Bio-Engineering
Falls in the elderly are associated with considerable morbidity and mortality. Most falls are preceded by what is generally known as a ‘loss of balance’ (LOB), yet a quantitative definition for a LOB is lacking. This study tests the hypothesis that a loss of balance is really a loss of control (LOC) in the engineering sense. We define LOC to be a system failure whose detection occurs at the time instant that the monitored performance variable exceeds the threshold of three standard deviation beyond a mean value.
Falls from ladders are the second most frequent cause of injury involving falls from elevation. In the elderly, standing on a raised surface is considered as one of the three most-challenging activities of daily living (Powell et al. 1995). The purpose of this study is to use a biomechanical model to analyze human movements on a stepladder. We found an 80% decrease in the region of stability when people stood on a 20% human-body-height (BH) stepladder than on the ground (0% BH). The findings may add more precise numbers on safety instructions to stepladder users.
How Human Can Stand on One-Leg

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In this presentation, we discuss the mechanics of how a human can stand on one-leg. It is shown that the nonlinearity of ankle and hip torque induces inherent limitation of balance. Then we prove the sensitivity of the human controller gain is adjusted to meet these criteria.
The wrist is the most commonly fractured site in the body at any age, commonly following a forward fall. To investigate whether wrist impact forces can be volitionally reduced by young males in standardized forward falls, we compared the impact forces before, and for three months after, a 10-min instructional intervention, and with those in untrained controls followed over the same period. Two hypotheses were explored: (1) the initial response to the 10-min. intervention was not due to self-learning; (2) in a prospective, controlled trial, the impact forces in trained subjects and untrained controls would not differ significantly at 3 or 12-week follow-up.
A combination of finite element modeling and sled test reconstruction of real-world infant head injury scenarios has been used to investigate infant head impact response and tolerance to skull fracture. In particular, it was desired to determine the role of cranial sutures on infant skull response. The specific injury scenarios selected for reconstruction involved infants in rear-facing child restraint systems (CRS) who sustained skull fractures and brain injuries from deploying passenger-side airbags. Approximations of the loading conditions for three injury cases, as well as estimates of loading conditions not expected to result in head injury, were produced in the laboratory. A finite element model (FEM) of a six-month-old infant head was developed using available material properties and humanlike geometry and used to simulate different loading conditions estimated in the reconstruction tests. Results include comparison of model and dummy responses, estimates of stresses associated with skull fracture tolerance, and recommendations to improve the dummy head design.
Why are the Elderly at Increased Risk for Falling While Turning?

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Hip fractures in the elderly are associated with high rates of death, disabilities, and costs ($8.7 billion/year). The elderly are 8-times more likely to fall and break a hip while turning than while walking straight. Why? Using 3-D kinematic and kinetic measures, we compared healthy young and older subjects while they performed, in the standing position: (a) 180° turns, and (b) 180° turns with a sudden direction reversal. Outcome measures include foot placement, timing, and separation distance, and CG movement relative to the base of support. The hypothesis is that age increases the frequency of foot-foot contacts, compensatory steps and postural unsteadiness.
Influence of Mechanics on Muscle and Tendon Development

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We have created self-assembling tendon-like constructs. The variation of certain parameters that we know influence the behavior of tendon fibroblasts in vitro will allow us to more closely mimic tendon physiology. Our goal is to combine these tendon constructs with self-assembled muscle constructs, termed myooids. Both constructs display an immature phenotype morphologically and mechanically however, which hinders their use as a model of in vivo function. It is well known that mechanical stimuli are an important factor in muscle and tendon development and we plan to manipulate this response to facilitate maturation.
Experiments on diabetic Sprague-Dawley rat nerve and nerve collagens

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Our study involved healthy and diabetic Sprague-Dawley rats, with 12-week STZ-induced diabetes. In addition to monitoring blood glucose, nerve conduction velocity (NCV), and body weight, we performed atomic force microscopy on extracellular matrix collagen, mechanically tested whole nerve, and performed in situ immunohistochemistry on transverse sections of sciatic nerve, in order to quantify structural changes in the collagen of the epineurium, perineurium and endoneurium. We found higher maximum stress in diabetic perineural tissue (40% strain) in the diabetic versus the healthy animals. No significant difference was detected in elastic moduli or stress relaxation constants. Atomic force microscopy (AFM) revealed larger collagen fibrils in diabetic endoneurium and epineurium. In situ immunohistochemistry revealed generally higher levels of types I, III, and IV collagen in whole nerve, but not significantly so. This suggests that the extracellular matrix of both the endoneurium and epineurium remodel in response to the modified chemical and mechanical environment present in diabetic peripheral neuropathy.
Collagen X is expressed at sites of endochondral ossification during skeletal development and new bone formation, such as fracture repair and osteoarthritis. It is restricted to the hypertrophic zone in the epiphyseal growth plate. Although collagen X appears to be required for normal skeletal morphogenesis, its molecular significance is not completely understood. Dr. Kathryn Cheah at the University of Hong Kong has developed a transgenic mouse that expresses collagen X with a missense mutation that alters the Gly18 at the –1 position of the putative signal peptide cleavage site. This mutation affects the ability of collagen X to function properly and in humans leads to the rare autosomal dominant disease Schmid metaphyseal chondrodysplasia. The specific objective of this project is to phenotype the transgenic mouse in an attempt to help researchers come one step closer to understanding the role of collagen X in bone formation.
This study is aimed at modeling the cochlea - a tiny organ inside our ears which converts sound vibrations to nerve impulses. A finite element model has been developed for predicting global cochlear responses and to better understand the working of the organ. Cochlea is modeled as a fluid filled rigid duct separated into two chambers by a cochlear partition. The fluid is modeled as a viscous and compressible fluid. For the cochlear partition two previously developed models are used and analysed. The final model is solved using the finite element formulation with a high degree of spatial resolution. Steady state response for both external (normal incoming sound) and internal excitation (electrically evoked emissions) will be presented.
Design and Manufacturing
Numerical Modeling of One-Dimensional Laser-induced Melting and Solidification in Metals Subjected to Time-Dependent Heat Input

