2005 SUMMARY OF ENGINEERING RESEARCH

A Report of Activities during 2004

This .pdf is part of the larger 2005 Summary of Engineering Research, available on the Web at www.engr.uiuc.edu/research and on CD-ROM. The Summary of Engineering Research represents the extensive engineering research program conducted in 2004 at the University of Illinois at Urbana-Champaign. Detailed statistics about research in the College of Engineering are included in the Directory of Engineering and Engineering Technology Programs and Research, published by the American Society for Engineering Education, Washington, D.C.

How to Use the Summary of Engineering Research: Research projects are listed by title, followed by the names of the investigators and the sponsoring agencies. Projects are sorted by major topic areas. Project descriptions are brief. Additional information on each project may be obtained from the investigator in charge (denoted by an asterisk). Mailing addresses are provided on the introductory page.

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Aerospace engineering requires depth in the engineering sciences and systems integration of technology contained in vehicles for commercial aviation, space flight, and national defense. Accordingly, research activities in the Department of Aerospace Engineering* encompass a wide range of technical areas in aerospace engineering and related engineering disciplines. Through its research program, the department maintains a prominent position in the rapidly changing environment of aerospace technology while educating future engineers for leadership roles in aerospace.

Active research programs include applied aerodynamics, composites, aircraft icing research, structural dynamics, dynamic fracture, aeroelasticity, stochastic dynamics, combustion, computational fluid dynamics, supersonic flow diagnostics, chemical propulsion, electric propulsion, chemical lasers, optimal orbit analysis, optimal spacecraft trajectories, two-phase flow, systems and control, autonomous vehicles, and information technology. The department promotes a strong interaction with aerospace industries and government agencies, which sponsor many of its research projects. The department also maintains close cooperation in research and education with other departments and research laboratories in the College of Engineering.

Supercomputer access, departmental workstations, and high-speed networking, along with a significant investment in modern experimental facilities, provide opportunities for computational research activities in various areas, including fluid dynamics, aerodynamics, structural analyses, vehicle performance simulation, space mission analyses, and optimization of high-energy lasers. Current major research initiatives include aircraft icing safety, self-healing composites, and research for the Center for Simulation of Advanced Rockets in the areas of fracture problems, crack propagation, and the combustion processes of a solid propellant rocket system.

*Formerly the Department of Aeronautical and Astronautical Engineering.

Faculty and Their Interests

Joanna M. Austin
Fluid mechanics, high-speed flow, combustion

Lawrence A. Bergman
Structural dynamics and control, stochastic dynamics, system identification, smart structures

Michael B. Bragg
Aerodynamics, flight mechanics, aircraft icing, unsteady aerodynamics

John D. Buckmaster
Fluid mechanics, applied mathematics, combustion

Rodney L. Burton
Electric and advanced chemical rocket propulsion, space exploration, hypersonic flows, hypervelocity accelerators

Bruce A. Conway
Celestial mechanics, optimal control, numerical optimization

Victoria Coverstone
Space mission design, optimal spacecraft trajectories

Gregory S. Elliott
Thermal and fluid sciences, laser diagnostic techniques, experimental supersonic and subsonic fluid mechanics, propulsion, combustion, plasmas

Philippe Geubelle
Aerospace system design, robotics, spacecraft control

Harry H. Hilton, Professor Emeritus
Solid mechanics, viscoelasticity, composites, structures, dynamics, numerical analysis, computer-aided engineering, aeroelasticity, structural control

John Lambros
Static and dynamic fracture mechanics

Ki D. Lee
Computational fluid dynamics, aerodynamics, transonic flows, design optimization
Eric Loth
Two-phase flow and compressible flow, fluid mechanics, micro-vehicles

N. Sri Namachchivaya
Nonlinear dynamical systems, including bifurcation theory, stability analysis, stochastic processes, structural dynamics

Natasha Neogi
Aerospace software, hazard elimination using backwards reachability techniques in discrete and hybrid models

John E. Prussing
Orbital mechanics, spacecraft trajectories, optimal control systems

Michael S. Selig
Applied computational and experimental aerodynamics; airfoil design and analysis; aircraft design, performance, stability, and control; flight simulation; wind energy

Lee H. Sentman, Emeritus
Chemical lasers, nonequilibrium flow modeling, molecular energy transfer, kinetic theory and statistical mechanics, fluid dynamics, space environmental effects on satellite motion

Wayne C. Solomon, Emeritus
Gas-phase kinetics, space systems, high-energy lasers

Petros G. Voulgaris
Robust control of time-varying and nonlinear systems, general systems theory, estimation and identification of complex systems, emphases on aerospace applications

Scott R. White
Manufacturing of composites, solid mechanics, composite materials, smart structures and materials

Aerodynamics

Hyersonic Transition and Turbulence with Nonequilibrium Thermo-Chemistry
J. M. Austin,* G. Elliott
jmaustin@uiuc.edu, elliottg@uiuc.edu
Multiuniversity Research Initiative, U.S. Air Force Office of Scientific Research

Understanding the relationship between ice accretion geometry and the resulting aerodynamic penalty is important for many applications, including establishing procedures to determine the most critical ice accretion shape for aircraft certification. Research is being conducted under this grant to improve our ability to accurately measure and predict airfoil performance with simulated ice. The presence of the simulated ice causes large regions of unsteady separated flow that make measurement of the aerodynamic performance and computational predictions difficult. First, this study is...
using detailed measurements of the turbulent wake and a reevaluation of the wake-survey method to improve wake measurement for airfoils with large unsteady wakes. Unsteady pressure measurements and PIV techniques are being used to understand the flowfield over an iced airfoil near stall including the 2-D and 3-D characteristics.

**Simulation Methods for Iced-Aircraft Aerodynamics**

M. B. Bragg,* A. P. Broeren, L. Blumenthal

mbragg@uiuc.edu

NASA Glenn Research Center

The objective of this research is to develop accurate aerodynamic simulations of ice accretions for aircraft within a known uncertainty. Currently aircraft certification and other tests use various means to simulate ice accretion, many of which are not well documented. This research will identify the critical physics for ice accretion aerodynamics and propose simulation methods based on an understanding of the dominant ice shape/flowfield features. Wind tunnel testing in three different facilities will be used at NASA, ONERA, and Illinois in conjunction with CFD studies to develop and validate the simulation methods. Results from this research will also be used to define the fidelity needed when simulating complex 3-D ice features when performing CFD modeling or computational ice accretion methods.

**Unsteady Flow about an Iced Airfoil**

M. B. Bragg,* J. Jacobs

mbragg@uiuc.edu

NASA Glenn Research Center

The prediction of the aerodynamic performance of airfoils and wings with ice accretion is complicated by the unsteady flow that exists near maximum lift. A major feature of this flow is the large separation bubble that occurs aft of the leading-edge ice horn. This experimental study will characterize the unsteady and three-dimensional behavior of this bubble using a specially constructed wind tunnel. Particle-image velocimetry (PIV) is being used to provide information on flow reattachment and details of the vortex structures.

**Yaw Control of a Lifting Body Reentry Vehicle at High Angle of Attack**

M. B. Bragg,* J. Merret

mbragg@uiuc.edu

NASA Johnson Space Center

The analysis of the yaw control of a lifting body reentry vehicle, simulating a future space station crew return vehicle, at high angles of attack is studied. As the angle of attack of a lifting body approaches 90 degrees, asymmetric vortex shedding from the nose begins to occur, which causes undesirable side forces on the body. This experimental study will analyze the effect of the vortex shedding on the control of the vehicle and develop flow control strategies. A six-component balance, oscillating model mount, pressure measurement, and surface flow visualization will provide details on the flow separation and side forces created by the asymmetric vortex shedding.

**Adaptive Laser Velocimeter Using Photo-EMF Sensors**

G. S. Elliott*

elliottg@uiuc.edu

Brimrose Corporation; NASA Langley Research Center, NASA SBIR 03-411

Photo-EMF sensors detect the motion of optical beat notes and generate photocurrents that are linearly proportional to the relative frequency difference between two intersecting laser beams. If one of the laser beams is the scattered light from a moving object, the frequency is changed relative to the reference beam by the Doppler shift. Once the Doppler shift frequency is measured, the velocity of the object can be determined. The goal of the current research program is to quantify the ability of photo-EMF sensors to measure velocity, investigate whether the sensor can be utilized for velocity measurements in flow fields, and evaluate the uncertainties associated with flow and solid body velocity measurements using photo-EMF sensors. Eventually these sensors may be incorporated in multi-element arrays, creating the possibility of instantaneously measuring an entire velocity field in a single image.

**Fundamental Physics and Practical Applications of Electromagnetic Local Flow Control in High-Speed Flows**

G. S. Elliott,* N. Glumac

elliottg@uiuc.edu

U.S. Air Force Office of Scientific Research, FA9550-04-1-0177

This is a multi-institution research project headed by Prof. Doyle Knight at Rutgers University (with Prof. Hong Yan) and includes collaborations with the University of Minnesota (Prof. Graham Candler) and the Institute of Theoretical and Applied Mechanics (Prof. Alexander Zheltovodov). The objective of the proposed research is to investigate unsteady laser, microwave, and combined laser/microwave energy deposition for localized flow control in high-speed flows. The proposed effort differs from previous investigations of energy deposition in its focus on localized, as opposed to global, flow control.
and is part of an emerging broader research thrust in electromagnetic local flow control (ELFC). The principal motivation for ELFC arises from a requirement of fast-response flow control systems for high-speed aircraft. As part of the proposed research program, experimental investigations will be conducted at the University of Illinois Urbana-Champaign campus for investigation of unsteady laser, microwave, and combined laser/microwave energy deposition in quiescent air (or other gas species) and high-speed flows. This experiment will consist of a pressure/vacuum chamber with optical access for the diagnostics used in the study and introduction of the laser beam used to create the plasma. Additionally, the experiment will be designed to allow the introduction of focused microwave energy to create plasma discharges. The second objective is to characterize the properties of the energy deposition process using the unique diagnostic capabilities, which we have developed at Illinois. This research will focus on conducting experimental measurements to develop improved models of unsteady laser, microwave and combined laser/microwave energy deposition for validation computational models developed by research partners. The third objective is to construct models and experimentally evaluate the capability of laser energy deposition for specific applications of local flow control in supersonic flows, namely, control of resonant pressure fluctuations in supersonic flow past an open cavity, control of shock wave turbulent boundary layer interactions, and control of shock-vortex interaction and vortex breakdown.

**High Repetition Rate Pulse-Burst Laser and Camera for Energy Deposition**

G. S. Elliott*
elliottg@uiuc.edu

*U.S. Air Force Office of Scientific Research, F49620-02-1-0283*

A high-speed camera and pulse-burst Nd:YAG laser system has been designed, assembled, and is currently being utilized for the development of novel diagnostic techniques and research associated with energy deposition and high-speed flows. This system allows a burst of laser pulses (for diagnostics and flow excitation utilizing laser energy deposition) and subsequent imaging at MHz rates. The laser is initiated with a cw Nd:YAG diode pumped laser, chopped with a programmable Pockels cell pulse shaper, and amplified by five Nd:YAG flashlamp stages. The system can provide a packet of pulses with over 28 mJ of energy with pulse separation variable from one microsecond and above. The laser and camera are being utilized in the study of energy deposition in supersonic flows and the development of temporally resolved flow visualization and quantitative diagnostics techniques of flow properties. The techniques developed will be applied to current research projects involving energy deposition for local flow control as well as other studies of research interest.

