2001 Summary of Engineering Research

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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.

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 pages to each department or laboratory.

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COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Aeronautical and Astronautical Engineering

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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 Aeronautical and Astronautical 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, chemical propulsion, electric propulsion, chemical lasers, optimal orbit analysis, optimal spacecraft trajectories, two-phase flow, systems and control, and wind energy. 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 provide new opportunities for computational research activities in various areas, including fluid dynamics, structural analyses, vehicle performance simulation, space mission analyses, and optimization of high-energy lasers. Current major research initiatives include smart meso flaps for aeroelastic transpiration, 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.

Aerodynamics

Effect of Large-Droplet Ice Accretions on Airfoil and Wing Aerodynamics and Control

M. B. Bragg,* A. P. Broeren, R. Arakoni
Federal Aviation Administration, DTFA MB 96-6-023

The objective of this research is to study the effect of ice accretion on subsonic aircraft aerodynamics and control. Ice accretion can occur in supercooled large-droplet icing as well as in smaller droplet clouds at temperatures near freezing. Using icing wind tunnels, ice accretions are obtained for airfoils with and without ice protection systems. Wind tunnel tests at Illinois and in NASA facilities using simulated ice accretions on an airfoil with a simple flap determine the sensitivity to ice size, shape, and location as well as the role of airfoil geometry. Experimental results to date have explained why certain airfoil designs are more sensitive to these ice accretions.

Experimental Study of Iced Airfoil Aerodynamics

M. B. Bragg*

NASA Glenn Research Center

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.

* Denotes principal investigator.

Laminar Airfoil Flow Control

M. Bragg,* A. Broeren
EideticsI

Flow control can be used to enhance turbulent boundary layer attachment and enable longer runs of laminar flow on highly optimized low-drag airfoils. Airfoils are designed and tested to develop this capability.

Smart Icing Systems

M. B. Bragg,* A. Broeren, S. Lee, J. Merret, K. Hossain, E. Whalen
NASA Glenn Research Center

This part of the larger interdisciplinary and interdepartmental research program addresses the aerodynamic and flight mechanics research required to develop a smart icing system for aircraft. A smart icing system would sense the effect of ice accretion on the aircraft performance and handling qualities and use this information to provide information to the flight crew, operate ice protection systems, provide envelop protection, and possibly adapt the flight control. The research conducted here involves developing robust aerodynamic and flight mechanic models of aircraft in icing conditions, detecting icing through changes in aircraft performance and control inputs, and sensing ice accretion through broad-area aerodynamic sensors. Fundamental research is being conducted in these and other areas in support of the overall Smart Icing Systems Research Program. Flight testing using a NASA aircraft is conducted to develop and test the methods.

Unsteady Flow about an Iced Airfoil

M. B. Bragg,* H. Gurbacki
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 behavior of this bubble using a specially constructed wind tunnel model. High-response pressure transducers will provide surface pressures and unsteady forces while PIV, surface hot films, and hot wires in the flowfield will 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
NASA Johnson Space Center

The analysis of the yaw control of a lifting body reentry 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, hot wires, and surface flow visualization will provide details on the flow separation and side forces created by the asymmetric vortex shedding.

Wind Tunnel Experiments on Meso Flaps for Shock Boundary Layer Interaction

E. Loth,* J. C. Dutton
Defense Advanced Research Projects Agency, F49620-98-1-0490

A novel meso flap system is designed and constructed to relieve the separated flow region caused by normal shock interactions on a supersonic turbulent boundary layer. The project is in cooperation with simultaneous testing to be conducted at the Glenn and Langley NASA Research Centers. Experimental techniques include pressure-sensitive paint, MHz cinematic photography, and LDA measurements. The meso flaps are fabricated from both conventional metal alloys and active smart materials.

3-D Influence Correction Scheme for Application to 2-D Design

M. S. Selig,* M. D. Soso
Ford Motor Co.

Two-dimensional airfoils designed for racecar applications undergo significant performance changes when their low aspect ratio, 3-D counterparts are used in the real situation. To compensate for these changes, endplates are attached to both ends of the wings. Research is being carried out to develop a 3-D influence correction scheme that incorporates the effective aspect ratio of the endplates into the initial 2-D airfoil design. This should allow closer matching of the initial design characteristics with the final product.

* Denotes principal investigator.

Blade Geometry Optimization for the Design of Wind Turbine Rotors

M. S. Selig,* P. Giguère
National Renewable Energy Laboratory

A computer program is being developed to facilitate the blade design of horizontal axis wind turbines in which considerations are given to aerodynamics, structures, noise, and cost. Given a set of design requirements and constraints, the program provides optimum blade geometries for minimum cost of energy. To capture the design trade-offs between competing objectives, the program has a multiobjective optimization capability. The program relies on a genetic algorithm-based optimization method and uses the PROPID code for rotor performance analysis. Overall, the proposed method is an efficient engineering tool to retrofit or design new wind turbine blades.

Correcting Inflow Measurements from Wind Turbines

M. S. Selig*
National Renewable Energy Laboratory

In order to provide accurate performance data for wind turbine design codes, 3-D field data must be tabulated in terms of sectional angles of attack. A 3-D lifting-surface inflow correction method (LSIM) is being developed, using a vortex panel code, to correct the measured local flow angles to angles of attack. The method has been tested using hypothetical 3-D data, based on field measurements from the National Renewable Energy Laboratory (NREL) and wind tunnel data from the Technical University of Delft. LSIM has been used to correct 3-D data from the combined experiment rotor at NREL.

Development of a Method for the Design of Aerodynamically Efficient Juncture Geometries

M. S. Selig,* B. A. Broughton
Private gifts

The design of junctures such as wing/fuselage intersections has traditionally followed a trial-and-error approach, which does not always guarantee an optimal juncture geometry. It is believed that a design method based on a solid understanding of the physics of the juncture flow could lead to significant drag reductions in these areas. The current research is aimed first toward a better understanding of the drag-producing mechanisms in juncture flows through experimental and numerical studies. Second, the knowledge gained will be implemented in an inverse/direct design method to generate highly efficient juncture geometries for a wide range of applications.

Horizontal Axis Wind Turbine Performance Prediction/Model Development

M. S. Selig*
National Renewable Energy Laboratory

Noticeable discrepancies exist between wind turbine field test data and predicted power output from the blade element/momentum methods. Power is typically underpredicted at high wind speeds and overpredicted at low wind speeds. These discrepancies can be attributed to induced effects that are not properly accounted for by the classical Prandtl tip-loss model. A more accurate and computationally efficient tip-loss model will be developed based on results from two state-of-the-art vortex-method rotor codes and recent field test data. The new model will then be integrated into existing performance prediction methods used in design.

Hybrid Wing Design to Simulate Full-Scale Ice Accretion

M. S. Selig,* S. V. Uppuluri
NASA Glenn Research Center

Aircraft wing ice accretion depends on several factors, but the most important is the airfoil leading-edge geometry where the ice first accretes. Owing to myriad scaling issues, full-scale tests are highly desirable, but the costs are often prohibitive. An approach has been devised for airfoils (2-D) that has the advantages of full-scale tests without the associated costs. In particular, the full-scale leading edge is tested along with a foreshortened aft section. This methodology is being extended to wings whereby a modified portion of the wing can be tested at conditions that simulate those of the full scale at a fraction of the cost of full-scale testing.

Low Reynolds Number Airfoil Design and Wind Tunnel Testing

M. S. Selig,* B. A. Broughton, C. A. Carroll
Private gifts

This research deals with enhancing the performance of airfoils for operation at low Reynolds numbers. For such airfoils, boundary-layer transition takes place through a laminar separation bubble that forms as the laminar boundary layer first separates, then becomes unstable, transitions to turbulent flow, and reattaches to the airfoil to form the bubble. High drag produced by the bubble is the principal cause for the performance degradation at low

* Denotes principal investigator.

Reynolds numbers. Wind tunnel tests are being performed to validate newly developed low Reynolds number airfoil design philosophies aimed at mitigating the adverse bubble effects.

Wind Turbine Post-Stall Performance Prediction

M. S. Selig*
National Renewable Energy Laboratory, XCX-7-16466-01

The aim of this research is to develop a post-stall model for design and analysis of wind turbines. The aerodynamics of wind turbine blades changes significantly due to 3-D rotational effects on the flow over the blades. The model being developed needs to incorporate these effects to enable accurate prediction of power. The preliminary model assumed a decrease in drag of the blade. Three key parameters associated with stall delay were identified. Further investigations into experimental and computational results revealed shortcomings in the drag model. An improved model is now nearly complete and is being tested.

Aerospace Systems Design

In-Space Technology Assessment and Low-Thrust Trajectory Analysis

R. L. Burton,* V. L. Coverstone*
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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.

Aerospace Vehicle Flight Simulation

Icing Encounter Flight Simulator

M. S. Selig,* J. A. Scott, B. Sehgal
NASA Glenn Research Center

Several groups at the University of Illinois are involved in the NASA Smart Icing Systems project. One aspect of this project is to develop a PC-based pilot-in-the-loop, real-time, reconfigurable flight simulator capable of modeling the system, including aerodynamic and control effects caused by aircraft icing. Such a simulator is being developed to model a typical commuter aircraft with and without ice while incorporating various ice accretion models. The simulator will be used to perform virtual flight tests of icing encounters so as to further develop and refine the overall smart icing system as well as the individual components.

Astrodynamics

Minimum-Fuel Recovery of Satellites that Fail to Achieve Geostationary Transfer Orbit

B. A. Conway*
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 consumed about half of the satellite's fuel supply for attitude 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 and thus, maximizing their lifetime.

Optimal Control for Atmospheric Reentry

B. A. Conway*
University of Illinois; NASA Langley Research Center

The problem of optimal control for atmospheric reentry is examined with the objective of minimizing the number and size of the controllers. For example, the trajectory of a future Space Shuttle type of vehicle might be determined

* Denotes principal investigator.

in such a way as to simultaneously minimize the fuel required for reentry and the size of flight control surfaces such as ailerons, elevators, and rudder needed for the vehicle to maneuver in the atmosphere. The DCNLP (direct collocation with nonlinear programming) method will be used to convert the continuous problem into a discrete problem.

Optimal Low-Thrust Trajectories for Asteroid Interception and Rendezvous

B. A. Conway*
The Boeing Company

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.

Optimal Very-Low-Thrust Orbit Raising

B. A. Conway*
The Boeing Company

Electric propulsion may soon be used for spacecraft maneuvering in low Earth orbit because of its very high efficiency. Approximate analytical solutions exist for very low thrust accelerations (< 100 micro-g's) for the circular orbit to circular orbit case. But there are no analytical solutions for elliptical orbit to elliptical orbit cases; numerical methods must be used. In this research, the method of direct collocation with nonlinear programming is used, with an improved, sparse NLP problem solver, to find optimal trajectories for such cases and to determine the lower bound on thrust acceleration for which such problems are tractable.

