# Smart Vehicle Concepts Center (SVC) Projects

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

### Smart Vehicle Concepts (SVC)

**Center Director:**
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Department of Mechanical and Aerospace Engineering  
The Ohio State University

[www.SmartVehicleCenter.org](http://www.SmartVehicleCenter.org)  
[https://svc.osu.edu](https://svc.osu.edu)

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### SVC Companies

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Axle and Manufacturing</td>
<td>Former Member</td>
</tr>
<tr>
<td>Advanced Numerical Solutions</td>
<td>Former Member</td>
</tr>
<tr>
<td>Army Research Laboratory</td>
<td>Former Member</td>
</tr>
<tr>
<td>Autoliv</td>
<td>Current Member</td>
</tr>
<tr>
<td>Battelle Memorial Institute***</td>
<td>Current Member</td>
</tr>
<tr>
<td>BorgWarner</td>
<td>Former Affiliate</td>
</tr>
<tr>
<td>Bridgestone Americas Tire Operations, LLC</td>
<td>Former Member</td>
</tr>
<tr>
<td>Eaton Innovation Center</td>
<td>Former Member</td>
</tr>
<tr>
<td>Edison Welding Institute</td>
<td>Former Member</td>
</tr>
<tr>
<td>Ford Motor Company</td>
<td>Former Member</td>
</tr>
<tr>
<td>F.tech R&amp;D *</td>
<td>Former Member</td>
</tr>
<tr>
<td>Goodyear Tire &amp; Rubber</td>
<td>Former Member</td>
</tr>
<tr>
<td>Honda R&amp;D Americas Inc. *</td>
<td>Current Member</td>
</tr>
<tr>
<td>Hyundai-Kia Motors *</td>
<td>Former Member</td>
</tr>
<tr>
<td>LMS Software</td>
<td>Invited Observer</td>
</tr>
<tr>
<td>MES, Inc.</td>
<td>Invited Observer</td>
</tr>
<tr>
<td>MIT Lincoln Laboratory</td>
<td>Former Member</td>
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<tr>
<td>Moog Inc.***</td>
<td>Current Member</td>
</tr>
<tr>
<td>MSC Software</td>
<td>Invited Observer</td>
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<tr>
<td>NASA Glenn Research Center **</td>
<td>Current Member</td>
</tr>
<tr>
<td>Owens Corning</td>
<td>Former Member</td>
</tr>
<tr>
<td>Parker Hannifin</td>
<td>Former Member</td>
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<tr>
<td>REL, Inc.</td>
<td>Former Member</td>
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<td>Romax</td>
<td>Invited Observer</td>
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<td>Solidica</td>
<td>Former Member</td>
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<td>Tenneco, Inc.</td>
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<tr>
<td>The Boeing Corporation</td>
<td>Former Member</td>
</tr>
<tr>
<td>Tokai Rubber</td>
<td>Former Member</td>
</tr>
<tr>
<td>Toyota Research Institute, Inc. *</td>
<td>Current Member</td>
</tr>
<tr>
<td>Transportation Research Center, Inc. *</td>
<td>Former Member</td>
</tr>
<tr>
<td>YUSA</td>
<td>Former Affiliate</td>
</tr>
</tbody>
</table>

*Multiple memberships  **Member and Invited Observer  ***Pending

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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 on smart materials and structures applied to ground and aerospace vehicles
• Build an unmatched base of research, engineering education, and technology transfer with emphasis on improved vehicle performance
• Prepare next-generation engineers who possess both theoretical and experimental expertise applicable to auto and aero vehicles

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

The Ohio State University
The Ohio State University

Membership Fee Structure
$40K/year – Full membership (one vote per full membership; access to all Center projects)
$14K/year – Affiliate (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

