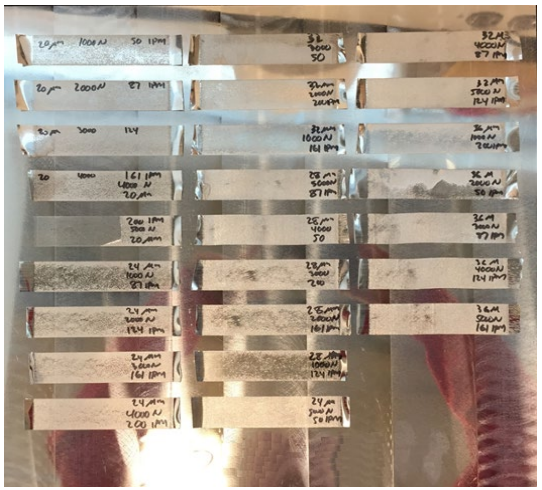
- Understand the cause for the knockoff in x-tensile (in-plane) strength resulting from the UAM process
- Develop weld parameters that can reduce or eliminate the knockoff

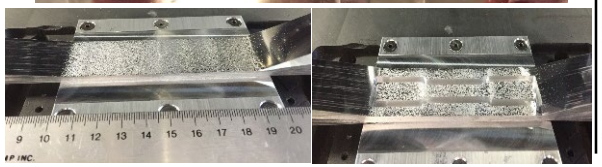



## Methodology:

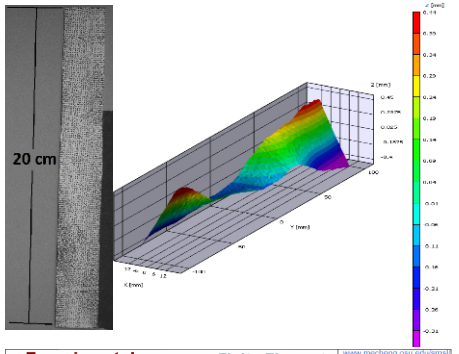
- Investigate process-property relationships through Design of Experiments study
- Prior pilot study focused on feasibility of welds
- DOE study focused on x-tensile testing
- FEA models developed to guide the experiments and assists with data analysis

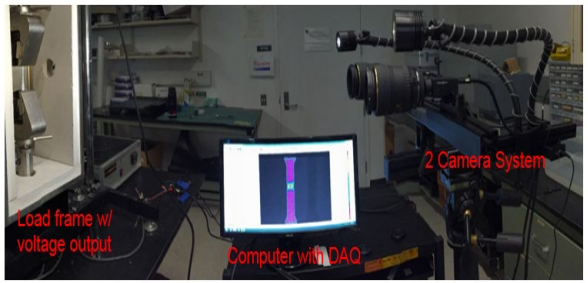




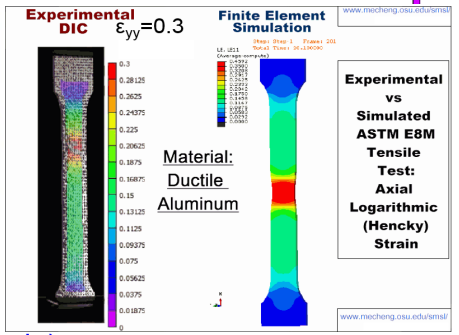
## DIC Testing and Modeling:

- Digital image correlation (DIC) used to measure 2D and 3D strain fields
- Permits local and global measurements




DIC system set up for tensile test.





Project Leaders: Marcelo Dapino (dapino.1@osu.edu) and Leon Headings (headings.4@osu.edu)



Project Initiated by Honda R&D and Battelle Memorial Institute



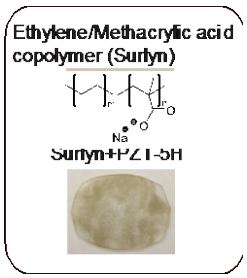
www.SmartVehicleCenter.org

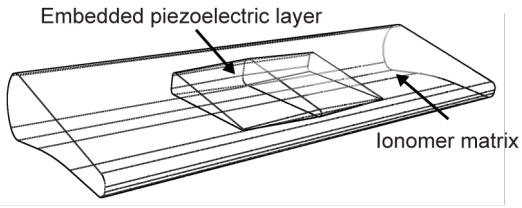
# Project #52: Design of Matrix and Particulates for 3D Printing

THE OHIO STATE UNIVERSITY

## Motivation

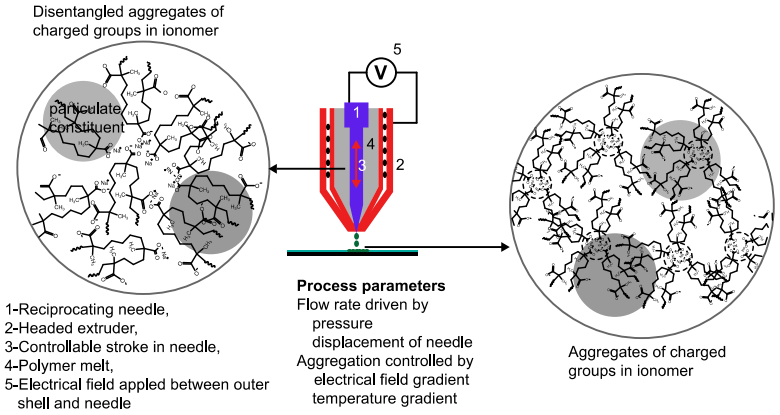
- Thermoelectric processing of polymer composites has been demonstrated by Sundaresan and coworkers as a way to 3D print structural composites
- Develop matrix libraries and particulate additives for thermoelectric processing of piezoelectric polymer composites
- Develop nozzle designs and extrusion modes for 3D printing




## Problem Formulation

- Surlyn (E/MAA) + PZT-5H has been shown to demonstration ionic aggregation of polymer and poling of piezoelectric phases respectively
- New material compositions, nozzle designs and extrusion process parameters for 3D printing will be studied through this project