Application of Parallel Recombinative Simulated Annealing to Propellant Minimizing Low-Thrust Trajectories

V. Coverstone,* J. Hartmann, W. Mason
University of Illinois

Parallel recombinative simulated annealing is a hybrid computer algorithm combining both simulated annealing and genetic algorithm concepts and attempts to incorporate and augment the traditional strengths of each while simultaneously eliminating their respective weaknesses. This optimization technique is applied to interplanetary missions. Trade studies involving minimum transfer time and maximum delivered mass are being performed. Preliminary results show that parallel recombinative simulated annealing combines the speed and parallel nature of genetic algorithms with the probabilistic hill-climbing ability, selectivity, and guaranteed convergence of simulated annealing.

Earth Escape Using a Solar Sail

V. Coverstone,* J. E. Prussing,* J. W. Hartmann
NASA/Caltech Jet Propulsion Laboratory

The feasibility of escaping Earth orbit using a solar sail is investigated. Starting in geosynchronous transfer orbit, the very small solar sail force per unit mass (less than 1 mm/s/s) can be used to gradually accelerate the spacecraft over several months until escape energy is attained. Optimal orientation of the sail at each point in the orbit is required to achieve the desired performance. Several constraints are important for an actual implementation, such as shadowing and sail attitude/angular rate constraints.

Optimal Constellation Design through Genetic Algorithms

V. Coverstone,* W. Mason
University of Illinois

Modern satellite systems have started using large constellations; however, little investigation has been performed to optimize their configuration. Historically, continuous global coverage has been the only consideration, but launch cost, manufacturing difficulty, and payload and communications performance are all issues directly affected by the choice of orbital configuration. A general tool for constellation design optimization is being developed which includes software that uses a genetic algorithm with flexible cost considerations and indicators of merit.

Optimal Control of a Multibody Spacecraft Using Averaging Theory

V. Coverstone,* W. T. Cerven
University of Illinois; National Science Foundation

The problem of reorienting multibody spacecraft through joint motion is addressed. The multibody space system presents a nonholonomic underactuated mechanical system. It is shown that, for small periodic controls, the nonlinearity of the system results in a secular variation of the states. This secular variation provides a mechanism to

* Denotes principal investigator.

reorient the multibody spacecraft to any arbitrary attitude. Optimal control theory is then applied to determine an analytic control algorithm that minimizes the required control effect. This control law is developed for a general four-body spacecraft system actuated by three revolute joints.

Optimal Interplanetary Spacecraft Trajectories via *a Pareto* Genetic Algorithm

V. Coverstone,* J. Hartmann
University of Illinois; NASA Jet Propulsion Laboratory

A Pareto genetic algorithm is applied to the optimization of low-thrust interplanetary spacecraft trajectories. A multiobjective, nondominated sorting algorithm is developed following existing methodologies. Verification of expected performance is accomplished through application of the algorithm to a suite of multiobjective test functions. A hybridized scheme is designed which integrates the Pareto genetic algorithm with a calculus-of-variations-based trajectory optimization algorithm. "Families" of Pareto optimal trajectories are generated for the cases of Earth-Mars flyby, Earth-Mars rendezvous, and Earth-Mercury rendezvous trajectories.

Optimal Orbit Transfer Analysis for Advanced Space Systems

V. Coverstone,* J. Hargens, J. Hartmann, W. Mason
University of Illinois; Spectrum Astro Inc.; NASA Goddard Space Flight Center

Techniques for effectively optimizing orbit transfers of advanced space systems employing low-thrust propulsion are investigated. The techniques of collocation and parallel shooting are used to solve boundary-value problems that result from applying the calculus-of-variations to optimal control problems. Genetic algorithms allow for the optimal selection of discrete parameter values such as thruster on/off cycles. The orbit transfer dynamics are modeled using variational equations based upon modified equinoctial elements. This model includes third-body, solar radiation pressure and shadowing effects. The techniques will be used to optimize low-thrust planetary orbit insertion and escape trajectories, low-thrust transfers from a planetary orbit to natural satellite orbit, and low-thrust transfers to liberation point orbits.

Optimal Spacecraft Trajectories via Higher Order Differential Inclusions

V. Coverstone,* J. Hargens
University of Illinois; Spectrum Astro Inc.; U.S. Air Force Phillips Laboratory

Higher order differential inclusions is a new modeling technique that is applied to the modeling and optimization of spacecraft trajectories. The spacecraft equations of motion are mathematically manipulated into differential constraints that remove explicit appearance of the control variables (thrust direction and magnitude) from the problem statement. These constraints are transformed into a nonlinear programming problem by using higher order approximations for the derivatives of the states. The new method is applied to three-dimensional propellant-minimizing low-Earth orbit to geosynchronous Earth orbit spacecraft transfer. Comparisons are made with results that were obtained using established modeling and optimization techniques.

Trajectory Modeling and Optimization for Future Space Systems

V. Coverstone*
University of Illinois; Spectrum Astro Inc.; U.S. Air Force Phillips Laboratory

In an effort to minimize the cost of deploying and operating space systems and to increase competitiveness, mission planners are examining a variety of new technologies for boosting space systems into orbit and for performing propulsive maneuvers to achieve and maintain mission orbits. In addition, spacecraft builders are producing smaller bus designs to allow for the use of smaller launch vehicles and for multiple launches aboard a single launch vehicle. Research into developing mathematical and computational modeling and optimization techniques to effectively perform the needed mission analysis and operational planning is being performed.

Trajectory Optimization of a Solar Sail Spacecraft in a Three-Body System

V. Coverstone,* J. Hartmann
University of Illinois

Propulsion of a spacecraft using a solar sail is an old concept that has recently gained popularity due to an industry drive for a cost-effective propulsion system. Most of the research to date has studied the effect of a solar sail on the position and stability of the equilibrium points in three-body systems, such as the Earth-Sun spacecraft or Earth-Moon spacecraft. This research computes a variety

* Denotes principal investigator.

of trajectories for a solar sail. Total flight time, solar array size, and payload capacity are varied to establish a trade space for mission-planning purposes.

Optimal Continuous-Thrust Escape Trajectories

J. E. Prussing,* M. C. Tanzillo
University of Illinois

Two types of continuous-thrust escape trajectories are investigated: constant-thrust acceleration and power-limited. For constant-thrust acceleration, maximization of the instantaneous rate of energy increase is obtained by thrusting along the velocity vector. However, a larger energy increase in a specified time (equivalent to minimum time for a specified energy increase) can be achieved using the optimal thrust direction obtained from primer vector theory. For power-limited trajectories, the optimal thrust direction is along the velocity vector. The existence of conjugate points on these optimal trajectories is also being investigated.

Second-Order Necessary and Sufficient Conditions for Optimal Control Problems

J. E. Prussing*
University of Illinois

A procedure is derived and applied to test second-order necessary and sufficient conditions for a weak local minimum of the Bolza optimal control problem. For a system with n state variables, an improved method is used to transform a test for the unboundedness of an $n \times n$ matrix (indicating a conjugate point) into a test for a scalar being zero. The procedure is being applied to various spacecraft trajectories that satisfy first-order necessary conditions.

Second-Order Necessary and Sufficient Conditions for Optimal Impulsive Spacecraft

J. E. Prussing,* B. S. J. Jea
University of Illinois

Primer vector theory for optimal (minimum-fuel) spacecraft trajectories involves only first-order necessary conditions. This theory is being extended to include second-order necessary conditions and sufficient conditions. A practical test is sought for determining locally minimizing solutions. These second-order conditions may also lead to more efficient iteration algorithms.

Combustion

Effects of Nonuniform Flows on Propellant Flames

J. Buckmaster*
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.

Holes in Diffusion Flames

J. Buckmaster,* T. L. Jackson (CSAR)
U.S. Air Force Office of Scientific Research, F49620-96-1-0031

In turbulent nonpremixed combustion, eddies can tear holes in the flame. The subsequent history of these holes (whether they close or get larger) is important in any understanding of the combustion field. Researchers have devised a model to examine holes and their propensity to close or open. A closely related problem is that of a flame-isola, an isolated region of burning, and its propensity to expand or shrink.

Oscillating Edge Flames

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

The edge of a flame spreading over liquid fuel beds at subflash temperatures will sometimes pulsate. Similar pulsations are seen in a candle flame burning under microgravity conditions. An edge flame model has been developed to study this phenomenon, which researchers believe is a Lewis number effect.

* Denotes principal investigator.

Sublimit Combustion and Flame Strings

J. Buckmaster,* M. Short (Theoret. & Appl. Mech.)
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.

The Effects of Convective Flows on Premixed Edge-Flames

J. Buckmaster*
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.

Two-dimensional Smolder Waves

J. Buckmaster,* Y. Zhang
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.

Computational Fluid Dynamics

Aeroelastic Design of Smart Meso Flaps for Aeroelastic Recirculation Transpiration (SMART)

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The preliminary computational design of a smart bleeding system for a supersonic inlet is performed through detailed 2-D aeroelastic simulations using the finite-element method. Recent developments in the use of the finite-element method in optimization problems are incorporated to achieve the bleeding system design resulting in optimal flow performance. Special emphasis is placed on the numerical study of the flutter of the proposed meso flap system.

Aerodynamic Design Optimization Using Parallel Computing

K. D. Lee,* M. Damodaran, J. Chung
University of Illinois

Researchers developed an aerodynamic design technique that combines CFD analysis with numerical optimization. It is based on high-level flow modeling to improve the reliability of designs. The Navier–Stokes equations are solved on refined grids to simulate the flowfield accurately. This implies that the design process requires large memory and long computing time. Those requirements are the primary factors that limit practical applications because of the high equipment and computing costs and slow turn-around time. A solution to this problem is the use of parallel computing. In this study, the design code will be ported to the parallel computing environment, and a parametric study will be conducted to improve the performance of parallel computing.

Aerodynamic Shape Design with Stochastic Optimization

K. D. Lee,* J. Kwon
University of Illinois

The objective is to investigate the feasibility of aerodynamic design using a number of variants of genetic algorithm and stochastic optimization methods. It is motivated by the availability of efficient computational prediction methods and cheap, powerful computing

* Denotes principal investigator.

resources. The flow is modeled with high-level physics to produce reliable designs. The project addresses the design efficiency issue by measuring performance gain with design cost. It is also aimed at overcoming the local minimum issue in the optimization of nonlinear problems.

Block-structured Grid Technology for the Analysis of Icing Effects on Airfoils

K. D. Lee,* J. Shim
NASA Glenn Research Center, NAG 3-2236

The objective is to develop a semiautomatic grid technology for the analysis of icing effects on single- and multi-element airfoils. It will consist of perimeter discretization adaptive to the ice shape, automatic domain decomposition using multiblocks, structured grid generation in each block, grid-quality improvement within blocks and across block boundaries, and integration with a flow solver. It will be furnished with a local regridding option to locally reinforce grid density or quality to accommodate flow features and be complemented with an interactive grid tool, SmaggIce of NASA Glenn.

Shape Optimization for Transonic Compressors Based on Navier–Stokes Physics

K. D. Lee,* J. Chung
NASA Lewis Research Center, NAG 3-1983

The objective of this research is to develop an automated CFD-based shape optimization tool for high-speed compressor designs. It will be based on Navier-Stokes physics with proper turbulence modeling and computational grids to produce reliable designs at operation conditions. It is to provide an inverse capability to find geometries that produce improved performance at various operating ranges. Constraints will be imposed to prevent downgrading of other performance characteristics while enforcing design objectives.