<table>
<thead>
<tr>
<th>Center Year</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021-22</th>
</tr>
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<tbody>
<tr>
<td>Membership Fee (a)</td>
<td>$40K</td>
<td>$40K</td>
<td>$40K</td>
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<tr>
<td>Project Fee (b)</td>
<td>$12K</td>
<td>$14K</td>
<td>$16K</td>
<td>$18K</td>
<td>$20K</td>
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<tr>
<td>Admin Fee (c)</td>
<td>$5.2K</td>
<td>$5.4K</td>
<td>$5.6K</td>
<td>$5.8K</td>
<td>$6K</td>
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<tr>
<td>Cost of Solo Membership (a + b + c)</td>
<td>$57.2K</td>
<td>$59.4K</td>
<td>$61.6K</td>
<td>$63.8K</td>
<td>$66K</td>
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For further details: https://svc.osu.edu/membership
**New Research Matrix for Phase III**

<table>
<thead>
<tr>
<th>Thrust</th>
<th>Interfacial Mechanisms</th>
<th>Safety, Comfort, and Health Monitoring</th>
<th>Adaptive Noise, Vibration, and Harshness (NVH)</th>
<th>Emerging Vehicle Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Characterization, constitutive modeling, system integration (sensors, actuators, dynamic simulation)</td>
<td>Machine and material diagnostics, human-machine interface, strain energy management</td>
<td>Active noise and vibration control, adaptive structures, system integration</td>
<td>Vehicle electrification, autonomous vehicles, lightweighting</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PAST Relevant Projects</th>
<th>40A, 40E, 40F, 55</th>
<th>46, 58, 58A, 58B</th>
<th>45, 52, 57, 57B</th>
<th>51A, 54B, 56</th>
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<tbody>
<tr>
<td>CURRENT Relevant Projects</td>
<td>60</td>
<td>49, 63</td>
<td>57C</td>
<td>51B, 51C, 51D, 51E, 54, 61, 61B*, 62, 64*</td>
</tr>
</tbody>
</table>

Typical Sponsors
- Ford, Honda D&M, NASA Glenn, Owens Corning, Tenneco, Toyota, TRC
- Autoliv, Bridgestone, Honda D&M, Moog
- CVG, Honda D&M, NASA Glenn, Toyota, Parker Hannifin, Tenneco, TRC
- Battelle, Honda D&M, NASA Glenn, Toyota, TRC

*new project
### 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

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**Project leader:** Marcelo Dapino (dapino.1@osu.edu)
**Project Initiated by Moog Inc.**
Motivation:
- Powertrain mounts affect the dynamic noise and vibration behavior of a vehicle.
- Motion control and vibration isolation can be better obtained via smart mounting systems.
- Improvements in torque roll axis decoupling of powertrains are possible with passive and active mounts.

Problem Formulation:
1. Model and characterize passive and smart mounts in the context of vehicle systems.
2. Develop new dynamic design tools for mounting system.
3. Specify components based on desired vehicle responses.

Methods:
- Develop multi-physics, multi-domain mathematical models for passive and smart mounts/mounting systems:
  - **Nonlinear modeling of mounts**
    - Passive/adaptive/active mounts
    - Comparative evaluation studies
    - Mount characterization
  - **Vehicle system studies**
    - Quarter/half/full vehicle models
    - Modal analyses
    - Forced response studies
  - **Powertrain system analyses**
    - 3 or 4 mounts (with 1 or more smart)
    - Torque roll axis (TRA) decoupling methods
    - Transient analysis

Recent Results:
- Hydraulic engine mount with multiple inertia tracks
  - Quasi-linear modeling (nonlinear damping)
  - Broadband mount response achieved
- Electro-magnetic active mount
  - Actuator dynamics
  - Evaluated using half vehicle model
- Improve methods for torque roll axis decoupling

Project Leader: Raj Singh <singh.3@osu.edu>
Project Initiated by: Transportation Research Center (TRC)
**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.

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

**Project Initiated by:** Eaton Corporation
Motivation:
Smart Materials and Elastomers have significantly variable properties and are highly non-linear.

In order to determine the best material for the application, key properties must be highlighted in the same context and tools must be developed to determine the best material for a given performance envelope.