**The Study of Turbulence and Compressible Flows Using Molecular Filtered Based Diagnostics**

G. S. Elliott*
elliottg@uiuc.edu

*National Science Foundation, 0314402*

The class of laser-based diagnostic techniques developed as part of this program is centered on molecular-filtered-based diagnostic techniques. In general, molecular-filtered-based techniques are a class of diagnostics that introduce laser light from an injection seeded Nd:YAG laser into a flow field and collect the scattered light from particles (artificially seeded into the flow) or the molecules (i.e. air, nitrogen, gas mixture) naturally present in the flow. The scattered light is then passed through a molecular filter and collected onto a CCD camera. Depending on the specific molecular filter technique, characteristics of the recorded intensity allow flow properties such as velocity, temperature, density, and pressure to be measured. The diagnostics developed as part of this program have been used to study compressible flows, blast waves, and plasmas.

**Bump Compression Model Test**

E. Loth, J. C. Dutton*
loth@uiuc.edu, j-dutton@uiuc.edu

*Boeing, Phantom Works (St. Louis)*

This project investigates the fluid dynamics associated with supersonic bump compression. In particular, a faired bump is placed in a Mach 3 wind tunnel to characterize its ability to favorably displace the boundary layer to the side. The motivation is an external compression surface for mixed-compression or external-compression inlets. Diagnostics include shadowgraphs, LDV, and pressure distributions. In addition, large eddy simulations are being conducted to understand the details of the unsteady three-dimensional structures within this complex supersonic turbulent boundary layer.

**Simulation of Icing Technology on Turbomachinery**

E. Loth,* M. Bragg
loth@uiuc.edu

*Ohio Aerospace Institute, CCRP 2003-05*

The objective of this study is to compute aerodynamic flow-fields associated with an inlet guide vane and a first
rotor stage (in a rotating coordinate reference frame) and to use this information to simulate droplet trajectory and impact that can lead to icing. In particular, this investigation will consider effects of nonhomogenous turbulence diffusion and poly-disperse droplet sizes with respect to droplet impingement physics. In addition, calculations will explore the ice shape growth for the unique characteristics of the thin sharp (small leading-edge) radius airfoil sections used in these blades.

**Virtual Icing Research Tunnel**

E. Loth*
loth@uiuc.edu
*NASA Glenn Research Center, NAG 3-2623

This two-pronged approach seeks to simulate the two-phase flow of the NASA Glenn Icing Research Tunnel and to develop an effective virtual reality environment for understanding and interaction with the numerical solutions. The first objective focuses on properly predicting the air turbulence and the water droplet distribution produced by spray bars in the NASA Glenn Icing Research Tunnel used to simulate clouds for icing tests. A computational fluid dynamics methodology is being developed that treats the droplets in Lagrangian form and the tunnel aerodynamics in Eulerian form. The second objective employs advanced graphical techniques to render a stereoscopic image with CAVE type facilities. This virtual reality representation allows immersive interrogation of the flow features.

**Use of a Four-Hole Unsteady Cobra Pressure Probe to Determine the Wake Characteristic of Rotating Objects**

M. S Selig,* S. Mallipudi
m-selig@uiuc.edu
*NASA Ames Research Center

This effort focuses on the wake characteristics of rotating objects found on U.S. Navy warships, and their effects on shipboard anemometer sensors. Areas of interest include investigating static and rotating sharp-edged bluff body wakes and effects of ship airwakes on anemometer indications. Three dimensional unsteady wind velocity is measured by a four-hole Cobra Pressure Probe, which is traversed in the wake of a 1/50 scale model of a typical radar reflector. Parameters investigated included wind speed, wind direction, radar size, emitter porosity, and emitter rate. Knowledge gained will be implemented on U.S. Navy ships, possibly through a wake detection algorithm.

**Airfoil Design, Analysis, and Validation**

M. S. Selig,* B. A. Broughton, J. B. Brandt
m-selig@uiuc.edu
*National Renewable Energy Laboratory; Luna Rossa; Continuum Dynamics, Inc.

For more than 100 years, airfoil design has captured the interest of practitioners of applied aerodynamics. The field continues to be fueled by the ever-growing combination of airfoil design requirements for unique applications. Low-noise airfoils for use on wind turbines, efficient high-lift airfoils for sailing, and new challenges in airfoil design for unmanned aerial vehicles are just a few examples. In each case, design and subsequent computational analysis and validation through wind tunnel testing is essential to minimize risk and maintain an economic cost advantage. This process of airfoil design, analysis, and validation continues to be refined at the University of Illinois at Urbana-Champaign.

**Development of a Hybrid Inverse Design Method for Complex Aerodynamic and Hydrodynamic Geometries**

M. S. Selig,* B. A. Broughton
m-selig@uiuc.edu
*Oracle BMW Racing

The design of complex geometries such as aircraft wing/fuselage combinations has traditionally followed a trial-and-error approach that does not always lead to the most efficient design. The availability of a general inverse design scheme would significantly reduce the number of iterations and the associated investment in time required for a new design. A 3-D inverse design methodology has been developed that is suitable for the inverse design of both lifting and nonlifting bodies, as well as more complex configurations with multiple components. The inverse scheme allows the designer to prescribe aerodynamic characteristics and geometric features simultaneously.

**Effects of Wing-Tip Planforms on the Development Tip Vortices**

M. S. Selig,* R. W. Deters
m-selig@uiuc.edu
*University of Illinois

Tip vortices, whether they are from a wing of rotor blade, play an important part in aircraft design. Much of the information available on the effects of wing-tip vortices influence the flow directly adjacent to the wing tip causing an increase in lift near the tip. Formation of tip vortices is dependent on the wing-tip planform. To study the effect of...
Tip vortices on the wing near the tip, different wing-tip shapes are being analyzed using CFD and wind tunnel testing.

**Low Reynolds Number Airfoil Design and Wind Tunnel Testing**
M. S. Selig,* J. B. Brandt, P. R. Gush
m-selig@uiuc.edu

This research deals with enhancing the performance of airfoils for operation at low Reynolds numbers. For such airfoils, boundary-layer transition takes place in a complicated manner as the laminar boundary layer separates, becomes unstable, transitions to turbulent flow, and reattaches to the airfoil to form a laminar separation bubble. High drag produced by the bubble is largely responsible for the performance degradation at low Reynolds numbers. Detailed investigations are under way to document the behavior of the laminar separation bubble in support of efforts aimed at improving performance predictions at low Reynolds numbers.

**Wind Tunnel Testing of Low Reynolds Number Propellers**
M. S. Selig,* J. B. Brandt, K. Tehrani
m-selig@uiuc.edu

This research involves testing the performance of low Reynolds number propellers. The data gathered will include the thrust produced, the power required, and the resulting efficiency over a range of advance ratios. The data will be collected to serve two main purposes. First, the propeller efficiencies can be combined with the remaining efficiencies of the propulsion system to yield more accurate predictions of the total propulsive efficiency. Further, collecting this data for a variety of propellers will allow favorable propeller characteristics to be identified for low Reynolds number applications, aiding in the design of a more efficient propeller.

**Aeroelasticity**

**Control of Piezoviscoelastic Lifting Surfaces**
H. H. Hilton,* C. E. Beldica*

A systematic analytical study has been initiated to investigate static and dynamic control of lifting surfaces through material and electric damping and control.

Sensitivity studies to determine significant parameters are in progress to control creep divergence, flutter, control surface effectiveness, and the impact of aerodynamic noise.

**Designer Materials Tailored for Structural Control of Aeroelastic Phenomena Using Inherent Viscoelastic Damping Properties**
H. H. Hilton*
h-hilton@uiuc.edu

Control of divers aero-viscoelastic phenomena, such as wing divergence, control reversal and flutter, and panel flutter and buckling due to aerodynamic noise, is being systematically investigated analytically through inverse approaches. Control is achieved through optimum viscoelastic composite material damping and is augmented by piezoelectric devices. The use of material damping in the control sequence leads to lighter weight aerospace structures.

**Torsion-Bending Flutter of Viscoelastic Wings**
H. H. Hilton*
h-hilton@uiuc.edu

An analysis of subsonic and supersonic torsion-bending flutter (including rotary inertia, shear, and hearing effects) of a time-dependent linear viscoelastic lifting surface consisting of either a Bernoulli-Euler or a Timoshenko beam, is formulated using aerodynamic strip theory. Complex moduli models for aluminum are characterized as functions of temperature and frequency by fitting Chebyshev polynomials to actual material experimental data. The flutter analysis is carried out in the complex plane and a computerized iterative method for the determination of flutter speeds and frequencies is developed. The influence of viscoelastic material properties (storage and loss moduli), temperature, rotary inertia, and shear effects is evaluated. Finite-element protocols are formulated and evaluated.

**Accurate and Conservative Fluid-Structure Interaction Techniques**
R. Jaiman, P. Geubelle,* J. Jiao, E. Loth*
geubelle@uiuc.edu, loth@uiuc.edu

This project focuses on improved description of fluid-structure interactions, particularly for high-speed flows and shock waves. The investigations have shown that a
common refinement technique allows orders of magnitude improvement in accuracy while maintaining conservation of the interface stresses. Applications under development include grid adaptation based on the interface information transfer and application to various fluid structure problems.

Aerospace Systems Design

Cost Modeling of Aerospace Vehicles
rburton@uiuc.edu
University of Illinois Critical Research Initiative

A Commercial Cost Model has been developed that empirically predicts aerospace vehicle operating costs as a function of thrust power. This model is being applied as a design tool for space launch vehicles.

In-Space Technology Assessment and Low-Thrust Trajectory Analysis
R. L. Burton,* V. L. Coverstone* rburton@uiuc.edu, vcc@uiuc.edu
NASA Marshall Space Flight Center; Science Applications International Corp., GS-23F-0107J

This research develops a comprehensive systems approach to the design of powered spacecraft for cislunar, planetary, and interstellar scientific space missions. The analysis includes chemical and low-thrust propulsion (for such uses as electric or solar sails); low-thrust trajectory analysis, including planetary gravitational assist; and structural, safety, and cost analysis. The goal is to provide a model for the design and selection of NASA space science missions beginning in the 2010 time frame.

Astrodynamics

Minimum-Fuel Recovery of Satellites that Fail to Achieve Geostationary Transfer Orbit
B. A. Conway* bconway@uiuc.edu
University of Illinois

In 1995, a partial failure of a launch vehicle upper stage left the Koreasat 1 spacecraft in an orbit 6351 km lower than the planned geostationary transfer orbit (GTO). A Lockheed-Martin company team performed a rescue that put the satellite on station, but it consumed about half of the satellite’s fuel supply for altitude control and station keeping. The sequence of maneuvers used was not determined optimally. There have been several subsequent failures of spacecraft to reach GTO. In this research scientists are developing an algorithm to find optimal, intermediate-thrust trajectories for such spacecraft, so that they may be recovered using minimum fuel, thus maximizing their lifetime.

Near-Optimal Low-Thrust Interplanetary Trajectories Found Using a Genetic Algorithm
B. A. Conway,* B. J. Wall bconway@uiuc.edu
University of Illinois

Low-thrust engines, i.e. engines with thrust acceleration smaller than 0.01 g, have recently begun to prove their usefulness for spacecraft propulsion. When using low-thrust engines that operate continuously, the mission designer must determine the optimal time-history of the thrust pointing direction in order to take the spacecraft from one planet to another. Finding this optimal control numerically can be very problematic using conventional methods. A relatively recent method, the genetic algorithm, mimics natural processes such as selection and mutation to take a population of random solutions and “evolve” to a near-optimal solution for the trajectory. The method is being applied to Earth–Mars trajectories to determine its usefulness and accuracy.