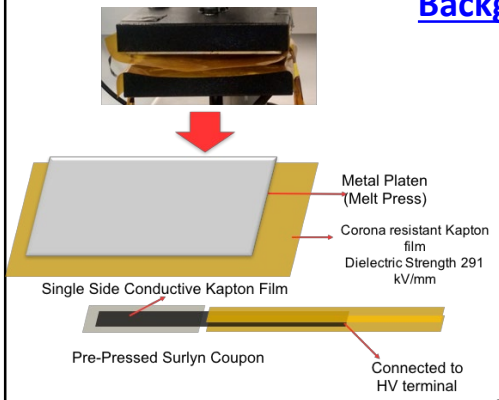


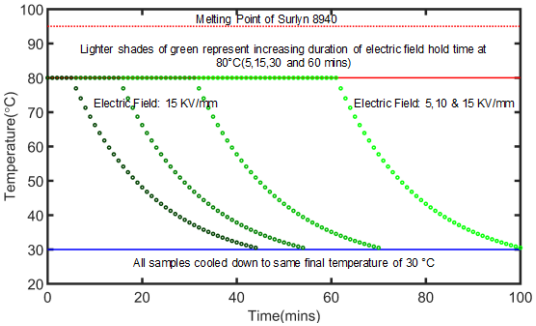

## Methods

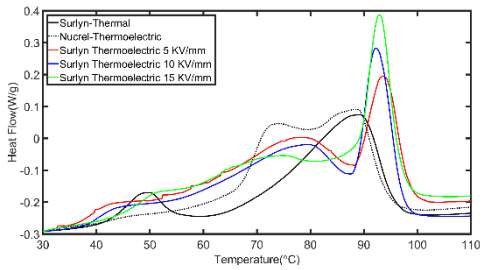
- Multiphysics modeling of thermoelectric extrusion of thermoplastic ionomers and piezoelectric work will be performed
- The model will be used to identify the influence of the following process parameters
  - Extrusion speed
  - Process temperature
  - Soak time
  - Electrical field

  on the following parameters
  - Build strength
  - Layer thickness
  - $d_{33}$ coefficient
  - Interfacial adhesion (piezoelectric and polymer phase)

## Background Work




**DSC shows the effect of thermoelectric processing in E/MAA**
**Narrowing of enthalpy peaks is representative of uniform dispersion of ionic groups, and this construct can be extended to other thermoplastic ionomers**

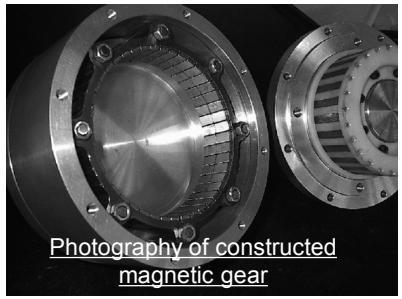

Project Leader: Vishnu Baba Sundaresan (sundaresan.19@osu.edu)
Project initiated by Parker Hannifin

# Project #54:
# Magnetic Additively-Manufactured Structural Hybrid (MASH)

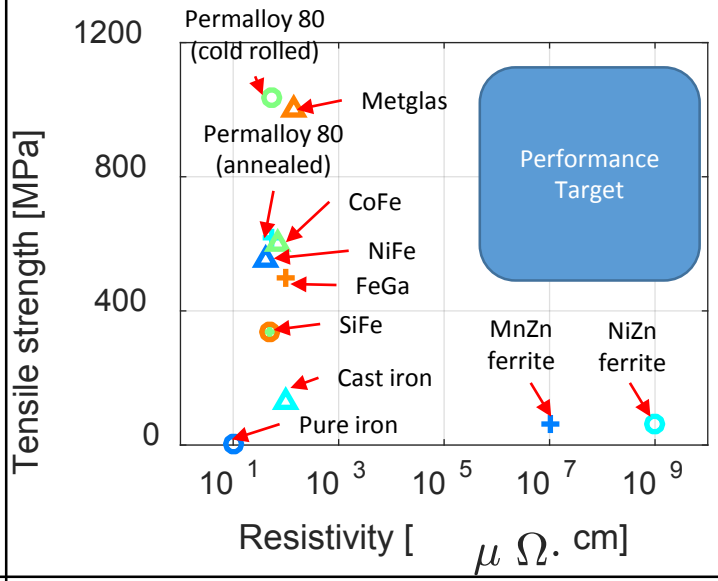
THE OHIO STATE UNIVERSITY

## Magnetic gears - challenges

- Specific torque (torque/mass) is lower than aerospace gearing
  - Structures have conflicting requirements in terms of strength, mass, and magnetic properties
  - Flux lost to the structure reduces torque coupling
- Efficiency is reduced at high speed due to eddy currents in the structures
- Typical laminated metals have limited geometry
- Permeable ceramic (ferrite) is brittle / hard to machine


Photography of constructed magnetic gear

## New magnetic materials are needed…




Features of new magnetic composites:

- Lightweight
- Strong magnetic coupling
- Low eddy current loss
- Robust and reliable
- Easy to manufacture
- Self-contained

## Research plan

**Part A: Investigation of Magnetic Gear Configurations**

Modeling of magnet gears

Requirements of MASH
- Machinability
- High magnetic permeability
- Geometry limitation
- High mechanical strength
- Low eddy current loss

**Part B: Survey of Material Candidates for MASH**

Material candidates I

Characterize stress-dependent magnetic properties

Material candidates II

Fabricate MASH

Material candidates III

Evaluate magnetic and mechanical properties of MASH

Material candidates IV

**Part C: Development of Magnetic Gear**

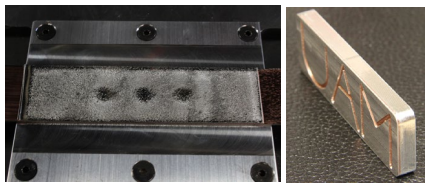
Magnetic gear demonstrator

## Approach – fabrication of MASH

Ultrasonic additive manufacturing or soft magnetic material powder consolidation

- Magnetic materials (high permeability / high resistivity) will be embedded in structural material (high tensile strength)
- Flux paths within the structures will maximize power transfer between rotors without excessive mass

9 kW SonicLayer 4000 Ultrasonic additive manufacturing (UAM) machine


3D printed structure with embedded magnetic features and circuits


Project Leaders: Marcelo Dapino (dapino.1@osu.edu) and Zhangxian Deng (deng.92@osu.edu)


Project Initiated by NASA Glenn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# Project #55: Multiscale Finite Element Simulation of the Mechanical Behavior of Fiberglass Insulation Packs