Project Goals:
- Extensive literature survey
- Compilation of the data into an easy to use format
- Development of a GUI based tool to utilize the data
- Development of design tools based on the GUI format
- Materials Testing and verification

Example for SMA Application:
Metal reinforcing strap
“Metal straps are made of a shape-memory material which can be a metal alloy such as NiTi, NiTiX (where X is Fe, Cu, or Nb),...” [US patent No.: US 6,401,779 B1]

- temperature value $A_f$: about 40 °C ~ 90 °C
- temperature value $A_s$: about 60 °C ~ 120 °C
- value of maximum stress at temperature $A_s$: 400 ~ 600 MPa

Design Considerations:
- Materials have a number of applications that range the space of
  - Force
  - Stroke
  - Bandwidth
  - Size
  - Weight
- Must consider
  - Hysteresis
  - Creep
  - Non linear stress-strain phenomena
  - The “illities”

Project Leader: Greg Washington, Project Initiated by: Goodyear
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

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

Typical Data

Composite mode identification

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (Hz)</th>
<th>Percent Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 (1$^{st}$ Bending)</td>
<td>948.22</td>
<td>------</td>
</tr>
<tr>
<td>Mode 2 (1$^{st}$ Torsion)</td>
<td>2456.3</td>
<td>0.32</td>
</tr>
<tr>
<td>Mode 3 (2$^{nd}$ Bending)</td>
<td>5166.4</td>
<td>0.12</td>
</tr>
<tr>
<td>Mode 4 (2$^{nd}$ Torsion)</td>
<td>7515.6</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias Field at 0 Stress (kA/m)</th>
<th>Frequency (Hz)</th>
<th>Percent Difference (%)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>948.44</td>
<td>0.08</td>
</tr>
<tr>
<td>1.13</td>
<td>2448.4</td>
<td>0.32</td>
</tr>
<tr>
<td>4.51</td>
<td>2451.6</td>
<td>0.19</td>
</tr>
<tr>
<td>8.95</td>
<td>2441.4</td>
<td>0.61</td>
</tr>
<tr>
<td>13.5</td>
<td>2434.4</td>
<td>0.90</td>
</tr>
<tr>
<td>17.6</td>
<td>2422.7</td>
<td>1.38</td>
</tr>
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</table>

In-depth data processing

<table>
<thead>
<tr>
<th>Mode 3 (2$^{nd}$ Bending)</th>
<th>Frequency (Hz)</th>
<th>Percent Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 4 (2$^{nd}$ Torsion)</td>
<td>5108.6</td>
<td>1.13</td>
</tr>
<tr>
<td>7463.3</td>
<td>0.70</td>
<td></td>
</tr>
</tbody>
</table>

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
**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

**Literature Review**

- **Superposition effect**
  - Severdenko et al. 1974
  - Stewart & Utter 2001
  - Siddiq & Ghassemieh 2012
  - Siddiq and Ghassemieh (2008)
- **Swaging effect**
  - Hayashi et al. and Hong et al. (2008)
- **Metallurgical properties**
  - Hong et al. 2007
  - Siddiq and Ghassemieh (2008)
- **Change of friction coefficient**
  - Dinwiddi et al. 1977
- **Reverting friction vector**

**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.

<table>
<thead>
<tr>
<th>Friction without US</th>
<th>22.88 - 27.52 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction with US</td>
<td>9.93 - 10.71 N</td>
</tr>
<tr>
<td>Friction reduction</td>
<td>56.8 - 61.1%</td>
</tr>
</tbody>
</table>

**Examples of Ultrasonic Metal Forming**

- **Sheet rolling**
  - Severdenko et al. (1974)
- **Wire drawing**
  - Murakawa et al. (2001)
  - Siddiq and Ghassemieh (2008)
- **Compressing**
  - Hung et al. (2007)
Project #40: Modeling & Characterization of Passive & Adaptive Bushings & Mounts (Sub-Project #40A: Rubber Bushings)

**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

**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

**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

**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

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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
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

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

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

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
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

Joint Identification Using Inverse Method:

Benchmark Stiffness Coupling Experiments:
Direct Joint Measurements

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
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.

