School of Aeronautics and Astronautics

Purdue University

Research Report 1999-2000 Academic Year

1282 Grissom Hall
West Lafayette, Indiana 47907-1282
(765) 494-5117
http://aae.www.ecn.purdue.edu

TABLE OF CONTENTS

OUR MISSION 2

ACADEMIC HIGHLIGHTS 2

ENROLLMENT AND DEGREES AWARDED 4

DEVELOPMENT HIGHLIGHTS 4

PUBLICATIONS 4

CO-OP PROGRAM 3

FACULTY FOR THE 1998-99 ACADEMIC YEAR 6

OVERVIEW OF RESEARCH AREAS AND FACILITIES 8

FACULTY SUMMARY 12

AERODYNAMICS 13

DYNAMICS & CONTROL 26

PROPULSION 39

STRUCTURES & MATERIALS 45

ACTIVE RESEARCH PROJECTS 73

RESEARCH AND OTHER SCHOLARLY ACTIVITIES 74

GRADUATE THESES 79

COLLOQUIUM SERIES 84

FACULTY HIGHLIGHTS 86

STUDENT HIGHLIGHTS 86

ALUMNI HIGHLIGHTS 86

OUTREACH HIGHLIGHTS 87

CURRICULUM AND COURSE OFFERINGS 88

OUR MISSION

Established as an independent school on July 1, 1945, the School of Aeronautics and Astronautics is committed to be a world-class leader in aerospace engineering education and fundamental and breakthrough research for aerospace vehicles and systems. Our mission of preparing men and women to be leaders in aerospace engineering by providing exceptional education and research programs for them is the focus of our life's work.

ACADEMIC HIGHLIGHTS

During the academic year 1998-99, 43 students earned their Bachelor of Science degree, 21 earned their Master of Science degree, and 11 earned their Doctor of Philosophy degrees. The *U. S. News and World Report* ranked our graduate program sixth in the nation. Again this year, the School and its faculty served as an aerospace resource to local, state and national media. During the academic year, nearly two dozen stories highlighting our faculty and students appeared in local and state media – John Glenn's flight, recollections of Neil Armstrong as a student, the Third Annual Fall Space Day and career opportunities in commercial space. Professor Howell is featured in the June 1999 issue of *Discover Magazine*. Professors Heister and Howell were also featured in an article "Space System Engineering Careers" in *Careers and the Engineer*.

The faculty used the pending ABET visit to begin augmenting our astronautics curriculum to provide students the option to take a sequence of courses leading to a specialization in astronautics rather than aeronautics as occurs at present by default. The astronautics initiative led to an interdisciplinary search for a faculty member in space systems, which is ongoing. The *Center for Satellite Engineering* was established, with the aid of reinvestment and Dean's funds, in the Schools of AAE, ECE and Science with the following objectives: to provide an impetus for undergraduate course development in the design, analysis, and testing of satellites; to provide a mechanism for joint AAE/ECE/Science research activities in evolving satellite technologies; to provide engineering students at Purdue with valuable expertise in the design of satellite systems; and to enhance Purdue's exposure and credentials in the satellites area as a mechanism to aid recruiting of both students and future faculty.

We continue to develop relationships with international universities. A formal exchange agreement has been signed with Bristol University and an agreement is imminent with Osaka University. In addition, this past academic year we hosted exchange students from the University of New South Wales and the Royal Melbourne Institute of Science and Technology. In total, more than 10% of our undergraduate population is made up of international students.

ENROLLMENT AND DEGREES AWARDED

The School had 241 undergraduate students (excluding freshmen) beginning the Fall of 1999. Graduate enrollment was 131, with 61 students in the M. S. Program and 70 in the Ph.D. program. A summary of degrees awarded is given below for the past five years. Master's and Ph.D. theses published during the 1998-99 academic year are summarized in the Graduate Theses section.

Degrees Awarded School of Aeronautics & Astronautics					
Year	**94-95**	**95-96**	**96-97**	**97-98**	**98-99**
B. S.	71	78	48	40	43
M. S.	35	36	30	19	21
Ph.D.	13	13	17	14	11

DEVELOPMENT HIGHLIGHTS

AlliedSignal, Boeing Company, Hughes Space and Communications Company, Northrop Grumman, Rolls-Royce Allison, Thiokol Corporation, and TRW supported the Industrial Affiliates Program (IAP) this year. Based on our Industrial Advisory Council (IAC) advice, we increased the annual membership from $5,000 to $10,000 to be more competitive. This was the first time an increase has happened since the IAP's inception in 1982. Rolls-Royce Allison is the newest member of the IAP.

PUBLICATIONS

Listings of books, journal articles, and other printed conference papers and reports published in calendar year 1998 are given in the "Faculty Summary" section of this report. Only documents which actually appeared in print during 1998 are listed. Note that 59 journal articles or book chapters, and 109 conference papers or technical reports, were presented or published. In addition to the published technical reports listed, many other technical progress reports were submitted directly to project sponsors.

CO-OP PROGRAM

During the 1998-99 academic year, 46 students were enrolled in the Cooperative Engineering Program with the 14 companies listed below. This popular program is limited only by the number of industry positions available. About 1 in 3 applicants received appointments this year.

Co-Op Companies
School of Aeronautics and Astronautics
July 1, 1998-June 30, 1999

Company	**Location**	**Number of A&AE Co-op Students**
Aerospace Corporation	Los Angeles, CA	1
Allison Gas Turbine	Indianapolis, IN	5
Ball Aerospace	Boulder, CO	1
Boeing Company	St. Louis, MO	3
Delta Airlines	Atlanta, GA	1
General Electric Aircraft Engines	Cincinnati, OH	2
Hughes Space & Communication	Los Angeles, CA	2
NASA-Dryden	Edwards, CA	3
NASA-Goddard	Greenbelt, MD	1
NASA-Johnson Space Center	Houston, TX	10
NASA-Langley Research Center	Hampton, VA	5
Structural Analysis Engineering	Cincinnati, OH	1
Structural Dynamics Research Center	Milford, OH	9
Wright-Patterson AFB	Dayton, OH	2

FACULTY FOR THE 1998-99 ACADEMIC YEAR

Aerodynamics

G. A. Blaisdell, Associate Professor, Ph.D., Stanford, 1991, computational fluid mechanics, transition and turbulence.

S. H. Collicott, Associate Professor, Ph.D., Stanford, 1991, experimental and low-gravity fluid dynamics, optical diagnostics, applied optics.

A. S. Lyrintzis, Associate Professor, Ph.D., Cornell, 1988, computational aeroacoustics, aerodynamics for rotorcraft and jet flows.

S. P. Schneider, Associate Professor, Ph.D., Caltech, 1989, experimental fluid mechanics, high-speed laminar-turbulent transition.

J. P. Sullivan, Professor, Sc.D., MIT, 1973, experimental aerodynamics, propellers, laser-doppler velocimetry.

M. H. Williams, Professor and Associate Head, Ph.D., Princeton, 1975, aerodynamics, computational fluid mechanics.

Dynamics and Control

D. Andrisani II, Associate Professor, Ph.D., SUNY at Buffalo, 1979, estimation, control, dynamics.

M. J. Corless, Professor, Ph.D., Berkeley, 1984, dynamics, systems, control.

A. E. Frazho, Professor, Ph.D., Michigan, 1977, control systems.

K. C. Howell, Professor, Ph.D., Stanford, 1983, orbit mechanics, spacecraft dynamics, control; trajectory optimization.

J. M. Longuski, Professor, Ph.D., Michigan, 1979, spacecraft dynamics, orbit mechanics, control, orbit decay and reentry.

M. A. Rotea, Associate Professor, Ph.D., Minnesota, 1990, robust and nonlinear multivariable control, modeling and identification.

Propulsion

S. D. Heister, Associate Professor, Ph.D., UCLA, 1988, rocket propulsion, liquid propellant injection systems.

J. J. Rusek, Assistant Professor, Ph.D., Case Western Reserve, 1983, experimental energy conversion and rocket propulsion.

Structures & Materials

W. A. Crossley, Assistant Professor, Ph.D., Arizona State, 1995, optimization, rotorcraft and aircraft design, structure design.

J. F. Doyle, Professor, Ph.D., Illinois, 1977, structural dynamics, experimental mechanics, photomechanics, wave propagation.

H. D. Espinosa, Associate Professor, Ph.D., Brown, 1992, micromechanics of ceramics and composites, experimental and computational mechanics.

T. N. Farris, Professor and Head, Ph.D., Northwestern, 1986, tribology, manufacturing processes, fatigue and fracture.
A. F. Grandt, Jr., Professor, Ph.D., Illinois, 1971, damage-tolerant structures and materials, fatigue and fracture, aging aircraft.
C. T. Sun, Professor, Ph.D., Northwestern, 1967, composites, fracture and fatigue, structural dynamics.
T. A. Weisshaar, Professor, Ph.D., Stanford, 1971, aircraft structural mechanics, aeroelasticity, integrated design.

OVERVIEW OF RESEARCH AREAS AND FACILITIES

Excellent computational facilities are available at Purdue University and include an 142-node Intel Paragon parallel computer, with 32 MB memory per node, which is available as a shared resource with unrestricted access. Purdue also owns an 18-node IBM SP-2.

In Spring '98 with the support of the **Boeing Company** and the **Intel Corporation**, the School was able to build its new Design/Build/Test Laboratory, which will prepare students for the integrated teams that industry uses for better design and reduced cycle time. The laboratory received use from many of our students during the inaugural year and DBT projects were performed by the 451 Capstone Design class, 520 Experimental Aerodynamics course, and individual special projects.

In addition, many workstations and personal computers are located throughout the School of Aeronautics and Astronautics. High performance computing is available using multiple IBM RS/6000, Silicon Graphics and Sun Microsystems computers. Cluster computing, using single and dual Intel Pentium Pro and Pentium II systems, is a recent addition, complementing the main Sun Microsystems compute servers.

AERODYNAMICS

Aerodynamics research is directed toward a better understanding of the fundamental laws governing the flow of fluids. Research topics of recent interest include: numerical methods in aerodynamics; computational fluid mechanics; separated flow around wings and bodies at high angles of attack; aerodynamics of rotors and propellers; boundary layers, wakes and jets in V/STOL applications and aerodynamic noise; hypersonic and chemically reacting flows; experimental measurements using laser systems; laminar-turbulent transition in high speed boundary layers.

Experimental facilities include four wind tunnels located at the **Aerospace Sciences Laboratory**. **The Boeing Wind Tunnel** is a large subsonic wind tunnel with two test sections -- a closed 4-by-6 foot section with a maximum speed of 250 miles per hour and a long test section adapted for high-lift research. The first test section is equipped with a six-component motorized pitch-and-yaw balance system. Instrumentation includes a two-component laser Doppler velocimeter system and a computer data acquisition system.

Three smaller low-speed wind tunnels are also located at the ASL. One has an 18-inch diameter test section, and the other two have test sections of 12x18 inches. Also, a 2-inch, supersonic, blow-down type wind tunnel that can operate from Mach 1.5 to Mach 4 is housed at the ASL. This tunnel's air supply can be used for an adjacent gas dynamical flow apparatus designed for nozzle-flow studies.

Lastly, a supersonic quiet flow Ludwieg tube with a 4-inch, Mach-4 test section is located in the **Boeing Compressible-Flow Laboratory,** which also houses other compressible-flow facilities. Both of the supersonic tunnels can be operated in pressure-vacuum mode. A 4-inch shock tube is available for instrumentation work. Several small smoke and calibration tunnels, water tables and tow tanks are also available.

DYNAMICS AND CONTROL

All modern aerospace vehicles rely upon an understanding of dynamics and control to improve system performance. Successful system design requires an understanding of the interactions of dynamic elements, and the trade-offs between vehicle dynamic characteristics, control system properties, and system performance.

Current research is divided into the following areas: aircraft design for improved handling qualities, astrodynamics, robust and nonlinear control theory, estimation theory, dynamics and control of flexible spacecraft, mission design, modeling and control of aeroelastic aircraft, spacecraft maneuvers and trajectory analysis and optimization.

Certain research projects and teaching activities require advanced and specialized laboratory facilities. The **Control Systems Laboratory** (CSL) contains high-end workstations. The mission of the CSL is to develop methods and tools (software) for the analysis and design of complex dynamical systems and to promote the availability and use of the methods by teaching relevant courses and interacting with industry. Experiments used for undergraduate instruction include a two-degree-of-freedom helicopter experiment, a three-degree-of freedom rotational system to emulate the attitude dynamics of a flexible spacecraft, and an inverted pendulum. **Remotely Piloted Vehicle**, currently under development, represents a unique research facility upon which to perform many experiments in vehicle dynamics and control. Data communication with a computer based ground station is provided by a seven channel telemetry downlink.

PROPULSION

The Propulsion group has unique facilities which are highly beneficial for the study of rocket propulsion and energy conversion. Laboratories are housed at Grissom Hall and at two major remote campus facilities: the Maurice Zucrow Laboratory (MZL), and the Aerospace Sciences Laboratory (ASL)

The ***Aerospace Post-Processing and Visualization Laboratory*** contains a variety of high-end computational assets. Several Silicon Graphics workstations are available for general computing, graphical visualizations, and digitization of images on videotape. In addition, a cluster of dual-chip Pentium machines running in a LINUX environment provides a resource for parallel computations of a significant scale.