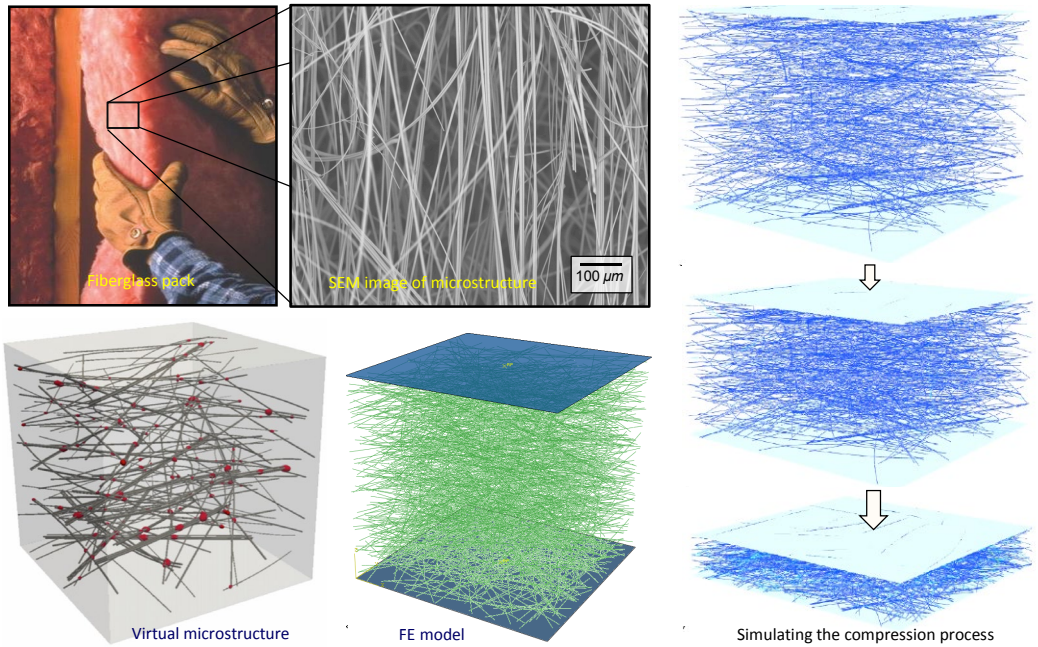
THE OHIO STATE UNIVERSITY

## Background and Objectives

**Objective:** to predict the mechanical behavior of fiberglass insulation packs fabricated by Owens Corning subject to compressive loads.

Fiberglass packs: composed of nonwoven entangled glass fibers and a polymeric binder (total volume fraction: less then 2%)

Due to economic considerations, fiberglass packs are compressed to 10% of their original thickness for efficient shipping and handling




## Approach

Develop a novel descriptor-based reconstruction algorithm to synthesize realistic 3D virtual models of the fiberglass pack.

Create reduced-order finite element (FE) models of fibers and the binder phase to simulate the deformation response

Calibrate with high fidelity FE results and study the impact of boundary conditions, size effects, and the binder on the mechanical behavior

## Applications and Benefits

Novel algorithm for the automated reconstruction of the microstructure and converting that into an appropriate FE model

- Realistic virtual microstructure informed by imaging data

New reduced-order model for simulating the mechanical behavior taking into account all sources of physical and geometrical nonlinearity

- Computationally efficient micromechanical model
- Performing simulations with millions degrees of freedoms


www.SmartVehicleCenter.org

**Project Leader: Soheil Soghrati (OSU)**

**Project Mentor: Andy Davis (Owens Corning)**

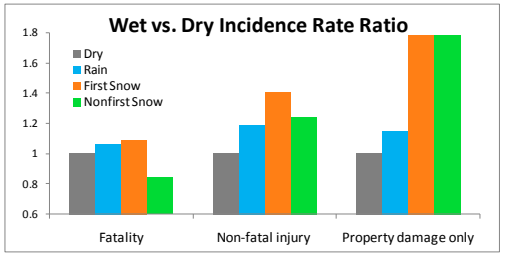
# Project #56: Dynamic Friction Characterization of Icy Road Surfaces for Conventional & Automated Vehicles

THE OHIO STATE UNIVERSITY

## Industry Need, Context, and Relevance

- Weather-related conditions associated with annual*
  - $42 Billion
  - 7000 fatalities & 800,000 injuries
- Improved traction technology may reduce these statistics
- Adaptive/predictive algorithms & reliable sensing needed for emerging autonomous tech

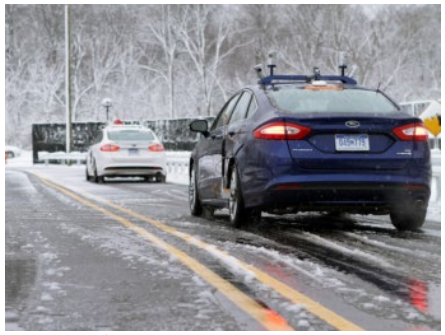
http://www.michiganautolaw.com




- Bridge laboratory and real-world experimental work
- Best practices and test strategies needed
- Broad applications to OEM, suppliers, regulatory agencies, etc.

* D. Eisenberg, K.E. Warner, Effects of snowfalls on motor vehicle collisions, injuries, and fatalities, *American Journal of Public Health* 95(1) (2005) 120-124.

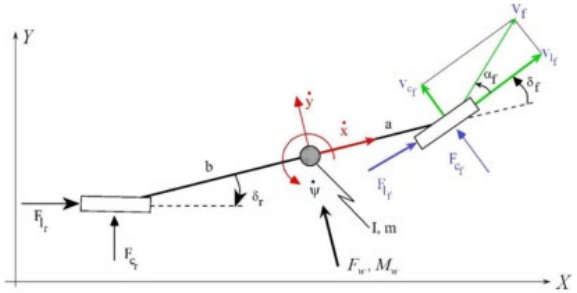
## Broader Impacts – Automated Vehicles



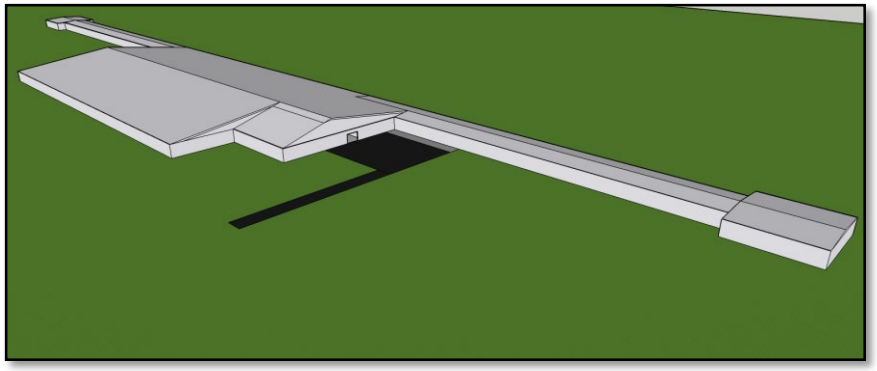
https://media.ford.com

- Emerging autonomous vehicle technology would require more reliable friction models.
- Adaptive or predictive steering algorithms rely on empirical friction models to ensure safe maneuvering
- Extreme conditions may surpass controller's ability to maintain on-road safety
- General lack of literature on autonomous vehicle performance in extreme winter conditions