Optimal Low-Thrust Trajectories for Asteroid Interception and Rendezvous
B. A. Conway,* A. Maxham bconway@uiuc.edu
University of Illinois

The recent NEAR spacecraft mission demonstrated dramatically the feasibility of asteroid rendezvous and landing. Asteroids are interesting bodies in their own right, but also pose concern regarding future impact of an asteroid with the Earth. Researchers must know much more about Earth-approaching asteroids in order to develop hazard mitigation strategies. This team has already developed a tool for optimal low-thrust asteroid interception. In this research, optimal low-thrust trajectories will be developed for two scenarios: the spacecraft is to be placed in orbit about the asteroid or the spacecraft is to land on the surface of the asteroid.

* Denotes principal investigator.
Control Response Methodology for the Ultra Large Solar Sail Technology
V. Coverstone,* R. Burton,* J. Hargens, B. Hartmann
vcc@uiuc.edu, burton@uiuc.edu
NASA Marshall Space Flight Center; CU Aerospace

Ultra Large Solar Sail Technology, or UltraSail, is a nontraditional solar sail concept achieved by combining formation-flying microsatellites with an innovative solar sail architecture. This sail architecture can achieve controllable sail areas approaching 1 km². UltraSail extends the deep space capability of solar sails beyond what is possible with current sail technology. A control response methodology and mission scenarios for UltraSail system are being developed.

Integrated Technology Assessment
V. Coverstone,* R. Burton,* J. Hartmann, B. Woo, E. Sklyanskiy
vcc@uiuc.edu, rburton@uiuc.edu
Science Applications International Corporation

Optimal trajectory data to support the development of integrated space technology assessment conceptual models (ICM) for inner and outer planetary missions are generated. The research focus is on the trajectory development effort required for the optimization of high delta-V missions (e.g. Titan Explorer mission, Neptune Orbiter mission, and Kuiper Belt Rendezvous) using high specific impulse electric thrusters. Many key parameters (e.g. specific impulses, system power level, trip time, etc.) are considered, including trajectories that require Venus gravity to assist as part of the optimization process. Resultant trajectory data are then integrated into an ICM spreadsheet environment.

Optimal Low-Thrust Trajectory Design for Mars Sample Return Mission
V. Coverstone,* B. Woo, J. Hartmann
vcc@uiuc.edu
Science Application International Corporation

Optimal mars sample return (MSR) trajectories are designed using the indirect optimization software, Solar Electric Propulsion Trajectory Optimization Program (SEPTOP). Various mission scenarios are reviewed, and the best scenario is compared with a conventional chemical mission. Several solar electric propulsion (SEP) engines and launch vehicles are compared as well as various arrival conditions at Mars. The objective of this research is to demonstrate strengths and weaknesses of the SEP engine in an MSR mission.

Solar Sail Escape Trajectories
V. Coverstone,* J. Prussing, J. Hartmann
vcc@uiuc.edu, prussing@uiuc.edu
University of Illinois

Current research involves the optimization of spacecraft trajectories using solar sail propulsion technology. Novel escape trajectories have been found using direct optimization methods. These locally optimal trajectories employ a counter-intuitive strategy for generating escape that can provide substantial improvements in escape time. A method for rapid generation of feasible solar sail escape trajectories is also being explored using a technique known as a Rapidly Exploring Random Tree. Development of a robust feasible trajectory generator that is capable of capturing counter-intuitive behavior is useful for providing initial guesses to gradient-base optimization methods, whose convergence is oftentimes highly sensitive to initial guess.

Comprehensive Optimal Impulsive Rendezvous Using the Primer Vector
J. E. Prussing,* S. L. Sandrik
prussing@uiuc.edu
University of Illinois

More than one optimal impulsive rendezvous solution can sometimes be found for the same transfer time and boundary conditions. A comprehensive study is being undertaken to determine all possible optimal solutions, including multi-impulse and multi-revolutions trajectories. Both the coplanar and inclined circle-to-circle cases are being thoroughly studied. A combination of Primer Vector Theory and a genetic algorithm is used.

Optimal Bi-Elliptic Transfers Using Primer Vector Theory
J. E. Prussing,* E. E. McCleery
prussing@uiuc.edu
University of Illinois

Optimal bi-elliptic impulsive transfers (coplanar and non-coplanar) have historically been determined by direct minimization of the total velocity change. Primer Vector Theory provides an indirect method using first-order necessary conditions. Analytical solutions are being investigated.

*Denotes principal investigator.
Second-Order Necessary Conditions and Sufficient Conditions Applied to Continuous-Thrust Trajectories
J. E. Prussing,* S. L. Sandrik
prussing@uiuc.edu

University of Illinois

A solution to an optimal spacecraft trajectories problem may or may not actually be optimal. They are typically obtained by either satisfying only first-order necessary conditions (indirect method) or by direct optimization of the cost followed by verification that the first-order necessary conditions are satisfied. But there is no guarantee of an optimal solution unless second-order necessary conditions and sufficient conditions are satisfied. In particular, the Jacobi no-conjugate-point necessary and sufficient condition is typically not tested due to the difficulty in doing so. A new procedure for applying second-order conditions is described and applied to several published continuous-thrust trajectories.

Combustion

Effects of Nonuniform Flows on Propellant Flames
J. Buckmaster*
limey@uiuc.edu

U.S. Air Force Office of Scientific Research, F49620-96-1-0031; DOE Center for Simulation of Advanced Rockets

Researchers are examining propellant flames supported by heterogeneous propellants in which time-periodic nonuniform flows are applied to simulate the effect of acoustic and turbulent disturbances in the rocket flow. These flows distort the flame structure, affect the mixing, and have a substantial influence on the heat flux to the propellant surface. This, in turn, affects the propellant regression rate.

Sublimit Combustion and Flame Strings
J. Buckmaster,* M. Short (Theoret. & Appl. Mech.)
limey@uiuc.edu

U.S. Air Force Office of Scientific Research, F49620-96-1-0031; National Aeronautics and Space Administration, NAG 3-1704

Edge flames are constructed by cutting a flame placed in a premixed fresh/fresh counterflow of reactants to form semi-infinite flame sheets. The edge of these sheets propagates in a wave-like fashion and defines the edge flame. When the Lewis number of the deficient reactant is small, the flame structure behind the edge is unstable and breaks up into flame strings, cylindrical flames that have been observed in microgravity experiments. The strings can survive straining rates that quench a one-dimensional flame and are sublimit structures.

Two-Dimensional Smolder Waves
J. Buckmaster,* Y. Zhang
limey@uiuc.edu

U.S. Air Force Office of Scientific Research, F49620-96-1-0031

A great deal of work has been done on one-dimensional smolder waves in which the area of the smolder front is fixed. Researchers are concerned with what happens when smolder is initiated in a restricted domain so that not only does it have the opportunity to move forward, it has the opportunity to move sideways, enlarging the area of the smolder front. Calculations are designed to explain what controls the sideways spread and what can prevent it from occurring.

The Effects of Convective Flows on Premixed Edge-Flames
J. Buckmaster*
limey@uiuc.edu

U.S. Air Force Office of Scientific Research, F49620-96-1-0031

A simple edge-flame model is examined for which the underlying one-dimensional system defines a deflagration. It is shown that edge oscillations can be induced by the imposition of an on-edge convective flow. On the other hand, imposition of an off-edge flow tends to suppress oscillations.

Convective Burning of Cracks in Energetic Materials
B. Roe, M. Short* (Theoret. & Appl. Mech.), P. Geubelle*
geubelle@uiuc.edu, short1@uiuc.edu

DOE Center for the Simulation of Advanced Rockets

As part of the activities of the Center for the Simulation of Advanced Rockets (CSAR), we are developing a 3-D multiphysics code to simulate the physical phenomena taking place in a notch present in a burning energetic material. Special emphasis is placed on capturing the aeroelastic coupling between the deformable solid and the notch flow.
Mesoscale Simulation of Combustion in a Damage Solid Propellant
K. Srivanasan, T. Jackson, K. Matous, P. Geubelle
geubelle@uiuc.edu, tlj@csar.uiuc.edu
DOE Center for the Simulation of Advanced Rockets

In this project, we are developing a multiphysics code to simulate at the mesoscale the propagation of a burning front in a damaged solid propellant (SP). The approach relies on a combination of a level set method used to capture the motion of the fluid/solid interface, and on the extended finite element method (X-FEM) to model the structural deformations of the SP.

Computational Fluid Dynamics

3-D Inverse Design Using Sectional 3-D Analysis
K. D. Lee, N. J. Sung, J. Chung
kdlee@uiuc.edu
University of Illinois

The objective is to develop an efficient three-dimensional (3-D) inverse design method that is based on sectional three-dimensional (S3-D) analysis. The inverse design method searches for geometry of aerodynamic configurations such as wings and compressor blades that produce desired performance characteristics through a numerical optimization process. The flow is modeled with high-level physics such as the 3-D Navier–Stokes equations to improve confidence on the design results. One of the disadvantages of numerical optimization is the requirement for a large number of function calls in its searching process, which can be overcome by the concept of S3-D analysis. In the present S3-D design, the design is performed in two dimensions but is based on 3-D physics.

Aerodynamic Design with an Analytical Asymptotic Solution Approach
K. D. Lee, J. Shim, A. Verhoff
kdlee@uiuc.edu
NASA Glenn Research Center, NAG 3-2314

An efficient aerodynamic shape optimization tool is being developed based on an analytical asymptotic flow solution and a genetic algorithm. The analytical flow solution is formulated in a streamline coordinate system, wherein the governing equations are transformed into a nonhomogeneous Cauchy-Riemann system. A sequence of coordinate transformation, mapping, and asymptotic expansion places the governing equations in a form suitable for classical mathematical techniques. The method has a particularly strong potential in aerodynamic design application, because the objective function of design can be evaluated at a very low cost. The efficiency of the analytical flow solver makes it an affordable tool to be used with stochastic optimization methods, such as genetic algorithm.

Dynamical Systems

Novel Passive Control Methods for Aerostructures
L. A. Bergman, A. F. Vakakis (Mech. & Indus. Engr.), D. M. McFarland, Y. S. Lee
lbergman@uiuc.edu
U.S. Air Force Office of Scientific Research, FA9620-01-1-0208

We are applying concepts of nonlinear localization and energy pumping to the vibration and shock isolation of structures representative of aircraft components. To achieve this, we use both analysis and experiments to gain a better understanding of the fundamental physics underlying both nonlinear localization and energy pumping. The research team is extending the energy-pumping concept to flexible continuous structures and to certain nonlinear systems.

A New Concept for LCO Suppression Based on Nonlinear Energy Pumping
U.S. Air Force Office of Scientific Research, FA9550-04-1-0073

Application of a nonlinear energy sink (NES) to an aeroelastic system has been successfully demonstrated by analysis and simulation. It was shown that the NES could...
be designed to drastically and robustly reduce, or even eliminate, limit cycle oscillations. Wind-tunnel tests on a model wing located at Texas A&M University are planned for summer, 2005.

**Biomolecular Dynamics**

N. S. Namachchivaya,* J. Park
navam@uiuc.edu
University of Illinois

This work is motivated by the study of long-term behavior of nonlinear oscillatory dynamical systems with multiple scales in time such as biomolecular dynamics. Mathematical and statistical modeling and developing efficient simulation algorithms to understand conformational dynamics of biomolecules are the main goals of this project. Various diffusion models in practice are far too complex even for long-term simulation. We are working on methods to extract macroscopic essential features of such diffusion models. Transitions between two conformations are rare events. We are interested in developing novel algorithmic methods, based on transfer operator theory, that decompose the stat space into metastable sets. Transition path computation between these sets based on variants of the classical Wentzell-Freidlin theory is also of interest.