The ***Propulsion and Power Laboratory*** is housed at MZL, and is comprised of two test cells. The test cells are of poured, reinforced concrete design with containment steel doors and explosive rated viewing windows. These cells are classed for both Class 1.1 and 1.3 explosives and are equipped with a frangible blowout wall, in case of major catastrophic events. Test Cell A currently contains a rocket thrust stand capable of handling thrust loads of up to 1000 lbf. Test Cell B will be outfitted to conduct turbine flow measurements using simulated PV drivers and catalytic chamber effluent. In local proximity is a dedicated oxidizer storage building, and a dedicated explosive / propellant storage bunker, rated for Class 1.1 materials.

The ***Energy Conversion Laboratory*** is housed at ASL, and is comprised of large four-function work areas. The *Propellant Area* is set up to synthesize and enrich / analyze Non-Toxic Hypergolic Miscible Fuels and Rocket Grade Hydrogen Peroxides, respectively. The *Electrochemistry Area* is designed to study the formation of hydrogen peroxide from water and electrical energy. The decomposition of hydrogen peroxide within a fuel cell is also studied in this laboratory. The *Physical Energy Conversion Area* was established to study thermoelectric and thermionic effects, as well as direct ion thruster technology. The *Catalysis Area* is used to synthesize and characterize heterogeneous and homogeneous substrates and additives for propulsion applications.

STRUCTURES AND MATERIALS

Structures and materials research includes work in composite materials, computational structural mechanics, damage tolerance analysis, experimental structural analysis, structural mechanics and aeroelasticity, tribology, manufacturing, wave propagation, smart materials and structures, and optimal design methods.

The **McDonnell Douglas Composite Materials Laboratory** contains equipment and facilities for general material testing and for fabrication of composite laminates. An autoclave specially designed for curing epoxy-matrix composites is available for laminate fabrication. A hot press is used for forming thermoplastic composites, and an EnTec filament winding machine is available for making cylindrical composite structures. A water jet cutting machine is used for specimen preparation. Four complete MTS material and fatigue testing machines (55 kip, 22 kip, 11 kip, and 1 kip capacity) and associated equipment are used to perform ultimate strength, stiffness, and fatigue tests on various composite materials. Nondestructive inspection equipment includes an x-ray machine and an ultrasonic C-scan system. Additional facilities for preparing laminated composites, impact testing, and creep testing are available.

The **Dynamic Inelasticity Laboratory** consists of a 3" gas gun and optical instrumentation for wave propagation studies. The facility has been designed for the investigation of damage and failure mechanisms in advanced materials. Soft recovery of the impacted targets, which is accomplished by specially designed target fixtures and energy dissipation mechanisms, allows the identification of stress-induced microdefects and phase changes by means of microscopy studies. Optical instrumentation, together with a 1 Watt single mode argon ion laser, and two four channel oscilloscopes (Tektronix DSA 602A, LeCroy 9384L) with maximum sample rate up to 4 Gs/sec, 1Ghz bandwidth, and a 8 MB memory allow the use of multi-point laser interferometry. The interferometry used for interface and free surface velocity measurements in wave propagation experiments includes: Normal Velocity Interferometer (NVI), Transverse Displacement Interferometer (TDI), Variable Sensitivity Displacement Interferometer (VSDI), and fiber optic Velocity Interferometer for any Reflecting Surface (VISAR). In addition to the laser interferometric technique, in-material stress measurements are performed using piezoresistance gauges. High temperature dynamic testing is performed with a Lepel LSP 12-25-30, 25 KW heat induction system and accessories for heating metallic and nonmetallic samples up to 1400°C. The lab computational facility consists of three Sun Workstations Sparc 20 and one Sparc 2 served by an Ultra Sparc 2 with two 167 MHz processors and 4GB+2GB hard disks, Hewlett Packard laser printers, and a PC with 150 MHz Pentium microprocessor, 1.6GB hard disk, 6x CD-ROM, 3.5 floppy drive, 28kb modem/fax.

The **Fatigue and Fracture Laboratory** is well-equipped to determine mechanical properties of structural materials. Two computer-controlled electro-hydraulic test machines (11 kip and 22 kip capacity) and associated equipment are available to measure fracture loads and to study fatigue crack formation and propagation in test specimens subjected to simulated aircraft or spacecraft load histories. Facilities are also available to artificially corrode specimens in connection with corrosion and/or corrosion/fatigue related research.

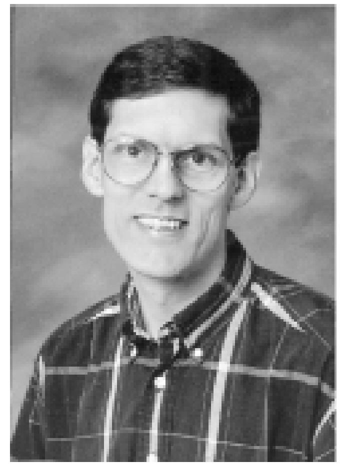
The **Structural Dynamics Laboratory** has the latest equipment for recording ultra-dynamic events. Major equipment includes Norland and Nicolet digital recorders, a one-million-frame-per-second dynamic camera, impact gun, and various computer peripherals for data acquisition. The primary research interest is in the impact of structures and the analysis of consequent stress waves.

The **Tribology and Materials Processing Laboratory** contains tribological instrumentation as well as up-to-date machines for manufacturing processes. Equipment includes a 22 kip computer-controlled electro-hydraulic test machine and associated equipment for fretting fatigue testing, infrared sensors for temperature measurements, a friction apparatus for both low and high speed sliding indentation, a residual stress analyzer, lapping and polishing equipment, a vibration isolation table, micropositioning stages, rolling contact fatigue testers, Talysurf profilometers, optical microscopes, and a high pressure pump used for dynamic fracture experiments. Also, access is available to a variety of machine tools including a precision lathe from Hardinge, a precision high speed surface grinder, a centerless grinder, and a super finishing machine, as well as associated piezoelectric force transducers.

SCHOOL OF
AERONAUTICS & ASTRONAUTICS

FACULTY SUMMARY

AERODYNAMICS



GREGORY A. BLAISDELL
1991
Associate Professor

Degrees

B. S., California Institute of Technology, Applied Mathematics, 1980
M. S., California Institute of Technology, Applied Mathematics, 1982
Ph.D., Stanford University, Mechanical Engineering, 1991

Interests

Computational fluid mechanics
Transition and turbulence

Awards and Major Appointments

NASA-ASEE Summer Faculty Fellowship, 1995-1996
W. A. Gustafson Teaching Award, Fall 1997

Research Areas

Current research interests involve the study of transitional and turbulent fluid flows using computational fluid dynamics (CFD) as an investigative tool. Most flows of engineering interest are turbulent and turbulence has a significant impact on the performance of engineering systems. The drag on a body is generally much greater if the boundary layer is turbulent. Turbulence also increases heat transfer between a fluid and a surface. In addition, turbulent mixing is important to combustion.

The physics of basic turbulent flows are studied using direct numerical simulations (DNS) and large-eddy simulations (LES). With LES the motion of the largest eddies are solved for directly while the effects of the unresolved small scale eddies are modeled. In contrast, with DNS all the relevant length scales within the turbulence are resolved and no modeling is needed. The results of the simulations are used to increase our understanding of turbulence and to test and improve turbulence models.

Current research projects are described below. Many of these investigations are being carried out using parallel processing computers. Parallel computing and advanced numerical methods is another area of interest.

Direct Numerical Simulation of a Turbulent Axial Vortex (sponsored by Purdue Research Foundation, IBM SUR Program, Student: Jim H. Qin; Computer Resources: PUCC (IBM SP2, Intel Paragon), PSC (Cray C90))

Axial vortices form in many engineering systems but are of particular importance to the wake hazard problem for commercial aircraft. The current study uses direct numerical simulation (DNS) to investigate an isolated turbulent axial vortex. The mean flow includes a wake-type axial velocity which causes the flow to be unstable. As the flow develops the wake deficit decreases to the point that the flow becomes stabilized, in agreement with previous simulation results. The Reynolds stress profiles from the DNS are found to compare well qualitatively with those from experiments. At later times the vortex core experiences negative diffusion of axial vorticity so that the vortex winds tighter. This is in contrast to the usual case in which turbulence is a diffusive process. An eddy viscosity based on the production of turbulent kinetic energy exhibits negative values in the core region. Such behavior is not captured by standard turbulence models. Examination of vortex structures during the period of turbulence growth shows the presence of helical vortices similar to the linear instability modes. As the flow is stabilized these large scale structures disappear.

Development of Large Eddy Simulation Methodology and Application to a Turbulent Axial Vortex (Sponsored by Purdue Research Foundation; Graduate student: Brijesh Eshpuniyani; Computer resources: PUCC (IBM SP 2))

This research project will consider means of accounting for the effect of truncation errors in LES. The techniques developed will then be applied to the large eddy simulation of a turbulent axial vortex. This study is a follow-on to the above project with Jim Qin using DNS. However, the DNS are limited to low Reynolds numbers - the DNS are at a Reynolds number that is three orders of magnitude lower than that of the wake vortices behind a typical large commercial airliner. Although LES on currently available computers will not be able to achieve full scale Reynolds numbers, it will allow the trends with increasing Reynolds numbers to be determined. This is important because Reynolds number is believed to have a significant effect on the development of turbulence within a vortex.

On the Development of Supersonic Jet Noise Prediction Methodology; Co-investigator: A. S. Lyrintzis (Purdue, AAE); Student: E. K. Koutsavdis; Sponsor: NASA Glenn

A new Computational Aeroacoustics (CAA) methodology for accurate prediction of supersonic jet noise from first principles is being developed. First, a three-dimensional Large Eddy Simulation (LES) code based on the dynamic subgrid scale model will be developed. Then Kirchhoff's or porous Ffowcs-Williams Hawhiges (FW-H) equation method will be employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's porous FW-H method allows radiating sound to be evaluated based on quantities on an arbitrary control surface, if the linear wave equation is assumed outside. The control surface is assumed to include all the nonlinear flow effects and noise sources. The solution on the control surface will be evaluated using the LES CFD code described above. The method will be enhanced to include nonlinear effects as well as refraction effects outside the Kirchhoff surface.

Modeling Diesel Engine Injector Flows (Co-investigator: Stephen D. Heister (Purdue, AAE); sponsor: Army Research Office)

This research effort will extend the development of a computational tool capable of resolving unsteady, viscous, cavitating flow fields inside diesel engine injector passages. Fully three-dimensional, unsteady calculations will be performed in order to assess the influence of injector design on the internal flow structure. In addition, a turbulence model will be added to the current laminar methodology in order to address complex processes in the wake and wall regions. Ultimately, this model will provide a tool with which engine manufacturers can evaluate design changes rapidly, thereby reducing product development times and improving engine efficiency. Moreover, the model could be useful in correlating internal flow variables with observed emissions data, thereby providing an important link/methodology to reduce emissions through prudent injector design.

Publications

Spyropoulos, E. T., and Blaisdell, G. A., "Large-Eddy Simulation of a Spatially Evolving Supersonic Turbulent Boundary-Layer Flow," *AIAA Journal,* Vol. 36, No. 11, Nov. 1998, p.p. 1983-1990.

Conference Proceedings, Presentations and Invited Lectures

Qin, J. H., and Blaisdell, G. A., "Numerical Simulation of a Turbulent Axial Vortex," abstract published in the *Bulletin of the American Physical Society,* Vol. 43, No. 9, p.p. 2014, Nov. 1998, and presented at the 51st Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Philadelphia, PA, Nov. 22-24, 1998.

Blaisdell, G. A., and Lyrintzis, A. S., "On the Development of Supersonic Jet Noise Prediction Methodology," presented at NASA Glenn Research Center, Oct. 15, 1998.

STEVEN C. COLLICOTT
1991
Associate Professor

Degrees

B. S., University of Michigan, Aerospace Engineering, 1983, magna cum laude
M. S., Stanford University, Aeronautics & Astronautics, 1984
Ph.D., Stanford University, Aeronautics & Astronautics, 1991

Interests

Experimental fluid mechanics
Low-gravity fluid dynamics
Optical diagnostics
Applied optics

Awards and Major Appointments

Presented the American Institute of Aeronautics and Astronautics "Special Service Citation," March 1997

Research Areas

Four topics are being researched: high-bypass turbofan duct-strut flow, cavitation in spray orifices, low-gravity fluid dynamics, and optical methods for studying hypersonic boundary layer transition.

A source of total pressure loss and non-uniform back pressure on the fan in modern and proposed high bypass ratio turbofan engines is the strut-endwall flow in the bypass duct. NASA-funded experiments, coordinated with advanced concepts research at Pratt & Whitney, explore the flow structure at Reynolds numbers typical of full-scale cruise conditions. The experiment is designed to also provide valuable checkpoints for the integrated design codes being developed by Pratt & Whitney.

Spraying of a liquid is a common commercial operation, yet little attention has been paid to the flow inside the spray orifice. Particularly in diesel fuel injectors, small-scale non-equilibrium cavitation exists, the behavior of which can not presently be predicted to any useful extent. This research, funded by the NSF-Career Award, probes the internal flow with specialized optics to uncover the physics of cavitation and turbulence in these flows. Coordination with Professor Heister's simulations with a pseudo-density model for non-equilibrium cavitating flows is crucial to the value of these experiments.