P. Falcone, et al., Predictive active steering control for autonomous vehicle systems, *IEEE Transactions on Control Systems Technology* 15(3) (2007) 566-580.



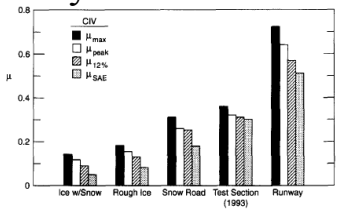

## Selected Experimental Approaches



- Planned Indoor Winter Conditions Facility (IWCF)
- Controlled conditions allowing indoor simulated winter testing
- Laboratory, scaled, and full-scale experiments planned

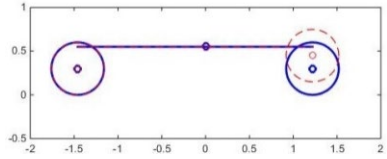
## Modeling Approach

### Dynamic friction

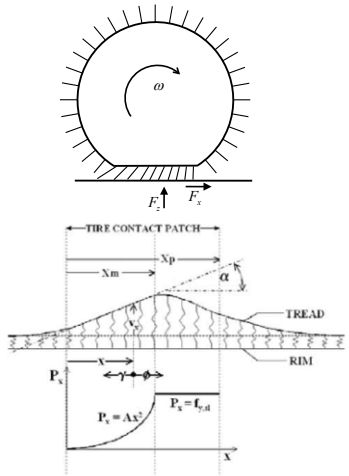



Shoop S, Young B, Alger R, Davis J, Effect of test method on winter traction measurements. *Journal of Terramechanics* 31.3 (1994) 153-161.

### Vehicle Dynamics




### Tires




Lacombe, James. "Tire model for simulations of vehicle motion on high and low friction road surfaces." *Proceedings of the 32nd conference on winter simulation*. Society for Computer Simulation International, 2000.

www.SmartVehicleCenter.org

**Project Leader: R. Singh, L. Fredette (OSU)** **Project Mentor: A. Mathers, R. Burton (TRC)**

# Project # 57:
# Flexible Piezoelectric Sensors for Vehicle Applications

THE OHIO STATE UNIVERSITY

## Problem Statement

The goals of the project are:

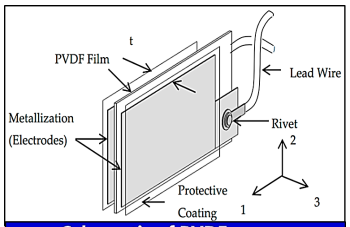
- Measurement of static and dynamic aerodynamic pressure in a representative small-scale vehicle structure
- Measurement of internal pressure in an inflatable structure
- Development of ideas to use flexible piezoelectric materials as advanced vehicle sensors or actuators

## Background

- There is a growing interest to track real time air pressure in order to assess and control the aerodynamic performance of vehicles
- Conventional pressure transducers, besides their high cost, typically cannot be distributed. Due to their fixturing for flush mounting, they produce significant distortion of pressure fluctuations in the dynamic range.

## Features of Flexible Piezoelectric Materials

- Flexible piezoelectric sensors are lightweight, non-invasive, and inexpensive; hence they are suitable for measurement of quasi-static and dynamic pressure measurements on the order of several kHz.
- A piezoelectric material of primary interest is polyvinylidene fluoride (PVDF), which is 10x more sensitive to stress inputs and 40x more compliant than conventional pressure and PZT transducers
- The primary focus will be on expanding the frequency range of pressure measurement into static regimes




**Schematic of PVDF sensor**
(source: www.measspec.com)

**(a) Standard wind tunnel test vs (b) PVDF films on a scaled aircraft model**

## Significance

### Research Gaps

- Direct measurement of static signals
- Development of compensators to mitigate environmental effects, such as temperature and electromagnetic interference
- Understanding of mechanical and sensing performance in harsh environments

### Opportunities

- Design concepts like electrode patterning to tailor sensitivity and minimize signal processing requirements
- Integration into micro-systems and wireless technologies
- Investigation of new fabrication processes like 3D printing, film forming and electrospinning

## Research Plan

### Task A: Literature Survey

- Survey the literature on smart sensors for pressure measurement, PVDF and related technologies. Survey and compare different methods to measure air pressure during wind tunnel testing.
- Address key research questions in terms of ability of PVDF to measure static pressure and its sensitivity to environmental effects.

### Task B: Sensor Modeling and Design

- Characterize PVDF, effect of shape, material, thickness etc. Develop multiphysics models of PVDF sensing systems to guide and supplement the characterization effort.
- Investigate new manufacturing and processing techniques. Characterize and analyze process-property relationships.