MEMS-based Microbubble Dispersion in Boundary Layers

E. Loth*
Defense Advanced Research Projects Agency, MDA 972-01-C-0042

There is little knowledge of how microbubbles disperse within the near-wall turbulence in a boundary layer. This study is intended to document and understand bubble dispersion caused by the eddy structures. Direct Numerical Simulations are used to model bubble convection and to optimize a MEMS-based injection process. The results will be used to understand how to accomplish drag control with microbubbles (for example, using micro-bubbles from surface ships or underwater, unmanned vehicles).

Simulation of Aeroelastic Transpiration for Shock Boundary

E. Loth*
Defense Advanced Research Projects Agency, F49620-98-1-0490

This study involves simulation of a novel concept to control shock boundary layer interaction. The system consists of a passive bleed/blowing cavity with a matrix of small flaps that deflect to optimize transportation, but revert to a flat plate in subsonic flow. The turbulent flow is investigated with numerically coupled aeroelasticity deforming flaps using an unstructured finite-element method throughout. This technology has possible applications in supersonic inlets and transonic aerodynamics.

Simulations of Ice Shape Induced Airfoil Separation Characteristics

E. Loth,* M. B. Bragg
Federal Aviation Administration, 99-DOT-B/L-1230

A 3-D Navier–Stokes methodology is used to investigate the effects of ice-shaped protuberances on airfoil aerodynamics. The separated flow regions are studied by both steady and unsteady approaches. Results indicate that large changes in the drag, lift, aerodynamic moment, and pressure distributions can occur for upper surface ice shapes with sizes on the order of 1% of the chord length.

Virtual Icing Research Tunnel

E. Loth*
NASA Glenn Research Center, NAG 3-2623

This two-pronged approach seeks to simulate the two-phase flow of the NASA 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 uniformity of the liquid water content 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.

* Denotes principal investigator.

Rarefied Gas Dynamics

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A Monte Carlo simulation technique is applied to solve directly the Boltzmann equation for rarefied gas problems encountered in modern aerospace vehicle design.
The solution procedure involves two explicit iterative steps. First, the collision integrals are evaluated at each computational node to define source terms in the Boltzmann equation. The source terms are then used to integrate the time-dependent multidimensional Boltzmann equation for the distribution function at the next time step. Steady-state solutions are achieved as a time asymptote. This integration scheme is well-suited to present-day supercomputers, which employ vectorization and parallel processing. The method is being validated for cases of simple geometry, and solutions are to be compared with those from the continuum approach (Navier–Stokes solutions).

Dynamical Systems

Delay-Differential Equations

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Unlike systems modeled by o.d.e.'s, mechanical systems modeled by delay-differential equations are, in some sense, infinite-dimensional. In this infinite-dimensional setting, the Hopf bifurcation theorem is not an elementary exercise, but requires some new ideas and some sophisticated mathematical machinery for its implementation. Researchers are studying the stability and bifurcations associated with delay-differential equations with multiple delays. In addition, a goal of this project is to examine the stability and bifurcations associated with stochastic time-delay systems. For a certain class of affine delay equations researchers obtain Lyapunov exponents. However, for general second-order systems with delay, researchers apply Lyapunov-like functions and the theory of differential inequalities in order to obtain stability in the p^{th} mean.

Global Behavior of Nonlinear Aeroelastic Flat Panels in Supersonic Flow

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U.S. Air Force Office of Scientific Research, 96-1-0265

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 nonlinearities 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.

Nonlinear Dynamics of Flexible Spinning Discs

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Under consideration are the transverse dynamics of a high-speed spinning disc, clamped at its inner radius and rotating with a time-varying spin rate, such as found in turbine rotor systems and computer memory storage devices. Dynamical disturbances from time-varying spin rates, interactions with external dynamical systems, and inherent nonlinear effects may lead to disc instability. Such instabilities reduce the performance of the rotating system and can, in extreme cases, lead to failure.
To examine these phenomena, the equations of motion of the system will be derived in detail. The effects of geometry, material characteristics, and aerodynamic interactions on disc displacement will be included. Local and global bifurcation analyses will then be implemented.

Nonlinear Dynamics of Parametrically Excited Gyroscopic Systems

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Gyroscopic systems occur in many areas of engineering. Some examples are pipes conveying fluid, axially loaded rotating shafts, and systems subjected to Lorenz forces. Because of the widespread usage of gyroscopic systems, their stability characteristics are important in engineering application. Often the required stability analysis is complicated by parametric excitations. The effects of such excitations upon the stability of gyroscopic systems will be investigated through application of local and global stability analysis to discretized equations of motion

* Denotes principal investigator.

incorporating the effects of symmetry breaking and linear and nonlinear dissipation. The results will be applied to several systems, analytically and numerically, and will be verified using a rotating shaft experimental apparatus.

Nonstandard Dimensional Reduction of Noisy Systems

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This project is concerned with certain methods of dimensional reduction of nonlinear systems with symmetries and small noise. In the presence of a separation of scales, where the noise is asymptotically small, one exploits symmetries to use well-known methods to find an appropriate lower-dimensional description of the system. The interest of this project is when classical methods fail because the lower-dimensional description has singularities.

Sample Stability of Stochastic Dynamical Systems

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Lyapunov exponents are a generalization of the characteristic Floquet exponents so that more general nonperiodic orbits can be characterized. The spectrum of Lyapunov exponents provides the average exponential rates of divergence or convergence of nearby orbits in phase space. In addition, the Lyapunov exponents characterize the almost-sure stability of dynamical systems perturbed by noise. Furthermore, the moment Lyapunov exponent describes the moment stability of such systems. Asymptotic expansions of these exponents are constructed for stochastic dynamical systems when the noise (white or colored) is small. These results are used to understand stability and bifurcation characteristics of stochastic systems and are applied to various practical dynamical systems.

Stability of Tethered Spacecraft

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Tethered spacecraft systems (TSS) have many applications ranging from the generation of electric power for a spacecraft to providing microgravity environments for experiments. The equations of motion governing the three dimensional motion of a two-body tethered system are highly nonlinear, yet most research on such systems has only considered the linear equations. Researchers propose to develop a low-dimensional nonlinear model for such systems to analytically study the stability, bifurcations, and chaos that may exist in these nonlinear systems. These analytic results will then be compared to numerical solutions to validate the low-dimensional model.

Stochastic Bifurcations

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In this study, stochastic bifurcation implies either qualitative changes to the invariant measures that can be observed by examining the Fokker-Planck equation, or the appearance of a new invariant measure which is, at present, generated numerically through the forward and backward solutions of the stochastic differential equations. Researchers examine various concepts to describe stochastic bifurcations, namely the P-bifurcation and D-bifurcation. The analysis is carried out through studying a noisy Duffing-van der Pol oscillator which exhibits a variety of co-dimension one bifurcations along with certain global bifurcations in the absence of noise.

Flight Vehicle Synthesis

Computerized Flight Vehicle Synthesis

H. H. Hilton*

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 output on Calcomp. Interactive plotting programs for graphical display of computational results have been developed and are operational.

* Denotes principal investigator.

Human-Powered Watercraft
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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 type of 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.

Lasers

Bench Top Cylindrical Laser
L. H. Sentman*
Schafer Corp.

Preliminary estimates indicate that, using four discharge tubes, it may be possible to operate a bench top cylindrical HF laser with an outer ring diameter of 6 inches with a 30-cm. gain length using the existing University of Illinois vacuum system. This design is being pursued to determine its feasibility.

Compound Wave Effects in Ring Resonators
L. H. Sentman,* R. G. Wright, J. F. Padilla
Schafer Corp.

An analytical model developed for TRW indicates that a reverse wave with as little as one part in 10^4 to 10^6 of the output power of a ring resonator may have a large effect on the output power of the ring resonator. A ring resonator, which duplicates the resonator used in the analytical model as closely as is practical experimentally, will be set up on the University of Illinois cw supersonic HF laser. The effect of the reverse wave on the performance of the ring resonator will be characterized as a function of the strength of the reverse wave.

Effect of Probe Beam Mode Structure on Measurement of Zero Power Gain
L. H. Sentman,* A. C. Duus, R. G. Wright, J. F. Padilla, G. L. Detweiler
TRW

The objective of this study was to determine the effect of the mode structure of the probe beam on the measurement of the zero power amplification ratios of a cw HF chemical laser. There was good agreement between the amplification ratios measured as a function of vertical position using a single line, single longitudinal mode, TEM_{00} probe beam and those measured using a multiline, multiple longitudinal mode, multiple transverse mode probe beam. This agreement showed the measurement of zero power amplification ratios is independent of the mode structure of the probe beam.

Feasibility of HF Chain Laser Operation
L. H. Sentman,* G. L. Detweiler
TRW

The data on cw HF chain laser operation are being reviewed and modeled to understand the reasons for the observed performance. This understanding will be used to determine the feasibility of increasing cold reaction cw HF laser performance by operation at conditions conducive to the occurrence of the hot reaction.

HF Kinetic Rate Investigation
L. H. Sentman,* J. F. Padilla
TRW

HF kinetic rates are being reviewed and updated to improve the agreement between laser simulations and measured gain and power spectral distributions.

An Experimental Investigation of the ELECTRICOIL Laser
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Research into the potential for development of a new hybrid chemical laser and electric laser concept has provided a significant advance in the field. Basic electric discharge physics and chemical laser technology are being combined to produce a new kind of device. This has the potential to provide high-power laser energy at the 1.3 micrometer wavelength for a variety of applications.

* Denotes principal investigator.

High-Energy Laser Systems Technology

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AFRL; Prime Contractors

This work involves research into the operation of a large-scale COIL laser for commercial applications. A new laboratory has been constructed for establishing a commercial technology for high-energy lasers. The initial project is the development of a prototype system to be used in laser processing of metals. This problem involves the development of a new laser technology, demonstration at a scaleable power level, and materials processing of lasers operating near 1 micrometer wavelength. Operation of the system demonstrated a kilowatt at 25% chemical efficiency and is being employed to devise new technology solutions to a variety of laser problems.

Large-Scale Simulations of Chemical Lasers

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Large 3-D simulations of chemical laser flowfields are being conducted to determine the most efficient configurations of hardware and software for the next generation of computing. Verification of experimental data and earlier, less complex computations is complete, and the system performance is being assessed. The work is being conducted using the reacting flow model provided by the BLAZE and GASP CFD simulations on a variety of parallel and high-speed processors.

Materials and Structures

3-D Dynamic Failure of Composite Materials

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In this project, researchers develop a numerical scheme, referred to as the spectral scheme, specially designed to tackle the complex phenomena associated with the delamination of fiber reinforced composite laminates. Special emphasis is placed on capturing with great detail the three-dimensional effects associated with the orthotropy of the surrounding medium. The issue of the existence of a limiting crack speed under both tensile and shear loading condition is addressed.

Dimensional Stability of Composites: Process Simulation and Optimization

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The objective of this project is to better understand the effect of the manufacturing process in the dimensional stability of composite parts. Of particular interest is the importance of capturing the evolution of the matrix material throughout the cure cycle on the final shape of the composite part. This particular project combines detailed 3-D coupled thermal, chemical, and mechanical finite-element simulations of the manufacturing process with optimization techniques to predict the final shape of the manufactured part.