Design of fuel tanks to control sloshing liquids during weightless space flight requires incorporation of nonlinear contact-line dynamics into numerical models. Even the determination of equilibrium interface topology requires considerable numerical work in many situations. Validation and application of an existing model for determining equilibrium interface topologies in main liquid helium tank of the Gravity Probe-B spacecraft has been performed for Lockheed and the GP-B project. Incorporation of physically important stick-slip contact line motion as non-linear boundary conditions in a Boundary Element Method (BEM) code for low-g large-amplitude fluid slosh prediction is being pursued with Professor Heister.

Hypersonic boundary layer transition is a critical event on high speed flight vehicles, including the Space Shuttle during re-entry. Professor Schneider's experiments involve an optical perturber and optical diagnostics, both under the responsibility of Professor Collicott. The perturber has been developed and is in regular use. High-sensitivity, high bandwidth Laser Differential Interferometry is being applied to detect and measure instability waves in millimeter and thinner boundary layers in flows at speeds in excess of one-half of a kilometer per second.

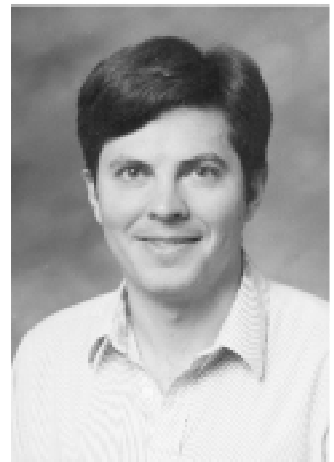
Conference Proceedings, Presentations and Invited Lectures

Collicott, S. H., "Increasing Freshman Experience in, and Awareness of, Aerospace Engineering at Purdue University," *36th AIAA Aerospace Sciences Meeting and Exhibit,* AIAA paper 98-0821, Reno, NV, Jan. 12, 1998.

Salyer, T., Randall, L., Collicott, S. H., and Schneider, S. P., "Use of Laser Differential Interferometry to Study Receptivity on a Hemispherical Nose at Mach 4," *36th AIAA Aerospace Sciences Meeting and Exhibit,* AIAA paper 98-0238, Reno, NV, Jan. 12, 1998.

Li, H., Sanchez, P. K., and Collicott, S. H., "Visualization of Cavitation in Low-Pressure Miniature Slot Flows," *Institute for Liquid Atomization and Sprays,* Americas, Sacramento, CA, May 1998.

Schmisseur, J. D., Collicott, S. H., and Schneider, S. P., "Laser Generated Localized Free Stream Perturbations in Supersonic/Hypersonic Flows," *AIAA Fluid Dynamics Conference,* Albuquerque, NM, June 1998.



ANASTASIOS S. LYRINTZIS
1994
Associate Professor

Degrees

Diploma, National Technical University, Athens Greece, Mechanical Engineering, 1981
M.S., Cornell University, Aerospace Engineering, 1985
Ph.D., Cornell University, Aerospace Engineering, 1988

Interests

Computational Aeroacoustics
Aerodynamics for rotorcraft and jet flows

Awards and Major Appointments

AHS (American Helicopter Society), Acoustics Committee
AIAA Aeroacoustics, Technical Committee; Awards Subcommittee (Chairman 96-97)
ASME: coordinating group for CFD
Associate Fellow AIAA

Research Areas

i) *Jet Aeroacoustics - Kirchhoff's Method:* The success of NASA's efforts to develop a High-Speed Civil Transport (HSCT) depends on the substantial reduction of jet exhaust noise. The important features of supersonic jet noise have been studied in the past by various investigators. A new approach (i.e. Kirchhoff's method) for shock generated noise and jet aeroacoustics is being investigated. The method is being extended for including sound sources outside the computational domain as well as refraction corrections.

ii) *Transonic Helicopter Impulsive Noise:* In the recent years, the increasing use of helicopters has drawn attention to the noise that they generate. Among the several types of helicopter noise, impulsive noise (i.e. Blade Vortex-Interactions (BVI) and High-Speed Impulsive (HSI)) is the most important. Our current research focuses in the formulation of a prediction model for impulsive noise for hovering and advancing rotors using the Kirchhoff technique for the far-field. Noise reduction techniques are also investigated.

iii) *Efficient Transonic Flow Calculations:* With the advent of parallel computers, development of efficient parallel CFD algorithms is needed. An efficient algorithm to parallelize the popular LU-SGS (Lower Upper -Symmetric Gauss Seidel) implicit operator for unsteady Euler equations has been developed. The algorithm was applied on the rotorcraft aerodynamics code TURNS (Transonic Unsteady Rotor Navier-Stokes) for the Euler equations mode of the parallel IBM SP-2 machine. The method is currently being extended to Navier Stokes equations, as well as overset grid methodologies (e.g. OVERFLOW code).

An alternative approach for transonic flow equations is to use a Newton technique. For each Newton step an efficient conjugate gradient-like iterative method (i.e. GMRES, s-step Orthomin) with proper preconditioning is used. The parallel efficiency for the above method for 3-D unsteady Euler codes was found to be very promising. We are currently investigating extension of this method for 3-D unsteady Navier Stokes codes used in the prediction of helicopter aerodynamics.

Sponsored Research Summaries

On the Development of Supersonic Jet Noise Prediction Methodology; Collaborator: G. A. Blaisdell (Purdue, AAE); Student: E. K. Koutsavdis; Sponsor: NASA Lewis

A new Computational Aeroacoustics (CAA) methodology for accurate prediction of supersonic jet noise from first principles is being developed. First, a three-dimensional Large Eddy Simulation (LES) code based on the dynamic subgrid scale model will be developed. Then Kirchhoff's or porous Ffowcs-Williams Hawhiges (FW-H) equation method will be employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's porous FW-H method allows radiating sound to be evaluated based on quantities on an arbitrary control surface, if the linear wave equation is assumed outside. The control surface is assumed to include all the nonlinear flow effects and noise sources. The solution on the control surface will be evaluated using the LES CFD code described above. The method will be enhanced to include nonlinear effects as well as refraction effects outside the Kirchhoff surface.

Parallel Computing Techniques for Rotorcraft Aerodynamics; Student K. Ekici, Sponsor: Purdue Research Foundation

The modification of unsteady Navier Stokes codes for application on massively parallel and distributed computing environments will be investigated. In our previous work we have worked with the Euler mode of the Navier-Stokes code TURNS (Transonic Unsteady Rotor Navier Stokes) that has been used for an accurate description of rotorcraft aerodynamics. For the efficient implementation of TURNS (Navier Stokes mode) on massively parallel and distributed computing systems, several algorithmic changes should be developed. We propose here: 1) Modification of the implicit operator LU-SGS to a parallel version for the Navier Stokes equations. 2) Implementation of a Newton-Krylov method with the use of efficient preconditioned conjugate gradient-type

(Krylov subspace) methods for the solution of the linear systems resulting from the linearization (Newton's step) at each time step. The modified parallel LU-SGS from step 1 will be used as a preconditioner. 3) Extension of the methodology to overset grid problems using the state-of-the-art OVERFLOW code. Since the MPI (Message Passing Interface) environment will be used we expect that our algorithms will be portable several parallel and distributed environments. We expect that efficient parallel processing will make TURNS and OVERFLOW more attractive for the rotorcraft industry. Our research will demonstrate parallel methodologies that can be easily implemented in other Navier Stokes codes as well.

Publications

Lyrintzis, A. S., Koutsavdis, E., Berezin, C., Visintainer, J., and Pollack, M., "An Evaluation of a Rotating Kirchhoff Acoustic Methodology," *Journal of the American Helicopter Society,* Vol. 43, No. 1, pp. 57-65, Jan. 1998.

Pilon, A. R., and Lyrintzis, A. S., "An Improved Kirchhoff Method for Jet Aeroacoustics," *AIAA Journal*, Vol. 36, No. 5, pp. 783-790, May 1998.

Pilon, A. R., and Lyrintzis, A. S., "Mean Flow Refraction Corrections for the Kirchhoff Method," *AIAA Journal of Aircraft,* Vol. 35, No. 4, pp. 661-664, 1998.

Liu, G., Lyrintzis, A. S., and Michalopoulos, P. G., "Improved High-Order Model for Freeway Traffic Flow," Transportation Research Record, No. 1644, paper 98-0455, pp. 37-46, 1998.

Conference Proceedings, Presentations, Invited Lectures

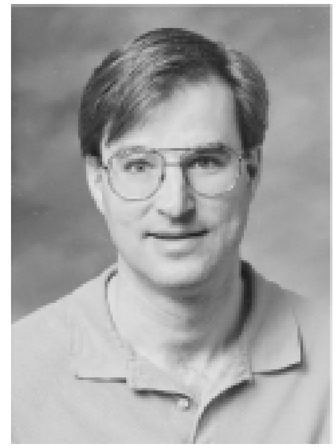
Spyropoulos, J. T., Douglas, J., and Lyrintzis, A. S., "A New Scheme for the Incompressible Navier-Stokes Equations Employing Alternating-Direction Operator Splitting and Domain Decomposition," AIAA paper 98-0126, presented at the *36th Aerospace Sciences Meeting,* Reno, NV, Jan. 1998.

Liu, G., Lyrintzis, A. S., and Michalopoulos, P. G., "An Improved High Order Model for Freeway Traffic Flow," Transportation Research Record, presented at the *Transportation Research Board 77th Annual Meeting,* Washington, DC, Jan. 1998.

Lyrintzis, A. S., "Some Recent Advances in the Use of Kirchhoff Methods for Computational Aeroacoustics," NCA Vol. 25, pp. 453-469, *ASME International Mechanics Engineering Congress and Exposition,* Anaheim, CA, Nov. 1998 (invited).

Lyrintzis, A. S., Koutsavdis, E. K., and Pilon, A. R., "An Extended Kirchhoff Method for Rotorcraft Impulsive Noise," ARO/DAAG55-97-1-0108, final report submitted, 32 pages, Feb. 1998.

Blaisdell, G. A., and Lyrintzis, A. S., “On the Development of Supersonic Jet Noise Prediction Methodology,” presented at NASA Glenn Research Center, Oct. 15, 1998.



STEVEN P. SCHNEIDER
1989
Associate Professor

Degrees

B.S., California Institute of Technology, Engineering & Applied Science, with Honors, 1981
M. S., California Institute of Technology, Aeronautics, 1984
Ph.D., California Institute of Technology, Aeronautics, 1989

Interests

Experimental fluid mechanics
High-speed laminar-turbulent transition

Research Areas

High-speed laminar-turbulent transition is critical for applications including hypersonic reconnaissance vehicles, thermal protection for re-entry vehicles, drag reduction on supersonic transports, and flow noise and heat transfer above IR windows on interceptor missiles. Unfortunately, nearly all existing high-speed experimental results are contaminated by facility noise, such as that radiating from the turbulent boundary layers normally present on the test-section walls of supersonic tunnels. Just as at low speeds, reliable experimental progress requires low-turbulence wind tunnels with noise levels comparable to those in flight.

Sponsored Research Summaries

NASA Langley has developed quiet supersonic tunnels over the last 25 years to address problems such as laminar-turbulent transition that are strongly affected by noise level. Detailed measurements of the mechanisms of transition are needed, under low noise conditions, in order to develop computational models that are grounded on the correct flow physics.

To complement the expensive quiet-flow facilities under development at NASA Langley, a low-cost 4-inch Mach 4 quiet-flow Ludwieg tube has been constructed at

Purdue. Quiet flow has been demonstrated to length Reynolds numbers of 400,000 (AIAA Journal, April 1995, p. 688). Studies of the crossflow instability on an elliptic cross-section cone are now underway, using two forms of controlled perturbations (see, for example, AIAA Papers 96-2191, 98-0532, and 98-0436). Localized hot-spot disturbances are repeatably generated by a pulsed Nd:YAG laser in order to generate repeatable wave packets in the flow, and surface perturbations are being generated by a glow perturber. Perturbations are being measured using hot wires, high-sensitivity laser differential interferometry, and arrays of surface hot films.

A new 18-inch stainless-steel Ludwieg tube is being constructed, for use with an 9.5-inch quiet-flow Mach-6 test section. Quiet-flow operation to a length Reynolds number of 13 million is projected (AIAA Paper 98-0547). The air and vacuum systems were completed by the end of 1998, with initial tunnel operation currently planned for Spring 2000. Modern digital and optical instrumentation will enable efficient use of the six-second run-time, and the short duration keeps operating costs low. The larger test section will enable testing with larger models and thicker boundary layers.

Publications

Schneider, S. P., and Munro, S. E., "Effect of Heating on Quiet Flow in a Mach-4 Ludwieg Tube," technical note, *AIAA Journal,* Vol. 36, No. 5, pp. 872-873, May 1998.

Ladoon, D. W., Schneider, S. P., and Schmisseur, J. D., "Physics of Resonance in a Supersonic Forward-Facing Cavity," *Journal of Spacecraft and Rockets,* Vol. 35, No. 5, pp. 626-632, Sept.-Oct. 1998.

Conference Proceedings, Presentations and Invited Lectures

Schmisseur, J. D., Schneider, S. P., and Collicott, S. P., "Receptivity of the Mach-4 Boundary Layer on an Elliptic Cone to Laser-Generated Localized Perturbations," AIAA paper 98-0532, presented at the *AIAA Aerospace Sciences Meeting,* 21 pages, Jan. 1998.