### Task C: Experimental Validation

- Benchmark PVDF for pressure measurement against a commercial pressure sensor
- Develop and demonstrate a method to measure static pressure. Demonstrate use in a small scale wind tunnel setup to measure static pressure.
- Demonstrate internal pressure measurement in an inflatable structure


Project Leader: Marcelo Dapino (dapino.1@osu.edu) and Leon Headings (headings.4@osu.edu)


Project Initiated by Toyota Technical Center

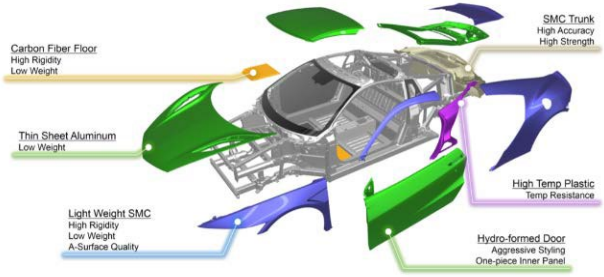
www.SmartVehicleCenter.org

# SVC Project #58: Architecture for Mechanoluminescent Structural Sensors and Sensing Platforms

THE OHIO STATE UNIVERSITY

## Industry Need, Context and Relevance

**Address challenges in health monitoring of multi-material components made of carbon fiber reinforced plastics(CFRP) in automotive and structural components**



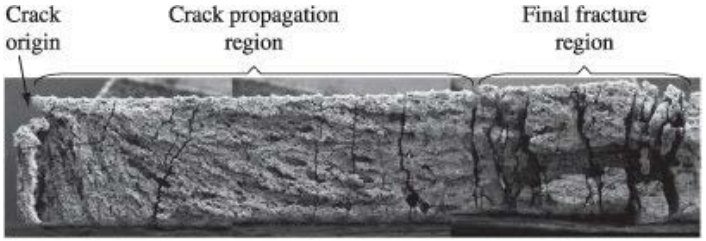

http://news.honda.com/newsandviews/article.aspx?id=8900-en

https://www.compositesworld.com/

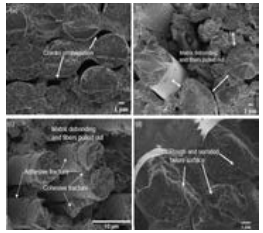
## Project Goals and Objectives

**Develop experimental techniques to report on:**

- **Distribution of internal Stress in the matrix and around the fibers**
- **Detecting the onset of damage**
- **Crack Propagation**
- **Extent of failure that will lead to abrupt structural damage**

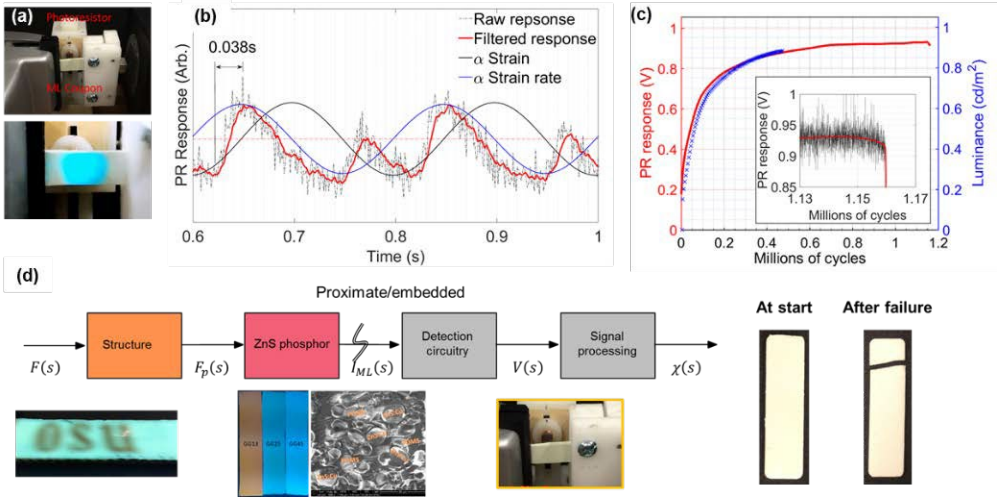



Srinivasa, Vinod, et al. "Fracture morphology of carbon fiber reinforced plastic composite laminates." *Materials Research* 13.3 (2010): 417-424.



Hernandez, Dany Arnoldo, Carlos Alberto Soufen, and Marcelo Ornaghi Orlandi. "Carbon Fiber Reinforced Polymer and Epoxy Adhesive Tensile Test Failure Analysis Using Scanning Electron Microscopy." *Materials Research* 20.4 (2017): 951-961.

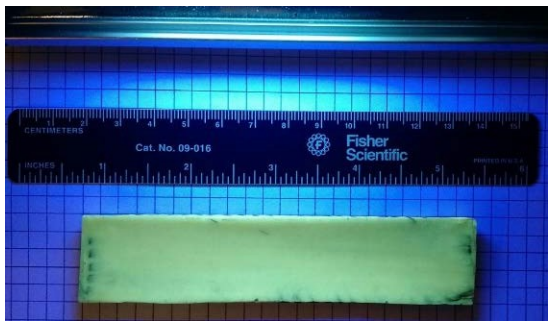
## Approach (Research Methods)




## Preliminary Results

**Vacuum Assisted Resin Transfer Molding(VARTM) is performed to fabricate carbon fiber composites with mechanoluminescent particles dispersed in the matrix**

**Lab Scale VARTM at OSU**




**Cured Composite under UV light**

www.SmartVehicleCenter.org

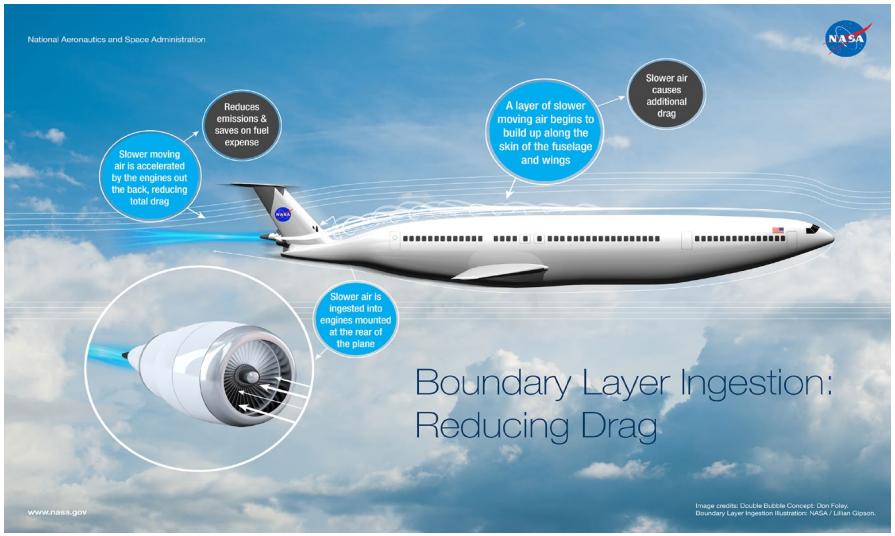
**Project Leader: Prof. Vishnu Baba Sundaresan (OSU) Project Mentor: Duane Detwiler, Allen Sheldon (HRA), Dr. Sandi Miller, Dr. Gary Roberts (NASA GRC)**