Problem Formulation:

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

FRF Based Substructuring:

Uncoupled System

Coupled System

Flexible Connection Matrix (Bushing or Mount)

Recent Results:

- Discrepancy suspected due to lack of rotational constraint in connection model

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
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.

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

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

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
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

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

Experimental

- Measured/Estimated
- Computational

```
<table>
<thead>
<tr>
<th>Laboratory experiment: 1-mount</th>
<th>Laboratory experiment: 4-mount</th>
</tr>
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<tbody>
<tr>
<td>$\omega_{1-6}$, $\eta$, FRFs</td>
<td>$\omega_{1-6}$, $\eta$, FRFs</td>
</tr>
<tr>
<td>Fine tune $E$</td>
<td>Fine tune $E$</td>
</tr>
<tr>
<td>Estimated $\eta$</td>
<td>Computed $[k]_{6x6}$</td>
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Project #42A: Enhanced Methods for Reducing Powertrain Vibration Transmitted through the Mounts

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

Remark to enhance mount designs for NVH control.

1. The paths 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.

Methods

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

- Shaker turned on
- Left stack turned on
- Right stack turned on

Control effort(s) calculated using model

Experimental Results

- Feasibility for motion control of source mass using piezo stacks is demonstrated.
- Experimental results are similar to simulated results.

Control effort(s) calculated using model

Remark

Project Leaders: Raj Singh (singh.3@osu.edu) and Jason Dreyer (dreyer.24@osu.edu)
Project initiated by Hyundai Motor Company (R&D Division)
**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 (anti-nodes)
- 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

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

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

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

- NiTi-Al composites are a lightweight 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.

**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.

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Project Leader: Marcelo Dapino (dapino.1@osu.edu)
Project initiated by MIT Lincoln Laboratory
Project #44: Smart Condition Detection and Monitoring

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

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

Prediction of Measured PVDF Voltage

- Rectangular shape (Length: L/2, L, 2L)
  - Prediction of generated charge
  - Prediction of generated voltage

- Stepped shape
  - Prediction of generated voltage

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

Power

- Sensor 1
- Sensor 2
- Sensor n

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

**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

**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.

**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 shaping 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

**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

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

Problem Formulation

- ZnS:Mn film
- Metal substrate
- PZT (disks/sheets) Support

- 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

\[ \text{Zn(C_2H_3O_2)_2 + Na}_2\text{S + PVP} \rightarrow \text{PVP-ZnS + NaC}_2\text{H}_3\text{O}_2 \]

- 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 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

---

**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 electromagnetic behavior of harvester/damper
- 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

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

Sub-project 47C:
- Magnetostrictive systems in relation to stiffness tuning, vibration damping, and energy harvesting
- Study the potential for:
  - Improved energy harvesting and damping
  - Robust and reliable stiffness tuning

---

**Background**

- NASA is investigating piezoelectric-based solutions
- Available magnetostrictive 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

---

**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

Technology Summary

- Metal matrix composites (MMCs) consisting of matrix and reinforcing material
  - Matrix: Al or Mg
  - Reinforcement: Al₂O₃, 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

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.
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

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

Project Leaders: Marcelo Dapino (dapino.1@osu.edu)
Project Initiated by Moog Inc.