Schneider, Steven P., “Survey of Flight Data for Boundary-Layer Transition at Hypersonic and Supersonic Speeds,” AIAA paper 98-0432, presented at the *AIAA Aerospace Sciences Meeting,* 23 pages, Jan. 1998.

Schneider, Steven P., “Design of a Mach-6 Quiet-Flow Wind Tunnel Nozzle Using the e**N Method for Transition Estimation,” AIAA paper 98-0547, presented at the *AIAA Aerospace Sciences Meeting,* 35 pages, Jan. 1998.

Ladoon, D. W., and Schneider, S. P., “Measurements of Controlled Wave Packets at Mach 4 on a Cone at Angle of Attack,” AIAA paper 98-0436, presented at the *AIAA Aerospace Sciences Meeting,* 12 pages, Jan. 1998.

Schneider, S. P., “Design and Fabrication of a 9-inch Mach-6 Quiet-Flow Ludwieg Tube,” AIAA Paper 98-2511, presented at the *20th Ground Testing Conference,* 22 pages, June 1998.

JOHN P. SULLIVAN
1975
Professor

Degrees

B. S., University of Rochester, Mechanical & Aerospace Sciences (with honors), 1967
M. S., Massachusetts Institute of Technology, Aeronautical Engineering, 1969
Sc.D., Massachusetts Institute of Technology, Aeronautical Engineering, 1973

Interests

Experimental aerodynamics
Laser instrumentation
Luminescent sensors for temperature and pressure measurements

Research Areas

Current research interest is in the area of experimental aerodynamics with particular emphasis on comparison of experimental data with computational analysis. Current programs include:

1. High lift systems.
2. Suction/blowing airfoils.

In addition to the above programs, work also continues on developing laser instrumentation (laser Doppler velocimeter, particle image velocimeter, laser sheet concentration, etc.) and pressure and temperature paint for:

1. Wind tunnels - low speed to hypersonic
2. Gas turbine engines
3. Flight tests

Publications

Cattafesta, L. N., Liu, T., and Sullivan, J. P., “Uncertainty Estimates for Temperature-Sensitive Paint Measurements with Charge-Coupled Device Cameras,” AIAA Journal, Vol. 36, No. 11, pp. 2102-2108, Nov. 1998.

Liu, T. S., and Sullivan, J. P., "Luminescent Oil-Film Skin-Friction Meter," AIAA Journal, Vol. 36, No. 8, pp. 1460-1465, Aug. 1998.

Conference Proceedings, Presentations and Invited Lectures

Erausquin, Jr., R., Cunningham, C., Sullivan, J. P., Asai, K., Kanda, H., Kunimasu, T., and Iijima, Y., "Cyrogenic Pressure Sensitive Fluorescent Paint Systems," AIAA Paper 98-0588, presented at the *36th Aerospace Sciences Meeting & Exhibit,* Reno, NV, Jan. 12-15, 1998.

Witte, G., Sullivan, J. P., Merchant, A., and Drela, M., "Experimental Investigation of a 40% Thick Boundary Layer Control Wing," AIAA paper 98-0407, presented at the *36th Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 12-15, 1998.

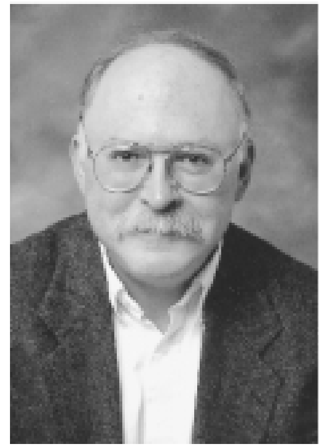
Crafton, J., Messersmith, N. M., and Sullivan, J. P., "Filtered Doppler Velocimetry: Development of a Point System," AIAA paper 98-0509, presented at the *36th Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 12-15, 1998.

Hoffenberg, R., and Sullivan, J. P. "Measurement and Simulation of a Decelerated Wake," AIAA paper 98-0522, presented at the *36th Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 12-15, 1998.

Campbell, B. T., Witte, G. R., and Sullivan, J. P., "Laser Spot Heating/Temperature-Sensitive Paint Heat Transfer Measurements," AIAA paper 98-2501, *AIAA 20th Advanced Measurement and Ground Testing Technology Conference,* Albuquerque, NM, June 15-18, 1998.

Asai, K., and Sullivan, J. P., "Luminescent Paint Technology for Temperature and Pressure Measurements in a Cyrogenic Wind Tunnel," ICAS 98-3,3,1, *21st Congress of the International Council of the Aeronautical Sciences,* Melbourne, Australia, Sept. 1998.

MARC H. WILLIAMS
1981
Professor and Associate Head



Degrees

B. S., University of Pittsburgh, Aeronautical Engineering, Magna Cum Laude, 1969
M. A., Princeton University, Aerospace & Mechanical Sciences, 1971
Ph.D., Princeton University, Aerospace & Mechanical Sciences, 1975

Interests

Aerodynamics
Computational fluid Mechanics

Research Areas

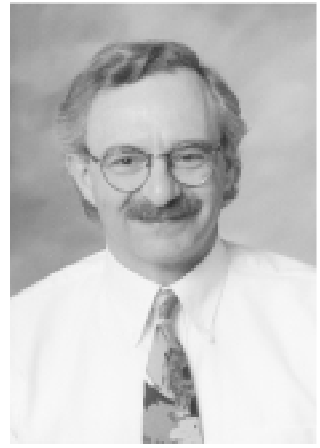
The determination of aeroelastic stability and forced response characteristics of flight vehicles requires methods for predicting the unsteady aerodynamic loads that are induced by structural deformation and/or free stream disturbances. Current research is directed at developing such methods for transonic flight and for rotating machinery.

Much of this work has been done for advanced propfan applications. These engines are intended for use on medium range commercial transports, which operate at low transonic Mach numbers. In order to maintain high operating efficiency and low noise, the blades are very thin and flexible. Therefore they are subject to substantial static and dynamic deformations which alter the aerodynamic loads on the blades. Computational methods have been developed to predict these loads, both for single and counter rotating systems. Flutter boundaries and forced vibration amplitudes have been successfully predicted for a variety of current propfan designs. The most successful schemes developed so far have been based on linearized aerodynamic models. Work is under way on including nonlinear transonic effects through three dimensional potential formulation with moving grids.

Conference Proceedings, Presentations and Invited Lectures

Beck, A., Williams, M., and Longuski, J., "Floquet Solution for a Spinning Rigid Body Subject to Constant Transverse Torques," *AIAA/AAS Astrodynamics Specialist Conference,* Boston, MA, Aug. 10-12, 1998.

DYNAMICS & CONTROL



DOMINICK ANDRISANI

1980

Associate Professor

Degrees

B. S., Rensselaer Polytechnic Institute, Aeronautical Engineering, 1970
M. S., State University of New York at Buffalo, Electrical Engineering, 1975
Ph.D., State University of New York at Buffalo, Electrical Engineering, 1979

Interests

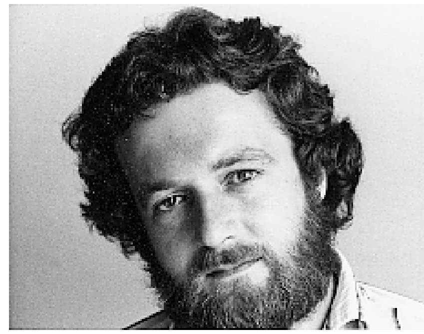
Estimation
Control
Dynamics
Flight Aircraft Flying Qualities

Research Areas

Extensive experience in experimental methods in the study of vehicle dynamics and control has focused teaching and research on practical and important aerospace problems in four areas. First is the area of estimation theory, where new estimation algorithms have been developed using the partitioning approach. The second area involves the application of estimation theory to aerospace problems. Here estimation theory has been used to develop a new class of target trackers. These trackers incorporate knowledge of the aerodynamic and thrust vectors to help improve the trackers ability to estimate target acceleration. The third area involves research towards the development of design specifications for helicopter flight control systems, i.e., helicopter flying qualities. The fourth area involves analysis and detection of pilot-in-the-loop oscillations.

Publications

Davidson, Jr., J. B., and Andrisani, II, D. A., "Gain-Weighted Eigenspace Assignment," *Journal of Guidance, Control, and Dynamics,* Vol. 21, No. 6, pp. 1009-1012, Nov.-Dec. 1998.



MARTIN CORLESS
1984
Professor

Degrees

B. E., (1st honors), University College, Dublin, Ireland, Mechanical Engineering, 1977
Ph.D., University of California, Berkeley, Mechanical Engineering, 1984

Interests

Dynamics
Systems
Control

Research Areas

Most of the research is concerned with obtaining tools which are useful in the analysis and control of systems containing significant uncertainty. These uncertainties are characterized deterministically, rather than stochastically. The systems treated can be linear or nonlinear and continuous-time or discrete-time. The major application of the research is in the analysis and control of aerospace and mechanical systems. In these applications, some of the research focuses on the effect of flexible elements.

Publications

Georgiou, I. T., Bajaj, A. K., and Corless, M., "Slow and Fast Invariant Manifolds, and Normal Modes in a Two-Degree-of-Freedom Structural Dynamic System with Multiple Equilibrium States," *International Journal of Nonlinear Mechanics,* Vol. 33, No. 2, pp. 275-300, 1998.

Corless, M., and Tu, J., "State and Disturbance Estimation for a Class of Uncertain Systems," *Automatica,* Vol. 34, No. 5, 1998.

Corless, M., and Glielmo, L., "New Converse Lyapunov Theorems and Related Results on Exponential Stability," *Mathematics of Control, Signals, and Systems,* Vol. 11, pp. 79-100, 1998.

Brockman, M. L., and Corless, M., "Quadratic Boundedness of Nominally Linear Systems," *International Journal of Control*, Vol. 71, No. 6, pp. 1105-1117, 1998.

Tsiotras, P., Corless, M., and Rotea, M. A., "Optimal Control of Rigid Body Angular Velocity with Quadratic Cost," *Journal of Optimization Theory and Applications*, Vol. 96, No. 3, pp. 507-532, 1998.

Tsiotras, T., Corless, M., and Rotea, M. A., "An L_2 Disturbance Attenuation Solution to the Nonlinear Benchmark Problem," *International Journal of Robust and Nonlinear Control*, Vol. 8, pp. 311-330, 1998.

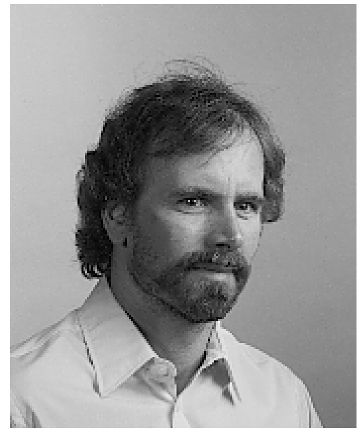
Conference Proceedings, Presentations, Invited Lectures and Reports

Sultan, C., Corless, M., and Skelton, R. E., "Nonlinear Robust Tracking Control of a Tensegrity Motion Simulator," 1998.

Corless, M., "Lyapunov Based System Analysis and Control Design," *International Mechanical Engineering Congress and Exposition*, Anaheim, CA, 1998.

Corless, M., and Tu, J., "A New Class of Adaptive Controllers," *10th Workshop on Dynamics and Control*, Lambrecht, Germany, 1998.

Leitmann, G., Lee, C. S., and Corless, M., "Analysis and Control of a Communicable Disease," Siena, Italy, 1998.



ARTHUR E. FRAZHO

Professor

1980

Degrees

B.S.E., The University of Michigan, Ann Arbor, Computer Engineering, 1973
M.S.E., The University of Michigan, Ann Arbor, Computer Information and Control Engineering, 1974
Ph.D., The University of Michigan, Ann Arbor, Computer Information and Control Engineering, 1977

Interests

Control systems

Research Areas

This research develops and applies operator theory to problems in deterministic and stochastic control systems. These techniques are used to design models for both linear and nonlinear control systems. We also obtain fast recursive algorithms for computing reduced order models. This also yields a theory of H^∞ controller reduction and pole placement with applications to large space structure control. Finally, these techniques are used to solve problems in signal processing and inverse scattering theory.

Publications

Foias, C., Frazho, A. E., Gohberg, I., and Kaashoek, M. A., "The Maximum Principle for the Three Chains Completion Problem," *Integral Equation and Operator Theory,* Vol. 30, pp. 67-82, 1998.

Book

Foias, C., Frazho, A. E., Gohberg, I., and Kaashoek, M. A., Metric Constrained Interpolation, Commutant Lifting and Systems, Birkhauser-Verlag, 587 pages, March 1998.

KATHLEEN C. HOWELL
1982
Professor

Degrees

B. S., Iowa State University, Aerospace Engineering, 1973
M. S., Stanford University, Aeronautical & Astronautical Engineering, 1977
Ph.D., Stanford University, Aeronautical & Astronautical Sciences, 1983

Interests

Orbit mechanics
Spacecraft dynamics, control
Trajectory optimization

Research Areas

In the area of astrodynamics, the complex missions envisioned in the next few decades will demand innovative spacecraft trajectory concepts and efficient design tools for analysis and implementation. In support of such plans, current research efforts focus on spacecraft navigation and maneuver requirements, and mission planning, both in the neighborhood of the Earth and in interplanetary space. Some sample projects are mentioned below.