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A simple one-dimensional model describing the physical mechanisms of heat transfer, melting and resolidification during and after the interaction of a laser beam with a bed of pure metal powder is presented. The physical model is based on the classical Stefan problem with appropriate boundary conditions to reflect direct selective laser sintering of metals. A numerical model is developed for three different time-dependent power input profiles. The computations are performed for variable beam diameter and scan speed for each power input profile and some non-dimensional relationships are derived. Furthermore, the temperature histories for three different power input profiles are compared with closed form solution.
Design and Manufacturing

Design Optimization for Crashworthiness of Vehicles using Equivalent Mechanism Approximations

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This study is motivated by the need to improve the safety of vehicles during crash events. The main difficulty in vehicle crashworthiness optimization is the massive computational resources required to run finite element crash simulation code. So far, crashworthiness optimization using full finite element models (FFEM) is limited to component-level optimization and/or local optimization methods. Popular alternatives to FFEM are response surface methods (RSM) and lumped parameter models (LPM). Our goals are to develop approximate models for simulating the crash event using equivalent mechanisms and to apply the approximation in breaking down the design optimization of full systems to the component level, which could then be handled using FFEM. It is perceived that the new approach could go beyond the capabilities of both RSM and LPM.
Motivated by the development of an innovative powder delivery system to make selective laser sintering (SLS) suitable for fabricating multi-material composite structures, an Eulerian multiphase CFD model is developed to study the granular flow of fine powders inside small-scale hoppers. The granular kinetic theory is adopted for the constitutive relations of particulate phase, and the interaction between gas and solid phases is modeled through drag force. The results will show detailed flow profiles of each phase in the hopper, such as velocity and mass flow of powders, local solid fraction, and the pressure distribution of the interphase gas. Comparison will be made between numerical and experimental results. The ultimate goal of this study is to provide a powerful tool for designing a micro-hopper based multi-powder deposition system for SLS process.
Reconfigurable manufacturing systems (RMS) are designed at the outset for rapid change in structure, hardware and software, to quickly respond to the needs of market in terms of both product variety and quantity. Our work focuses on the design of a reconfigurable assembly machine for heat exchangers. Rapid changes in the market, demand that the assembly systems used for manufacturing heat exchangers be reconfigurable. At this stage, we have restricted ourselves to a modular design that can be readily integrated to the existing system and further revisions are easier to make. The new design is constrained by the need to reduce cycle time and minimize additional cost and machine complexities. The goal is accomplished by studying timing charts of the existing assembly process, and thoroughly analyzing the functionality of the individual components.
Chip Formation and Cutting Forces in Micro-Milling

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This study is motivated by the fact that the mechanisms of chip formation in milling may change depending on the length-scale of the process. Preliminary experiments revealed that the milling cutter may rotate several times without removing any material in micro-milling. Based on this result, a new model of chip formation is developed and verified by comparing predicted cutting forces with experimental data. This study contributes to a comprehensive understanding of the micro-milling that will allow engineers to develop improved tools and processes.
The Impact of Product Architecture on the Reusability of Manufacturing Systems and the Environment

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How to economically produce diverse products and minimize adverse environmental effects has been a challenging task in manufacturing engineering. The main goal of this research is to quantitatively investigate reusing manufacturing systems. Quantitative metrics were developed to evaluate the reusability of manufacturing systems, changes in products, and the environmental impact of system reuse. The research also entailed developing novel mathematical mapping methods to establish relationships among the metrics. The validity of the metrics and methods will be verified by being applied to an assembly system in the automotive industry. The results of the research will provide new decision-making tools for the life-cycle-engineering of manufacturing systems.
Design of a Novel Compliant Transmission for Secondary Microactuators in Disk Drives

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One of the bottlenecks limiting the data density in conventional disk drives is the resonant frequency of the suspension arm connecting the actuator and the read-write elements. In this work we present a compliant transmission to be integrated with a secondary microactuator to deal with this limitation. The compliant transmission was designed to reduce overall footprint current microactuator designs while maintaining static and dynamic criteria. The topology for the compliant mechanism was derived from an analogous rigid link mechanism. Size and shape parameters of the topology were then optimized in ANSYS.
Decomposition-based Assembly Synthesis for In-process
Dimensional Adjustability

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This study presents a method of assembly synthesis focused on the in-process adjustability, where assembly synthesis is defined as the decomposition of the end product design prior to the detailed component design phase. Focusing on the effect of joint configurations on dimensional integrity of complex assemblies, the method recursively decomposes a product configuration and assigns joint configurations according to simple rules, in order to achieve a designed dimensional adjustability and non-forced fit. The rules employed during the decomposition process are drawn from the previous works of assembly design. An augmented AND/OR graph is utilized to represent a process of assembly synthesis with the corresponding assembly sequences, and the algorithm for generating the AND/OR graph is discussed. The method is applied to two dimensional skeletons of product designs at very early stage of the design process. The relation of the assembly synthesis to Datum Flow Chain (Mantripragada and Whitney, 1998) is discussed. It is also shown that each final design from the assembly synthesis defines its own Datum Flow Chain.
Simultaneous Tolerance Synthesis through Process Modeling