# SVC Seed Grant: Aeromechanic Analysis and Optimization of Boundary Layer Ingestion Turbomachinery

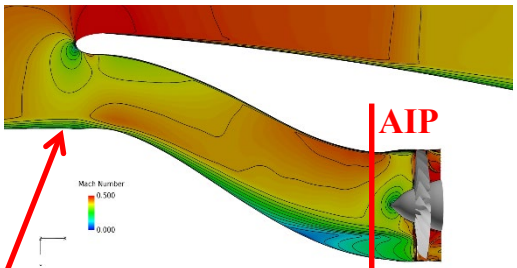
THE OHIO STATE UNIVERSITY

## Motivation

- NASA subsonic transport system metrics: Fuel Burn Reduction N+1 (2015) 33%, N+2 (2020) 50%, N+3 (2025+) 70%
- 3-5% fuel reduction by ingesting boundary layer (BL) flow
- Non-uniform BL ingestion and inlet geometry create flow distortions that negatively impact engine performance and structural integrity
- A need to study inlet/fan interaction through CFD simulation to understand fan response to inlet distortion to mitigate aero and aeroelastic challenges

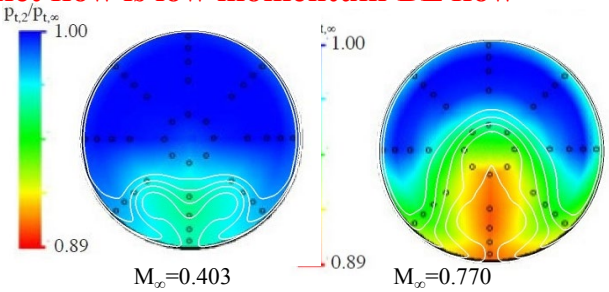



**Accurate computational simulation coupled with inlet and blade optimization is necessary to bring this technology to production level**

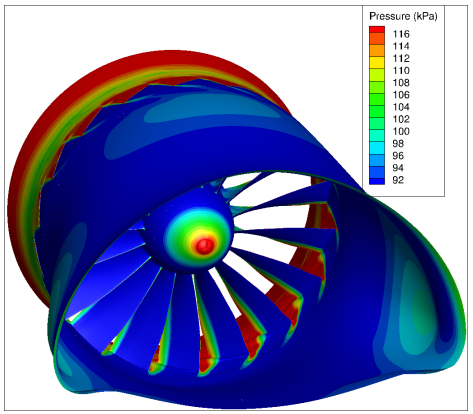


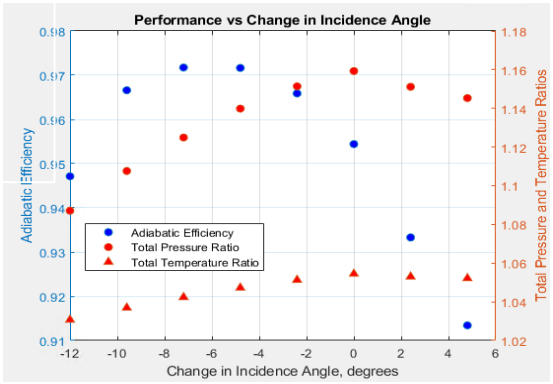

**25% to 30% of inlet flow is low momentum BL flow**

**Total pressure distortion upstream of compressor**




- Highly 3D swirling flow enters the inlet and interacts with the fan
- The fan experiences large changes in Angle of Attack




- Optimizing the geometry of the blade allows for increased overall performance and longer life for the blade


**Project Leader: Jen-Ping Chen (chen.1210@osu.edu)**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# SVC Seed Grant: Solution Processing of Thermochromic Vanadium Dioxide Smart Windows

THE OHIO STATE UNIVERSITY

## Industry Need, Context, Relevance

- Need to efficiently regulate temperature of internal environments with smart windows
- Impact on energy efficiency can be up to 42%[1] of total energy consumption for residential cooling and heating
- Need rapid synthesis methods to reduce processing time
- Need control over optical transmittance for smart windows applications

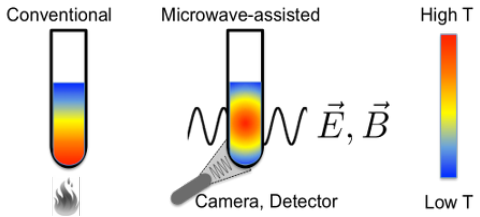
[1] S. Selkowitz 2010

## Project Objectives

- Reduce typical synthesis of bulk materials from *days* to *minutes*
- Develop solution-processable low-temperature method for coating procedure

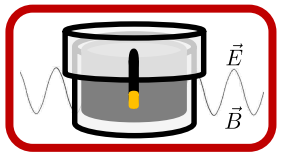
## Research Plan

- Control microwave-assisted heating conditions to achieve phase purity of targeted materials

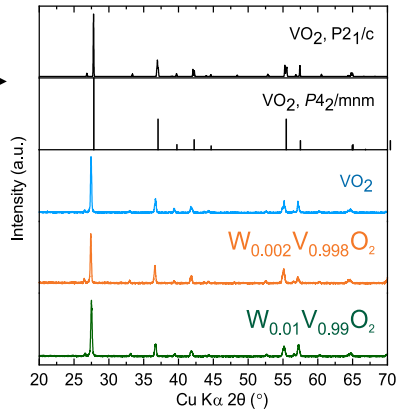



- Characterize phase purity of products and transition temperature
- Translate microwave-assisted heating conditions to solution-phase synthetic methods to control nanostructured morphology

## Preliminary Results/Applications




Achieved phase purity




Preliminary results show phase purity of bulk smart materials. Next steps include film deposition and controlling opacity.