Much recent research activity has involved libration point orbits in the three- and four-body problems. The *n*-body problem in orbital mechanics generally considers trajectory solutions when (n-1) gravity fields are significant. Spacecraft in the vicinity of libration points thus operate in an environment in which gravity forces due to two or three (or more) celestial bodies may result in trajectories that appear as three-dimensional, quasi-periodic Lissajous paths. Such three-dimensional trajectories are of considerable interest in connection with any future lunar operations. In the near term, missions involving libration point satellites are included in a number of programs that the U. S. is planning with international partners. Technical studies involve trajectory design and optimization including optimal control strategies for out-of-plane motion in consideration of communication and other operational specifications. Analyses of station-keeping requirements for such trajectories are also currently under study.

The subject of optimal transfer trajectories is of considerable importance and rapidly growing in complexity as well. New types of problems now facing mission designers render standard optimization strategies inadequate, particularly for application in the *n* -body problem. Nominal transfer trajectory determination and optimization is the focus of an expanding investigation. Various projects range from development of new computational techniques to application of geometric nonlinear dynamical systems theory to these problems.

A related problem of interest involves Earth orbiting vehicles that repeatedly pass close to the Moon. Such trajectories use lunar gravity to effect trajectory changes. Not only can such a swingby aid in minimizing mission fuel requirements, it also creates trajectory options that may otherwise be impossible. Analysis is complicated, however, by the strong solar perturbation. Multi-conic analysis has proven promising and work is continuing to develop tools to make optimal trajectory design efficient and accurate. Design strategies can also be extended to other multi-body systems. Such applications are under considerations as well.

Publications

Wilson, R. S., and Howell, K. C., "Trajectory Design in the Sun-Earth-Moon System Using Multiple Lunar Gravity Assists," *Journal of Spacecraft and Rockets,* Vol. 35, No. 1, pp. 191-198, March-April 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Gomez, G., Howell, K. C., Masdemont, J., and Simo, C., "Station-Keeping Strategies for Translunar Libration Point Orbits," *AAS/AIAA Space Flight Mechanics 1998,* Advances in Astronautical Sciences, Vol. 99, Part II, J. Middour, L. Sackett, L. D'Amario, and D. Byrnes (editors), pp. 969-988, 1998.

Barden, B. T., and Howell, K. C., "Formation Flying in the Vicinity of Libration Point Orbits," *AAS/AIAA Space Flight Mechanics Meeting 1998,* Advances in the Astronautical Sciences, Vol. 99, Part II, J. Middour, L. Sackett, L. D'Amario, and D. Byrnes (editors), p. 969-988, 1998.

Guzman, J. J., Cooley, D. S., Howell, K. C., and Folta, D., "Trajectory Design Strategies for Libration Point Missions that Incorporate Invariant Manifolds and SWINGBY," *AAS/GSFC International Symposium on Space Flight Dynamics,* Greenbelt, MD, May 1998.

Howell, K. C., "Families of Orbits in the Vicinity of the Colliniear Libration Points," *AIAA/AAS Astrodynamics Conference,* Boston, MA, Aug. 1998 (invited).

Lo, M., Williams, B., Bollman, W., Han, D., Hahn, Y., Bell, J., Hirst, E., Corwin, R., Hong, P., Howell, K. C., Barden, B., and Wilson, R., "GENESIS Mission Design," *AIAA/AAS Astrodynamics Specialist Conference,* Boston, MA, Aug. 1998.

Howell, K. C., Wilson, R. S., Barden, B. T., and Lo, M. W., "Trajectory Design and Shadowing Analysis for the FIRST Mission," technical report, Feb. 1998.

Howell, K. C., "Implementation Issues Associated with Station-Keeping Strategies," The Third Libration Point Mission Design Workshop, invited seminar presentation at the California Institute of Technology, Pasadena, CA, Feb. 1998.

Howell, K. C., "Dynamical Systems Investigations to Support Trajectory Design in Three-Body Regimes," invited presentation NASA Goddard Space Flight Center, Greenbelt, MD, April 1998.

JAMES M. LONGUSKI
1988
Professor

Degrees

B.S.E., The University of Michigan, Aerospace Engineering - Cum laude, 1973
M.S.E., The University of Michigan, Aerospace Engineering, 1975
Ph.D., The University of Michigan, Aerospace Engineering, 1979

Interests

Spacecraft Dynamics
Orbit Mechanics
Control
Orbit decay and reentry

Research Areas

Current research efforts include 1) analytic theory and control of spinning-up and thrusting vehicles, 2) mission design and trajectory design for interplanetary flight, 3) orbit decay and reentry problems, and 4) tethers in space.

In 1) breakthroughs were achieved earlier at the Jet Propulsion Laboratory in the analysis of the Galileo spacecraft maneuvers. The current goal is to extend this work to a general analytic theory (which provides solutions for angular velocity, the attitude, the angular momentum vector and the translational velocity of rigid and elastic bodies subject to arbitrary body-fixed torques and forces) and to develop control laws based on the analytic theory.

In 2) mission design tools developed at the Jet Propulsion Laboratory have been acquired for research use at Purdue. Both theoretical and computational techniques are being employed to analyze the ΔV gravity-assist problem in terms of identifying potential trajectories (such as the Voyager Grand Tour and the Galileo VEEGA) and optimizing the launch energy and propellant requirements for these trajectories.

In 3) analytic solutions have been obtained for the probability of immediate reentry and of orbit decay, as well as escape, in the event of misdirected interplanetary injection maneuvers occurring at low earth orbit. The solutions have relevance to safety issues involving nuclear power plants aboard deep space probes.

In 4) the feasibility of using tethers for aerobraking has been demonstrated. The basic idea is to connect an orbiter and a probe together by a long tether, for missions to planets with atmospheres. The probe enters the atmosphere and is used to reduce the hyperbolic speed of the orbiter to capture speed, thus eliminating the large retro maneuver normally required. New issues being addressed include analysis of the flexible tether, tether guidance and control, and spacecraft (endpoint) attitude control.

Publications

Patel, M. R., Longuski, J. M., and Sims, J. A., "Mars Free Return Trajectories," *Journal of Spacecraft and Rockets,* Vol. 35, No. 3, pp. 350-354, May-June 1998.

Biswell, B. L., Puig-Suari, J., Longuski, J. M., and Tragesser, S. G., "Three-Dimensional Hinged-Rod Model for Elastic Aerobraking Tethers," *Journal of Guidance, Control, and Dynamics,* Vol. 21, No. 2, pp. 286-295, April 1998.

Tragesser, S. G., and Longuski, J. M., "Analysis and Design of the Aerobraking Tether for Stochastic Errors," *Journal of Spacecraft and Rockets,* pp. 683-689, Sept.-Oct. 1998.

Conference Proceedings, Presentations, Invited Lectures, and Reports

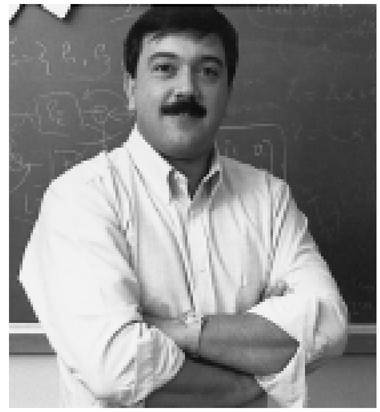
Petropoulos, A. E., Longuski, J. M., and Bonfiglio, E. P., "Trajectories to Jupiter via Gravity Assists from Venus, Earth, and Mars," AIAA paper 98-4284, *AIAA/AAS Astrodynamics Specialist Conference,* Boston, MA, Aug. 10-12, 1998.

Beck, R. A., Williams, M. H., and Longuski, J. M., "Floquet Solution for a Spinning Symmetric Rigid Body with Constant Transverse Torques," AIAA Paper No. 98-4385, AIAA/AAS Astrodynamics Conference, Boston, Massachusetts, August 10-12, 1998.

Petropoulos, A. E., and Longuski, J. M., "Low-Thrust and Gravity-Assist Trajectory Design for Planetary Missions," Progress Report #1, Prepared for Jet Propulsion Laboratory by Purdue University, June 1998, 54 pages.

Petropoulos, A. E., and Longuski, J. M., "Low-Thrust and Gravity-Assist Trajectory Design for Planetary Missions," Progress Report #2, Prepared for Jet Propulsion Laboratory by Purdue University, September 1998, 34 pages.

Bonfiglio E. P., and Longuski, J. M., “Low-Thrust and Gravity-Assist Trajectory Design for Planetary Missions,” Progress Report #3: Aerogravity-Assist Study, Prepared for Jet Propulsion Laboratory by Purdue University, November 1998, 19 pages.



MARIO A. ROTEA
1990
Associate Professor

Degrees

Electronic Engineer Degree (6-year curricula), Universidad Nacional de Rosario, Argentina, 1983
M.S.E.E., University of Minnesota, Electrical Engineering, 1988
Ph.D., University of Minnesota, Control Science & Dynamical Systems, 1990

Interests

Robust and nonlinear multivariable control
Modeling, identification, and control of flow and combustion instabilities; turbomachinery; rotorcrafts; and manufacturing processes
Real-time optimization

Awards and Major Appointments

NSF Young Investigator Award
Center for Satellite Engineering, Co-director

Research Areas

Our group develops theory, methodology, and software productivity tools for the analysis/design/implementation of control systems. Our methods and tools integrate the most sophisticated (classical and modern) theory with commercial software for the creation of control laws—the brain of a control system— with minimal development effort. We have developed systematic optimization-based design procedures that are capable of generating elaborated proof-of-concept control laws in just a few hours of work. Our methods and tools are part of the graduate curriculum at Purdue University. We have successfully applied these techniques to several technology areas including active suppression of chatter in industrial machine tools, and active vibration reduction in civil engineering structures, helicopter rotor systems, and turbomachinery. We are also developing new tools for the prediction and optimization (passive control) of worst-case forced response in bladed-disks assemblies with a large number of degrees of freedom. NSF, United Technologies Corporation, and the Boeing Company fund our basic and applied research.

Publications

Rotea, M. A., Tsiotras, P., and Corless, M., "Suboptimal Control of Rigid Body Motion with a Quadratic Cost," *Dynamics and Control*, Vol. 8, No. 1, pp. 55-81, 1998.

Petersen, I. R., MacFarlane, D., and Rotea, M. A., "Optimal Guaranteed Cost Control of Discrete-Time Uncertain Linear Systems," *International Journal of Robust and Nonlinear Control*, Vol. 8, No. 8, pp. 649-657, July 1998.

D'Amato, F., and Rotea, M. A., "Limits of Achievable Performance and Controller Design for the Structural Control Benchmark Problem," *Earthquake Engineering and Structural Dynamics*, Vol. 27, No. 11, pp. 1203-1204, Nov. 1998.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Viassolo, D., and Rotea, M. A., "Practical Design of Multirate Output Controllers," *Proceedings of the* 37^{th} *IEEE Conference on Decision and Control*, Tampa, FL, Vol. 1, pp. 337-342, Dec. 1998.

Rotea, M. A., "A Dual Optimization Approach for Solving Constrained Least-Squares Problems," Chapter 3, UTRC Report R98-05, Jan. 1998.

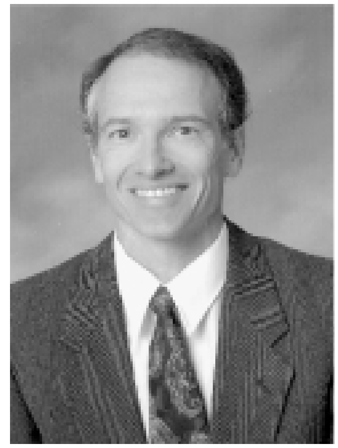
Rotea, M. A., "Performance Limits and Actuator Requirements Analysis for the Sikorsky Active Noise Control Systems," Chapter 4, UTRC Report R98-05, Jan. 1998.

Rotea, M. A., and Weller, W. H., "Aeromechanical Stabilization: Correlation with the 1997 test program RAH-066 projection, UTRC Report, 10 pages, June 1998.

Rotea, M. A., "Calibration of the F119 HFB FEM: Data Analysis and Sensor Requirements," 10 pages, April 1998.

Rotea, M. A., "Fifth Annual NSF-YIA Progress Report," Award Number ECS-93-58288, 76 pages, Nov. 1998.

PROPULSION



STEPHEN D. HEISTER
1990
Associate Professor

Degrees

B.S.E., The University of Michigan, Aerospace Engineering, 1981
M.S.E., The University of Michigan, Aerospace Engineering, 1983
Ph.D., Univ. of California at Los Angeles, Aerospace Engineering, 1988

Interests

Rocket propulsion
Liquid propellant injection systems

Research Areas

Current research interests in the field of propulsion are aimed at increasing understanding of liquid injection processes and combustion in hybrid rocket systems.

Liquid jet atomization is a problem of fundamental importance in liquid and hybrid rocket engines, as well as in airbreathing engines or any other device using liquid fuel. The focus of our research is to develop numerical models capable of describing the time-dependent, non-linear evolution of liquid jet surface as the jet exists the orifice. The analytic approach involves the use of Boundary Element Methods, which are an attractive tool for problems involving free surfaces. Initial modeling efforts have focused on inviscid flows with negligible gas phase interaction. In the near future, the presence of the gas phase will be included in models, and in coming years we shall consider the effect of liquid viscosity on the complex atomization process.