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Simultaneous tolerance synthesis is to specify the permissible amount of variation for component dimensions and to select corresponding manufacturing process at the same time. One important aspect for simultaneous tolerance synthesis is to incorporate process parameters into tolerance stackup models. In this paper, a process model is used to describe how the equipments and process affect part deviation and how the deviation is transmitted in the process. Through process modeling, product tolerance and process selection are simultaneously determined by optimization techniques.
Design Of Large-Displacement Compliant Joints

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Flexure joints are widely used to approximate the function of traditional mechanical joints, while offering the benefits of high precision, long life, and ease of manufacture. We have investigated the drawbacks of typical flexure connectors and are presenting several new designs for highly-effective, kinematically-behaved compliant joints. A revolute and a translational compliant joint are proposed, both of which offer great improvements over existing flexures in the qualities of (1) large range of motion, (2) minimal axis drift, (3) increased off-axis stiffness, and (4) reduced stress-concentrations. Analytic stiffness equations are developed for each joint and parametric computer models are used to verify their superior stiffness properties. A catalog of design charts based on the parametric models is also presented, allowing for rapid sizing of the joints for custom performance. Two multi-degree-of-freedom joints are also proposed as modifications to the revolute joint. These include a compliant universal joint and a compliant spherical joint. Several applications in machine tools, precision guided weapons, and adaptive optics will be presented.
Productivity of Serial Transfer Lines with Reserve Capacity and Buffers

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The traditional method to improve the productivity of serial transfer line manufacturing systems is to isolate system failures from individual machine failures by placing buffers between each machine. However, as CNC machines have become more inexpensive, a new option to improve productivity has become feasible: reserve capacity. Reserve capacity is the provision of multi-capable CNC machines in parallel to the transfer line, which can substitute for any operation in the main line should it fail. In evaluating a transfer line design, the employment of the reserve capacity option requires an understanding of its improvement to productivity so the economic trade-off between inventory costs and reserve capacity cost can be evaluated. This work provides a methodology to predict the productivity of a serial transfer line utilizing reserve capacity with and without buffers.
In Analytical Target Cascading (ATC) the targets at the supersystem level are considered as given. Setting the top targets is a critical enterprise decision. An interdisciplinary enterprise decision model or Analytical Target Setting (ATS) problem, which couples engineering and financial aspects of design decisions, has been developed to set the targets analytically. Solving the Analytical ATS and ATC problems iteratively, we can ensure that the targets set are the best possible. ATS will be demonstrated in a truck design problem.
The performance of many mechanical systems is directly related to the geometric shapes of their components, such as aircraft wings and antenna reflectors. These systems are mostly designed to have one fixed shape, optimized with respect to a particular operating condition. In order to enhance the system flexibility and functionality under varying operating conditions and external disturbances, the component shape has to change adaptively to maintain optimal system performance. The objective of this research is to develop a systematic compliant mechanism synthesis approach for a desired shape change. The methodology, using genetic algorithm, is applied to design of antenna reflectors.
Manufacturing System Convertibility Analysis

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Manufacturers must be able to quickly assess the performance of different system configurations and alternatives, particularly with regard to responsiveness issues. One aspect of responsiveness is convertibility, which is defined as the capability of a system to adjust production functionality, or change from one product to another, with consideration of costs and time. Two approaches are proposed: a manufacturing system-based approach which can be used to analyze the convertibility of different system configurations early in the design process, and a product-based approach which requires more detailed information about the products and part families that are being manufactured.
**Dynamic Air Brake System Modeling for Medium Size Trucks**

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Designing an air-brake system to meet the vehicle safety requirements is an expensive and time-consuming process. The state of the art for air-brake design is a trial and error approach, which requires many iterations of prototype building and testing in order to achieve the desired performance. As an alternative, modeling and simulation can significantly improve the design process while reducing the cost and time associated with building and testing prototypes. Different designs can be virtually tested using the computer model before moving to the final testing with the prototype system.

The objective of this project is to develop and validate an air brake system model for a commercial truck. Models are built using the AMESim modeling and simulation environment. The dynamic system models are developed with variable complexity to predict accurately critical parameters like activation times of relay valves, compressor build-up time etc. Model validation would be carried out in the later stages of the project. Use of the air-brake system models can reduce the cost and time to develop a system that meets the safety regulations.
Solid Mechanics and Materials
Frictional heating generated in brakes and clutches system causes thermoelastic distortion that modifies the contact pressure distribution. When the generated heat is high enough, the system becomes unstable and hot spots appear on the surface of the contact bodies. This phenomenon is known as thermoelastic instability. A steady state finite element analysis is used for two-dimensional three layers model to study this phenomenon. The problem is thermomechanical coupled between frictional heating and thermoelastic distortion. This coupling required developing separate algorithms for each one of them and combined the results through an iterative method. The model is verified against known analytical solution. Then, it is used to investigate the stability and the behavior of the system at varies sliding speed.
Modeling of Void Formation in Polycrystalline Solids

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Void formation in metallic interconnects causes open-circuit failure in semiconductor devices. Prevention of this type of failure necessitates a better understanding of the process of void nucleation in polycrystalline solids. The underlying mechanisms are stress-driven self-diffusion and electromigration. These lattice level processes are incorporated into a continuum field formulation. The coupled problems of mechanics and diffusion are solved using a staggered finite-element scheme. Preliminary results are presented. The ultimate goals of this effort include studying the processes of void growth and movement, and investigating the effects of deposition- and operating-temperatures, temperature gradients, plasticity and anisotropic material properties.
Modified Anisotropic Gurson Yield Criterion for Porous Ductile Sheet Metals with Planar Anisotropy