**Global Behavior of Nonlinear Aeroelastic Flat Panels in Supersonic Flow**

N. S. Namachchivaya,* S. Choi, K. Onu
University of Illinois

The interaction of aerodynamic forces with a flexible structure such as a panel can create complicated vibrational effects that may adversely affect overall aircraft performance. Large-amplitude flutter, buckling, and fatigue failure are all possible results of the flow-induced dynamics. Researchers investigate the effect of nonlineairities on the global dynamics of flat panels in supersonic flow. The first part involves modeling the aerodynamic forces and moments that act on the flight vehicle and the nonlinearities that are inherent in the panel. The second part is concerned with the effects of boundary-layer turbulence on the panel dynamics.

**Mixing of Passive S Tracers**

N. S. Namachchivaya,* K. Onu
navam@uiuc.edu
University of Illinois

This work is motivated by the study of motion of passive marker particles in an unsteady incompressible two-dimensional flow. The purpose of this study is to understand efficient mixing or stirring of passive marker particles in fluid due to small noise. They are useful in the study of mixing of chemicals in fluid flow and mixing of granular materials, both of which are important operations in the chemical, pharmaceutical, and ceramic industries. When two chemicals are independently introduced into a fluid, turbulent fluctuations provide an efficient mixing that enables chemical reactions to occur, hence enhancing, for example, combustion. Natural questions we would like to answer in this project are: What are the trajectories of passive marker particles of different color that are initially distributed within each region of the phase-space with different unperturbed flow characteristics? What are the probabilistic characterizations, such as the probability density function, of the passive marker particles?

**Noisy Nonlinear Nonsmooth Systems**

N. S. Namachchivaya,* J. Park, R. Sowers (Mathem.)
National Science Foundation, CMS-00-84944

Interactions of mechanical and structural systems with the boundaries are either of short duration, modeled as impacts, or sustained, necessitating contact descriptions, as in the presence of friction. Mathematically, such interactions result in nonsmooth nonlinear effects, which usually give rise to complex noise-induced oscillations. Our goal is to develop a general collection of mathematical techniques that can be applied to understand stability properties. We shall achieve this through several specific physically motivated problems, such as dead band or free play, dry friction, and stiction.

**Nonlinear Functional Differential Equations with Periodic Delay**

N. S. Namachchivaya,* L. Vedula, W. F. Lanford (Univ. of Guelph), H. J. Van Roessel (Univ. of Alberta)
National Science Foundation, CMS 03-44525

We investigate the effect of periodic time delay and noisy perturbations upon delay differential equations. These theoretical developments will be directly applicable to the study of machine tool chatter in the presence of noise and spindle speed variations. This work addresses the suppression of machine tool chatter.

**Reduction of Noisy Nonlinear Systems**

N. S. Namachchivaya,* K. Onu, J. Park, L. Vedula
National Science Foundation, CMS-03-01412

Many physical systems have nonlinearities and symmetries. Often there are additional small random perturbations, and one would like to develop techniques of stochastic dimensional reduction to find a simpler
model that captures relevant dynamics of the system. The goals of this project are the development of general techniques of stochastic averaging of randomly perturbed typical and relevant four-dimensional gyroscopic systems, autoparametric systems, and fluid dynamical system.

**Stability of Nonlinear Stochastic Systems**

N. S. Namachchivaya,* D. Kok, L. Arnold (Univ. of Breman), P. Imkeller (Humboldt-Univ. of Berlin)

*National Science Foundation, CMS-03-01412; U.S. Office of Naval Research, N001-15-005*

The primary concern in the analysis of nonlinear dynamical systems is the determination and prediction of steady-states or stationary motions or the invariant measures of the local random dynamical systems. The main goal of this research is to develop new mathematical techniques to determine their almost-sure (Lyapunov exponents) and moment (moment Lyapunov exponents) stability properties. The second objective of this project is to determine how these invariant measures can bifurcate due to various parameters.

**Flight Vehicle Synthesis**

**Computerized Flight Vehicle Synthesis**

H. H. Hilton*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications*

An overall systems concept using an integrated approach incorporating basic aerodynamic, guidance, control, propulsion, and structural principles is being used to develop comprehensive generalized simulation computer programs for flight vehicle synthesis. The purpose is to develop educational and research tools to be used in the teaching of and research in flight vehicle synthesis and optimization. Current capabilities include space vehicle flight programs, airplane missions, various structural programs to determine minimum weight and optimum construction, and printed and terminal graphical. Interactive plotting programs for graphical display of computational results have been developed and are operational.

**Lasers**

**Experimental Verification of the Cause of High Frequency Oscillations that May Occur in Unstable Resonators**

L. H. Sentman,* D. L. Carroll, S. J. Mayer, A. D. Palla

sentman@uiuc.edu

*Northrup-Grumman Space Technology*

Previous experimental measures and computer simulations of the time-dependent oscillations that may occur in unstable resonators on lines whose saturated gain does not fill the resonator showed that the mechanism responsible for these oscillations is a competition between the chemical pumping and the radiative deactivation of the upper laser levels. The oscillations occur only if the medium is not strongly coupled to the optical fields diffractively or geometrically. New unstable resonator experiments and computer simulations verified this mechanism.

**Investigation of the ElectriCOIL Laser**


wsolomon@uiuc.edu

*Ballistic Missile Defense Office*

This laser research project is aimed at the evolution of a new hybrid electro-chemical laser. We have achieved a significant advance in the field and are in the final stages of experimental design. The essence of the system allows combination of the advantages of plasma discharge technology with the efficiencies of a chemical laser system to produce a new hybrid kind of device. This has the potential to provide 1.3 micrometer of radiation to a wide variety of systems.

**Human-Powered Watercraft**

S. White*

*University of Illinois; Society for Advanced Materials and Process Engineering*

A human-powered watercraft is being designed and built to break the world speed record for this class of vehicle, which currently stands at 18.5 knots (23.4 miles per hour). The vehicle is a hydrofoil, and composite materials are being used extensively in its construction. A systems engineering approach, drawing on principles of propulsion, aero/hydrodynamics, structural mechanics, biomechanics, and materials, has been used to design the vehicle. New types of materials, manufacturing techniques, and components are being utilized to push the speed of the vehicle above the 20-knot barrier.

*Denotes principal investigator.
Multidisciplinary Research for ElectriCOIL Lasers
W. C. Solomon,* J. Verdeyen, M. Kushner (Elect. & Comput. Engr.); N. Richardson, J. Zimmerman, B. Woodard
wsolomon@uiuc.edu
U.S. Air Force Office of Scientific Research; Multidisciplinary Research Initiative

This research is a multiuniversity program to investigate the theoretical and experimental properties of electronically excited oxygen plasma discharges. This major effort involves workers at AFIT, Emory University and CU Aerospace, and it will further develop the scientific basis for the electriCOIL laser. It involves studies of the mixing of excited states of oxygen with molecular and atomic iodine to produce new laser systems.

Materials and Structures

Dynamic Fracture and Fragmentation of Brittle Granular Materials
P. Geubelle,* S. Maiti, P. Nittur
http://ssm7.ae.uiuc.edu/PHG_GROUP
geubelle@uiuc.edu
National Science Foundation CAREER, CMS-9734473

This project goal is to simulate the mechanics of rapid crack propagation and fragmentation of brittle materials possessing a granular microstructure, such as ceramics. Emphasis is placed here on capturing the effect of the microstructure on the initiation and propagation of one or multiple intergranular cracks. The numerical method adopted in this study is an explicit grain-based cohesive/volumetric finite element scheme that includes a robust contact detection and enforcement algorithm to capture the complex contact events taking place between the newly created fracture surfaces and between dislodged grains.

High-Performance Computing for 3-D Dynamic Fracture Problems
P. Geubelle,* M. Breitenfeld, L. Kale (Comput. Engr.)
http://ssm7.ae.uiuc.edu/PHG_GROUP
geubelle@uiuc.edu
DOE Center for the Simulation of Advanced Rockets

The numerical simulation of 3-D dynamic fracture events is one of the most challenging computational issues in solid mechanics, due to the extreme refinement needed to capture continuously evolving geometries (as the fracture surface extends) and rapidly moving stress waves. The objective of this project is to develop and implement high-performance numerical tools used to simulate a variety of spontaneous dynamic fracture events (for which the crack path is not specified a priori but is part of the solution itself). Great emphasis is put on the implementation of the dynamic fracture codes on massively parallel computing platforms.

Quasi-Static and Dynamic Fracture of Reinforced Composite Panels
P. Geubelle,* J. V. Dantuluri
http://ssm7.ae.uiuc.edu/PHG_GROUP
geubelle@uiuc.edu
U.S. Air Force Office of Scientific Research; Small Business Innovation Research Phase 2

In collaboration with AdTech Engineering, Dayton, Ohio

Z-pin reinforcement and stitching have been proposed to address one of the main limitations of laminate composites: their relatively low resistance to delamination fracture. The objective of this project is to develop numerical tools based on the cohesive element scheme to simulate the quasi-static and dynamic fracture of reinforced composites and to compare the simulation results with experiments conducted at AdTech and at WPAFB.

Rocfrac: A General 3-D Structural Solver for Solid Propellant Rocket Simulations
P. Geubelle,* M. S. Breitenfeld
geubelle@uiuc.edu
DOE Center for the Simulation of Advanced Rockets

Rocfrac is a general explicit finite element solver used to simulate structural dynamics of the various components of a solid propellant rocket. It relies on an Arbitrary Eulerian Lagrangian formulation, includes a wide range of element types and constitutive models, and has been optimized for large-scale multiprocessor simulations.

Analytical Determination of Optimum Viscoelastic Material Properties
H. H. Hilton,* C. E. Beldica*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications, DAHC94-46-C-0005 (HPCMP-PET)

The influence of complex modulus shapes and parameters on creep, relaxation, and damping is being investigated. These moduli will be used to solve dynamic and static problems, such as bending, torsion, and flutter of lifting surfaces. The results will yield a categorization of viscoelastic material behavior in its relation to creep,
relaxation, and damping. Both isotropic and anisotropic materials are being considered. Such an analytical catalog of material behavior then can be employed to fabricate real materials to conform to such modulus specification. Selection of these materials has direct application in the design of soundproofing, shock absorbers, composites, and helicopter blades.

**Characterizations and Analysis of Optimum Linear and Nonlinear Viscoelastic Designer Functionally Graded Materials**

H. H. Hilton*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications

A pilot study of the elastic and viscoelastic behavior of functionally graded materials (FGMs) has been initiated by considering them solely and primarily as having prescribed nonhomogenous mechanical properties, such as relaxation moduli and/or failure envelopes. Such an umbrella FGM definition, of course, includes composites. The consequences of FGM prescriptions on solution patterns are examined in detail. Protocols have been formulated for the analytic determination of material properties tailored to specific service conditions. The inherent difficulties associated with such inverse approaches used to generate expressions for designer FGMs are discussed.

**Electro/Magneto—Viscoelasticity: Characterization, Material Property Optimizations, and Structural Control**

H. H. Hilton,* A. Preumont,* G. Yang*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications; Universite Libre de Bruxelles

Characterization of electro/magneto-rheological behavior is formulated analytically in terms of generalized viscoelastic constitutive relations, which include electric current and temperature effects represented by relaxation moduli and shift factors. The analytical model results are compared to experimental data. Computer simulations are carried out in order to gain behavioral pattern knowledge over a wide range of parameters and state variables.