Another area of research involves modeling of the flow processes inside an orifice of a high pressure injector. In liquid rocket and diesel engines, the injection pressures can be high enough to cause cavitation within the injector passages thus leading to pitting of injector surfaces and changes in spray quality. We are developing numerical models to describe this two-phase (and possibly unsteady) flow process. Current efforts are underway to extend our axisymmetric model to three dimensions in order to analyze flows in diesel injectors manufactured by Cummins Engines Incorporated of Columbus, Indiana.

A promising new area of research involves experimental determination of the combustion characteristic of hybrid rocket engines using concentrated hydrogen peroxide as an oxidizer. An experimental facility has been constructed for the purpose of these activities.

Sponsored Research Summaries

1. Atomization modeling - Under **AFOSR** sponsorship, a number of atomization models have been developed to study the unsteady evolution of liquid jets and droplets. These simulations utilize boundary element methods to provide high-resolution of very large surface distortions and atomization processes. In fact, a number of the models can carry out calculations beyond atomization events. Currently, we are developing a more comprehensive model to treat the entire spray formed by a high-speed injection process. This model incorporates detailed drop dynamics including collisions and secondary atomization of droplets in the spray. Current models track upwards of 500,000 droplets simultaneously in a parallel-processing approach. As a result of these developments, we have modified existing models to address electrostatic forces and are currently working a project (with Professor Sojka of Mechanical Engineering) on electrostatic atomization. This effort is funded by **Proctor and Gamble**.

2. Rocket Combustion Experiments - This effort involves the use of the Purdue University Rocket Propulsion and Power Lab (PURPPL); a facility housed at the Maurice Zucrow Labs. Lab scale motors have been fired to assess basic combustion phenomena in hybrid rockets. Over 100 firings of a hydrogen peroxide/polyethylene propellant combination have been conducted during the past four years. Due to the high level of interest in the clean burning, safe handling aspects of hydrogen peroxide, numerous other opportunities are being investigated for potential application in the PURPPL facility. These efforts are heavily coupled with Professor Rusek’s present research group.

3. Diesel Engine Injector Modeling - This project, funded by **Cummins Engine Company**, **NSF**, and **ARO** is aimed at developing computational tools for use in simulating internal flows in diesel injector passageways. Due to the high injection pressures, cavitation is a crucial feature which must be incorporated in the modeling. To this end, we have developed a new cavitation treatment capable of addressing hydrodynamic nonequilibrium effects in a fully viscous calculation. Two-dimensional simulations have been compared to experimental measurements from Professor Collicott’s research group with favorable results. A full 3-D model has recently been developed making use of advanced parallel processing schemes in a LINUX computing environment. The model shows complex unsteady flow behavior under cavitating conditions. Presently, a turbulence model is being incorporated in the 2-D codes.

Publications

Rump, K. M., and Heister, S. D., "Modeling the Effect of Unsteady Chamber Conditions on Atomization Processes," *Journal of Propulsion and Power* (tech. note), Vol. 14, pp. 576-578, 1998.

Caravella, J. R., Heister, S. D., and Wernimont, E. J., "Characterization of Fuel Regression in a Radial Flow Hybrid Rocket," *Journal of Propulsion and Power,* Vol. 14, No. 1, pp. 51-56, 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Vandenboom, M. R., and Heister, S. D., "Application of Advanced Materials in a Lined, Carbon-Carbon Nozzle," AIAA paper 98-3971, *34th AIAA Joint Propulsion Conference,* Cleveland, OH, 1998.

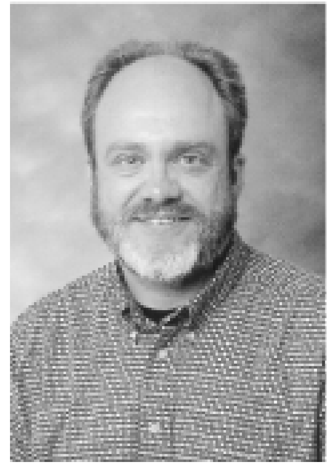
Heister, S. D., "Modeling Primary Atomization Processes," AIAA paper 98-3837, *34th AIAA Joint Propulsion Conference,* Cleveland, OH, 1998.

Heister, S. D., Wernimont, E. J., and Rusek, J. J., "High Test Peroxide Hybrid Rocket Research," *Hydrogen Peroxide Propulsion Workshop,* Surrey, England, July 1998.

Bunnell, R. A., Heister, S. D., Yen, C., and Collicott, S. H., "Numerical Modeling of Cavitated Slot Flows," *ILASS-98 Conference Proceedings,* Sacramento, CA, 1998.

Heister, S. D., and Howell, K. C., “Space Systems Engineering Careers,” *Careers and the Engineer*, Vol. 11, No. 1, pp. 44-45, Spring 1999.

JOHN J. RUSEK
1998
Assistant Professor



Degrees

B. S., Case Western Reserve University, Chemical Engineering, 1976
M. S., Case Western Reserve University, Chemical Engineering, 1981
Ph.D., Case Western Reserve University, Chemical Engineering, 1983

Interests

Energy Conversion
Propulsion
Power Generation

Awards and Major Appointments

William B. McLean Laureate, United States Navy Air Technology Medal - 1998
USN Rear Admiral Commendation for Young Astronauts Program - 1998

Research Areas

Current research is directed towards obtaining a fundamental understanding of hydrogen peroxide decomposition via heterogeneous and homogeneous catalysis for use in rocket propulsion and power generation. Major focus concerns the synthesis, characterization, and testing of these novel catalysts in rocket propulsion, turbine, and fuel cell applications; areas of interest include the experimental and analytical understanding of catalytic reaction kinetics and thermodynamics.

Another major research direction is the fundamental understanding of aerospace materials, specifically in the safe containment of exotic propellant ingredients. International collaboration with government, academic, and industrial research centers is playing an important part in this research.

Patent

U. S. patent #5,932,837, Non-Toxic Hypergolic Miscible Bipropellant, John J. Rusek, Nicole Anderson, Bradley M. Lormand, and Nicky L. Purcell, Aug. 3, 1999.

U. S. patent #4781988, Corrosion-Resistant Coating, John J. Rusek, Dick L. Tomlinson, Nov. 1, 1988.

Conference Proceedings, Presentations, and Invited Lectures

Rusek, J. J., and Anderson, N., Heterogeneous Decomposition of Rocket-Grade Hydrogen Peroxide, *1st Annual International Symposium of High Test Peroxide,* Aug. 1998.

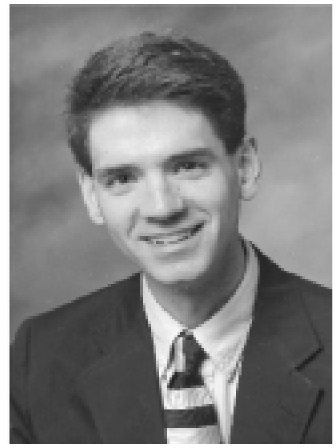
Rusek, J. J., and Lormand, B., Non-Toxic Hypergolic Miscible Fuels for In-situ Decomposition of Rocket-Grade Hydrogen Peroxide, *1st Annual International Symposium of High Test Peroxide,* Aug. 1998.

Rusek, J.J., and B. Guest, Containment of Rocket Propellants by Advanced Liquid Crystal Polymers, *1st Annual International Symposium of High Test Peroxide,* Aug. 1998.

Wernimont, E., Heister, S., and Rusek, J. J., Hybrid Motor Experiments Using Rocket-Grade Hydrogen Peroxide, *1st Annual International Symposium of High Test Peroxide,* Aug. 1998.

Rusek, J. J., Lormand, B. M., Purcell, N. L., and Pavia, T. C., "Non-Toxic Hypergolic Propellant Demonstrations," presented at the *AIAA 1998 Missile Sciences Conference,* Monterey, CA, Nov. 1998.

STRUCTURES & MATERIALS



WILLIAM A. CROSSLEY
1995
Assistant Professor

Degrees

B.S.E. University of Michigan, Aerospace Engineering, 1990
M. S. Arizona State University, Aerospace Engineering, 1992
Ph.D. Arizona State University, Aerospace Engineering, 1995

Interests

Optimization
Rotorcraft and aircraft design
Structure design

Research Areas

Professor Crossley's major research interests are in the area of design methodologies and optimization, with emphasis on the use of genetic algorithms for aerospace engineering design problems. Techniques like the genetic algorithm will allow optimization-like techniques to be applied in the conceptual phase of design, which traditionally has been dominated by qualitative or subjective decision making. There are two major areas of research being pursued by Professor Crossley and his students - genetic algorithm roles in aerospace design and optimization, and genetic algorithm methodology development. Other research topics related to aerospace design are also investigated.

Sponsored Research Summaries

Topology Design of Rotor Blades for Aerodynamic and Structural Concerns. This computational research effort strives to develop a new and unique rotor blade design strategy with the potential to improve the aerodynamic, structural and dynamic performance of advanced rotorcraft. This work will investigate the use of a Genetic Algorithm (GA) as the means to combine aerodynamic and structural concerns for topology design of rotor blades. Inverse airfoil design and optimal airfoil design are receiving much attention in both industry and academia; the same holds true for structural optimization. The combination of the two concerns for *topology* design has not been fully addressed. A multidisciplinary approach combining structural and aerodynamic concerns for optimal topology design of rotor blades provides potential benefit to the rotorcraft design process. (Supported by the NASA Graduate Student Researchers Program, NASA Ames Rotor Aeromechanics Branch. David Fanjoy, graduate student.)

Development of a Genetic Algorithm for Conceptual Design of Aircraft. Air vehicle conceptual design appears to be a promising area for application of the genetic algorithm as an approach to help automate part of the design process. This approach can reduce some of the subjective decision-making often associated with conceptual design, while also determining optimal parameter values for the aircraft. Work has been extensively conducted for helicopters, some additional work has been conducted for high-speed VTOL rotorcraft (e.g. tilt-rotor and tilt-wing aircraft), and work is currently beginning for fixed-wing aircraft. Because the GA-based approach to conceptual design helps to reduce the number of qualitative decisions needed from the design team, this appears to have great potential for application to aircraft design. This is particularly true for aircraft whose configurations may be significantly different than current aircraft, such as V/STOL aircraft, unmanned (UAV) and remotely piloted vehicles (RPV). Potential applications also exist for commercial aircraft. (Supported by the NASA Graduate Student Researchers Program, NASA Langley Systems Analysis Branch. Gregory Roth, graduate student.)

Application of Genetic Algorithms to Hybrid Rocket Booster Design. Hybrid rockets have recently garnered much attention as cost-effective means for launch vehicle boosters. The ability of the hybrid to be throttled and a high specific impulse make the hybrid appealing compared to solid-rocket boosters, while the use of a single liquid offers greater simplicity in construction and operation than liquid bi-propellant systems. Performance of a hybrid rocket depends greatly on continuous variables like chamber pressure and oxidizer mass fuel rate; however, integer and discrete variables like the number and shape of fuel ports and choice of oxidizer and fuel system, also impact the rocket's performance. Because of this combination of design variables, this problem appears well suited to the genetic algorithm. Research is being conducted to determine appropriate GA techniques for hybrid rocket boosters. (Philip Schoonover graduate student, Prof. Heister co-advisor.)

Improved Satellite Constellation Design and Optimization. Improving satellite constellation design is of great interest to any users of satellite communication (e.g. cellular phones, television), location (e.g. global positioning system) and/or observation (e.g. weather). Many of today's satellite constellation designs rely on the "Walker Constellations", a series of designs developed in 1970, which have rarely been improved upon. These constellations make use of symmetric constellations with circular orbits. Using the genetic algorithm to search the constellation design space has begun to yield constellation designs not previously envisioned but with performance equal to or greater than comparable Walker or "streets of coverage" constellations. Research is ongoing for sparse coverage constellations, constellation build-up problems, multiobjective constellation concerns and elliptic orbit constellations. (Partially supported by The Aerospace Corporation. Edwin Williams, graduate student.)

Aerodynamic and Aeroacoustic Optimization of Airfoils via a Parallel Genetic Algorithm. A parallel genetic algorithm coupled with a viscous aerodynamic analysis code will generate, in a single run, a family of aerodynamically efficient, low-noise rotor blade designs representing the Pareto optimal set for a typical flight condition. The *n*-branch tournament, uniform crossover, genetic algorithm (GA) will operate on twenty design variables representing the airfoil surface. The GA maximizes the use of available computer resources by operating in either serial mode, manager/worker parallel mode or island model parallel mode. It will maximize lift-to-drag while simultaneously minimizing loading noise and thickness noise. Constraints are placed on the minimum lift coefficient, the pitching moment and the upper surface, flow separation location. The GA currently functions in serial and manager/worker mode and has successfully completed testing with various mathematical test functions. Current work focuses on integrating XFOIL as the aerodynamic analysis application. The performance of the resulting Pareto-optimal airfoil set will be compared to the performance of a typical rotorcraft airfoil under identical flight conditions. (Brian Jones, graduate student. Prof. Lyrintzis, co-advisor.)