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The influence of plastic anisotropy on the plastic behavior of porous ductile materials is investigated by a three-dimensional finite element analysis. A unit cell of cube containing a spherical void is modeled. The Hill quadratic anisotropic yield criterion is used to describe the matrix anisotropy including planar anisotropy. The matrix material is first assumed to be elastic perfectly plastic. Macroscopically uniform displacements are applied to the faces of the cube. The finite element computational results are compared with those based on the closed-form anisotropic Gurson yield criterion (Liao et al., *Mech. Mater.* 1997, pp. 213-226) in terms of an average anisotropy parameter. Three fitting parameters are used in the closed-form anisotropic Gurson yield criterion to fit the results of finite element computations. When the strain hardening of the matrix is considered, the computational results of the macroscopic stress-strain behavior are in fair agreement with those based on the closed-form anisotropic Gurson yield criterion under selected monotonically increasing loading conditions.
We conduct static test to investigate the influence of shear stress on the crush behavior of honeycomb materials. A test fixture and honeycomb specimens are designed. The experimental results indicate that both the bare compressive and crush strengths under combined compressive and shear loads are lower than those under pure compressive loads. Also, the energy absorbing capability is reduced under the combined loads. A yield function is suggested for honeycomb materials based on a phenomenological plasticity theory. The experimental observations show the inclined staking patterns of folds and the ruptures of aluminum cell walls along the adhesive lines.
The technique of using both spot-welding and adhesive bonding in the same joint, known as weldbonding, allows automobile manufacturers to produce structures that are stiffer, stronger, and safer than those produced using either method alone. Accurate predictions for the behavior of the resulting structures, however, require that the material properties and deformation/fracture behavior of the individual joints be known. A technique for measuring the material properties of weldbonded joints using experimental and finite element methods will be presented and implications for future analyses will be discussed.
Behavior of Pressure Sensitive Adhesive Joints

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Simulation of Fatigue Crack Growth in Adhesive Joints Using a Cohesive Zone Model

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The use of adhesive bonding for structural applications has been inhibited by an incomplete understanding of how to predict their long term reliability. This study focuses on fatigue behavior in terms of crack initiation and growth in the adhesive joint. An FEA model is created of a double cantilever beam with the joint represented with a cohesive zone model. The fundamental mechanical behavior of the adhesive is captured in the traction law of the cohesive zone model. Preliminary results will be shown of the FEA simulation and comparison to experimental data.
Fatigue Life Prediction of Fillet Rolling Tool of Crankshaft

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Deep fillet rolling process has been done to improve the fatigue strength of crankshaft in the automotive industry. This study is motivated by the need to improve the fatigue life of the fillet rolling tool to reduce the manufacturing efforts and cost. Hertzian contact theory and multiaxial fatigue theory have been used in an attempt to predict the life of roller and the estimated fatigue life can be considered as reasonable in this preliminary study. The ultimate goal of this study is to understand the effect of roller geometry, rolling load and rolling angle on the roller life and to develop the better design of roller, which should also satisfy the requirements of the fatigue strength of crankshaft.
Fatigue Life Prediction For Spot Welds in Various Specimens

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A fracture mechanics approach is adopted here to examine the fatigue lives of spot welds in coach-peel and lap-shear specimens. The paths of fatigue cracks near the spot welds in these two types of specimens are first discussed. A fatigue crack growth model is then developed for spot welds in these two types of specimens based on the Paris law for crack propagation and the global and local stress intensity factor solutions for kinked cracks. Various global stress intensity factor solutions for spot welds in these specimens are used to obtain the local stress intensity factor solutions with the experimentally determined kink angles. The results indicate that the fatigue life predictions based on accurate global stress intensity factor solutions are compared well with the experimental results.
Variational Multiscale Methods to Embed Macromechanical Formulations with Fine Scale Physics

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As deformation phenomena approach the length scale of grains, the interaction between defects and the effects of their elastic fields play increasingly important roles. Conventional macroscopic theories of inelasticity – such as plasticity – fail to resolve these effects. However these effects can be explained with notable success by various classes of Strain Gradient Plasticity theories which are microscopic theories. The approach of embedding micromechanical models in macroscopic ones comes as an answer to the computational cost which would be involved in the inclusion of fine scale physics associated with microscopic features in an otherwise macroscopic domain.
Coupling a Fine-Scale Constitutive Equation into the Macro-Scale Equation of Motion via Variational Multiscale Techniques

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A Variational Multiscale approach is taken to endow macro-mechanical continuum formulation with fine scale physics. Proposed are enhancements to a plasticity model developed at Sandia National Laboratory that will enable it to account for dislocation proliferation and other phenomena associated with material science. The problem is solved by a technique called Variational Multiscale Method whereby two dislocation fields $u_a$ and $u_b$ are used and a mixed strain is introduced. Field $u_a$ represents displacement due to plastic flow, while $u_b$ represents displacement due to the elastic response of inter-atomic forces when external loads are applied (as exhibited in a purely elastic problem). The mixed strain is used to emulate, but not equal the gradient of $u_b$. Moreover, the constitutive equation is non-local and encompasses strain gradients and a natural length scale.
A Steady State Solution of Thermoelastic Sliding Contact Bodies Using Finite Element Method