$A_xV_{1-x}O_2$

Vary x to control transition temperature

Project Leader: Vicky Doan-Nguyen (doan-nguyen.1@osu.edu)

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# SVC Seed Grant: Integrated hyperdamping material systems for vibration, noise, and shock attenuation

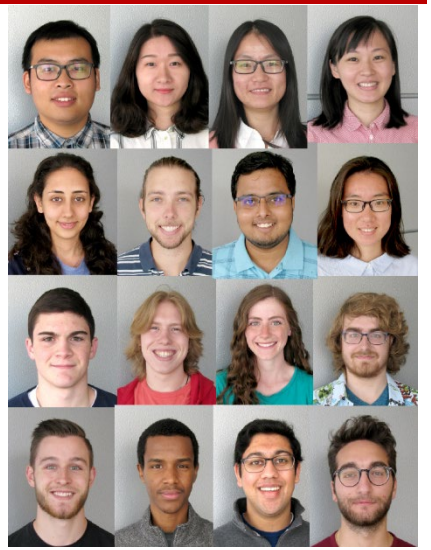
THE OHIO STATE UNIVERSITY

**LSVR**:
Advancing basic and applied science in vibrations, acoustics, mechanics, and smart materials.

**Director**:
Prof. Ryan L. Harne

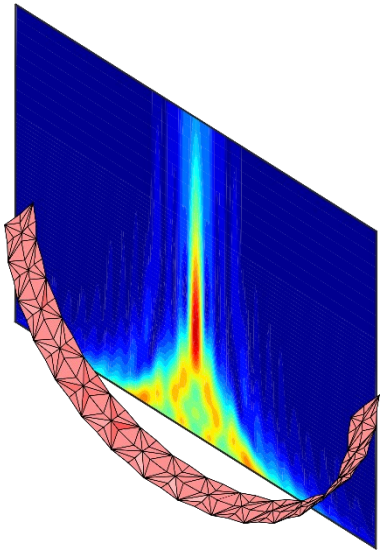
*Thanks to our many industry, federal, and defense sponsors!*

**Research Student Team**



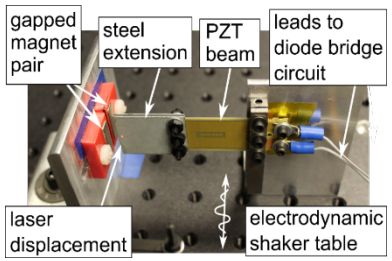
*Origami-Inspired, Foldable Acoustic Arrays for Deployable Medical Ultrasound Devices*:

Acoustics, wave physics, mechanics, design



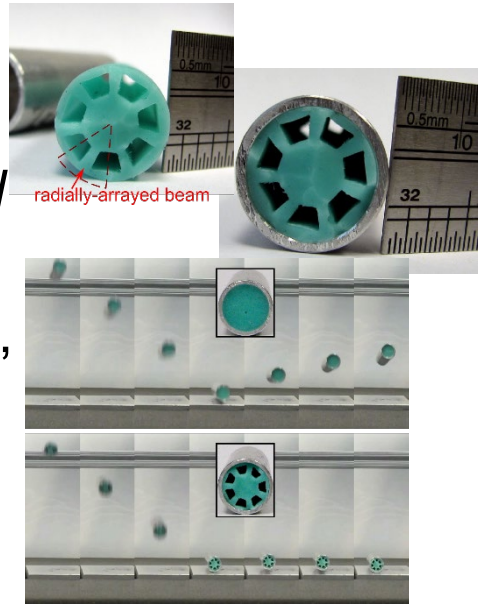
*Understanding, Predicting Response of Multistable Structures Operating in Extreme Environments*:

Analytical dynamics, energy harvesting, hypersonic multiphysics




*Lightweight Material Systems to Control Shock, Vibration, and Sound*:

Structural mechanics, materials science, design and manufacturing




Project Leader: Ryan Harne (harne.1@osu.edu)

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# SVC Seed Grant: 'Seeing' the temperature inside a 3D printed part

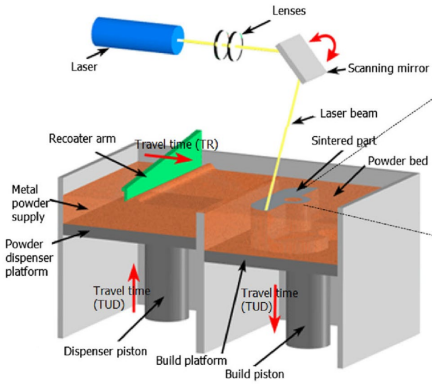
THE OHIO STATE UNIVERSITY

## Background and Objectives

- Metal Powder Bed Fusion (PBF) is an additive manufacturing (AM) process that fabricates 3D parts from powdered metal feedstock
- Emerging manufacturing process for low-volume, high value-added parts and tooling
- There remain significant thermal management problems that reduce part quality and yield

**Objective: Develop a state estimator framework to estimate unmeasurable temperature states inside a part that is being built.**

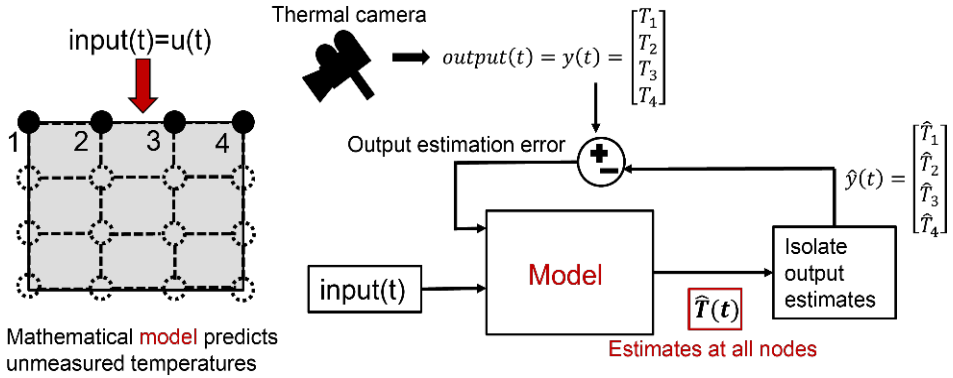
## Metal PBF Process




(Verna, et al., *Int. J. Adv. Manuf. Tech.*, 2015)