Dynamic Fiber Pull-Out in Polymeric Composites

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When a composite structure fails and a crack propagates perpendicularly to the fiber direction, a substantial amount of energy is dissipated in the progressive debonding and sliding on the fibers. Preliminary experimental investigations have shown that these two processes can be quite different under high strain rate conditions than in a quasi-static situation. In this combined experimental and analytical research program, the dynamic failure of a model composite is examined using a specially adapted version of the Split Hopkinson Bar apparatus and a special form of the finite-element scheme.

High-Performance Computing for 3-D Dynamic Fracture Problems

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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

* Denotes principal investigator.

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.

High-Speed Grinding of Ceramic Materials: Process Simulation and Damage Assessment

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Many applications of structural ceramics require high dimensional accuracy and/or surface finish, and grinding is often required at the end of the manufacturing process. However, the brittle granular nature of ceramics renders the surface machining process more complicated than in metals, and surface cracks are often found to extend well into the ceramic part. High-speed machining has been proposed recently to reduce the grinding-induced subsurface damage. Researchers are using a special finite-element-based numerical scheme to simulate the grinding process, with special emphasis on the associated intergranular fracture process. This project involves collaboration with Professor Ghatu Subhash from Michigan Tech. This research group is conducting detailed experiments on the topic.

Intersonic Crack Propagation under Shear-dominated Loading Conditions

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The issue of limiting crack speeds in dynamically failing structures is still an active topic of research. While it is accepted that the Rayleigh wave speed constitutes the theoretical limit under tensile (mode I) conditions, recent observations of dynamic failure in homogeneous specimens subjected to shear-dominated loading conditions indicated that intersonic crack motion (that is, higher than the shear wave speed but lower than the dilatational wave speed) is possible. The objective of this project is to investigate the subsonic-to-transonic transition process using a specially developed spectral scheme.

Mechanics of Live Propellant Failure

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The initiation and propagation of one or more cracks in the solid propellant (SP) or along the grain/case interface can have dramatic repercussions on the rocket performance. By creating additional burning surfaces in the SP, the propagation of one or more cracks can greatly affect the pressure history in the rocket chamber. In some cases, this can lead to the complete failure of the rocket. Using 2-D and 3-D fully coupled **explicit** aeroelastic finite-element/finite-volume codes, researchers are investigating various accident scenarios associated with the presence of pre-existing cracks at various locations in the solid booster, with special emphasis on SP/liner interfacial failures.

Role of the Cohesive Failure Model in Quasi-Static and Dynamic Fracture

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Cohesive failure models are often used in the analytical and numerical study of spontaneous crack propagation. These simple models have been shown to capture some important dynamic fracture effects, such as maximum crack speed, crack branching, and unsteady crack energetics. The primary objective of this research project is to gain a better understanding of the importance of the often ignored rate-dependent effect on the spontaneous propagation behavior of a crack. The numerical tool used in this study is a spectral form of the boundary integral formulation of the elastodynamic relations, which allows for the incorporation of a wide range of cohesive models.

Analytical Determination of Optimum Viscoelastic Material Properties

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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

* Denotes principal investigator.

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.

Probabilistic Minimum Weight Analysis

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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 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

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Analytical studies are presented which 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.

Fracture Mechanics of Crystalline Aluminosilicate Oxides

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Zeolites are porous structures that are used in numerous industries, including the oil industry, as catalysts in reactive flows. It has been observed that upon continued use their catalytic ability diminishes. This is believed to be a consequence of mechanical loads on the zeolites. This particular project is focused on the determination of elastic and failure properties of such zeolites. Since the catalyst particles are usually of small size and primarily undergo compressive loading by contact with other particles, it was decided to test as small a zeolite crystal as possible in compression. A compressive load frame was custom built using a stepper motor actuator. Zeolite crystals were synthesized in the laboratory to facilitate testing. The average crystal size was around 500 microns and contained pores of the order of 5 nm. It was seen that the crystals are extremely brittle and are prone to excessive microcracking under continued compressive fatigue loading.

Fracture of Polymeric Matrix Composites

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The use of polymeric matrix fiber reinforced composites is constantly increasing in the aerospace industry. Such materials may provide several benefits, including significant weight savings and corrosion resistance, over traditional structural materials. However, because of their multiphase nature the failure processes composites undergo are considerably more complex than those in more traditional solids. This project deals with the numerical and experimental investigation of quasi-static fracture of polymeric matrix long fiber reinforced composites. Finite element simulations are used to determine the extent and amount of three dimensional deformation regions in cracked thick composite plates. Experimental confirmation of the numerical simulations is done by using full-field lateral shearing interferometric techniques to image the near-tip region in the cracked composite plates. The experiments are also used to determine regions of dominance of anisotropic asymptotic crack-tip fields and extract values of the composite fracture toughness. A study of the effects of fiber direction and applied load mixity is also performed.

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Fundamental Problems in Dynamic Fracture Mechanics

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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.

High Strain Rate Properties of Advanced Materials for Use by the U.S. Navy

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Accurately determining the high strain rate mechanical response of polymers and polymeric matrix composites is of interest in this work. Dynamic experiments are conducted using either a compression or tension split Hopkinson bar. The bars provide a real-time signal of stress and strain in the sample. For a complete characterization of sample response, however, independent measurement of temperature is required. For this purpose, simultaneously with stress and strain, sample surface temperature is measured in real time using an HgCdTe high- speed infrared radiation detector array. The measured heat emitted during deformation is then related to the amount of mechanical work imparted in the sample during loading. For ductile polymers, such as polycarbonate, the amount of plastic work converted to heat is found to be around 50%. That is much less than occurs in most metallic materials (about 95%). For brittle systems, such as Plexiglas™ and composites, significant damage-induced heating is also seen to occur.

Numerical and Experimental Modeling of a Cellulose Cutting Process

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Cellulose is a plant-based polymer that has found widespread use in many applications ranging from toothpaste and drugs, to packaging and paints. In most cases cellulose is used in particle form (for example as a moisture retention agent). Thus, controlling the particle size while cutting raw cellulose is critical to its usefulness. The present project is concerned with determining micromechanical properties of cellulose fibers and using these properties in numerical simulations that accurately predict cellulose fiber failure. The fibers are about 2mm to 3mm in length and 50 microns in width. A special microtensile tester device, using a stepper motor for actuation and a high precision load cell for load measurement, was designed and constructed in-house. The microtensile tester was successfully used to measure elastic and failure properties of wood- and cotton-based cellulose fibers. The statistical distribution of fiber strength measured experimentally was then fit to a Weibull strength distribution model.

Quasi-static Fracture of Functionally Graded Materials

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Functionally graded materials (FGMs) are materials that exhibit a spatially continuous variation of mechanical properties (graded metal-ceramic structures, for example). Such materials would possess the benefits of metals (conductivity, ductility, and so forth) on one side and those of ceramics (including hardness, insulation, and stiffness) on the other side, without the adverse effects of an interface between the two solids being present. Understanding the fracture response of such graded microstructures is critical in developing design procedures for their beneficial use. In this work, researchers perform macroscopic fracture experiments on a model polymer-based functionally graded material. The full-field optical technique of digital image correlation is used to visualize the displacement field of an edge crack propagating in the FGM under remote loading. The experimental results are then used to extract values of the stress intensity factor and thus construct resistance curves for crack growth in FGMs. It is seen that FGMs possess a "built-in" fracture

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resistance curve by requiring constantly increasing amounts of energy to be supplied to the crack tip. The effect of the amount and orientation of material gradient is also investigated.

Thermomechanical Effects During Dynamic Fracture of Glassy Polymers

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When a crack propagates rapidly through a solid, significant amounts of heat generation may occur. For the case of metals, the temperature increase surrounding a dynamically growing crack has seen to be of the order of several hundreds of degrees. For polymeric materials this is expected to be less, but such materials are much more susceptible to even small temperature variations than metals. This project deals with the experimental and analytical investigation of heat generation during dynamic fracture of polymers. An HgCdTe high-speed infrared radiation detector array is used to measure in real time the temperature generated during dynamic crack growth in a nominally ductile polymer, polycarbonate, and a nominally brittle one, PlexiglasTM. Both symmetric (mode I) and predominately antisymmetric (mode II) crack growth is investigated. It is found that the temperature increase may be of the order of the glass transition temperature in both polymers and is substantially more for the shear dominated case. A cohesive failure-based formulation is used to theoretically predict the amount of heat generated at the dynamically propagating crack and to understand the partition of fracture energy into elastic deformation, plastic deformation, new surface generation and heat emission.

Damage Detection in Composite Materials Using Magnetostrictive Tagging

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Knowledge of the health of a material or structure is critical for timely maintenance and repair of components. This is especially difficult for composites because subsurface flaws are hidden from visual inspection. By incorporating smart material tags into the matrix of a polymer composite and then interrogating these tags, the state of health of a composite structure can be qualified throughout its processing and service life. TERFENOL-D, a magnetostrictive material, is used for tagging. The tagged material emits a magnetic signature that is proportional to the applied stress. The location of cracks is detected by local peaks in magnetic signature.

Design and Manufacture of Adaptive Structures

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Adaptive structures and materials sense their environment and react to these sensory inputs in some logical fashion. The sensor/actuator materials for these applications can take many forms: shape-memory alloy wires, piezoelectric patches, fiber optics, and so forth. This research investigates the design and manufacture of shape-memory alloy composites, piezoelectric composites, and hybrids combining the two sensor/actuators. The approach builds upon investigations at the microlevel (interfacial bonding, residual stresses) to the macrolevel (structural mechanics of beams/tubes, process modeling). These types of materials have wide-ranging applications in the civil infrastructure, aerospace, and automotive industries.

Design, Manufacture, and Testing of Polymer Composite Bridges

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Polymer composite materials are particularly well suited for use in civil infrastructure applications due to their high specific strength and stiffness and resistance to environmental degradation. A unique design has been developed for large vehicular bridges based on integrated composite shells manufactured by filament winding. Scale models (1/10) of a 60-ft span bridge are manufactured and tested in static and dynamic loading conditions.

Magnetic Domain Imaging of Magnetostrictive Materials Subject to Coupled Field Loading

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Magnetostrictive materials such as TERFENOL-D are composed of small magnetic domains. The domains are distinguished by alignment of magnetic dipoles within regions of the material. The magnetostrictive behavior of TERFENOL-D arises through changes in the magnetic domains under the influence of stress and magnetic field. Magnetic force microscopy (MFM) is used to visualize the magnetic domains of TERFENOL-D while applying magnetic and mechanical loads.

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Manufacture and Testing of Composite Couplings for Building Systems
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The use of composite materials in civil infrastructure applications such as building superstructures is currently limited by the ability to connect composite components together. Standard fastening techniques, such as bolts, welding, and rivets, are not suitable for use with polymeric composites. A novel type of fastener utilizing composite materials formed into sleeves that nest with structural components has been designed. Manufacturing techniques suitable to high-speed, low-cost production are being developed using liquid molding processes.
The novel fasteners are tested for mechanical performance under various types of loads.