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Frictional heating generated in brakes and clutches system causes thermoelastic distortion that modifies the contact pressure distribution. When the generated heat is high enough, the system becomes unstable and hot spots appear on the surface of the contact bodies. This phenomenon is known as thermoelastic instability. A steady state finite element analysis is used for two-dimensional three layers model to study this phenomenon. The problem is thermomechanical coupled between frictional heating and thermoelastic distortion. This coupling required developing separate algorithms for each one of them and combined the results through an iterative method. The model is verified against known analytical solution. Then, it is used to investigate the stability and the behavior of the system at varies sliding speed.
In this work, plane elastic wave propagation in periodically heterogeneous structures is studied in the frequency domain. In the literature, a computational methodology is available for the dispersive modeling of such structures at low frequency ranges. The methodology is based on an assumed strain variational method, and utilizes multiscale projections and high-order homogenization theory. A new development is proposed that extends the capability of the current technology to higher frequencies. The new approach involves enhancing the multiscale projections. The enhancement is achieved by enriching the projection space with a set of vectors that better characterize the dynamics of the structure. Numerical results are presented and show good agreement with exact solutions.
Fluid Mechanics, Heat Transfer and Combustion
Modeling the Effects of Gas Exchange Processes on HCCI Combustion

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Homogeneous Charge Compression Ignition (HCCI) is a process driven mainly by chemical kinetics. Gas exchange processes and mixing can have a significant effect on ignition timing and burn duration. This work presents a procedure for modeling the full operating cycle of an HCCI engine. A multi-dimensional fluid mechanics code (KIVA-3V) is used to simulate the gas exchange processes. The results are then used to initialize the calculation with a multi-zone code with detailed chemical kinetics, which computes the combustion event. The methodology is validated against experimental data and is then used to evaluate various valve event strategies as means of capturing internal EGR and controlling HCCI.
Unsteady Spherical Diffusion Flames in Microgravity

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The objective of this research is to investigate experimentally and theoretically suppression of diffusion flames in \( \mu \)g. We want to identify conditions such as ambient atmosphere, fuel flow rate, and fuel type that lead to natural suppression of a diffusion flame. The research will examine the role flame radiation plays in extinction as well as the interaction between radiation and chemistry. Experimental work will be conducted in the 2.2 second drop towers at NASA Glenn Research Center. The aim is to improve our fundamental understanding of combustion processes and help develop suppression and detection technology for space.
Cavitation and Internal Flow Calculation inside a Diesel Injector VCO Nozzle

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The simulation of diesel spray breakup used in diesel engines is currently being done by assuming initial and boundary conditions at the nozzle exit, due to the limited knowledge of internal flow and cavitation phenomena inside the injector nozzle. This study focuses on a CFD analysis of cavitation inside a Valve Covered Orifice (VCO) nozzle, typically used in diesel engines. The effect of the internal geometry on the emerging spray structure is also investigated.
Vapor-deposited bismuth telluride (n-type) and antimony telluride (p-type) films are used in a micro, column-type, patterned thermoelectric cooler. The optimum number of thermoelectric pairs and operating current are predicted. In the analysis, various interfacial resistances (phonon boundary scattering and thermal and electrical contact resistances) have been included. In the fabrication, the stoichiometry of the deposited films, patterned film deposition, and conducting connectors, are discussed.
Turbulence Properties of High and Low Swirl In-Cylinder Flows

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In previous work, Reuss (SAE 2001-01-0246) studied the cycle-to-cycle variation in the large-scale velocity structures of high and low-swirl in-cylinder flows of an IC engine. The vector flow fields were obtained from PIV measurements in a two-valve, pancake-shaped, Transparent Combustion Chamber (TCC) engine. In this study, the Reynolds-decomposed turbulence properties such as kinetic energy, length scales, and dissipation rate were directly measured for the two cases. The results demonstrate that, at TDC compression, the low-swirl flow is dominated by turbulence at the largest scales, whereas the high-swirl flow has a considerably lower turbulence Reynolds number. The dissipation rate and length scale calculated from mixing-length theory greatly exceeded the dissipation computed from the 2-D velocity-gradients and integral-length scales computed from the autocorrelation, respectively.
Optical Phonon Contribution to Lattice Thermal Conductivity

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Models describing heat transfer in dielectric crystals typically assume that the dominant energy carriers are acoustic phonons. These correspond to long wavelength vibrational waves that travel at the speed of sound through the lattice. In crystals with more than one atom per unit cell, optical phonon modes also exist, and are usually assumed to have a negligible contribution to the heat transfer. This assumption is not always justified. Using molecular dynamics and lattice dynamics calculations, the contributions of acoustic and optical phonons to the thermal conductivity of silica and Lennard-Jones crystals are identified, and interpreted with respect to existing theoretical models.
This work presents a liquid-vapor phase equilibrium study to assist the assessment of the performance of liquid fuel film measurements in a direct injection engine using laser-induced fluorescence (LIF) of ketonic dopants added to non-fluorescing fuels. The evaporative characteristics and relative concentrations of individual species of the mixture including air were evaluated by a PSRK equation of state approach. It was found to be important to extend the computations beyond the typical binary mixtures computations to faithfully represent the evaporation of tracers in the presence of air.