Genetic Algorithm Methods for Multiobjective Design. The Genetic Algorithm (GA) can combine discrete, integer and continuous variables in a single problem and can find solutions to complex design problems. This provides great potential for many "real world" engineering design problems. Current research is comparing and contrasting several GA approaches for multiobjective design. Of primary interest is the development of new selection operators and of new ways to construct the fitness function to find designs that perform well on more than one objective. Ability of the approaches to find non-dominated Pareto-optimal designs will be assessed. Because the GA uses a population-based search, it appears likely that the Pareto front can be fairly accurately estimated with one complete run of the genetic algorithm.

Methods to Assess Commercial Aircraft Technologies. Increasing competition in the commercial aircraft industry requires that airframe manufacturers be judicious with technology research and development efforts. Currently, technology development strategies for commercial aircraft appear to be lacking; this research presents a methodology to assess new technologies in terms of both cost and performance. This methodology encompasses technologies that can be applied to the aircraft design and technologies that improve the development, manufacturing, and testing of the aircraft. This differs from past studies that focussed upon a small number of performance-based technologies. The method is divided into two phases. The first phase evaluates technologies based on cost measures alone. The second phase redesigns an aircraft with new technologies, assesses the relative importance of performance-based technologies, and recognizes technology interactions using Taguchi's Design of Experiments. For a wide-body transport aircraft example, the methodology identifies promising technologies for further study. Recommendations and conclusions about the methodology are made based on the results. (Partially supported by the NSF Center for Collaborative Manufacturing at Purdue University. Tamaira Ross, graduate student.)

Publications

Fanjoy, D. W., and Crossley, W. A., "Aerodynamic Shape Design for Rotor Airfoils via Genetic Algorithm," *Journal of the American Helicopter Society*, Vol. 43, No. 3, pp. 263-270, July 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Williams, E. A., and Crossley, W. A., "Empirically-Derived Population Size and Mutation Rate Guidelines for a Genetic Algorithm with Uniform Crossover," Soft Computing Engineering Design and Manufacturing, P. K. Chawdhry, R. Roy, and P. K. Pant (editors), Springer-Verlag, pp. 63-172, 1998.

Ross, T. E., Crossley, W. A., and Roth, G. L., "Multiobjective Optimization of Commercial Transport Aircraft for Cost and Weight," AIAA paper 98-0911, *36th AIAA Aerospace Sciences Meeting and Exhibit*, Reno, NV, Jan. 12-15, 1998.

Norris, S., and Crossley, W. A., "Selecting Pareto-Optimal Controller Gains with a Genetic Algorithm," AIAA paper 98-1010, *36th AIAA Aerospace Sciences Meeting and Exhibit*, Reno, NV, Jan. 12-15, 1998.

Ely, T. A., Crossley, W. A., and Williams, E. A., "Satellite Constellation Design for Zonal Coverage Using Genetic Algorithms," AAS paper 98-128, *AAS/AIAA Space Flight Mechanics Meeting*, Monterey, CA, Feb. 1998.

Crossley, W. A., Cook, A. M., Fanjoy, D. W., and Venkayya, V. P., "Using the Two-Branch Tournament Genetic Algorithm for Multiobjective Design," AIAA paper 98-1914, *Proceedings of the 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Long Beach, CA, Apr. 20-23, 1998.

Crossley, W. A., “Using Genetic Algorithms to Encourage Engineering Design Creativity,” WSC3: 3rd On-line World *Conference on Soft Computing in Engineering Design and Manufacturing*, Jun. 21-30, 1998, [www http://garage.cps.msu.edu/wsc3/index.htm].

Schoonover, P. L., Crossley, W. A., and Heister, S. D., "Application of a Genetic Algorithm to the Optimization of Hybrid Rockets," AIAA paper 98-3349, *34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, Cleveland, OH, July 13-15, 1998.

Roth, G. L., and Crossley, W. A., " Commercial Transport Aircraft Conceptual Design using a Genetic Algorithm Based Approach," AIAA paper 98-4934, *7th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, St. Louis, MO, Sept. 2-4, 1998

Jones, B. R., Crossley, W. A., and Lyrintzis, A. S., "Aerodynamic and Aeroacoustic Optimization of Airfoils via a Parallel Genetic Algorithm," AIAA paper 98-4811, *7th*

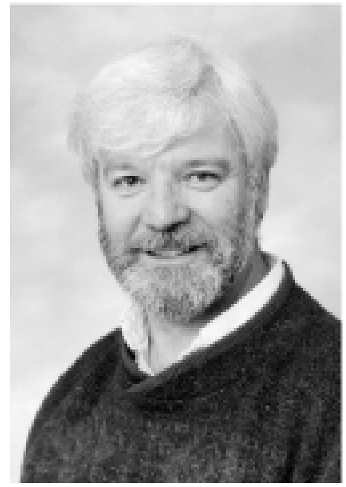
AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, St. Louis, MO, Sept. 2-4, 1998.

Crossley, W. A., "Genetic Algorithm Actuator Placement for Flow Control for Maneuverability: Preliminary Results and Research Issues," NASA Langley Research Center, Hampton, VA, July 20, 1998.

Crossley, W. A., "Engineering Design and Optimization with the Genetic Algorithm," NASA Ames Research Center, Moffett Field, CA, Aug. 13, 1998.

Crossley, W. A., "Genetic Algorithms for Engineering Design and Optimization: An Introduction," six-hour short course presented to FAAC Incorporated, Ann Arbor, MI, Dec. 11, 1998.

JAMES F. DOYLE
1977
Professor



Degrees

Dipl. Eng., Dublin Institute of Technology, Ireland, 1972
M.Sc., University of Saskatchewan, Canada, 1974
Ph.D., University of Illinois, 1977

Interests

Structural dynamics
Experimental Mechanics
Inverse Problems
Wave propagation

Research Areas

Wave Motion in Structures

Because of their size and low stiffness, large space structures are susceptible to wave motions due to transients. New, spectrally formulated, elements are being developed that are suitable for dynamic problems and have the following advantages:

Single elements can extend from joint to joint thus giving a remarkable reduction in the size of the system to be solved (with no loss of resolution.)

Inverse problems can be solved conveniently, thus making it useful for experimental systems identification studies.

Experimentally characterized substructures (such as joints) may be easily incorporated in the modeling.

Spectral elements have already been developed for rods, beams and shafts, and their implementation in a general 3-D structural analysis computer program accomplished.

Impact and Damage of Structures

A very important aspect of structural performance is the ability to withstand impact and minimize the amount of damage caused. Impact had two effects on damage: (1) Generation if new damage near the impact site or at a stress concentrator. (2) Increased damage at pre-existing flaws caused by the propagated energy. Current investigations involve wave interactions with delamination flaws. This has direct application to damage in composite materials. Other aspects of the problem include:

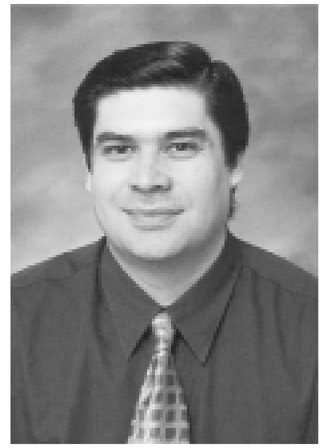
FORCE IDENTIFICATION: from measurements made on the structure being able to determine the impact of force history.

REMOTE SENSING: from analysis of the reflected and transmitted waves being able to locate flaws and estimate their size.

LOCAL/GLOBAL ANALYSIS: separate the global structural dynamics from the local behavior near the flaw, thus leading to computational efficiencies. A novel layered spectral element has been developed for use with composite materials.

Whole Field Image Characterization

An alternative to strain gages and accelerometers in dynamic measurements is to use ultra-high speed photography coupled with such methods as photoelasticity; and moiré. The question being investigated is: Under what circumstances is a single (or a limited number) of photographs capable of completely characterizing the wave information? This touches on some fundamental aspects of transform theory coupled with measurement theory. The payoff is that photographs combined with digital imaging techniques offer unique possibilities for recording and post-processing the data. This is essentially an experimental problem because experimental data is always incomplete, so questions of quality of the data, the amount of data, etc. must be confronted, as well as the following aspects: (1) High-Speed photography and photoelasticity (2) Digital imaging techniques (3) @-D Fast Fourier Transforms.



HORACIO D. ESPINOSA

1992

Associate Professor

Degrees

Sc.B., Northeast National Univ., Magna Cum Laude, Civil Engineering, Argentina, 1981
Sc.M., Polytechnic of Milan, Italy, Structural Engineering, 1987
Sc.M., Brown University, Solid Mechanics, 1989
Sc.M., Brown University, Applied Mathematics, 1990
Ph.D., Brown University, Solid Mechanics, 1992

Honors and Awards

- ONR-YIP Award, 1997
- NSF-CAREER Award, 1996
- NSF-Research Initiation/Instrumentation Awards, 1993

Research Interests

a. Development of novel experiments with interferometric diagnostic techniques including full field velocity and temperature measurements.

b. Dynamic propagation of cracks in brittle solids. Examination of critical conditions for crack initiation and propagation. Speckle and Moire′ techniques applied to crack tip dynamic measurements.

c. Microcracking and inelasticity of brittle materials. Identification and modeling of failure mechanisms. Effect of grain size, second phases, and texture on the dynamic response of ceramics and glasses.

d. Tribomechanics and machining of nanostructured materials. Assessment of local inelasticity, microplasticity and microcracking, in the frictional behavior of interfaces as a function of surface characteristics and lubrication.

e. High temperature dynamic testing and modeling of ceramic tailored microstructures. Derivation of multidimensional constitutive models.

f. Plastic flow and shear localization in amorphous materials.

g. Computational algorithms for parallel computing, mesh adaptivity, and discrete fragmentation.

Research Areas

Research interests are in the area of constitutive modeling, dynamic failure and wave propagation studies in ceramics and composites. These materials have attracted a great deal of attention because of their outstanding, often unique, properties that allow them to perform a wide variety of functions. For instance, ceramics are emerging materials with a great potential in applications such as thermal spray coatings, turbine blade coatings, cutting tools, wear parts, sensors, magnetic recording media, structural and electronic components, multi-layered armor, and pharmaceutical/medical systems (e.g., alumina prosthetic articulating joints). In all these applications fundamental understanding of their mechanical properties and failure mechanisms is needed. In an attempt to properly characterize the mechanical response of these advanced materials, a unique experimental and computational approach is being pursued.

- *Experimental and Computational Mechanics*

Our research involves the testing of ceramics and composites under a variety of impact loading configurations. The experimental technique consists of generating normal and shear waves with a time resolution of a few nanoseconds and magnitudes up to several gigapascals (GPa), in specially designed target plates. In the case of recovery experiments, postshock examination of the specimens by means of electron microscopy and other observational methodologies, allows the identification of inelasticity and damage. These observations form the bases for (i) the comprehensive understanding of processes (microcracking, phase transformations, microplasticity) occurring at the microstructural level and (ii) the formulation of physically based constitutive models. Interferometric records, performed during the wave propagation event, are used as a diagnostic tool in the examination of derived or postulated models. In addition, cell calculations of random microstructures are performed to identify the role of grain size, grain boundary structure, second phases and grain morphology in the failure mechanisms. Our numerical simulations account for crystal elastic and thermal anisotropy, grain plasticity, and grain boundary decohesion. The primary goal of this research is the derivation of continuum multiple-plane models that can predict macroscopic material behavior and in particular failure due to damage or shear localization.

Computer simulations of experiments conducted in our Dynamic Inelasticity Laboratory are performed. The simulations examine the role of microstructure, deformation rate, and state of multi-axial loading in the interpretation of wavefront attenuation, pulse spreading, and damage induced anisotropy. An explicit finite element code incorporating finite deformations, inelasticity, contact between bodies, and adaptive meshing is used. Furthermore, novel wave propagation experiments are under development to extend the impact technique to penetration mechanics, dynamic friction, and material instability studies.

Sponsored Research Summaries

Effect of Grain Size and Second Phases in the Dynamic Failure of Ceramics (Sponsored by the National Science Foundation; students and post-docs: Pablo D. Zavattieri, Sunil Dwivedi)

General objectives of the research are: 1) to numerically investigate the effect of ceramic microstructures on failure mechanisms through simulation of cells containing a distribution of grains with random and preferred orientations, second phases in the form of particles and/or thin intergranular layers with or without glass pockets, 2) to conduct impact recovery experiments that will enable microscopic observations and the interferometric recording of velocity histories. This experimental/computational approach will be used to assess and model inelasticity in ceramic materials. The investigation will be extended to the study of material behavior at high temperatures. Such research is of high priority because it will allow the use of ceramics and ceramic composites in engine components. An instrumentation proposal from the Air Force Office of Scientific Research (AFOSR) was awarded for this study.

Dynamic Friction Studies on Nanostructured Materials (Sponsored by NSF through young investigator award NSF-Career; students and post-docs: Alejandro Patanella, Y. Xu)

This research is being supported by an NSF-CAREER award. Research objectives are the assessment of the role of local inelasticity, microplasticity and microcracking in the frictional behavior of interfaces as functions of surface characteristics and lubrication. Moreover, the development of a finite element code capable of predicting mechanistic aspects of friction and wear will be pursued. Basic understanding of frictional behavior at interfaces will be gained by performing pressure-shear experiments at pressures, slipping velocities, temperatures and surface roughnesses typical of manufacturing processes. The pressure-shear soft-recovery technique we developed, offers the additional and unique feature of allowing a correlation between dynamic loading of the interface and microstructural features observed on recovered samples at the surfaces of interest. This information will be used in the formulation of sliding and friction models, and their performance will be assessed through numerical simulations of the plate impact experiment. Cell calculations of random microstructures will be performed to gain insight into the effects of grain size, grain boundary structure, and grain anisotropy and orientation on the frictional behavior of brittle materials.