Project #51: Ultrasonic Additive Manufacturing for Automotive 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

DIC Testing and Modeling:
• Digital image correlation (DIC) used to measure 2D and 3D strain fields
• Permits local and global measurements

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

Ultrasonic Additive Manufacturing:
• 3D printing technology based on ultrasonic metal welding
• Low-temperature process
• Dissimilar metal parts and integrated structures

Periodic machining shapes part and maintains uniform welding surface

Horn
Transducer
Metal Base Plate
Transducer
Metal Tape
Down Force
Vibration

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

Successive application of metal tape builds part

Ultrasonic Additive Manufacturing with rolling horn application

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
**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

**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

**Problem Formulation**
- Surlyn (E/MAA) + PZT-SH has been shown to demonstrate 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

**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**
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

New magnetic materials are needed...

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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

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
Project #55: Multiscale Finite Element Simulation of the Mechanical Behavior of Fiberglass Insulation Packs

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 than 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

Project Leader: Soheil Soghrati (OSU)  
Project Mentor: Andy Davis (Owens Corning)
Project #56: Dynamic Friction Characterization of Icy Road Surfaces for Conventional & Automated Vehicles

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

![Image of winter road conditions]

Industry Need, Context, and Relevance

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

![Chart showing Wet vs. Dry Incidence Rate Ratio]

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

Broader Impacts – Automated Vehicles

Selected Experimental Approaches

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

![Diagram of planned indoor winter conditions facility]

Broader Impacts – Automated Vehicles

Modeling Approach

- Dynamic friction
- Vehicle Dynamics

![Diagram of dynamic friction model]


- 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

![Diagram of vehicle dynamics]


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Project #57: Flexible Piezoelectric Sensors for Vehicle Applications

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

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

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

- Schematic of PVDF sensor (source: www.measpec.com)
- (a) Standard wind tunnel test vs (b) PVDF films on a scaled aircraft model

Significance
- 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

Opportunities
- 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

Research Gaps
- 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
Project #58: Architecture for Mechanoluminescent Sensors and Sensing Systems

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

Project Goals and Objectives
Experimental and in-field detection technique to report
(a) distribution of internal stress in the matrix and around the fibers,
(b) detecting the onset of damage, crack propagation
(c) extent of failure that will lead to abrupt structural damage, and
(d) machine learning to detect percentage life left in structure

Approach (Research Methods)

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<th>Task Name</th>
<th>Status</th>
<th>Comment</th>
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<td>Algorithm for SHM</td>
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Results
Fabrication of test samples, instrumentation for load characterization, machine learning for health determination

Project Leader: T. Hery, V. Sundaresan (OSU)  
Project Mentor: Duane Detwiler et al (HRA)
Motivation

• Demonstrating distributed programmable structural logic for generating dynamic shape changes, leading towards structural computing

• Versatile and scalable distributed actuation realized using COTS materials and implementation of digital logic using electronic circuit

Objectives

- Develop the digital logic and the electronic circuit to support that in simulation environment
- Building a fully characterized mechanical model of the programmable structure along with the digital logic in Simulink
- Selection of fabrication materials for the structure and the actuators
- Fabrication and characterization of the distributed programmable actuation platform

Summary

- Simscape model of $7 \times 7$ array of spatially distributed actuators built and simulated different input configs