Although the interaction parameter of O$_2$-CH$_3$CO in the functional group of UNIFAC for vapor-liquid phase equilibrium is not available, modeling was completed using the average value of O$_2$-H$_2$O and O$_2$-CH$_3$ groups. In comparison with experimental results and various mixture systems, the predicting capability of PSRK has been validated. Concentrations of individual components in both phases were determined using flash calculation, which also provided the amount of liquid that existed at equilibrium. Two tracers, 3-pentanone and 2-hexanone, were examined for their evaporation behaviors in iso-octane. The effect of gas solubility on liquid phase tracer concentrations and possible oxygen quenching of the LIF signals are discussed.
Novel Microfluidic Devices Using Mobile Polymer Monoliths

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Many applications of microfluidics are focused on chemical analysis instrumentation to make common laboratory procedures cheaper, quicker, and more precise. The goal of our current research is to create novel devices that allow us to integrate benchtop laboratory procedures (such as filtration, measuring organic content, and mixing) into microfluidic systems. A variety of devices created by polymerizing functional polymers in situ within microfluidic channels will be demonstrated. In addition to previous work that demonstrated 5000-psi valves and 10 nL pipettes, we will show preliminary results of devices such as an organic sensor, protein preconcentrator, and an on-chip filter.
A Computational Study of Silane Combustion

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Due to varied interests in silane (SiH₄) combustion, the ability to reliably model Si-H-O combustion is a valuable resource. Recent studies have provided improved estimates of thermochemical and chemical kinetic data for the Si-H-O system. The SiH₃ + O₂ reaction has been of considerable interest, due to its important reactions in silane oxidation, particularly at low temperatures. A detailed chemical mechanism for silane combustion is presented, including recent estimates for the SiH₃+O₂ overall rate constant and product branching fractions. The mechanism is validated by comparison of calculated ignition delay times with shock tube data at high temperatures and constant volume explosion data at low temperatures. Sensitivity and species flux analyses are performed to identify reactions playing key roles in silane combustion and to identify significant reaction paths.
Effective Diffusivities of Fibrous Gas-Diffusion-Layer

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The gas diffusion layer (GDL) supplying reactants to polymer electrolyte membrane (PEM) fuel cell, is composed of aligned hydrophobic fibers (random in a plane, aligned perpendicular to it). Presence of liquid water in GDL further reduces this anisotropic effective diffusivity tensor \( \langle D_{m,i} \rangle \), which depends on porosity, pore size, fiber radius, and liquid-water saturation \( s \) (fraction of pore volume occupied by liquid). Using pore models of stack rectangular pores enclosed by four inter-woven fibers, we determine \( \langle D_{m,i} \rangle \). Since the dependence on \( s \) is expected to be highly non-linear, we look for presence of a threshold \( s \) for which diffusion choking may occur.
A Computational Study of the effects of EGR on the HCCI Engine Performance

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Numerical simulations of a single zone model for the in-cylinder combustion of a HCCI engine are undertaken to investigate the effects of exhaust gas recirculation (EGR) on the ignition timing, duration of burning and operational stability. Previous experimental studies have demonstrated that EGR is a viable control approach to achieve smooth combustion primarily by increasing the fresh charge temperature and reducing the reactivity of the mixture. In this study, we simulate these effects in a methane-air system and determine the operational limits with EGR addition. The results at various mixture conditions and engine speeds demonstrate the smoothing effect of EGR on HCCI combustion. Dilution of the mixture with exhaust gases reduces the amount of excess air available and this is found to be a major inhibitor of knocking. It is also seen that there exists an upper limit for EGR, beyond which an excessively lean mixture will result in incomplete combustion or misfire. The feasibility of blending two fuels with different ignition properties as a means of controlling the ignition timing has also been investigated. Further studies will be performed to determine the effects of mixture stratification and mixing on homogenous combustion.
The Study of Ignition Delay Times in HCCI Combustion Systems

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Homogeneous charge compression ignition (HCCI) has the potential to dramatically reduce NOx and particulate emissions from internal combustion engines, while simultaneously achieving high thermal efficiencies. However, the lack of the knowledge of when autoignition occurs prevents further developing and deploying of HCCI technology.

Motivated by the need to understand the physical chemistry of ignition delay times in the HCCI system, free-piston rapid-compression facility (RCF) experiments have been designed. Final pressures of up to 4 MPa, temperatures of up to 2300 K and compression ratios from 30:1 to 50:1 can currently be achieved using the RCF facility. Results of preliminary RCF/HCCI research are presented. An outline of the future direction of the study is also presented. We intend to measure ignition delay times, combustion durations, time-resolved temperature and species concentration histories, and develop a detailed chemical kinetics model of HCCI combustion. Our ultimate goal is to develop libraries of experimental data for verifying chemical kinetics models and for advancing HCCI control strategies.
This study is motivated by the need to improve the environmental impact of combustion systems. In an attempt to understand and control the time-varying characteristics of pollutant formation in flames, a computer-controlled time-varying burner has been developed. Its purpose is to explore the fundamentals behind transient flames by improving mechanisms to reduce pollutant emissions and maintain combustion efficiency. Suggested control strategies are developed based upon effects of strain rate and frequency of fuel concentration and flow field oscillations. These experimental results are verified numerically with a large eddy simulation program, Fire Dynamics Simulator (FDS), developed at the National Institute of Standards and Technology.
Dispersion of solute in spatially-periodic chromatography media

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The purpose of this study is to investigate the effects of spatially periodic chromatography media on the dispersion of solute in microfluidic systems. Two numerical methods are used to model this process -- a method for calculating dispersion in porous media devised by Brenner (1980) and also a direct numerical solution based on Monte Carlo methods. Data reduction is achieved through correlation between the periodic geometries modelled and dispersivity coefficients.
One Dimensional Analysis of Gas Metal Arc Welding (GMAW) Metal Transfer