**Probabilistic Minimum Weight Analysis**

H. H. Hilton*

h-hilton@uiuc.edu

*University of Illinois

An analytical method has been developed for designing structures having a prescribed probability of failure so that the overall weight is minimal under combined loads. The solution is obtained for structures consisting of components having normal, Weibull beta-distributed applied and failure stresses, and it is applicable to combined loading conditions. The loading conditions are such that general relations can be used to relate the mean stresses to the cross-sectional area. Weight comparisons with standard design procedures based on the margin of safety concept are made and indicate the possibility of substantial weight savings.

**Random Viscoelastic Material Effects**

H. H. Hilton*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications

Analytical studies are presented that extend the elastic-viscoelastic analogies to stochastic processes caused by random linear viscoelastic material properties. Separation of variable as well as integral transform correspondence principles is formulated and discussed in detail. The statistical differential equation of the moment characteristic functional is derived, but rather than solving the highly complex functional equation, the solutions are formulated in terms of the first- and second-order statistical properties. Gaussian, Weibull, and beta distributions are considered for the probability density distributions of creep and relaxation functions, and their effectiveness is evaluated.

**Very Large Scale Adaptive Simulation of Dynamic Fracture on BlueGene**

L. Kale* (Comput. Sci.), P. H. Geubelle,*

M. Breitenfeld, S. Mangala

http://ssm7.ae.uiuc.edu/PHG_GROUP

geubelle@uiuc.edu

*National Science Foundation

In this project, we are developing the framework to simulate very large dynamic fracture problems on BlueGene, the one-million processor machine under development at IBM. The approach adopted relies on the Charm++ Finite Element Framework developed over the past few years in L. Kale’s research group in the Computer Science Department at the University of
Illinois at Urbana-Champaign. Special emphasis has been placed on the adaptive aspects of the dynamic fracture simulations, including adaptive mesh refinement and dynamic insertion of cohesive elements.

**Dynamic Delamination of Thin Films**
S. Kandula, J. Hendrickx, P. Geubelle,* N. Sottos (Theoret. & Appl. Mech.)
geubelle@uiuc.edu

*Denotes principal investigator.

**National Science Foundation, CMS Program**

Characterizing the adhesive strength of thin films is a key parameter in their design. The laser-induced delamination technique introduced recently by N. Sottos and co-workers has proven to be a very attractive alternative to more conventional contact-based tests. To support this experiment, we are developing a spectral scheme to simulate the dynamic failure of thin films. The method relies on an exact spectral formulation of the elastodynamic relations in the film and in the substrate, and on their coupling through a general cohesive failure model.

**Simulation of Quasi-Static and Dynamic Fracture of Functionally Graded Materials**
S. Kandula, P. Geubelle,* J. Lambros
geubelle@uiuc.edu

*Denotes principal investigator.

**National Science Foundation, CMS Program**

Functionally graded materials constitute a new class of materials that have a continuous spatial variation of their microstructures, and thereby, of their constitutive and failure properties. The objective of this project is to develop numerical methods to simulate the failure of FGMs, with special focus on the quasi-static failure of model ECO-based FGMs developed by J. Lambros, and on the dynamic failure of metal/ceramic FGMs for armor applications.

**Determining the Mechanical Constitutive Properties of Metals as a Function of Strain Rate and Temperature: A Combined Experimental and Modeling Approach**
lambros@uiuc.edu

*Denotes principal investigator.

**U.S. Department of Energy, DEFG03-02NA00072**

Here we characterize the high rate response of BCC and FCC metals over a range of temperatures. Intermediate loading rates are achieved in the compression split Hopkinson bar and higher loading rates are obtained using a laser loading system where a thin sample is loaded by a high power (1 J) short duration (10 ns) laser pulse. Progressive loading recovery experiments of controlled amounts of strain are performed. In situ TEM testing is then performed on the recovered samples and the information is used to build a predictive model for the material response. The model is finally validated by direct comparison to experiments.

**Fundamental Problems in Dynamic Fracture Mechanics**
J. Lambros,* J. Kimberley, J. K. Patel

http://ssm7.ae.uiuc.edu/Lambros

lambros@uiuc.edu

*Denotes principal investigator.

**National Science Foundation CAREER, CMS-0296130**

This project deals with the fundamental understanding of dynamic debonding in homogeneous and bimaterial systems that exhibit planes of preferential crack growth. Of particular interest is the effect of applied loading mixity in the development of contact regions aft of the propagating crack tip. In addition, limiting crack growth speeds in bimaterial and homogeneous material systems are investigated. The study is performed using optical interferometry in conjunction with high-speed photography to image in real time the deformation fields surrounding the propagating crack tip.

**Multiscale Simulation of Fatigue Response of a Self-Healing Composite**
S. Maiti, P. Geubelle,* S. R. White
geubelle@uiuc.edu

*Denotes principal investigator.

**U.S. Air Force Office of Scientific Research, MEANS Program**

Led by S. R. White, a University of Illinois team has been working over the past five years on the development of a new class of materials able to heal internal damage in a completely autonomic fashion. Recent advances have focused on the ability of the material to extend its fatigue life. This aspect of the project aims at the development of a multiscale cohesive finite element scheme to simulate the competition between fatigue failure and healing kinetics.

**Multiscale Adaptive Simulation of Damage and Fracture in Heterogeneous Materials**
K. Matous, H. Inglis, P. Geubelle*
geubelle@uiuc.edu

*Denotes principal investigator.

**DOE Center for the Simulation of Advanced Rockets**

In this Center for the Simulation of Advanced Rockets (CSAR) project, we are developing an adaptive numerical scheme to capture the complex phenomena associated with
the quasi-static and dynamic failure of reinforced rubbery materials, such as solid propellant. The scheme relies on a hierarchy of physical models of increasing complexity, tied together with rigorous error estimates.

**Dynamic Fracture of Functionally Graded Materials (FGMs)**

G. H. Paulino,* (Civil & Environ. Engr.), P. H. Geubelle, J. Lambros, J. Abanto-Bueno, Soma Kandula

http://ssm7.aae.uiuc.edu/Lambros

lambros@uiuc.edu

National Science Foundation, CMS-0115954

In this project we perform a closely coupled experimental and numerical analysis of dynamic fracture of FGMs. Dynamic fracture and deformation experiments are performed on a variety of monolithic zirconia and steel samples. The results are used to theoretically build up a deformation and failure model for the graded material. The model is then incorporated into a finite element scheme that accounts for dynamic effects and allows for spontaneous fracture surface generation through the use of a cohesive element formulation. Finally, the results of the analysis are validated against dynamic fracture experiments on real zirconia/steel FGMs.

**Nanostructure Materials for Self-Healing**


National Science Foundation, Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems, University of Illinois

Utilizing the unique capabilities of nanoscale manufacturing, research is being undertaken to develop self-healing functionality with resolution at the nanoscale. In the first phase of the research, nano-CEMMS are being adapted to manufacture nanoscale vesicles in which the necessary healing chemistry is stored. In the second phase of this research, the nano-CEMMS toolbit will enable precise, localized control over the distribution of the self-healing material constituents, resulting in a functionally graded material that has healing functionality only where needed.

**Structural Health System for Crew Habitats**


NASA Jet Propulsion Lab

Research and development efforts are being undertaken to demonstrate a prototype structural health system for Lunar and Mars Exploration crew habitats. The goal is to design a system that continuously monitors the health of the habitat structure, alerts the crew in real time when adverse conditions are detected, and autonomically corrects for these conditions when possible. Materials systems that incorporate embedded sensors and self-healing functionality are being developed for these purposes.

**Development of Self-Healing Polymer Coatings and Composites**


Northrop Grumman Ship Systems

A novel approach is proposed for improving the durability of polymeric coatings and composites used in naval applications through the use of self-healing technology to repair cracks in polymeric coatings autonomically, increasing durability and lifetime of coated components. A comprehensive experimental program will be initiated to screen appropriate material systems based on healing efficiency and environmental stability and to develop appropriate processing techniques and mechanical characterization of thin film coatings.

**Multiscale Modeling and Experiments for Design of Self-Healing Structural Composite Materials**


U.S. Air Force Office of Scientific Research, F49620-02-1-0080

The objective of this research is to develop a set of multiscale materials systems, which design tools focused on issues relevant to self-healing structural composites. A computational framework will be created for materials system design spanning from atomistic to macroscopic (structural) length scales and properly validated with relevant experimental databases. Simulations at three distinct levels are planned with a coupling approach that utilizes not only the transfer of relevant levels, but supporting and validating experiments at a number of different length and time scales. Research is being pursued on coupled physiochemical analytical tools, multiscale experimental characterization techniques, and generic computational design tools for materials engineering.

**Self-Healing Composite Armor**

S. White,* N. Sottos* (Theoret. & Appl. Mech.), A. Patel

Army Research Lab

Self-healing structural polymers and composites are one approach to designing multifunctional composites combining structural and ballistic protection functions.
In this study, the feasibility of applying self-healing technology to composite armor systems currently under development by ARL will be investigated. The recovery of structural properties of self-healing composite armor subjected to impact and ballistic loads will be assessed. The operative mechanisms (e.g. inherent toughening vs. self-healing) will be identified and refinements in material design proposed.

Self-Healing Composite Materials
U.S. Air Force Office of Scientific Research, F49620-00-1-0094

Self-healing polymer composites are obtained by storing a repair agent in microcapsules that are dispersed throughout the matrix. Triggering of the repair process occurs when the cracks encounter an embedded microcapsule and break the shell material open. The repair agent stored inside the capsule is released into the crack plane and a rebonding of the fracture plane is initiated. Experiments are conducted to assess the capability of several candidate polymers for self-healing potential. The kinetics of the repair process are assessed and modeled, and the formulation of optimal repair agents is sought.

Three-Dimensional Microvascular Networks
U.S. Air Force Office of Scientific Research; National Science Foundation

Three dimensional (3-D) microvascular networks with pervasive, interconnected channels may find widespread application in microfluidic devices, including those used in biotechnology, autonomic materials, sensors, chemical reactors, and fluidic-based computers. Although microchannel arrays are readily constructed in two-dimensions by lithographic techniques, their construction in three-dimensions remains a challenging problem. The 3-D microvascular networks have been fabricated by direct-write assembly of a fugitive organic ink that yields a pervasive network of smooth cylindrical channels (~10-300 mm) with defined connectivity. Research is being pursued to optimize the processing technique, tailor fugitive ink designs, and characterize the properties of microvascular materials.

Three-Dimensional Microvascular Networks for BioMEMS
S. White,* J. Lewis* (Mat. Sci. & Engr.), W. Wu, T. Simpson
Grainger Foundation Technology Fund

This early stage seed proposal will exploit our newly reported direct-write assembly technique for creation of three-dimensional (3-D) microvascular networks. These microfluidic networks contain pervasive, interconnected channels less than 300 microns in diameter, which may find potential application in BioMEMS, autonomic materials, and assembly of novel colloidal building blocks. New fugitive inks and matrix materials are under development to demonstrate microvascular networks of increased complexity at finer length scales.