- Fabrication and characterization of a $2 \times 2$ distributed programmable actuation platform prototype

- Prospective design concepts already underway for a larger prototype and associated drive electronics

Next Steps

- Design a single bimorph followed by a $2 \times 2$ prototype using the new design process
- Fabrication of the larger prototype – $10 \times 10$ array planned
- Characterization of the larger prototype
Project 61: Dynamic Self-Reforming Interfaces for Solid-State Batteries

Industry Need, Context, and Relevance

- Realization of a rechargeable lithium metal battery needed to meet increasing demand for electric vehicles.
- Lithium metal batteries with high energy density allow for decreased battery pack size and weight in electric vehicles.

Project Objectives

Overall goal: Enhancement of lithium metal and solid electrolyte interface for long-term stability and high-energy density battery.

Self-reforming interface from conducting polymers that will continuously reform and maintain interface.

Research Plan

Task 1: Electrochemical testing of baseline lithium metal solid-state half-cells.
Task 2: Fabrication and characterization of conducting polymer or conducting polymer composite for use as self-reforming interface.
Task 3: Electrochemical testing half-cells and full cells with self-reforming interface.

Preliminary Results/Applications

- Baseline lithium metal solid-state half-cells have demonstrated early failure under low assembly and operating stack pressure.
- Free-standing conducting polymer film fabricated from polypyrrole doped with dodecylbenzenesulfonate and characterization ongoing.
Project #61B: 3D Structural Batteries in Fiber Reinforced Composite Panels

Motivation
• Multifunctional structure capable of electrochemical energy storage
• Improvement in the range and energy density of EVs due to the significant weight saving

Summary
1. UV cured 100k MW PEO based GPE exhibited steady cycling against Li electrodes
2. Different carbon fiber anodes are characterized against standard cathodes (NMC, LFP)
3. UV cured GPE did not exhibit acceptable electrochemical performance
4. Thermally cured GPE has avg IC of 0.1 mS/cm
5. Pouch cells fabricated with thermally cured GPE exhibited lower specific capacities when compared to reference literature

Objectives
1. Synthesize free standing planar, thin film GPE
2. Characterization of GPE
3. Characterization of carbon fiber as anode
4. Fabrication of structural battery cell
5. Electrochemical and mechanical characterization of cells

Next Steps
• Conventional graphite anode cells to verify performance of GPE
• Replace LiTf with LiTFSI to reduce instability
• Thermally cured PAN based GPE to improve specific capacity
Industry Need, Context, Relevance

- Li-S batteries offer high capacity of 1672 mAh/g vs. 272 mAh/g for cobalt-oxide based cathodes.
- Sulfur (S) composite cathodes offer a sustainable materials solution ($150/ton for S) as compared to cobalt oxide-based intercalation cathodes ($10,000/ton).

Project Objectives

Overall goal: Develop synthesis methods for a library of metal nanostructures (spheres, wires) as structural additives to sulfur composite electrodes.

Prevent deleterious polysulfide dissolution

Research Plan

Task 1: Synthesis of copper nanowires for suppression of lithium polysulfide shuttling.

Task 2: Chemical and Structural characterization of metal nanowires for a synthetic feedback loop.

Task 3: Electrochemical testing of lithium-sulfur cells.

Preliminary Results/Applications

Achieved phase pure nanoparticles with diameter = 7.5 nm – 15 nm
Motivation

Current needs: Conventional three-point seatbelts fail in certain types of side impact cases in current vehicle designs. Center-mounted airbags are ineffective because they float when deployed.

Future needs in autonomous vehicles: Reconfigurable or "smart" restraints are required to address challenging safety conditions arising from the occupant’s variable seating position and orientation.

Concepts

Reconfigurable seatbelts: Develop versatile buckle-free restraining mechanisms for reconfigurable seats.

Reversible fastening mechanisms: Develop smart embedded latches/buckles that have extremely high shear strength but can be peeled off with a nominal normal force.

Methodology

Novel restraining mechanisms: Develop alternative restraint designs outside the belts-and-buckle paradigm.

Example: "wearable" restraint that forms part of the seat and can be worn like a garment by the occupant.

Current Work

Tensile tests & simulation of a candidate fabric: Kevlar 49

ISO 13934-1 Textile Tensile
Rate of elongation: 20 mm/min
Gauge length: 200 mm
Width: 50 mm, 25 mm
Textured aluminum end tab is used to prevent slipping.

Properties | Value
--- | ---
Weight | 5 oz./yd^2
Fiber | Kevlar 49, 1140 Denier
Thickness | 0.010 inches
Weave | plain
Count | 17 x 17

Comparison

Tests

Simulation