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The objective of this study is to exam the formation of metal droplets in gas metal arc welding (GMAW) process. One-dimensional governing equations derived from finite volume method are solved with the aids of numerical technique. The effects of surface tension and electromagnetic force on GMAW metal transfer are studied in detail.
Laser-induced fluorescence (LIF) has wide application in internal combustion (IC) engines. In many engine experiments, the fuel of interest either does not fluoresce at the available laser wavelengths or fluoresces in some way that prevents quantitative results from being obtained. Therefore it is necessary to use appropriate fluorescence tracer to track the fuel. The purpose of this work is to study the characterization and fluorescence properties of the tracers often used for LIF investigations within the engine environment. Furthermore, a quantitative multistep decay model for fluorescence yield is developed, considering the fluorescence quenching effect. The numerical results are then compared with the experimental results.
Dynamics, Systems and Controls
Driver models play essential roles in design of vehicle dynamic control (VDC) systems. In the early stages of controller design, simulations are the major sources of feedback for the better controller performance. System inputs such as steering and braking profiles are often generated through either “Open loop” or “Closed loop” tests. Former use predefined time trajectories of the inputs (e.g. J-Turn, Fishhook), latter use the inputs from a driver model whose goal is to follow a certain vehicle path (e.g. Double Lane Change, Moose Test). In the industry vehicle performances under path-following driving maneuvers (Closed Loop Tests) are scrutinized because most of the ratings are based on such maneuvers. Therefore good driver models capable of representing the actual driver behavior are crucial in the design of controller and vehicle systems. A new human driver model which is flexible enough to represent wide range of human driving characteristics will be described in an optimal control setting.
Enhanced Mobility via Cooperation

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Mobile robots can be used for applications such as search and rescue, urban infiltration etc. We are working on designing mechanisms and behaviors for a team of small, cheap robots that cooperate to enhance the team's overall mobility. Simplicity is the underlying design principle: each team member is cheap and hence disposable, the physical connection between the robots is passive, the communication protocols among the robots are simple, and each robot controls its own state. A feasibility analysis for cooperation shows how motor torque and ground friction limits drive the mechanical and control system design. Simulation demonstrates a decoupled, distributed control architecture.
Modeling, Identification and Air Flow Control of a low pressure Fuel Cell Stack with a DC Blower

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An existing MATLAB/Simulink model of a high pressure direct-hydrogen fuel cell will be modified to model the behavior of a small (2.5 kW, 24 cell) low pressure (near ambient) fuel cell stack. This new model is validated on a physical system at the Fuel Cell Control Laboratory. We review the basic principles of the reactant flow control problem in Fuel Cells and summarize the development, challenges, and results of the low-pressure air flow control experiment. The study entails system identification, modeling, control and experimentation on a fuel cell system to better understand transient operation. This project is funded by the Automotive Research Center (ARC) and the National Science Foundation (NSF).
Optimal Capacity Management in Stochastic Market Demands

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An optimal solution, based on Markov decision theory, is presented for the capacity management problem with a non-stationary stochastic market demand with a time delay between the time capacity change is ordered and the time it is delivered. The optimal policy in this paper is presented as optimal boundaries representing the optimal capacity expansion and reduction levels inspired by optimal inventory interval policy. The effects of change in the cost function parameters and the delay time on the optimal boundaries are presented for a capacity management scenario. The major differences between this research and the ones in inventory control lie in two folds. One is the fact that unlike inventory, capacity levels can be reduced according to the market demand. The other one is the novel approach presented in this paper to solve the delay problem which unlike the inventory control does not account for the cumulative unmet demand as a decision factor. Capacity management with policy refinement is also introduced as a sub-optimal solution for a Geometric Brownian market demand, and numerical examples are presented to represent the solutions.
The microstructure of composite materials can be tailored to produce desired mechanical properties. This work presents a design methodology for the development of periodically layered structures with desired plane harmonic wave propagation characteristics. The results are verified using time simulations.
A Methodology for Generating the Part Handling Logic Control of a Flexible Manufacturing System

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In this research, we present a methodology for generating the modular logic control for the part handling of a flexible manufacturing system given a model of the plant and a workplan for each part entering the system. The model of the plant and of each of the workplans for this system will be written in sequential function charts (SFC). Given this information, the logic control for the part handling of a flexible system can be generated in SFC using the methodology we are presenting. By generating this logic using our methodology, it will be guaranteed to be live, safe, and reversible.
Nested Plant/Controller Optimization with Application to Combined Passive/Active Automotive Suspensions

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A system-level, two degree-of-freedom linear and time-invariant quarter-car model is used to simultaneously optimize the active and passive subsystems in a car suspension. The model’s ability to correctly capture the influence of the passive suspension stiffness on the mean square rattlespace is shown to depend on the ground disturbance model. Nested optimization, a strategy which guarantees system-level optimality, is presented and used to find the system-optimal combined passive/active suspension design. This design exhibits superior performance compared to the traditional purely passive and purely active suspension designs because it accounts for the coupling between the passive and active suspension optimization problems.
Development of Advanced Methodologies for Internet-Distributed Simulation

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Previous ARC research has established the fundamental need for and framework for network-distributed simulation. Gluing algorithms were established that represent the foundation upon which to interconnect dynamical systems. Current research is focused on building an applicable distributed simulation environment. Our efforts are directed in three directions. First, we introduced alternate forms of glue that may be more amenable to implementation with legacy code. In addition, we have developed a general and efficient model description for simulation, using XML. Finally, we worked on the design of a distributed architecture in which SOAP is adopted for platform-independent communication.
The problem of design targets reduction and balancing among subsystems is addressed. A new approach is proposed that aims at reducing the number of targets used to quantify the performance of an engineering system, consisting of several subsystems, using the properties of system norms. The proposed approach also provides a systematic means of balancing the cascaded targets among the constituent subsystems in order to deliver the desired system performance. The approach is illustrated on a simple example featuring coupled beams.
Terrain Characterization for Durability Predictions

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Currently, the accuracy achieved by the US Army in predicting durability of their ground vehicle components is extremely poor. The terrain specification standards used by the army lack the richness needed to get accurate loading time histories. This in turn affects the fatigue life predictions by a very large factor.