Process Optimization for Dimensional Accuracy for Polymer Composites: Experimental Characterization of Warpage
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National Science Foundation, DMI 96-10382

The residual stresses induced during processing of polymer matrix composites manifest themselves as warpage in the finished structure. The overall objective is to develop models that can be used to predict these processing-induced deformations so that molds and curing schedules can be designed to account for warpage in the final structure. Experiments are being conducted to measure the processing-induced warpage in both flat plate and complex curvature geometries.

Process Optimization for Dimensional Accuracy for Polymer Composites: Material Characterization and Micromechanical Modeling
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National Science Foundation, DMI 96-10382

Residual stresses developed during the manufacture of composites have a strong influence on the final shape of the manufactured part. A precise understanding of the phenomena leading to the appearance of these residual stresses is the primary objective of this project, in which special emphasis is placed on characterizing the polymeric matrix composite during the manufacturing process.
A full experimental characterization of the viscoelastic mechanical properties during cure is necessary in order to develop appropriate micromechanical models.

Self-Healing Composite Materials
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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.

Shape-Memory Microflaps for Active Flow Control
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Defense Advanced Research Projects Agency, F49620-98-1-0490; U.S. Air Force Office of Scientific Research, F49620-98-1-0381

Conventional bleeding of the boundary layer for supersonic inlet ducts utilizes fixed holes with active-passive transpiration. Improvement in efficiency can be obtained by using an active flow control device based on the development of shape-memory microflaps that open and close under certain operating conditions. Shape-memory composites and bilayers are proposed to be used to fabricate these microflaps. This project entails significant experimental characterization of the constituent materials, analytical modeling of the constitutive and structural behavior, and mechanical-wind tunnel testing of performance.

Use of Corn Byproducts for Structural Composite Materials
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University of Illinois

Two important issues have gained national priority in recent years: the development of alternative markets for corn and its byproducts and the revitalization of the U.S. civil infrastructure. These two issues are synthesized in the current project that focuses on the development of cheaper composite materials for civil engineering applications by using corn byproducts as reinforcements

* Denotes principal investigator.

in polymer matrix composites. Husks, fiber stalks, kernels, and fiber silks are mechanically tested both individually and as embedded reinforcements in several different polymer matrices. Once a reasonable database has been established for the mechanical properties of corn byproducts, their potential for structural composites will be evaluated.

Propulsion and Combustion

Analysis of Mean Flow and Turbulence Effects on Acoustic Response Threshold in Solid Propellant Rockets

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Nonlinear combustion stability theories require and depend strongly on what is traditionally termed a velocity response function. Through computational solutions of a turbulence and combustion model, prior work has shown that a significant source of response to solid rocket aeroacoustics can result from the interaction between acoustically induced turbulence and combustion processes. This research effort undertakes an approximate analysis of the effects of mean and oscillatory flow on the velocity response threshold condition using linear, hydrodynamic stability theory. Recent results include the prediction of the threshold condition and the discovery of a new, parametrically excited vortex instability mode.

Stability of Flows through Porous Media at Large Reynolds Number

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Porous walls are often used for the surfaces of rocket chambers and their experimental simulators. It has been experimentally observed that as the Reynolds number of the flow based on pore size becomes of the order 10 or more, the flow becomes unstable, with large magnitude nonuniformities. These disturbances are observed to be nearly random spatially, but temporally steady. This is a "pseudo-turbulence" phenomenon that has not been analytically addressed in the literature. The mechanism is related to the nonlinear drag terms in the equations of motion. Linear instability techniques are being employed to analyze the flow.

Flows in Star-Grained Propellants

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The flow in a solid propellant rocket chamber is essentially inviscid, albeit rotational. In this study, researchers are concerned with the flow in the arms of star-grained propellants. Results are also applicable to the flow in propellant cracks, an important issue in accident scenarios.

Homogenization Issues in Modeling Heterogeneous Propellants

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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.

Ignition Models for Solid Propellant Rocket Motors

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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 Center for the Simulation of Advanced Rockets for the complete simulation of the rocket.

* Denotes principal investigator.

Toward a Numerical Simulation of the Combustion Layer in a Solid-Propellant Rocket Motor

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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.

Multipass Herriot Cell for Density Diagnostics in Pulsed Thrusters

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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 gasdynamic models of PPT operation

Performance of Coaxial Teflon Pulsed Plasma Thrusters

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Pulsed plasma thrusters (PPTs) with Teflon™ propellant can operate at low power and high specific impulse for such satellite propulsion objectives as attitude control, formation flying, and orbital transfer. The coaxial Teflon™ PPT has demonstrated much higher thrust impulse than other geometries, and the goal of this research is to increase the specific impulse of this device to the 1,000-second level, while reducing thermal and two-phase flow losses.

Structural Dynamics

Damping in Bolted Joints

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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 microslip in the vicinity of connectors, such as bolts, and slap 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.

Dynamics and Control of Highway Bridges

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In this project, various strategies for extending the life of highway bridges will be examined, including passive, semiactive, and active control strategies for limiting bridge response to heavily loaded vehicles. Efficient methods leading to low-order control-oriented models for the bridge-vehicle system have been developed, and various vehicle suspensions are being studied. A series of model experiments are under way to assess effects of bridge damage on response.

Novel Passive Control Methods for Aerostructures

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Researchers are applying nonlinear localization and energy pumping to the vibration and shock isolation of structures representative of aircraft components. To achieve this, researchers 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.

* Denotes principal investigator.

Acoustic and Viscoelastic Wave Propagations with Absorbing Boundaries

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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.

Control of Piezoviscoelastic Lifting Surfaces

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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.

Finite-Element Analysis of Anisotropic Viscoelastic Composites

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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

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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 oscillators' performance. It has been found that generalized viscoelastic material behavior profoundly affects the displacements and phase relations of these oscillators.

Torsion-bending Flutter of Viscoelastic Wings

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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.

Linear and Nonlinear Passive Vibration Control of Mechanical Systems

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Researchers develop linear and nonlinear vibration isolation designs for naval application and passive control designs for shipboard truss-like structures. The team also examines passive approaches for ice delamination on airplane wings.

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Nonlinear Localization for Shock Isolation of Flexible Structures

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A goal of this project is to develop a new kind of shock isolation system, based on the concept of nonlinear localization, whereby induced vibrational energy is passively confined to a preassigned secondary system and away from the primary system to be isolated. Researchers show that a robust nonlinear localization phenomenon can be effected by tuning the shock isolation system so that a 1:1 resonance exists between the secondary substructure and a mode of the primary one, or by inducing a strongly localized nonlinear normal mode that is partially confined to the secondary substructure. An experiment is currently in the design stage.

Structural Mechanics

Anisotropic Piezo-Electro-Thermo-Viscoelasticity Theory with Applications to Composites

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The general, nonlinear, 3-D, large deformation theory of anisotropic piezo-electro-thermoviscoelasticity is formulated and represents the confluence of anisotropic elasticity and thermoviscoelasticity, nonhomogeneous layered media, and piezoelectricity. For linear materials and small deformations, a piezoelastic/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 piezoelastic solutions and conducting sensitivity analyses of piezoviscoelastic parameters.

Anisotropic Viscoelastic Fractional Derivative Material Characterization

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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

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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. Since viscoelastic responses are accelerated in time by increases in temperature and moisture content, significant damping effects will be experienced in warm, moist soils.

Large Deflections of Linearly Elastic and Viscoelastic Columns with Follower Loads

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A large-deflection analysis of nonhomogeneous linearly elastic or viscoelastic columns with initial curvature and with variable areas subjected to follower loads is formulated. Column end shortening due to both

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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, and variable area on elastic and viscoelastic columns are studied in detail.

Mathematical and Numerical Analysis Issues in Nonlinear Anisotropic Viscoelastic Composites

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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

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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).

Stochastic Delamination Buckling of Viscoelastic Columns

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The effects of random failure criteria on delamination 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

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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.

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Structural Integrity of Solid Propellants and Filament-Wound Rocket Cases

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Nonlinear analytical and massively parallel numerical analyses of propellants and cases have been initiated. Time-dependent probabilities of failure are determined and finite-element massively parallel protocols are being developed.

Finite-Element Analysis of Coarse-grained Vector Machines of Residual Stresses in Viscoelastic IC Packages during Surface-mounting Processes

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Nanyang Technological University; University of Illinois

Moisture and temperature distributions and residual stresses in plastic-encapsulated IC packages are evaluated to assess product reliability. Finite-element analyses (FEA) are done on the NTU CRAY T94 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

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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

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Interlaminar stresses near free laminate edges may result in delamination onset and growth and may also 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

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University of Illinois; National Center for Supercomputing Applications; Nanyang Technological University; U.S. Department of Energy, DAHC94-46-C-0005 (HPCMP-PET)

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 $(45/-45)_S$T300/5208 laminate are also presented.

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Performance Evaluations of Viscoelastic Finite-Element Analyses on Coarse Grained and Massively Parallel Supercomputers

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Performance evaluations of dynamic viscoelastic finite-element procedures and codes on coarse grained and massively parallel supercomputers such as the CRAY Y-MP, CRAY C-90, and the Connection Machine 5 (CM-5) have been undertaken. The element stiffness computations are in the range of 73 to 183 mega floating-point operations per second (Mflops) on the NCSA CRAY Y-MP. Using four node plane elements and the 256-processor CM-5, a speedup factor of about 22 over the CRAY Y-MP was obtained for calculating 1.6×10^5 element stiffness matrices, which is 1.65 Gflops. The performances of the conjugate gradient method on the CRAY Y-MP and CM-5 are also evaluated and are compared with those of the Cray sparse matrix and of the Feable solvers.

Process-induced Residual Thermal Stresses and Deformations in Thick Thermosetting Matrix Composite Laminates

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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 Non-Anticipated Ecological Policy

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Researchers 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 the government regulations is anticipated and for the case in which it is not anticipated.

Optimal Control for Air Combat

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University of Illinois; Japan Defense Agency

In this work, two highly maneuverable (F-16 type) airplanes are engaged in combat. The problem can be formulated as a problem in differential games, a so-called minimax problem. In this problem, the pursuer airplane is trying to minimize the time required to intercept the evader airplane, while the evader airplane is trying to maximize this same time (and make it infinite if possible). This is a very complicated optimal control problem since the optimal trajectory for each aircraft depends on what the other aircraft does. It is solved using a newly-developed variation of the method of collocation with nonlinear programming.

Autopilot Analysis and Adaptation in Icing Conditions

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Icing during flight can cause significant degradation in the performance of the flight control system, even to the point of generating catastrophic failures. In this project, researchers analyze the behavior of the autopilot functions and their safety characteristics. The team investigates techniques to adapt autopilot parameters based on information about the icing state of the aircraft. Researchers also study the performance limitations of the flight control system based on saturation constraints on the control surface deflections and models of icing dynamics. Envelope protection algorithms are also developed based on this approach.

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Remote and Distributed Control over Networks
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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.

Journals and Books

Aerodynamics

Whale, J., C. J. Fisichella, and M. S. Selig. **Correcting inflow measurements from wind turbines using a lifting-surface code.** *ASME J. Solar Energ. Eng., 122,* 196-202 (Nov. 2000).

Astrodynamics

Coverstone-Carroll, V., J. W. Hartmann, and W. M. Mason. **Optimal multi-objective low-thrust spacecraft trajectories.** *Comput. Methods Appl. Mech. Eng., 186,* 387-402 (2000).