Use of Composite Materials to Refurbish the Civil and Military Infrastructure
S. White,* N. Sottos* (Theoret. & Appl. Mech.), J. Kamphaus
U.S. Department of Energy, Sandia National Laboratories

The goal of this project is to establish bonded composite doublers as a reliable and cost-effective structural repair method for civil and military structures and to develop adequate real-time monitoring and self-healing systems to ensure the long-term integrity of such structures with minimal need for human intervention. This investigation will establish the effectiveness of composite materials to strengthen damaged or deficient steel structures.

Propulsion

Ignition Models for Solid Propellant Rocket Motors
J. Buckmaster,* P. Alavilli, T. L. Jackson (CSAR); M. Short (Theoret. & Appl. Mech.)
U.S. Air Force Office of Scientific Research, F49620-96-1-0031; DOE Center for Simulation of Advanced Rockets

Solid propellant rocket motors are ignited by a flux of hot gases from an igniter at the head of the chamber. Modeling of the subsequent transients is an important issue, for if they are too violent the integrity of the motor can be compromised. Researchers are developing ignition models for inclusion in the large numerical code being developed within the Center for the Simulation of Advanced Rockets for the complete simulation of the rocket.
Homogenization Issues in Modeling Heterogeneous Propellants
J. Buckmaster*
DOE Center for Simulation of Advanced Rockets; U.S. Air Force Office of Scientific Research

In modeling the combustion of heterogeneous propellants, strategies are needed to account for oxidizer particles that are too small to resolve numerically. These particles are homogenized with the fuel binder, to form a mixture in which the larger resolvable particles are imbedded. The properties of the mixture (that is, heat conduction coefficient) have to be determined from the properties of the individual components and the characteristics of the small particles, which is the goal of this project.

High Frequency Surface Temperature Diagnostics in Pulsed Thrusters
R. L. Burton,* E. Antonsen
rburton@uiuc.edu
U.S. Air Force Research Laboratory, F04700-98-W-1204

The low neutral density in the exhaust of a pulsed plasma thruster (PPT) can be measured if the optical path length is sufficiently long. This measurement, requiring at least 12 passes of a laser beam through the exhaust plume of the PPT, can be achieved with a Herriot cell coupled to an interferometer. This research effort has designed and fabricated a Herriot cell for PPT density measurements and is performing the measurements under typical PPT operating conditions. The resulting measurements will be used to validate gas dynamic models of PPT operation.

UltraSail High Performance Solar Sail System
R. L. Burton,* V. Coverstone*
rburton@uiuc.edu, vcc@uiuc.edu
NASA MSFC STTR Phase II; CU Aerospace, NAS8-03039

One goal of the NASA emerging propulsion program is to develop practical solar sails with areal densities approaching 1 gram/square meter. Following analytical work with a Phase I STTR, this Phase II effort consists of experimental deployment of micron-thick films in vacuum and the design of solar sail spacecraft and of a microgravity deployment experiment.

Very High Performance Heat Exchangers for Air Liquefaction and Separation
R. L. Burton,* K. Brown, A. Jacobi
(Mech. & Indus. Engr.)
rburton@uiuc.edu
University of Illinois Critical Research Initiative

Very high performance heat exchangers are needed for air breathing propulsive systems that can liquefy ingested air. This experimental effort measures heat transfer coefficient at Reynolds numbers approaching 100,000 to investigate higher than expected performance at those conditions. Liquid air separation techniques are also being investigated using zeotropic distillation.

Toward a Numerical Simulation of the Combustion Layer in a Solid-Propellant Rocket Motor
J. Buckmaster,* T. L. Jackson, J. Hoeflinger (CSAR)
U.S. Air Force Office of Scientific Research, F49620-96-1-0031; DOE Center for the Simulation of Advanced Rockets

The Center for the Simulation of Advanced Rockets is concerned with the simulation of an entire solid propellant rocket system, the combustion, the gas flow and acoustics, the structure, and the material behavior. Different groups in various departments of the college are responsible for different ingredients in this study. This research team is concerned with the combustion processes that occur near the surface of the solid propellant and their detailed numerical simulation.

Structural Dynamics

Damping in Bolted Joints
lbergman@uiuc.edu
Sandia National Laboratories, DOE SNL BF-0162

Mechanical joints are recognized to be responsible for much of the uncertainty in the behavior of otherwise linear structures. Two mechanisms that have been identified as both present and important are micro- and macroslip in the vicinity of connectors, such as bolts, and microslap between adjacent parts of a structure, particularly at high frequencies. Analysis and experiments have been used to characterize the behavior of two beams connected by a bolted lap joint, with work continuing on the development of predictive models.
Acoustic and Viscoelastic Wave Propagations with Absorbing Boundaries
H. H. Hilton,* M. J. Yedlin* (Univ. of British Columbia)
h-hilton@uiuc.edu
University of Illinois; University of British Columbia

The previous work of Yedlin and Luo is extended and generalized to 1-D and 2-D linear viscoelastic wave propagations with absorbing boundaries. Formal analytical solutions are developed, showing that the governing relations and BCs for the 1-D and 2-D problems are of sufficient complexity that they are not amenable to analytic solutions. However, numerical formulations using finite elements and finite differences are employed, yielding excellent results. Appropriate solution methodologies are discussed and evaluated, and the influence of the various viscoelastic material parameters is examined in detail by illustrative examples. It is also shown that, as inverse problems, these formulations and their attendant solutions can be readily used for experimental material characterizations.

Finite-Element Analysis of Anisotropic Viscoelastic Composites
H. H. Hilton,* C. E. Beldica*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications

Advanced composite laminates are being used in flight vehicles to improve performance by substantial structural weight savings. Present numerical analysis requires computers with large storage and lengthy real-time to complete the calculations. The method under development uses Laplace transforms and thereby requires computer real-time use comparable to elastic anisotropic analyses. Results of various loading conditions compare extremely well with exact analytical solutions. Finite-element analyses for dynamic loadings on anisotropic viscoelastic composites that save extensive computer time and storage have been developed. The numerical results compare extremely well with analytical exact solutions.

Generalized Viscoelastic 1-DOF Deterministic and Stochastic Nonlinear Oscillators
H. H. Hilton,* S. Yi* (Portland State Univ.)
h-hilton@uiuc.edu
University of Illinois; Portland State University

In this study, the theory of deterministic and stochastic generalized viscoelastic Duffing, Roberts, and van der Pol oscillator responses are formulated and evaluated. Numerical solution protocols are developed and the results are evaluated to determine the influence of viscoelastic damping on the performance of oscillators. It has been found that generalized viscoelastic material behavior profoundly affects the displacements and phase relations of these oscillators.

Structural Mechanics

Anisotropic Piezo-Electro-Thermo-Viscoelasticity Theory with Applications to Composites
H. H. Hilton,* J. R. Vinson* (Univ. of Delaware), S. Yi* (Portland State Univ.), C. E. Beldica*
h-hilton@uiuc.edu
University of Illinois; University of Delaware; Portland State University; National Center for Supercomputing Applications

The general, nonlinear, 3-D, large deformation theory of anisotropic piezo-electro-thermo-viscoelasticity is formulated and represents the confluence of anisotropic elasticity and thermoviscoelasticity, nonhomogeneous layered media, and piezoelectricity. For linear materials and small deformations, a piezoelectric/piezoviscoelastic analogy is established in terms of integral Fourier and Laplace transforms. To demonstrate the effectiveness of the piezoviscoelastic constitutive relation derivations, several piezoelastic examples of beam and plate solutions have been reformulated in terms of piezoviscoelastic constitutive relations and solved analytically and numerically using viscoelastic finite-element analyses. Researchers are making comparisons with piezoelectric solutions and conducting sensitivity analyses of piezoviscoelastic parameters.

Anisotropic Viscoelastic Fractional Derivative Material Characterization
H. H. Hilton*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications

Isotropic linear and nonlinear fractional derivative constitutive relations are formulated and examined in terms of generalized Kelvin models. These are analytically extended to cover general anisotropic viscoelastic behavior. Integral constitutive relations (which are more powerful computationally) are derived from fractional differential ones, and the associated anisotropic temperature-moisture-degree-of-cure shift functions and reduced times are established. Approximate Fourier transform inversions for fractional derivative relations are formulated and their accuracy is evaluated. The
efficacy of integer and fractional derivative constitutive relations is compared, and it is found that use of the former is preferable in analyzing isotropic and anisotropic real materials.

**Generalized Linear and Nonlinear Viscoelastic Earthquake Motion Simulations**

H. H. Hilton,* Y. K. Lin* (Florida Atlantic Univ.)
h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications, Florida Atlantic University*

The governing relations for nonlinear and linear viscoelastic vertical ground motions caused by an earthquake are formulated. The boundaries of the ratio of vertical to horizontal motion velocity are investigated, and it is shown that they lie in the range from 1.23 to 1.73 for all physical elastic and viscoelastic materials. Numerical simulations indicate that both response displacement and acceleration amplitudes and frequencies are affected by viscoelastic properties of the medium. Because viscoelastic responses are accelerated in time by increases in temperature and moisture content, significant damping effects will be experienced in warm, moist soils. Various soil models are under investigation.

**Hierarchical Learning Network**

H. H. Hilton,* T. L. Wentling* (NCSA)

*University of Illinois; National Center for Computing Applications; NASA*

The project seeks to develop novel and unique learning modules, protocols, and web-based instructional material for a hierarchical learning network through high performance computing, modeling, simulations, visualization, human/computer interactions, and networking. The group will create advanced learning paradigms, including multiuniversity group teaching in aero-viscoelasticity, structural control, virtual experiments, tailored materials, and prototypes of learning networks. The end product will ensure the availability of knowledge databases and rapid instruction transfer, and of research results to academia, government laboratories, and industry, without geographic constraints.

**Large Deflections of Linear and Nonlinear Elastic and Viscoelastic Columns with Follower Loads**

H. H. Hilton*
h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications*

A large-deflection analysis of nonhomogeneous linear and nonlinear elastic or viscoelastic columns with initial curvature and with variable areas subjected to follower loads is formulated. Column end shortening due to both curvature and compressible loads is taken into account, and the governing coupled nonlinear differential equations are solved numerically. The linear elastic-viscoelastic integral transform analogy is analytically extended to this nonlinear problem. The effects of end shortening, follower load angle, nonhomogeneous material properties, structural control, and variable area on elastic and viscoelastic columns are studied in detail.

**Mathematical and Numerical Analysis Issues in Nonlinear Anisotropic Viscoelastic Composites**

H. H. Hilton,* C. E. Beldica*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications*

Complete 3-D anisotropic, nonhomogeneous, large deformation, nonlinear, viscoelastic constitutive relations are formulated including aging, moisture, temperature, degree of cure, and change of state effects. Anisotropic nonlinear heat and temperature relations for cure processes are also studied. The coupled system is solved using combined spatial finite-element and temporal finite-difference and/or fourth-order Runge-Kutta approaches. Stochastic failure criteria are used to determine probabilistic survival times to delamination onset during service and manufacturing conditions. Mesh and incremental time step sizing influences on convergence of numerical results are evaluated, and comparisons of stresses and deformations with experimental data are carried out.

**Optimum Material Property Formulation for Anisotropic Viscoelastic Damping**

H. H. Hilton,* C. E. Beldica*

h-hilton@uiuc.edu

*University of Illinois; National Center for Supercomputing Applications*

Anisotropic viscoelastic material properties are formulated analytically taking into account fiber orientations and stacking sequences for laminated composites. The detailed
influences of resulting anisotropic moduli are investigated in terms of material response to loads and deformations and the ability to dissipate energy (that is, damp out undesirable motion). Structural control in the form of viscoelastic piezoelectric action is included in the analyses.