This project tries to study the terrain-vehicle model coupling in detail. Both, the "stochastic terrain roughness model" as well as the "multi-body simulation model" need to be of comparable fidelity for accurate results. The effects of various terrain characterization methods on the suspension forces of a 'half-car' model are analyzed. It is realized that methods used to characterize paved roads are not suitable to characterize off-road terrains for durability purposes. From the results, some insight is gained towards developing appropriate "terrain-vehicle" models. The future work would be to come up with some standardized specifications to be given to ground vehicle manufacturers to help design components with more accurate durability estimates.
Ethernet as a Control Network: Guidelines and Implications

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Centralized point-to-point architectures are increasingly being replaced by distributed common-bus systems to address issues such as the interchangeability, reliability, and interoperability. To date, guidelines to optimize the performance of networked control systems have not been clearly defined. Because of its low cost, availability, and higher communication rates, Ethernet is potentially the most practical network solution. The non-deterministic nature and collision detection mechanism used by Ethernet to resolve contention is one of the drawbacks to its use as a control network, because response time magnitudes cannot be guaranteed. In this presentation, we describe the implications of using Ethernet as a control network and present a set of guidelines describing what conditions are necessary for the successful use of Ethernet as a control network.
Modeling of bladed disks assemblies in presence of periodic frictional contact

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In this work, a family of 3-D models of flexible friction dampers is introduced for the prediction of the forced response of turbomachinery blades having periodic 3-D frictional constraints. The complex dynamics of the contacting interfaces feature in-plane stick-slip phenomenon, variable normal load, and in extreme circumstances separation of the two contacting bodies. The forced response of the blade is analyzed with a multi-harmonic frequency/time method which is adapted to the study of simple, cyclic systems as well as large, mistuned assemblies. Numerical simulations of the behavior of such friction damped systems are presented and analyzed.
Analysis and Cancellation of Vibration Feedthrough in Joystick Controlled Vehicles

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Joystick-controlled vehicles, e.g. helicopters, bulldozers and tanks often suffer from a problem called biodynamic feedthrough, a vibration caused by the inertia forces acting on the operator’s body. To eliminate such oscillations, the construction of a force-reflecting joystick and a model-based controller was proposed. In initial studies, the operator was modeled as a lumped second order system. The feedthrough phenomenon was demonstrated for this scenario on a Ride Motion Simulator and on a vibration test bed. Feedthrough cancellation was realized on the test bed. In forthcoming studies, the cancellation algorithm will be extended to human subjects performing tracking tasks.
Numerical Simulation of Contorted Cables

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The objective of this research is to simulate efficiently the nonlinear dynamics of large deformations in cables. The challenges include implementing an adaptive code: 1) modeling the cable as being perfectly flexible in high tension zones for reduced computational effort while as a “rod” in low tension zone with pronounced flexural and torsional effects, 2) modeling cable self-contact and intertwining, and 3) modeling fluid interactions (like vortex-induced vibrations) and elastic surface contact. The applications range from sub-sea cable deployments to nucleic acid’s stereo-dynamics.
Real-time Simulation of Tracked Vehicles

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This study is motivated by the need to develop a high mobility model of tracked vehicles that can be used in a real time simulator and controller design. The challenges in modeling tracked vehicles result from difficulties in characterizing the mechanics and surface topology of the terrain, the nonlinear mechanics of the track, the mechanics of track-terrain interaction, and the coupling to the remainder of the vehicle. To reduce the extensive numerical effort, this study contributes simple analytical approximations of track-terrain interaction that then lead to real-time computations of tracked vehicle response.
Computing Equilibria on Superpositions of Logarithmic-radial Potential Fields

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Many distributed manipulation systems are capable of generating planar force fields which act over the entire surface of an object to manipulate it to a stable equilibrium within the field. Passive air flow and other physical phenomena, naturally generate force fields through the linear superposition of logarithmically varying radial potential fields. The main advantage of these fields is that they are realizable through very simple actuation. However, they do not lend themselves to analytical prediction of net forces or equilibria. This paper presents an efficient means of numerically computing the net force and moment exerted by such fields on objects composed of multiple simple shapes, as well as efficient means of finding equilibrium points on these fields.
Reliable on-line vehicle parameter estimation is important for reduced emissions, increased fuel efficiency and enhanced safety and drivability of Heavy-Duty Vehicles. Mass and road grade are of particular concern for identification of longitudinal dynamics of the truck. The challenge arises from large variations of mass in different loading scenarios for an HDV together with the time-varying nature of road grade and uncertainties in available measurements. In this presentation we first summarize some of the existing estimation schemes for time-varying parameters in general and for mass and grade in particular. We then present a novel time-varying least square estimation scheme for simultaneous estimation of mass and time-varying grade. Accurate mass estimation and good tracking of time-varying grade is demonstrated in simulations and experimental data.