Horie, K. and B. A. Conway. **Optimization for fighter aircraft vertical maneuvering using poststall flight.** *J. Aircr., 37:6* (2000).

Jo, J. W. and J. Prussing. **A procedure for applying second-order conditions in optimal control problems.** *J. Guidance, Control, and Dynamics, 23:2,* 241-250 (2000).

Prussing, J. **A class of optimal two-impulse rendezvous using multiple-revolution Lamber solutions.** *J. Astronautical Sciences, 48:2 & 3,* 131-148 (2000).

Williams, S. and V. Coverstone-Carroll. **Mars missions using solar electric propulsion.** *J. Spacecr. Rockets, 37:1,* 71-77 (2000).

Combustion

Buckmaster, J. and T. L. Jackson. **The effects of time-periodic shear on a diffusion flame anchored to a propellant.** *Combust. Flame, 120,* 211-222 (2000).

Buckmaster, J. and T. L. Jackson. **Flames supported by heterogeneous propellants.** *American Institute of Aeronautics and Astronautics reprint, AIAA 00-0306* (2000).

Buckmaster, J. and T. L. Jackson. **Holes in flames, flame-isolas, their edges.** *Proc. Combustion Institute, 28* (2000).

Buckmaster, J., A. Hegab, and T. L. Jackson. **The effects of convection and cold probes on oscillating edge-flames.** *American Institute of Aeronautics and Astronautics reprint, AIAA 00-0847* (2000).

Buckmaster, J., A. Hegab, and T. L. Jackson. **More results on oscillating edge-flames.** *Phys. Fluids, 12,* 1592-1600 (2000).

Jackson, T. L., J. Buckmaster, and J. Hoeflinger. **3D flames supported by heterogeneous propellants.** *J. Proc. Combustion Institute, 28* (2000).

Jackson, T. L., and J. Buckmaster. **Non-premixed periodic flames supported by heterogeneous propellants.** *J. Propul. Power, 16,* 498-504 (2000).

Kochevets, S., J. Buckmaster, and T. L. Jackson. **Random propellant packs and the flames they support.** *American Institute of Aeronautics and Astronautics reprint, AIAA 00-3461* (2000).

* Denotes principal investigator.

Dynamical Systems

Namachchivaya, N. S. and L. Vedula. **Real noise stabilization of linear systems: application to flow-induced oscillations.** *J. Dynamics Stabil. Syst., 15:2,* 185-208 (2000).

Namachchivaya, N. S., R. Sowers, and L. Vedula. **Stochastic averaging on graphs: noisy Duffing-van der Pol equation, pp. 332-342.** *In Stochastic and Chaotic Dynamics in the Lakes. American Institute of Physics, Melville, N.Y.* (2000).

Xie, W. C., N. S. Namachchivaya, and B. Balachandaran. **Nonlinear Dynamics and Stochastic Mechanics.** *American Society of Mechanical Engineers AMD 241. New York, N.Y.* (2000).

Lasers

Carroll, D. L., D. M. King, L. Fockler, D. Stromberg, W. C. Solomon, L. H. Sentman, and C. H. Fisher. **High-performance chemical oxygen-iodine laser using nitrogen diluent for commercial applications.** *IEEE J. Quantum Electron., 36:1,* 40-51 (2000).

Materials and Structures

Anlas, G., M. H. Santare, and J. Lambros. **Numerical calculation of stress intensity factors in functionally graded materials.** *Int. J. Fract., 104:2,* 131-143 (2000).

Breitenfeld, M. S. and P. H. Geubelle. **Parallel implementation of a spectral scheme for the simulation of 3D dynamic fracture events.** *Int. J. High-Perform. Comput. Appl., 14:1,* 26-38 (2000).

Hwang, C. and P. Geubelle. **A spectral scheme to simulate dynamic fracture problems in composites.** *Comput. Model. Eng. Sci., 1:4,* 45-56 (2000).

Kim, C. and S. White. **Continuous curing and induced thermal stresses of a thick filament wound composite cylinder.** *J. Reinf. Plast., Compos., 20:2,* 166-180 (2000).

Li, H., J. Lambros, B. A. Cheeseman, and M. H. Santare. **Experimental investigation of the quasi-static fracture of functionally graded materials.** *Int. J. Solids Struct., 37:27,* 3715-3732 (2000).

Li, Z. and J. Lambros. **Thermomechanical dynamic behavior of fiber reinforced composites.** *Composites A, 31,* 537-547 (2000).

O'Brien, D. and S. White. **Viscoelastic properties of an epoxy resin during cure.** *J. Compos. Mater., 35:10,* 883-904 (2000).

Prabhu, S. and J. Lambros. **A combination optical method of lateral shearing interferometer and caustics.** *Exp. Mech., 40:4, 376-383* (2000).

Prabhu, S. and J. Lambros. **Effect of mode mixity on K-dominance and three-dimensionality in cracked plates.** *Int. J. Fract., 104:1,* 51-69 (2000).

Prabhu, S. and J. Lambros. **A numerical investigation of three-dimensional effects in cracked unidirectional fiber reinforced composite plates.** *J. Compos. Mater., 34:2,* 116-134 (2000).

Santare, M. H. and J. Lambros. **Use of a graded finite element to model the behavior of nonhomogeneous materials.** *J. Appl. Mech., 64:1, 819-822* (2000).

Propulsion and Combustion

Burton, R. L., F. Rysanek, E. A. Antonsen, M. J. Wilson, and S. S. Bushman. **Pulsed plasma thruster performance for microspacecraft propulsion, Chapter 13.** *In Micropropulsion for Small Spacecraft, AIAA Progress Series, Vol. 187* (2000)

Krier, H., R. L. Burton, and J. C. Melcher. **Combustion of aluminum particles in solid rocket motor flows, Chapter 2.2.** *In Solid Propellant Chemistry, Combustion, and Motor Interior Ballistics, AIAA Progress Series, Vol. 185* (2000).

* Denotes principal investigator.

Structural Dynamics

Liew, K. W., L. A. Bergman, T. Y. Ng, and K. Y. Lam. **Three-dimensional vibration of cylindrical shell panels-solution by continuum and discrete approaches.** *Comput. Mech., 26,* 208-221 (2000).

Ma, X., T. A. Nayfeh, A. F. Vakakis, and L. A. Bergman. **Experimental verification of shock reduction achieved through non-linear localization.** *J. Sound Vibr., 230:5,* 1177-1184 (2000).

Pesterev, A. V. and L. A. Bergman. **An improved series expansion to the solution of the moving oscillator problem.** *ASCE J. Vibr. Acoust., 122:1,* 54-61 (2000).

Yang, B., C. A. Tan, and L. A. Bergman. **A direct numerical procedure for the solution of moving oscillator problems.** *ASCE J. Eng. Mech., 126:5,* 462-469 (2000).

Structural Mechanics

Hilton, H. H. **Aerospace structures in the first year of the new millennium and beyond.** *Aerosp. Am., 38:12,* 70-71 (3000).

Systems and Control

Melody, J. W., T. Basar, W. R. Perkins, and P. G. Voulgaris. **Parameter identification for in-flight detection of aircraft icing.** *Control Eng. Pract., 8,* 985-1001 (2000).

Two-Phase Flow

Loth, E. **Numerical approaches to dilute two-phase flow.** *Prog. Energ. Combust. Sci., 26:3,* 161-223 (2000).

Ford, B. and E. Loth. **Diffusion of ellipsoidal bubbles in a turbulent shear layer.** *Int. J. Multiphase Flow, 26,* 503-516 (2000).

Papers Presented at Conferences and Symposia

Aerodynamics

Broeren, A. P. and M. B. Bragg. **Unsteady stalling characteristics of thin airfoils at low-Reynolds number.** Proc. Conf. on Fixed, Flapping and Rotary Wing Vehicles at Very Low Reynolds Numbers (Notre Dame, Ind., Jun. 2000) 396-420 (2000).

Gefroh, D., E. Hafenricheter, J. C. Dutton, S. McIlwain, and E. Loth. **Experiments of aeroelastic mesoflaps.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0355 (2000).

Gefroh, D., E. Hafenricheter, J. C. Dutton, S. McIlwain, E. Loth, and P. Geubelle. **Simulation and experimental analysis of a novel SBLI flow control system.** AIAA Fluid Dynamics 2000 (Denver, Colo., Jun. 2000) AIAA 2000-2237 (2000).

Giguère, P. and M. Selig. **Blade geometry optimization for the design of wind turbine rotors.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0045 (2000)

Gopalarathnam, A. and M. S. Selig. **A hybrid approach to inverse design of complex aerodynamic systems.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0784 (2000).

Kumar, S. and E. Loth. **Aerodynamic simulations of airfoils with large-droplet ice-shapes.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0238 (2000).

Lee, S., H. Kim, and M. B. Bragg. **Investigation of factors that influence iced-airfoil aerodynamics.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan, 2000) AIAA 2000-0099 (2000).

Lu, B. and M. B. Bragg. **Experimental investigation of airfoil drag measurement with simulated leading-edge ice using the wake survey method.** Proc. 18th AIAA Applied Aerodynamics Conf. (Denver, Colo., Aug. 2000) AIAA 2000-3919, 12-21 (2000).

* Denotes principal investigator.

Selig, M., A. Gopolarathnam, P. Giguère, and C. Lyon. **Systematic airfoil design studies at low Reynolds numbers.** Proc. Conf. on Fixed, Flapping, and Rotary Wing Vehicles at Very Low Reynolds. (Notre Dame, Ind., Jun. 2000) (2000).

Wood, B., E. Loth, P. Geubelle, and S. McIlwain. **A numerical methodology for an aeroelastic SBLI control.** AIAA 38th Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0522 (2000).

Astrodynamics

Cerven, W. T. and V. Coverstone-Carroll. **Optimal reorientation of a multibody spacecraft through joint motion using averaging theory.** AAS/AIAA Spaceflight Mechanics Mtg. (Clearwater, Fla., Jan. 2000) AAS 00-203 (2000).

Lakso, J. and V. Coverstone-Carroll. **Optimal tether deployment/retrieval trajectories using direct collocation.** AIAA/AAS Astrodynamics Specialist Conf. (Denver, Colo., Aug. 2000) AIAA 2000-4349 (2000).

Prussing, J. E. **A class of optimal two-impulse rendezvous using multiple-revolution Lambert solutions.** The Richard H. Battin Astrodynamics Symp. (College Station, Tex., Mar. 2000) Paper AAS 00-250 (2000).

Prussing, J. E. **A class of optimal two-impulse rendezvous using multiple-revolution Lambert solutions.** Univelt Inc. (San Diego, Calif., Mar. 2000) Vol. 106, pp. 17-39 (2000).

Combustion

Buckmaster, J., T. L. Jackson, A. Hegab, and S. Kochevets. **Modeling propellants and modeling propellant flames.** Proc. 37th JANNAF Combustion Mtg. (Monterey, Calif., Nov. 2000) (2000).