**Shape Memory Alloys for Nonlinear Viscoelastic Structural Components**
H. H. Hilton,* D. M. McFarland*
hilton@uiuc.edu
*University of Illinois; National Center for Supercomputing Applications*

Analyses and numerical simulations are presented for beams and columns made of nonlinear generalized viscoelastic materials with imbedded shape memory alloys (SMA). These structures are loaded by external loads and internal thermal distributions. Active control is exercised by SMA wires placed in the axial direction of the beams and columns, while simultaneously viscoelastic dissipative material properties provide passive control. The dependence of material properties on temperature distributions is taken into account, resulting in even more pronounced nonhomogenous media than those produced by the SMA alone. All mechanical properties are considered deterministic. However, nondeterministic failure property (delamination) experimental data are available, allowing for probabilistic simulations of failure stress conditions as well as survival times.

**Stochastic Delamination Buckling of Viscoelastic Columns**
H. H. Hilton,* C. E. Beldica*
hilton@uiuc.edu
*University of Illinois; National Center for Supercomputing Applications*

The effects of random failure criteria on delamination linear and nonlinear creep buckling are studied under deterministic loads, geometries, moduli, temperatures, and moisture contents. This allows for an analysis that focuses on and isolates random delamination buckling criteria effects under otherwise deterministic conditions. Viscoelastic failure stresses and moduli decrease in time, while bending stresses, strains, and deformations increase with time. Using the experimentally determined delamination probability distributions reported by Hiel et al. in conjunction with the combined load stochastic failure criterion of Hilton and Ariaratnam, probabilities of delamination onset occurrences as time functions are formulated.

**Stochastic Viscoelastic Delamination Onset Failure Analysis of Composites**
H. H. Hilton,* S. Yi* (Portland State Univ.)
hilton@uiuc.edu
*University of Illinois; National Center for Supercomputing Applications; Portland State University*

The analysis includes stochastic processes due to combined random loads and random delamination failure stresses as well as random anisotropic viscoelastic material properties, including the influence of stochastic temperature fields, moisture contents, and boundary conditions. It is shown that times for delamination onset occurrences in composites can be predicted probabilistically depending on any one or all of the above conditions. For cases where deterministic criteria predict no delamination failures, the present stochastic failure theory indicates high probabilities of failure at either early or long times depending on the load-time relations. The effects of fiber orientation and of number of plies on delamination probabilities are examined.

**Structural Integrity and Failure Probabilities of Dental Materials**
H. H. Hilton,* P. Spencer,* G. Thiagarajan*
hilton@uiuc.edu
*University of Illinois; National Center for Supercomputing Applications; University of Missouri at Kansas City*

An integrated multidisciplinary fundamental scientific research program has been initiated to produce analytical formulations and optimal analyses based on dental, material science, numerical, and solid/structural mechanics scientific principles. This research includes applications of advanced aerospace solid mechanics concepts to full and partial dentures, through optimum configurations of reinforced materials and bonding, as well as their manufacture. This research program represents a fusion of dental, material, aerospace, and solid mechanics scientific and engineering approaches to achieve realistic solutions to the bonding problem between teeth and plate and to the structural integrity of the teeth and plate through fundamental studies of optimum current and “designer” materials, light weight-high strength configurations, and overall structural integrity based on failure probabilities.
Finite-Element Analysis of Residual Stresses in Viscoelastic IC Packages during Surface-Mounting Processes
S. Yi* (Portland State Univ.), H. H. Hilton*
h-hilton@uiuc.edu
Portland State University; University of Illinois; National Center for Supercomputing Applications

Moisture and temperature distributions and residual stresses in plastic-encapsulated IC packages are evaluated to assess product reliability. Finite-element analyses (FEA) are generated in order to calculate hygrothermally induced anisotropic viscoelastic deformations and stresses in plastic IC packages during surface-mounting processes. Numerical results show that substantially high stresses in silicon chips and lead frames occur when LOC TSOP packages are exposed to reflow soldering processes. Numerical results also demonstrate that residual stress values in IC packages are sensitive not only to the magnitude of the loads but also to the loading history because of the hygro-thermo-viscoelastic behavior of plastic mold compound IC materials.

Finite-Element Analysis of Thick Thermosetting Matrix Composite Manufacturing Cure Process
S. Yi* (Portland State Univ.), H. H. Hilton*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications; Portland State University

A transient heat transfer finite-element model is introduced to simulate the curing process of polymer matrix composites, and a 3-D anisotropic cure simulation for a thick laminated composite is performed. The temperatures inside of the laminates can be evaluated by solving the 3-D nonlinear anisotropic heat conduction equations including the internal heat produced by chemical reactions. The internal heat generation term can be expressed in terms of the cure rate. Correlation between experimentally measured and predicted temperature gradients is presented for various cure cycle histories. Probabilities of delamination during cure are evaluated.

Free Edge Stresses in Elastic and Viscoelastic Composite Laminates under Uniaxial Extension, Bending, and Twisting Loadings
S. Yi* (Portland State Univ.), H. H. Hilton*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications; Portland State University

Interlaminar stresses near free laminate edges may result in delamination onset and growth and also may result from mismatches in layer properties. Little is known about interlaminar stresses caused by bending and/or twisting loads. A finite-element procedure for the analysis of time-dependent interlaminar stresses in elastic and viscoelastic laminated composites subjected to arbitrary combinations of axial extension, bending, and/or twisting loads is developed based on displacement fields for laminates under a generalized plane deformation state. Parametric studies are presented to demonstrate the accuracy of the numerical procedures.

Nonlinear Thermoviscoelastic Analysis of Interlaminar Stresses in Laminated Composites
S. Yi* (Portland State Univ.), H. H. Hilton,* C. E. Beldica
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications; Portland State University

A finite-element formulation for analyzing interlaminar stress fields in nonlinear anisotropic viscoelastic laminated composites is presented, and it includes the hygrothermal formulation. Schapery’s single integral formulation is extended to account for anisotropy and multiaxial stress states. Numerical results obtained from the present formulation are compared against experimental data and excellent agreement is obtained between these results. As illustrative examples, inplane and interlaminar stresses for (45/-45)_{30} T300/5208 laminate are also presented.

Process-Induced Residual Thermal Stresses and Deformations in Thick Thermosetting Matrix Composite Laminates
S. Yi* (Portland State Univ.), H. H. Hilton*
h-hilton@uiuc.edu
University of Illinois; National Center for Supercomputing Applications; Portland State University

A transient heat transfer, finite-element model is introduced to simulate the curing process of polymer matrix composites. Temperature distributions inside the laminates are evaluated by solving the nonlinear anisotropic heat conduction equations, which include the internal heat produced by chemical reactions. The internal heat generation contribution is expressed in terms of cure rates. Correlations between experimentally measured and predicted temperature gradients are found for various cure cycle histories. The effects of temperature and cure rate on viscoelastic responses of graphite-epoxy laminated composites are investigated using finite-element analyses. Residual stresses for these composite plates subjected to temperature cycles are also determined.
Systems and Control

Endogenous Growth and Unanticipated Ecological Policy
B. A. Conway,* K. R. Schenk-Hoppe* (Univ. of Zurich)
bconway@uiuc.edu
University of Illinois; University of Zurich

We study the impact of ecological policy on economic growth in an endogenous growth model having production and research sectors. The model assumes complete mobility of capital and relative immobility of labor. At a certain point in time, government regulations for environmental protection cause a sharp decrease in returns of production. Optimal control theory and numerical optimization are used to determine the time history of the system for the case in which the imposition of government regulations is anticipated as well as for the case in which it is not anticipated.

Optimal Control for Recovery from Engine Failure on Takeoff
B. A. Conway*
bconway@uiuc.edu
University of Illinois

Flight instructors teach student pilots that in the event of engine failure on a takeoff in a single engine airplane, the best procedure is to attempt a landing straight ahead. This is because too much altitude is lost in making a turn to allow landing on the departure runway. However, this strategy may be problematic at an airport surrounded by unforgiving terrain or in a congested area. In this work, methods of numerical optimization are being used with a dynamical model of a Piper Cherokee airplane to find the optimal control for the return to land on the departure runway; i.e. the pitch and bank control yielding a safe return from the lowest altitude.

Efficient Resource Management for Controlled-Mobility Wireless Networks
frazzoli@uiuc.edu, neogi@uiuc.edu
National Science Foundation, Information Technology Research Program, CCR-0325716

Today’s embedded computers are increasingly mobile and ubiquitous, are capable of interacting with the environment, and can communicate with one another over possibly vast and pervasive networks. Mobile wireless networks are envisaged to revolutionize the way people and organizations will interact and communicate. While most of the wireless networks are not expected to be capable of controlling their own motion, new technological possibilities are emerging to provide small embedded devices with the means to propel themselves, with an energy expenditure that is comparable to the energy budget of communication and computation. Since the power required for propulsion typically decreases with the mass of the device, cheap mobility has the potential to dramatically impact the way networks of small, “smart” devices are designed and operated. We will call a network of embedded devices endowed with computation, communication, and motion capabilities a controlled-mobility wireless network. The purpose of this project, and its intellectual merit, are to be found in the development of a new conceptual framework for the design, development, and operation of efficient and reliable networks with such characteristics.

Creating An Integrated Modular Environment for the Modeling, Analysis and Verification of Embedded Hybrid Systems
N. Neogi,* B. Sanders
neogi@uiuc.edu
National Science Foundation, CCR-0311616

This project involves the development of an integrated modeling environment for the fast simulation and verification of systems that have both continuous and discrete components, such as air traffic control systems and biological systems. The modeling environment uses an abstract functional interface to allow a wide variety of modeling formalisms and solvers to be incorporated and leveraged throughout the simulation and verification process.

Fast Simulation of Hybrid Biological Systems
B. Sanders,* N. Neogi
neogi@uiuc.edu
Pioneer Corporation

This project investigates techniques for the fast simulation of large discrete event systems that are prevalent in biological models. The research leverages hybrid modeling techniques that allow for the approximation of discrete interactions by continuous differential equations. Examples of current relevance, such as the biological toggle switch, are currently being studied.

*Denotes principal investigator.
Control of Spatio-Temporal Systems
P. G. Voulgaris,* G. Bianchini, B. Bamieh
petros@decision.csl.uiuc.edu
National Science Foundation

Many modern applications of controlling distributed systems pose spatial invariance. A typical example is a symmetric array of micromechanical systems, where many such devices are located according to some usually symmetric pattern. Using suitable extensions of the one-dimensional results, one can design optimal and robust controllers. However, the resulting control algorithms are, in general, centralized and impractical to implement. To alleviate this difficulty, a degree of decentralization is imposed on the controller, and algorithms are developed to optimize performance under such information-limiting constraints. The approach resorts to convex formulations of the underlying optimization.

Distributed Control for Large Telescopic Systems
P. G. Voulgaris,* S. Jiang, L. Thompson, N. Holloway
petros@decision.csl.uiuc.edu
University of Illinois

In this project we study and develop distributed control methods for the primary mirror of large segmented telescopes. The aim is to determine the limits of imaging accuracy that can be achieved by the use of closed loop control of the individual mirror segments. Wind disturbances and structural couplings play a major role in limiting the position accuracy of such large structures. The main tools that we use in this study are recently developed robust control techniques for spatio-temporal systems.