Project Leader: Prof. Marcelo Dapino, Dr. Leon Headings, Prof. Sheng Dong (OSU)
Project Mentor: Ryan Hahnlen, Skye Malcolm (Honda R&D Americas), Bengt Pipkorn (Autoliv)
**Motivation**

- Aluminum die cast components used significantly in electric vehicle powertrain – covering shells for battery, inverters, power converters, e-motor, transmission etc.
- MES seeks to develop a deeper understanding and build their technical knowledge of thermal characteristics of EV components.
- Drive design changes in die-cast components – specifically inverter & battery housings

**Project Goals**

Develop understanding of thermal behavior and design features of EV inverter housings to guide design and manufacturing process

**Objectives**

1. Develop three-dimensional physics-based numerical models to simulate heat dissipation through inverter housings
2. Develop understanding of heat generation characteristics of IGBT modules using experimental testing
3. Develop a combined experimental and numerical framework for investigation of different inverter designs

**Approach**

- Literature review for thermal packaging studies of inverter modules
- Develop 3D thermal modeling framework for analysis of heat dissipation through inverter housings
- Develop power loss models to predict power dissipation from IGBT-diode pairs
- Conduct parametric studies to predict heat dissipation under different operating conditions, housing materials and thickness
- Experimental testing of BYD and Cascadia inverters for validation of numerical models and thermal data

**Research Plan**

<table>
<thead>
<tr>
<th>Experimental Testing</th>
<th>Validation</th>
<th>3D Thermal Modeling</th>
<th>Design and analysis tool</th>
</tr>
</thead>
</table>

**Project Leaders:** Ardeshir Contractor (contractor.15) and Navni Verma (verma.55@osu.edu)
SVC Seed Grant: Aeromechanic Analysis and Optimization of Boundary Layer Ingestion Turbomachinery

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

Optimizing efficiency of 3D fan using hub and tip twist angles and chord length

Preliminary results show significant efficiency improvement over baseline design used in original study

<table>
<thead>
<tr>
<th>Case</th>
<th>$\frac{P_{out}}{P_{in}}$</th>
<th>% Diff. from Base</th>
<th>$\eta$</th>
<th>% Diff. from Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>1.2071</td>
<td>0.00%</td>
<td>0.8918</td>
<td>0.00%</td>
</tr>
<tr>
<td>Case 1 (3D)</td>
<td>1.1680</td>
<td>-3.29%</td>
<td>0.9362</td>
<td>4.86%</td>
</tr>
<tr>
<td>Case 2 (3D)</td>
<td>1.1723</td>
<td>-2.92%</td>
<td>0.9352</td>
<td>4.75%</td>
</tr>
<tr>
<td>Case 3 (3D)</td>
<td>1.1378</td>
<td>-5.91%</td>
<td>0.9444</td>
<td>5.73%</td>
</tr>
<tr>
<td>Case 4 (3D)</td>
<td>1.1890</td>
<td>-1.51%</td>
<td>0.9677</td>
<td>1.76%</td>
</tr>
<tr>
<td>Case 4.1 (3D)</td>
<td>1.1355</td>
<td>-6.11%</td>
<td>0.9444</td>
<td>5.72%</td>
</tr>
</tbody>
</table>

Optimization performed at design condition of baseline geometry

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)
**Motivation**

- Develop a computational research tool that serves as a platform to analyze the performance of vehicular integrated photovoltaic (VIPV) systems in various automotive formats and drive cycle applications.
- For automotive manufactures, the model provides support for evaluation and design of VIPV systems.
- For photovoltaic manufacturers and solar research centers, the model provides analytical ability to support research in high efficiency cells for automotive applications.

**Project Goals**

- Study interplay between 4 sub-systems of model:
  - **Solar Insolation**
    - location, season, time
    - 3D curved roof shapes
    - changing PV orientation
  - **PV Energy Conversion**
    - cell type
    - cell interconnection
  - **Charging & Power Delivery**
    - battery charging interval
    - battery capacity
    - auxiliary power demand
  - **Powertrain & Drive Cycles**
    - vehicle formats – car, utility van, bus, truck
    - different drive patterns

**Approach**

- **Solar Resource Model**
  - Location Day Season
- **Vehicle Model**
  - Powertrain Model
  - Drive cycle
  - Vehicle type
- **PV System Model**
  - PV area
  - PV efficiency
  - PV orientation
  - PV curvature
  - PV output
- **Battery Model**
  - Pack voltage capacity
  - Power demand at wheels
  - Auxiliary power demand

**Research Plan**

- Account for curvature effects of vehicle roofs on insolation.
- Include dynamic vehicle load and higher order model for battery sub-system.
- Model integration of PV in fuel cell electric vehicles and option of PV energy supply for ancillary or refrigeration systems.
- Analyze vehicle integrated PV as solution to anti-idling regulations.
- Explore higher efficiency cells –
  - Interconnection, stringing and form-factors for high yield
  - Performance analysis
  - Economics and life-cycle analysis