Computational Fluid Dynamics

Choo, Y., K. D. Lee, D. Thompson, and M. Vickerman. **Surface preparation and grid generation for the simulation of icing effects on airfoil performance and for the prediction of ice accretion on airfoils.** 7th Int. Conf. on Numerical Grid Generation in Computational Field Simulations (Whistler, B.C., Sep. 2000) (2000).

Chung, J. and K. D. Lee. **Shape optimization of transonic compressor blades using quasi-3D flow physics.** 45th ASME International Gas Turbine and Aerospace Congr. (Munich, Germany, May 2000) AIAA 2000-GT-0489 (2000).

Chung, J., J. Shim, and K. D. Lee. **3D transonic compressor design optimization with quasi-3D flow physics.** ASME Fluids Engineering Ann. Mtg. (Boston, Mass., Jun. 2000) FEDSM 00-11075 (2000).

Chung, J., J. Shim, and K. D. Lee. **Design of 3D transonic compressor blades using numerical optimization.** 38th AIAA Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0227 (2000).

Chung, J., J. Shim, and K. D. Lee. **Turbomachinery design strategy with 3D Navier–Stokes equations.** UKC 2000 (Chicago, Ill., Sep. 2000) ATS-4-4 (2000).

Eyi, S. and K. D. Lee. **Turbomachinery blade design via optimization.** 38th AIAA Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0740 (2000).

Lee, K. D. and J. Shim, J. **A computational investigation of aircraft icing effects in aviation safety.** UKC 2000 (Chicago, Ill., Sep. 2000) ATS-3-3 (2000).

Shim, J., J. Chung, and K. D. Lee. **A comparison of turbulence modeling in flow analysis of iced airfoils.** 18th AIAA Applied Aerodynamics Conf. (Denver, Colo., Aug. 2000) (2000).

Shim, J., J. Chung, and K. D. Lee. **A grid generation strategy for CFD analysis of iced airfoil flows.** 7th Int. Conf. on Numerical Grid Generation in Computational Field Simulations (Whistler, B.C., Sep. 2000) (2000).

* Denotes principal investigator.

Dynamical Systems

McDonald, R. J. and N. S. Namachchivaya. **Dynamics of a pipe conveying pulsating flow near criticality.** Nonlinear Dynamics and Stochastic Mechanics, AMD 241, American Society of Mechanical Engineers (New York, N.Y., 2000) 13-20 (2000).

Namachchivaya, N. S., R. B. Sowers, and L. Vedula. **Nonstandard reduction of noisy mechanical systems.** EUROMECH-413-Colloq. on Stochastic Dynamics of Nonlinear Mechanical Systems (Palermo, Italy, Jun. 2000) 10 pages, CD-ROM (2000).

Ramakrishnan, N. and N. S. Namachchivaya. **Near-resonant motion of randomly perturbed two-frequency intergrable systems.** 8th ASCE Joint Specialty Conf. on Probabilistic Mechanics and Structural Reliability (Notre Dame, Ind., Jul. 2000) 12 pages, CD-ROM (2000).

Vedula, L. and N. S. Namachchivaya. **Stochastically perturbed nonlinear gyroscopic systems: application to rotating shafts.** 8th ASCE Joint Specialty Conf. on Probabilistic Mechanics and Structural Reliability (Notre Dame, Ind., Jul. 2000) 12 pages, CD-ROM (2000).

Vedula, L. and N. S. Namachchivaya. **Nonstandard reduction of noisy structural systems: shallow arches.** Nonlinear Dynamics and Stochastic Mechanics, AMD 241, American Society of Mechanical Engineers (New York, N.Y., 2000) 1-81 (2000).

Lasers

Carroll, D. L. and W. C. Solomon. **ElectriCOIL: An advanced chemical iodine laser concept.** XIII Int. Symp. on Gas Flow and Chemical Lasers and High-Power Lasers (Florence, Italy, Sep. 2000) (2000).

Carroll, D. L., W. C. Solomon, D. M. King, L. Fockler, D. Stromberg, M. Sexauer, A. Milmoe, and L. H. Sentman. **Advanced mixing nozzle concepts for COIL.** Int. Conf. on Lasers 1999 (Quebec City, Que. Dec. 1999) (2000).

King, D. M., D. L. Carroll, J. K. Laystrom, J. Verdeyen, M. Sexauer, and W. C. Solomon. **ElectriCOIL: preliminary experiments of excited oxygen generation by RF discharge.** Proc. Int. Conf. on Lasers 2000 (Albuquerque, N. Mex., Dec. 2000) (2000).

Stromberg, D. S., L. A. Fockler, D. L. Carroll, and W. C. Solomon. **New simulations for COIL lasers from the University of Illinois.** Laser Optics 2000 (St. Petersburg, Russia, Jun. 2000) (2000).

Materials and Structures

Brown, E., N. Sottos, S. White, P. Geubelle, and J. Moore. **Self-healing composites using embedded microspheres: fracture toughness of epoxy matrix.** ICTAM 2000 Conf. (Chicago, Ill., Aug. 2000) (2000).

Geubelle, P. H. **Numerical simulation of dynamic fracture problems.** MAPINT2000 (Dayton, Ohio, Aug. 2000) (2000).

Geubelle, P. H. **Spectral scheme simulations of dynamic fracture problems. ASME** IMECE 2000 (Orlando, Fla., Nov. 2000) (2000).

Geubelle, P. H. and A. Acharya. **Thermoelastic spectral analysis of dynamically propagating cracks.** 37th Ann. Tech. Mtg. of the Society of Engineering Sciences (Columbia, S.C., Oct. 2000) (2000).

Geubelle, P. H., M. S. Breitenfeld, D. Kubair, and C. Hwang. **Simulation of fundamental dynamic fracture problems using a spectral scheme.** ICES2K (Anaheim, Calif., Aug. 2000) (2000).

Hwang, C. and P. H. Geubelle. **Subsonic and intersonic crack propagation in unidirectional and cross-ply composites.** ASME IMECE 2000 (Orlando, Fla., Nov. 2000) (2000).

Krishnan, S. S. H. Yoon, and S. R. White. **Dynamic mechanical analysis of nitinol beams.** Adaptive Structures and Materials Systems Symp., ASME IMECE 2000 (Orlando, Fla., Nov. 2000) 13-18 (2000).

Kubair, D. and P. Geubelle. **Intersonic crack propagation in homogeneous media under shear-dominated mixed-mode loading.** ICTAM 2000 Conf. (Chicago, Ill., Aug. 2000) (2000).

* Denotes principal investigator.

Maiti, S. and P. Geubelle. **Simulation of damage mechanisms in high-speed grinding of ceramics.** ICTAM 2000 Conf. (Chicago, Ill., Aug. 2000) (2000).

White, S., P. Geubelle, and C. Tucker. **Process optimization for dimensional accuracy for polymer composites.** 2000 NSF Design and Manufacturing Grantee's Conf. (Vancouver, B.C., Jan. 2000) (2000)

Zhu, Q. and P. H. Geubelle. **Effects of the manufacturing process on the dimensional accuracy of thermoset composites.** ASME IMECE 2000 (Orlando, Fla., Nov. 2000) (2000).

Zhu, Q. and P. Geubelle. **Process-induced residual stresses and warpage in polymer composites.** ICTAM 2000 Conf. (Chicago, Ill., Aug. 2000) (2000).

Propulsion and Combustion

Antonsen, E. L, R. L. Burton, S. F. Engelman, and G. G. Spanjers. **Herriott cell interferometer for unsteady density measurements in small length scale thruster plasmas.** 36th AIAA Joint Propulsion Conf. (Huntsville, Ala., Jul. 2000) AIAA 2000-3431 (2000).

Beddini, R. A. and Y. Lee. **Visco-acoustic and resonant interactions in solid and hybrid propulsion chambers.** 2000 JANNAF CS/PSHS/APS Joint Mtg. (Monterey, Calif., Nov. 2000) (2000).

Beddini, R. A. and C. E. Low. **Hydrodynamic stability of flow in homogeneous porous media.** 20th Int. Congr. of Theoretical and Applied Mechanics (Chicago, Ill., Aug. 2000) (2000).

Lee, Y. and R. A. Beddini. **Effect of solid rocket chamber pressure on acoustically-induced turbulent transition.** 36th AIAA Joint Propulsion Conf. (Huntsville, Ala., July 2000) AIAA 2000-3802 (2000).

Melcher, J. C., J. T. Brzozowski, H. Krier, and R. L. Burton. **Combustion of aluminum in solid rocket motor flows.** 36th AIAA Joint Propulsion Conf. (Huntsville, Ala., Jul. 2000) AIAA 2000-3333 (2000).

Rysanek, F. and R. L. Burton. **Effects of geometry and energy on a coaxial teflon pulsed plasma thruster.** 36th AIAA Joint Propulsion Conf. (Huntsville, Ala., Jul. 2000) AIAA 2000-3429 (2000).

Servaites, J. C., R. L. Burton, J. C. Melcher, and H. Krier. **Ignition and combustion of aluminum particles in shocked $H_2O/O_2/Ar$ and $CO_2/O_2/Ar$ mixtures.** 36th AIAA Joint Propulsion Conf. (Huntsville, Ala., Jul. 2000) AIAA 2000-3331 (2000).

Structural Dynamics

Caicedo, J. M., G. Turan, S. J. Dyke, and L. A. Bergman. **Comparison of modeling techniques for dynamic analysis of a cable-stayed bridge.** 14th ASCE Engineering Mechanics Conf. (Austin, Tex., May 2000) CD-ROM (2000).

Dyke, S. J., J. M. Caicedo, L. A. Bergman, and G. Turan. **Introducing a benchmark control problem for a cable-stayed bridge subjected to seismic excitation.** US-China Millennium Symp. on Earthquake Engineering (Beijing, China, Nov. 2000) (2000).

Dyke, S. J., G. Turan, J. M. Caicedo, L. A. Bergman, and S. Hague. **Benchmark control problem on the seismic response of cable-stayed bridges.** 2nd European Conf. on Structural Control (Paris, France, Jul. 2000) (2000).

Pesterev, A. V., B. Yang, L. A. Bergman, and C. A. Tan. **Response and stress calculation of an elastic continuum carrying multiple moving oscillators.** Proc. Int. Conf. on Advances in Structural Dynamics (Hong Kong, Dec. 2000) 545-552 (2000).

Wojtkiewicz, S. F. and L. A. Bergman. **Numerical solution of high-dimensional Fokker-Planck equations.** 8th ASCE Joint Specialty Conf. on Probabilistic Mechanics and Structural Reliability (Notre Dame, Ind., Jul. 2000) CD-ROM (2000).

* Denotes principal investigator.

Structural Mechanics

Beldica, C. E. and H. H. Hilton. **Aero-viscoelasticity and structural failure.** Proc. MAPINT 2000 (Dayton, Ohio, Aug. 2000) 12-13 (2000).

Beldica, C. E. and H. H. Hilton. **Delay of creep buckling and of probabilistic failures of linear viscoelastic plates.** Proc. AIAA Structures, Structural Dynamics and Materials Conf. (Atlanta, Ga., Apr., 2000) AIAA 2000-1648, 129-138 (2000).

Beldica, C. E. and H. H. Hilton. **The influence of viscoelastic wave generation on experimental material property characterization—analytical and computational simulations.** Proc. IUTAM Symp. on Mechanical Waves for Composite Structures Characterization (Chania, Crete, Jun. 2000) 27-32 (2000).