Remote and Distributed Control over Networks
P. G. Voulgaris*
petros@decision.csl.uiuc.edu
National Science Foundation

Remote and distributed control over networks is a powerful concept that exploits the capabilities of the Internet (or any network) in order to remotely control critical tasks and complex dynamical interactions over long distances. The strategy of remote and distributed control also carries the great potential to lead to the development and deployment of new applications and technologies that can be very significant for the scientific and commercial worlds. Driven by the need for a systematic study of this concept, the research here aims at designing and developing novel algorithms, software, middleware, and prototypes for remote, real-time control of interacting complex systems over heterogeneous hierarchical networks built around the Internet backbone. A particular problem that is studied is the effect of decentralization and delayed information sharing in a networked system to the overall system performance.

Robust Communication
P. G. Voulgaris,* C. Hadjicostis, R. Touri
petros@decision.csl.uiuc.edu
National Science Foundation

The problem of reconstructing discrete valued signals is traditionally dealt with from a probabilistic point of view. In this project we develop a complementary, worst-case approach to this problem. The motivation comes from applications where security to malicious attacks is of paramount importance, and hence, hard performance guarantees are essential. The theoretical tools of optimal and robust control and filtering play a key role in this development. Connections to probabilistic approaches are also developed, and several trade-offs are analyzed in this new framework.

Structured Control and Application to Atomic Force Microscopy
P. G. Voulgaris,* M. Salapaka (Iowa State Univ.)
petros@decision.csl.uiuc.edu
National Science Foundation

In this project the theory of optimal and robust design is developed when structural constraints are imposed on the controller architecture. Such constraints can be generated, for example, due to limited information exchanges among different local subcontrollers in a large and complex system. Although the general problem of optimal design with decentralized control is very hard to solve, there are certain specific classes of such problems that admit a convex formulation. Included are platoons of vehicles, MEMS, networked systems, congestion control and integrated based imaging where an array of microcantilevers is used to scan the sample. The speed and the accuracy of the scan depend crucially on the coordination of the microcantilevers, which in turn requires effective structured and distributed control algorithms.

*Denotes principal investigator.
Journal Articles

Aerodynamics


Astrodynamics


Combustion


Computational Fluid Dynamics


Dynamical Systems


Lasers


Materials and Structures


Propulsion


Structural Dynamics


Systems and Control


Books

Aerodynamics


Aeroelasticity


Structural Dynamics

Book Chapters

Astrodynamics


Dynamical Systems


Structural Mechanics


Systems and Control


Papers Presented at Conferences and Symposia

Aerodynamics


Astrodynamics


Computational Fluid Dynamics


**Lasers**


**Materials and Structures**


**Dynamical Systems**


**Propulsion**


Cupples, M., Coverstone, V., and Hartmann, J. *Application of solar electric propulsion to a comet surface sample return mission*. American Institute of Aeronautics and Astronautics/American Society of Mechanical Engineers/Society of Automotive Engineers/American Society for Engineering Education 40th Joint Propulsion Conference and Exhibit (Fort Lauderdale, FL, Jul. 2004).

Donahue, B., Green, S., Coverstone, V., and Woo, B. *Chemical and solar electric propulsion systems analyses for mars sample return missions*. American Institute of Aeronautics and Astronautics/American Society of Mechanical Engineers/Society of Automotive Engineers/American Society for Engineering Education 40th Joint Propulsion Conference and Exhibit (Fort Lauderdale, FL, Jul. 2004).

**Structural Dynamics**


**Structural Mechanics**


**Systems and Control**


Neogi, N. Utilizing the structure of safety properties to aid in the verification of hybrid controllers. American Conference on Control (Boston, MA, Jun. 2004).


Aeroelasticity


Astrodynamics


Computational Fluid Dynamics


Theses

Aerodynamics


Lasers


Materials and Structures


Propulsion


Structural Dynamics


Systems and Control


Patents

Materials and Structures


Awards and Honors

Lawrence A. Bergman
Fellow, American Society of Mechanical Engineers
Fellow, Japan Society for the Promotion of Science
Associate Fellow, American Institute of Aeronautics and Astronautics
ASCE State-of-the-Art in Civil Engineering Award, American Society of Civil Engineers, 1983
Associate Editor, Shock and Vibration Digest, 1998-
Editorial Board, Journal of Vibration and Control, 1994-
Japan Society for the Promotion of Science (JSPS) Fellowship, 1998
ASCE Norman Medal, American Society of Civil Engineers, 1999
A. M. Freudenthal Guest Professorship, Universitat Innsbruck, 2000
Editor, Transactions of the ASME, Journal of Vibration and Acoustics, 2000-2004
Editorial Board, Probabilistic Engineering Mechanics, 2000-
IASSAR Senior Award, Computational Stochastic Mechanics, Eighth ICOSSAR (International Association for Structural Safety and Reliability), 2001
Charles E. Schmidt Distinguished Visiting Professorship, Center for Applied Stochastics Research, Florida Atlantic University, 2002

Michael B. Bragg
College of Engineering Research Award, Ohio State University, 1986
Outstanding Recent Alumnus Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1988
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1990
Associate Fellow, American Institute of Aeronautics and Astronautics, 1992
University of Illinois Critical Research Initiatives Implementation Grant, 1997
Losey Atmospheric Science Award, American Institute of Aeronautics and Astronautics, 1998
University Board of Visitors, United States Air Force, 2000-
“Revolutionize Aviation” Award to Aircraft Icing Research Team, NASA TGIR, 2001
“Revolutionize Aviation” Award to AGATE Alliance Project Team, NASA TGIR, 2002
Advisors List, University of Illinois College of Engineering, 2003
Fellow, American Institute of Aeronautics and Astronautics, 2004
Stanley H. Pierce Award, University of Illinois College of Engineering, 2004

John D. Buckmaster
Fellow, American Physical Society
Fellow, Japan Society for the Promotion of Science
Fellow and Chartered Physicist, Institute of Physics Fellow, J. S. Guggenheim Foundation
Associate Fellow, American Institute of Aeronautics and Astronautics
Senior U.S. Scientist Award, Alexander von Humboldt Foundation, Germany
Editorial Board, Combustion Theory and Modeling
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1997

Rodney L. Burton
Associate Fellow, American Institute of Aeronautics and Astronautics
Ralph R. Teetor Award, Society of Automotive Engineers Senior Member, Institute of Electrical and Electronics Engineers
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1993, 1994
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1993, 1999

Bruce A. Conway
Associate Fellow, American Institute of Aeronautics and Astronautics

Victoria Coverstone
Associate Fellow, American Institute of Aeronautics and Astronautics
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1993, 1994
NASA-American Society for Engineering Education Summer Faculty Fellow, Jet Propulsion Laboratory, 1993
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 1994
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1994, 1997, 2001
National Academy of Engineering, Frontiers of Engineering Symposium, 2002
National Academy of Engineering, German-American Frontiers of Engineering Symposium, 2004
Research Publication Award, Department of Navy 2004

Philippe Geubelle
Faculty Early Development Program (CAREER), National Science Foundation, 1998
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1998
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1999
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 2000
Director, NASA Illinois Space Grant Consortium, 2003-Bliss Faculty Scholar, University of Illinois College of Engineering, 2005-

Harry H. Hilton, Professor Emeritus
Fellow, American Institute of Aeronautics and Astronautics (AIAA)
AIAA Faculty Advisory Award, 1965
AFLC Award for Lifetime Commitment to Civil Liberties, 2002
Long Term AIAA Membership Award, 1985
Charles E. Schmidt Distinguished Visiting Professor, Florida Atlantic University, 1997-2001
Fifty Year Award, American Institute of Aeronautics and Astronautics, 1997
Association of College Honor Societies Award, 2000
Best Paper Award, AIAA Dayton Aerospace Science Symposium, 2002, 2004

**John Lambros**
Faculty Early Development Program (CAREER), National Science Foundation, 1999
Associate Technical Editor, *Experimental Mechanics*, 1999-

**Ki D. Lee**
Associate Fellow, American Institute of Aeronautics and Astronautics (AIAA)
Summer Faculty Fellow, NASA Ames Research Center, 1993
Summer Faculty Fellow, NASA Langley Research Center, 1994
Visiting Professor, Vrije Universiteit Brussel, Belgium, 1994
Visiting Summer Faculty, the Boeing Company, 1996
Special Service Citation, AIAA, 1998
Oversea Member, National Academy of Engineering of Korea, 1999-
Award for Turning Goals into Reality, NASA, 2001
Invited Professor, Seoul National University, 2001

**Eric Loth**
Associate Fellow, American Institute of Aeronautics and Astronautics, 2000
Exceptional Performance Award, Department of the Navy, 1989
Research Initiation Award, National Science Foundation, 1990
Undergraduate Instructional Support Award, International Paper Company, 1991
AFOSR Summer Faculty Associate, AEDC, 1993
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1993
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1994
Senior Fellow, Naval Research Lab, 1995
Faculty Fellow, National Center for Supercomputing Applications, 2000-2001
“Revolutionize Aviation” Team Award, NASA, 2001
Willett Faculty Fellow, University of Illinois College of Engineering, 2002-2005

**N. Sri Namachchivaya**
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1989, 1993

**Presidential Young Investigator Award**, National Science Foundation, 1990
Visiting Scientist Award, Fields Institute for Research in Mathematical Science, Canada, 1993
University Distinguished Visiting Professor, Technical University of Vienna, Austria, 1997
Editorial board, *Journal of Nonlinear Science*, 1997-
Charles E. Schmidt Distinguished Visiting Professorship, Center for Applied Stochastics Research, Florida Atlantic University, 1998
Editorial board, *MECCANICA*, 1998-
Southwest Mechanics Lecture Series Lecturer, 1999
Editorial board, *Stochastics and Dynamics*, 2000-
Editorial board, *Journal Nonlinear Studies*, 2001-
Associate Editor, *Journal of Applied Mechanics*, 2003-

**John E. Prussing**
Fellow, American Institute of Aeronautics and Astronautics
Fellow, American Astronautical Society
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1975, 1979, 1984, 1991
Dirk Brouwer Award, American Astronautical Society, 1994
Best Paper Award, AAS/AIAA Space Flight Mechanics Meeting, 1998
Mechanics and Control of Flight Award, American Institute of Aeronautics and Astronautics, 2002

**Michael S. Selig**
Summer Faculty Fellow, Department of Energy National Renewable Energy Laboratory, 1993
“Turning Goals into Reality,” Aircraft Icing Project Team Award, NASA, 2001
Wind Energy Academic Award, American Wind Energy Association, 2002

**Lee H. Sentman, Emeritus**
Fellow, American Institute of Aeronautics and Astronautics
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 1969
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1993
Teacher of the Year Award, University of Illinois Department of Aeronautical and Astronautical Engineering, 1995-1996
Plasmadynamics and Lasers Award, American Institute of Aeronautics and Astronautics, 1999

Wayne C. Solomon, Emeritus
Associate Fellow, American Institute of Aeronautics and Astronautics
Director, NASA Illinois Space Grant Consortium, 1991-2003

Petros G. Voulgaris
Research Initiation Award, National Science Foundation, 1993
Young Investigator Award, U.S. Office of Naval Research, 1995
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1996

Scott R. White
Research Initiation Award, National Science Foundation, 1992
Young Investigator Award, U.S. Office of Naval Research, 1993
Undergraduate Instructional Support Award, International Paper Company, 1995
Research Development Award, U.S. Army Corps of Engineers, 1997
Editorial Board, Journal of Composite Materials, 2000-
The Tech Museum Award Finalist, The Tech Museum of Innovation, 2001
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2001
American Society for Composites, Best Paper Award, 2002, 2003
Willett Faculty Fellow, University of Illinois College of Engineering, 2002-2005