**Project Leaders:** Ardeshir Contractor (contractor.15) and Navni Verma (verma.55@osu.edu)
**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


**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)
<table>
<thead>
<tr>
<th>Research Student Team</th>
<th>Origami-Inspired, Foldable Acoustic Arrays for Deployable Medical Ultrasound Devices:</th>
<th>Lightweight Material Systems to Control Shock, Vibration, and Sound:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LSVR:</strong></td>
<td>Advancing basic and applied science in vibrations, acoustics, mechanics, and smart materials.</td>
<td>Structural mechanics, materials science, design and manufacturing</td>
</tr>
<tr>
<td><strong>Director:</strong></td>
<td>Prof. Ryan L. Harne</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thanks to our many industry, federal, and defense sponsors!</td>
<td></td>
</tr>
</tbody>
</table>

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

Analytical dynamics, energy harvesting, hypersonic multiphysics

**Project Leader:** Ryan Harne (harne.1@osu.edu)
**Objective:** Estimating mid-build temperature fields in the metal PBF process using an Ensemble Kalman Filter.Estimated temperature fields can be correlated with process defects and features of interest, thus advancing in-situ PBF quality control.

**Description of Effort:**
- Theoretic analysis and numerical implementation of state estimators on a class of large-scale linear time-varying systems.
- Kalman filtering in the absence of \textit{a priori} knowledge of system noise statistics.

**Benefits of proposed technology:** In-situ PBF quality control would save practitioners substantial time, money, and effort. This proposed technology is a substantial advancement of this as-yet-unrealized goal.

**Challenges:** PBF modeling generates large systems that present obstacles to practical computation, and prohibit several common control theory. Variability in part geometry challenges theoretical analysis by limiting \textit{a priori} knowledge of the system structure.

**Maturity of technology:** This technology is still being tested in simulation, with initial experimental results to be delivered by year’s end.

**Project milestones:**
- 2021: Gathering of experimental data, initial Ensemble Kalman Filter validation, development of feedback control algorithm environment.
- 2023: Completion of feedback control simulation environment.

**Proposed funding:** DAGSI grant C.N. RX9-OSU-20-5-AFRL2

**Program cost:**
- 2021: $80,000
- 2021: $81,000
- 2023: $82,000

**Project Leader:** Nathaniel Wood (OSU)  
**Project Mentor:** David Hoelzle (OSU)
Motivation

- Corrosion is a serious problem significantly affecting the lifetime of vehicles and thus the 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].

- To date, the macro-scale electrochemical measurements have revealed 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 mass 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]

**Industry Need**

- **Advanced lightweight materials** offers great potential to boost the fuel economy of vehicles, especially important for electric and hybrid vehicles.
- A 10% reduction in vehicle weight can result in a 6%-8% fuel economy improvement.
- Current efforts are mainly devoted to replacing cast iron and traditional steel components with lightweight materials
  - high-strength steel
  - magnesium (Mg) or aluminum (Al) alloys
  - carbon fiber reinforced composites

**Project Objectives**

We propose a new material design inspired by the structure and processes of bone tissue to improve upon current processes with a more complex material design that provides lightweight, self-stiffening structural materials for energy-efficient transportation systems.

**Transduction Mechanism:**
- **Piezoelectricity**
  - Transduce the force input to electrical signals to control mineralization

**Stiffening Mechanism:**
- **Mineralization**
  - A soft polymer template is locally reinforced by stiff mineral

**Template:**
- 3D Printed Metamaterial
  - Complex microstructures to encode local force distributions
  - Diverse geometries and scales

**Research Plan**

Projection micro-stereolithography (PµSL) is used to 3D print piezoelectric lattice structures.

This material undergoes cyclic, periodic loading over time in a mineral solution, which facilitate the mineralization of the lattice.

- We successfully fabricated two different types of piezoelectric lattice structure, that can vary the type of force loading.
- We will optimize the polymer composition to maximize the piezoelectric effect during loading.
- Based on the first results, we will further optimize the lattice structure to provide an effective base template for the self-stiffening mechanism.

**Results and Future Works**

**Stretch-dominated octet-truss**

**Bend-dominated Kelvin form**

**Project Leader:** Hanna Cho (cho.867@osu.edu)

**Project Mentor:** Sajan Patel