Beldica, C. E. and H. H. Hilton. **Lateral creep buckling and failure probabilities of linear viscoelastic beams.** 7th Int. Conf. on Composites Engineering, ICCE (Monterey, Calif., Jul. 2000) 73-74 (2000).

Beldica, C. E. and H. H. Hilton. **Nonlinear creep stall, torsional divergence and failure probabilities of viscoelastic lifting surfaces.** Int. Conf. on Nonlinear Problems in Aviation and Aerospace (Daytona Beach, Fla., 2000) 18-19 (2000).

Beldica, C. E. and H. H. Hilton. **Optimum composite material property configurations for piezo-viscoelastic structural control: analytical and computational simulations.** Proc. 15th Ann. Tech. Conference of the American Society for Composites (College Station, Tex., Sep. 2000) 329-334 (2000).

Beldica, C. E. and H. H. Hilton. **Piezoelectric control of deformations and failure probabilities in viscoelastic Timoshenko beams.** Int. Congr. on Theoretical and Applied Mechanics (Chicago, Ill., Aug. 2000) 180 (2000).

Beldica, C. E. and H. H. Hilton. **Piezoelectric control of lateral creep buckling and failure probabilities of linear viscoelastic beams.** Proc 37th Annual Tech. Mtg. of Society of Engineering Science (Columbia, S.C., Oct. 2000) LL:248 (2000).

Beldica, C., H. Hilton, and S. Koric. **Viscoelastic torsion under piezoelectric control—analytical and massively parallel computational simulations and performance evaluations.** Proc. Applications of High Performance Computing in Engineering V (Maui, Hawaii, Feb. 2000) 147-156 (2000).

Beldica, C. E., H. Hilton, and S. Koric. **Viscoelastic bending and torsion under piezoelectric control—analytical and massively parallel computational simulations and performance evaluations.** Proc. 25th Annual Aerospace Science Symp. (Dayton, Ohio, Mar. 2000) 31-32 (2000).

Hilton, H. H. **Nonlinear viscoelastic analysis and simulation of lifting surface instabilities with piezoelectric control.** Proc. Third World Congr. of Nonlinear Analysts (Catania, Sicily, Jul. 2000) 1492-1521 (2000).

Systems and Control

Voulgaris, P. G. **Control of nested systems.** Proc. American Control Conf. (Chicago, Ill., Jun. 2000) (2000).

Voulgaris, P. G. **Optimal control of systems with delayed observation sharing patterns via input-output methods.** 38th IEEE Conf. on Decision and Control (Sydney, Australia, Dec. 2000) (2000).

Voulgaris, P. G. **Robust and multiobjective control.** Summer School on Advanced Control. (Bertinoro, Italy, 2000) (2000).

Voulgaris, P. G., G. Bianchini, and B. Bamieh. **Optimal decentralized controllers for spatially distributed systems.** 38th IEEE Conf. on Decision and Control (Sydney, Australia, Dec. 2000) (2000).

Two-Phase Flow

Felton, K. and E. Loth. **Turbulent bubble dispersion in boundary layer.** ASME Summer Fluids Engineering Mtg. (Boston, Mass., Jul. 2000) FEDSM 2000-11140 (2000).

* Denotes principal investigator.

Hancir, P., A. Anderson, and E. Loth. **Computations of droplet distribution in the NASA IRT.** 38th AIAA Aerospace Sciences Mtg. (Reno, Nev., Jan. 2000) AIAA 2000-0101 (2000).

Loth, E. **An Eulerian model for free-shear multiphase turbulent diffusion.** ASME IMECE Mtg. (Orlando, Fla., Nov. 2000) (2000).

Theses

Aerodynamics

Chenoweth, J. **Porous wedge flows in a solid rocket motor.** M.S. thesis, M. Bragg, adviser (2000).

Gefroh, D. **Experimental study of mesoflaps to control oblique-shock/boundary-layer interaction.** M.S. thesis, E. Loth, adviser (2000).

Gurbacki, H. **Sensing aircraft icing effects from flap hinge-moment measurement.** M.S. thesis, M. Bragg, adviser (2000).

Kumar, S. **Reynolds-averaged Navier-Stokes (RANS) and detached eddy simulation (DES) applied to iced-airfoil aerodynamics.** M.S. thesis, E. Loth, adviser (2000).

Raj, N. V. **An improved semi-empirical model for 3-D post-stall effects in horizontal axis wind turbines.** M.S. thesis, M. Selig, adviser (2000).

Astrodynamics

Tanzillo, M.C. **Optimal escape using low-thrust trajectories.** M.S. thesis, J. Prussing, adviser (2000).

Trask, A. **Optimal powered aeroassisted orbit transfers using solar electric propulsion.** M.S. thesis, V. Coverstone, adviser (2000).

Combustion

Kochevets, S. **Cellular instability of diffusion flames in the counterflow configuration.** M.S. thesis, J. Buckmaster, adviser (2000).

Dynamical Systems

McDonald, R. **Bifurcations of parametrically excited gyroscopic systems near A 0:1 resonance.** Ph.D. thesis, S. Namachchivaya, adviser (2000).

Materials and Structures

Berman, J. **Investigation of residual stresses in shape memory alloy (SMA) composites.** Ph.D. thesis, S. White, adviser (2000).

Krishnan, S. **Experimental characterization and finite element analysis of shape memory alloy flaps for aeroelastic transpiration.** M.S. thesis, S. White, adviser (2000).

Li, J. **Magnetostrictive tagging of composite materials and their magnetomechanical behavior.** M.S. thesis, S. White, adviser (2000).

Viswanathan, S. **Micromechanical modeling of self-healing polymeric composites.** M.S. thesis, P. Geubelle, adviser (2000).

Zhu, Q. **Dimensional accuracy of thermoset polymer composites: process simulation and optimization.** Ph.D. thesis, P. Geubelle, adviser (2000).

Propulsion and Combustion

Servaites, J. **Combustion of aluminum particles in rocket motor oxidizers within a shock tube.** M.S. thesis, R. Burton, and H. Krier (Mechanical Engineering), advisers (2000).

Low, C. E. **Hydrodynamic instability of fluid flow through homogeneous porous media.** Ph.D. thesis, R. Beddini, adviser (2000).

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Structural Dynamics

Wojtkiewicz, S. F. **Contributions to the computational analysis of multi-dimensional stochastic dynamical systems.** Ph.D. thesis, L. Bergman, adviser (2000).

Awards and Honors

Robert A. Beddini
Associate Fellow, American Institute of Aeronautics and Astronautics
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1986
Award for International Program Development, Midwest Universities Consortium for International Activities, 1986
NATO AGARD Lectureship (individual) ONERA, France, 1990
Andersen Consulting Award for Advising Excellence, U of I College of Engineering, 1991

Lawrence A. Bergman
Fellow, American Society of Mechanical Engineers
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Associate Fellow, American Institute of Aeronautics and Astronautics
State of the Art in Civil Engineering Award, American Society of Civil Engineers, 1983
Norman Medal, American Society of Civil Engineers, 1999
Editor, *Transactions of the ASME, Journal of Vibration and Acoustics,* 2000-

Charles E. Bond, Emeritus
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1980, 1989
General Electric Scholar, U of I Academy for Excellence in Engineering Education, 1997

Michael B. Bragg
Associate Fellow, American Institute of Aeronautics and Astronautics
College of Engineering Research Award, Ohio State University, 1986
American Institute of Aeronautics and Astronautics, Losey Atmospheric Science Award, 1998
Outstanding Recent Alumnus Award, U of I Department of Aeronautical and Astronautical Engineering, 1988
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1990
Air University Board of Visitors, United States Air Force, 2000-

John D. Buckmaster
Fellow, American Physical Society
Fellow and Chartered Physicist, Institute of Physics
Fellow, Japan Society for the Promotion of Science
Fellow, J. S. Guggenheim Foundation Fellow
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, U of I, 1997
Distinguished Lecturer Cup, U of I Department of Theoretical and Applied Mechanics, 1997

Rodney L. Burton
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NASA-ASEE Summer Faculty Fellow, Jet Propulsion Laboratory, 1993
Everitt Award for Teaching Excellence, U of I College of Engineering, 1994
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1994, 1997
Engineering Council Advisors List for Outstanding Advising, U of I, 1996, 1997, 1999

Philippe Geubelle
CAREER Award, National Science Foundation, 1998
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1998
Xerox Award for Faculty Research, U of I College of Engineering, 1999

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Harry H. Hilton, Emeritus
Associate Fellow, American Institute of Aeronautics and Astronautics
Long Term AIAA Membership Award, 1985
Charles E. Schmidt Distinguished Visiting Professor, Florida Atlantic University, 1997, 1998, 1999, 2000
Fifty Year Award, American Institute of Aeronautics and Astronautics, 1997
Association of College Honor Societies Award, 2000

Ki D. Lee
Associate Fellow, American Institute of Aeronautics and Astronautics

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Associate Fellow, AIAA
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, U of I College of Engineering, 1993
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1994
Senior Fellow, Naval Research Lab, 1995
Faculty Fellow, National Center for Supercomputing Applications, 2000-2001

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Xerox Award for Faculty Research, U of I College of Engineering, 1989, 1993
Presidential Young Investigator Award, National Science Foundation, 1990
Visiting Scientist, The Fields Institute for Research in Mathematical Science, Canada, 1993
Southwest Mechanics Lectures, 1999

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Andersen Consulting Award for Advising Excellence, U of I College of Engineering, 1989, 1990, 1991, 1998, 1999
Dirk Brouwer Award, American Astronautical Society, 1994
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Best Paper Award, AAS/AIAA Space Flight Mechanics Meeting, Monterey, Calif., 1998

Michael S. Selig
Summer Faculty Fellow, Department of Energy National Renewable Energy Laboratory, 1993

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

Kenneth R. Sivier, Emeritus
Twenty-five Year Membership Certificate, American Institute of Aeronautics and Astronautics
Associate Fellow, American Institute of Aeronautics and Astronautics
Stanley H. Pierce Award, U of I College of Engineering, 1985
Teacher of the Year Award, U of I Department of Aeronautical and Astronautical Engineering, 1987

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

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, U of I College of Engineering, 1996

* Denotes principal investigator.

Scott R. White
Research Initiation Award, National Science Foundation, 1992
Office of Naval Research Young Investigator, 1993
Undergraduate Instructional Support Award, International Paper Company, 1995
Engineering Council Advisers List for Outstanding Advising, U of I College of Engineering, 1996, 1998, 1999, 2000
Research Development Award, U.S. Army Corps of Engineers, 1997
Editorial Board, *Journal of Composite Materials,* 2000-

S. M. Yen, Emeritus
Associate Fellow, American Institute of Aeronautics and Astronautics
Andersen Consulting Award for Advising Excellence, U of I College of Engineering, 1989

Adam R. Zak, Emeritus
Associate Fellow, American Institute of Aeronautics and Astronautics

Patents

Aerodynamics

M. B. Bragg and H. M. Gurbacki. Aircraft Surface Contamination Sensing System Using Control Surface Hinge Moment Measurements, # 6,140,942, October 31, 2000.

* Denotes principal investigator.