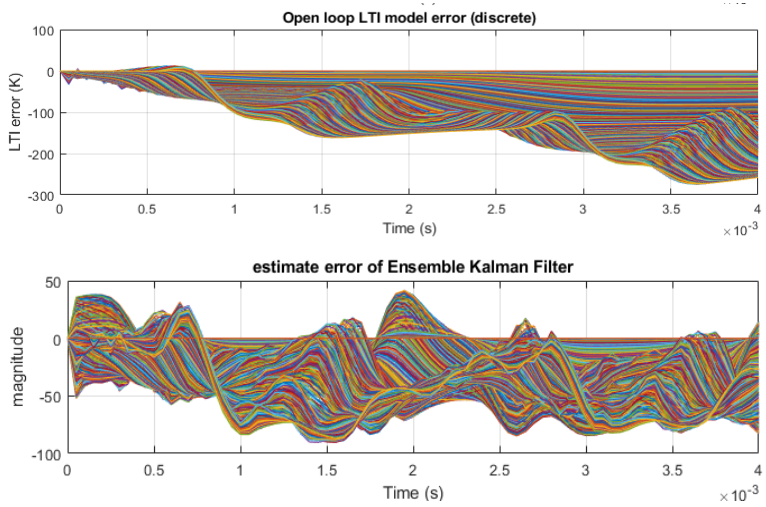
Inputs: Laser energy at coordinate (*x*,*y*) and boundary conditions
System: Complex geometry thermal domain dominated by conduction
Output: Temperature field on the top surface

## Methods




Merge experimental data with process model: provides internal temperature states and estimate covariance statistics: Extended Kalman Filter

## Simulation Results




Estimates diverge for standard computational models

Estimates remain bounded using an extended Kalman filter


Project Leader: David Hoelzle (hoelzle.1@osu.edu)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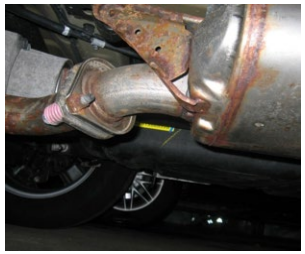
# NSF REU Project: Investigation of Metal Corrosion by In-situ Electrochemical Force Microscopy

THE OHIO STATE UNIVERSITY

## Motivation

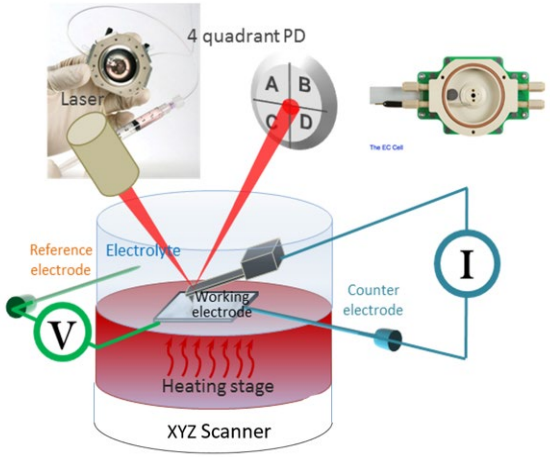
- Corrosion is a serious problem significantly affecting the lifetime of vehicles and thus automobile industry. For example, Toyota Motor Corporation has agreed to pay up to about $3.4 billion in 2016 to settle claims that certain of its trucks and sport-utility vehicles lacked proper rust protection, leading to premature corrosion of vehicle frames [1].



***Rust in 2011 Toyota RAV 4 in muffler (carcomplaints.com)***

- To date, the macro-scale electrochemical measurements have reveals the effect of electrochemical potentials, temperatures, solution conditions, timescales, and other factors on the global corrosion process for various metallic materials, while the local properties and conditions are trivialized.

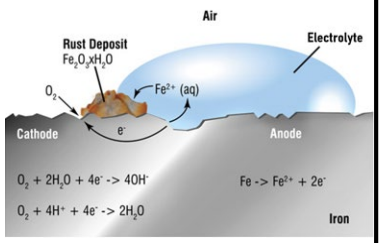
## In-Situ Electrochemical Force Microscopy



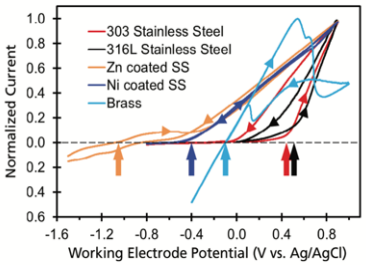

- ✓ Nanoscale characterization
- ✓ In-situ measurement:
  - In liquid; In electrolytes
  - Temperature control
  - Electrical input/output
- ✓ Measuring the potential dependence of corrosion current
- ✓ Local electrochemical behavior

## Background and Objective

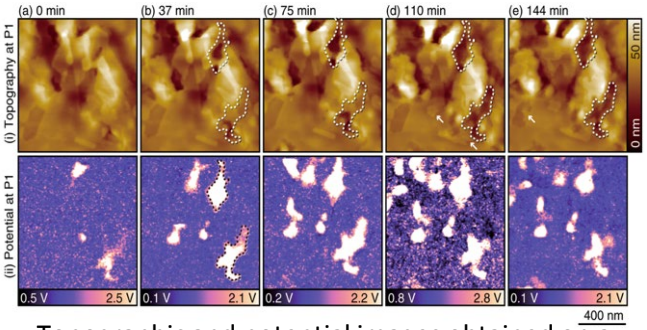
- Localized corrosion accounts for 70 percent of material failures, and these failures are catalyzed by varying particular abnormalities affecting the metallic surface [2].
- Water (electrolyte) comes in contact with the surface of metal, while in the presence of air. With these three parts in contact, the metal becomes polarized and electrons flow through the metal, ultimately creating a mas build up of iron oxide, commonly known as rust.
- Nanoscale corrosion studies depend on the ability to mimic the real-world conditions that promote corrosion in a shorter time scale.
- By leveraging the PI's expertise in AFM, we aim to investigate the corrosion process of various metallic alloys frequently used in automobile production by employing the state-of-the-art in-situ Electrochemical Force Microscopy (EFM) based on Atomic Force Microscopy (AFM).




## Typical Data




Cyclic voltammograms of various metallic samples [3]




Topographic and potential images obtained on a stainless steel sample in a 10 mM NaCl solution via Electric Potential Microscopy [4]


[1] https://www.wsj.com/articles/toyota-in-3-4-billion-settlement-over-corrosion-in-some-trucks-and-suvs-1478972740

[2] http://www.npl.co.uk/upload/pdf/beginners_guide_to_corrosion.pdf

[3] https://www.oxford-instruments.com

[4] Honbo, K., Ogata, S., Kitagawa, T., Okamoto, T., Kobayashi, N., Sugimoto, I., Shima, S., Fukunaga, A., Takatoh, C., and Fukuma, T., Visualizing Nanoscale Distribution of Corrosion Cells by Open-Loop Electric Potential Microscopy, ACS Nano 10 (2), 2575-2583 (2016).



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