Damage and Energy Dissipation Mechanisms in Ballistic Impact (Sponsored by the U.S. Army Research Office; students and post-docs: H-C. Lu and Gang Yuan)

In many ballistic impact test, often only the incident and residual velocities are recorded. To understand the penetration process, recording the complete velocity history of the projectile is highly desired. Professor Espinosa and his students developed an experimental technique using laser interferometry to measure the surface motion of both the projectile and the target plate. Penetration experiments will be conducted with a light gas gun. The projectile holder is designed such that a normal velocity interferometer can be obtained on a laser beam reflected from the back surface of the projectile. In addition to this measurement a multi-point velocity interferometer will be utilized to continuously record the motion of the target back surface. In order to obtain full field out-of-plane displacement gradients, a shearing interferometric technique will be used. In this technique a laser beam reflected from the specimen surface is diffracted by two gratings separated by a fixed distance and filtered by a lens and a screen. A high-speed digital camera records the out-of-plane displacements. Research will focus on the comprehensive understanding of failure mechanisms and the formulation of physically based micromechanical models. Delamination history, fiber breakage, and membrane effects will be examined. Rate effects on these failure mechanisms will be systematically investigated. A numerical algorithm to simulate penetration experiments in multi-layered targets will be developed. A Lagrangian FEM with dynamic contact, and finite deformation capabilities is currently under development. The contact law has been augmented with a decohesion law to simulate delamination and friction between plies.

Dynamic Delamination under Compression-Shear (Sponsored by the U.S. Army Research Office; students and post-docs: G. Emore, H-C. Lu, and Sunil Dwivedi)

The objective of this research is to investigate shear induced delamination in fiber reinforced composites, when compressive tractions are superimposed, and to formulate a contact model with decohesion law to simulate delamination and friction. Understanding critical conditions for dynamic crack propagation in composite interfaces is essential in the design of composite materials and structures. Crack initiation and propagation between plies in fiber composites, as a function of interface properties and remote loading, will be examined. Furthermore, the existence of a critical energy release rate as a function of load mixity will be investigated. Knowledge of dynamic fracture toughness of interfaces under mixed-mode loading conditions is very limited, mainly because of the difficulties involved in the design of appropriate experiments. The methodology proposed here consists of manufacturing of a crack-like defect in half of the interface plane by means of established manufacturing processes. This design will allow the study of crack propagation in composite interfaces under well defined dynamic loading conditions. By proper selection of plate thicknesses and angles of impact, pure shear, pure tension, and combined loading can be achieved. The precise stress field for crack initiation, as a function of mode-mixity, will be identified by monitoring the emanating waves from the crack-tip. Velocity measurements will be accomplished by means of a variable sensitivity displacement interferometer (VSDI). The structure of the interface and its defects at the crack tip will be identified through electron microscopy studies. Furthermore, 3-D finite element numerical simulations of the dynamic event will be performed with a contact/cohesive law in order to identify interface toughness.

Dynamic Fracture Toughness of Propagating Cracks in Brittle and Nano Materials (Sponsored by the Office of Naval Research through a young investigator award, ONR-YIP; post-doc: Y. Xu)

The effect of loading rate in failure mode transition in steel has been successfully studied. No such studies exist for the case of brittle and nano-materials. The research efforts towards the understanding of size and material microstructure effects in brittle failure can be significantly augmented by the study of dynamically loaded cracks. Professor Espinosa proposed to investigate failure modes by means of the impact of precrack specimens. A *laser speckle technique* will be used to examine strain fields surrounding cracks in ceramics and glasses. A light gas gun will be employed to dynamically load the samples. Real time specklegrams will be recorded in a high-speed camera. View area, and frame rate will be selected to measure grain plasticity, grain boundary shearing, and crack tip damage. A ceramic with tailored microstructure with an average grain size of 100-150 μm will be investigated. Fluorescent coatings will be used to obtain temperature fields.

Publications

Espinosa, H. D., Zavattieri, P. D., and Emore, G. L., "Adaptive FEM Computation of Geometric and Material Nonlinearities with Application to Brittle Failure," in special issue of *Mechanics of Materials,* Vol. 29, pp. 275-305, Aug. 1998.

Espinosa, H. D., Zavattieri, P. D., and Dwivedi, S., "A Finite Deformation Continuum/Discrete Model for the Description of Fragmentation of Damage in Brittle Materials," in special issue of *Journal Mechanics and Physics of Solids,* Vol. 46, No. 10, pp. 1909-1942, 1998.

Espinosa, H. D., Dwivedi, S., Zavattieri, P. D., and Yuan, G., "A Numerical Investigation of Penetration in Multi-Layered Structure/Material Systems," *International Journal of Solids and Structures,* Vol. 35, No. 22, pp. 2975-3001, 1998.

Espinosa, H. D., "Recent Developments in Velocity and Stress Measurements Applied to the Dynamic Characterization of Brittle Materials," in special issue of *Mechanics of Materials,* Vol. 29, pp. 219-232, Aug. 1998.

Espinosa, H. D., Lu, H-C., and Xu, Y., "A Novel Technique for Penetrator Velocity Measurement and Damage Identification in Ballistic Penetration Experiments," in *Journal of Composite Materials,* Vol. 32, No. 8, pp. 742-743, 1998.

Brar, N. S., and Espinosa, H. D., "A Review of Micromechanics of Failure Waves in Silicate Glasses," in *Journal of Chemical Physics* (in Russian) which is translated to *Chemical Physics Reports* (in English), Vol. 17, No. 1-2, pp. 317-342, 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Espinosa, H. D., Dwivedi, S., Zavattieri, P. D., and Raghuram, P. V., "Modeling Size Effects in Brittle Materials Undergoing Damage and Fragmentation," presented at *13th U. S. Congress of Applied Mechanics,* Florida, June 1998.

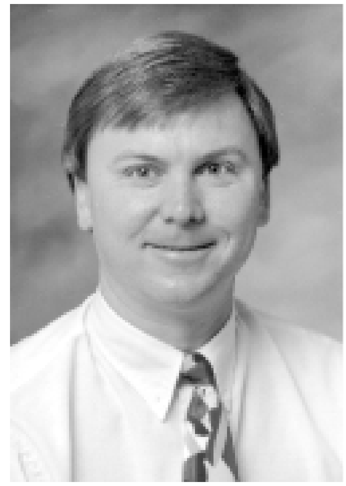
Espinosa, H. D., Zavattieri, and Dwivedi, S., "Mesh Adaptivity Applied to the Solution of Large Deformation Dynamic Fields," presented at the *13th U. S. National Congress of Applied Mechanics,* Florida, June 1998.

Espinosa, H. D., Patanella, A., and Xu, Y., "Dynamic Compression-Shear Loading of Brittle Materials with Specimen Recovery," in *Proceedings of the 11th International Conference on Experimental Mechanics,* edited by I. M. Allison, Oxford, UK, pp. 223-229, 1998.

Brar, N. S., Espinosa, H. D., and Yuan, G., "Experimental Study of Interface Defeat in Confined Ceramic Targets," in Proceedings of Joint AIRAPT-16 and HPCJ-38, *The Review of High Pressure Science and Technology*, edited by Masaru Nakahara, Vol. 7, pp. 855-857, 1998.

Espinosa, H. D., "Dynamic Failure of Advanced Materials in Experimental and Computational Investigation," Harvard University, Massachusetts Institute of Technology, and Rutgers University, Fall 1998.

THOMAS N. FARRIS
1986
Professor and Head



Degrees

B.S., Rice University, Cum Laude, Mechanical Engineering, 1982
M.S., Northwestern University, Theoretical and Applied Mechanics, 1984
Ph.D., Northwestern University, Theoretical and Applied Mechanics, 1986

Interests

Tribology
Manufacturing processes
Fatigue and fracture

Research Areas

In tribology, a major research effort is underway in the experimental and analytical characterization of fretting fatigue. The experimental work uses a unique fixture design that allows independent control of the applied clamping and tangential forces. Analytical work combines boundary and finite element analysis of the effect of forces, microslip, and geometry on subsurface stresses. Multiaxial fatigue theories are being used to correlate these stresses with experimentally observed crack nucleation and fracture mechanics is used to predict growth of these cracks. The calculations will then be used to predict the effect of fretting on multi-site damage nucleation and growth in the aging aircraft problem. The approach is being used to address fretting fatigue in jet engines as part of the Air Force High Cycle Fatigue initiative.

Manufacturing process research includes experimental and analytical work on grinding and super finishing of hardened steels and ceramics for precision components. The focus is on understanding the mechanics of the material removal process so that the effect of process parameters on component performance can be predicted. To this end, deformation induced during the controlled static and sliding microindentation is being studied. An example of the results of this research is a recently established relationship between grinding temperatures and near surface residual stress and microstructure of the ground component. A model of free abrasive machining that predicts statistical properties of the load/particle relationship has been developed. The model can be used to predict finished surface roughness. A new effort in the area of form generation in centerless grinding is underway. The use of high pressure fracture to produce smooth defect free ceramic surfaces is also being pursued.

Additional work in the area of manufacturing processes is directed at modeling of the heat treatment process. A commercial finite element package has been adapted to predict the microstructure, deformation, and stress induced by quenching of steel structures. The model includes the effects of latent heat and volumetric strains induced by phase changes. Industrial collaborators are providing requisite material properties as a function of temperature as well as assistance with experimental validation of the modeling.

Fatigue and fracture research includes finite element calculation of residual stresses in railway rails. These residual stresses provide guidelines for the development of rail grinding strategies. Additional railway application includes modeling the effect of roller straightening induced stresses on fast fracture of rail webs. In addition, the failure mode of the mechanical fuse that causes the greatest energy dissipation is being pursued. Finally, boundary element analysis of fracture of smart materials and structures is being developed.

Publications

Hill, L. R., and Farris, T. N., "Three-Dimensional Piezoelectric Boundary Element Method," *AIAA Journal*, Vol. 36, No. 1, pp. 102-108, 1998.

Bulsara, V. H., Chandrasekar, S., and Farris, T. N., "Mechanics of Polishing," *ASME Journal of Applied Mechanics*, Vol. 65, No. 2, pp. 410-416, 1998.

Harish, G., and Farris, T. N., "Shell Modeling of Fretting in Riveted Lapjoints," *AIAA Journal*, Vol. 36, No. 6, pp. 1087-1093, 1998.

Ahn, Y., Farris, T. N., and Chandrasekar, S., "Sliding Microindentation Fracture of Brittle Materials: Role of Elastic Stress Fields," *Mechanics of Materials*, Vol. 29, No. 3-4, pp. 143-152, 1998.

Szolwinski, M. P., and Farris, T. N., "Observation, Analysis and Prediction of Fretting Fatigue in 2024-T351 Aluminum Alloy," *West*, Vol. 221, No. 1, pp. 24-36, 1998.

Ju, Y., Farris, T. N., and Chandrasekar, S., "Theoretical Analysis of Heat Partition and Temperatures in Grinding," *ASME Journal of Tribology*, Vol. 120, No. 4, pp. 789-794, 1998.

Hill, L. R., and Farris, T. N., "Piezoelectric Boundary Element Crack Closure Calculation of 3D Strain Energy Release Rates," *Journal of Intelligent Materials System and Structures*, Vol. 9, April 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Szolwinski, M. P., Harish, G., and Farris, T. N., "The Role of Fretting Damage Mechanisms in the High Cycle Fatigue of Titanium Alloys," *Proceedings 3rd National High Cycle Fatigue (HCF) Conference,* Session 10, San Antonio, TX, Feb. 1998.

Sakagami, T., Madhavan, V., Harish, G., Krishnamurthy, K., Farris, T. N., and Chandrasekar, S., "Full-Field IR Measurement of Subsurface Grinding Temperatures," Prof. Thermosense XX, *SPIE,* Vol. 3361, pp. 234-245, Orlando, FL, April 1998.

Harish, G., and Farris, T. N., "Effect of Fretting Contact Stresses on Crack Nucleation in Riveted Lapjoints," *Proceedings 39th AIAA/ASME/ASCE/ASC Structures, Structural Dynamics and Materials Conference,* pp. 383-391, Long Beach, CA, April 1998.

Bougher, J. A., Chandrasekar, S., Farris, T. N., and Mann, J. B., "Gross Part Deflection and Process Capability in the Hard Turning of Precision Mechanical Components," *Proceedings CIRP International Workshop on Modeling of Machining Operations,* pp. 337-346, Atlanta, GA, May 1998.

Farris, T. N., Harish, G., Szolwinski, M. P., and Sakagami, T., "Coupled Thermoelastic Stress Measurement Applied to Fretting," *Proceedings SEM Spring Conference on Experimental and Applied Mechanics,* pp. 433-436, Houston, TX, June 1998.

Sakagami, T., Szolwinski, M. P., Harish, G., and Farris, T. N., "Full-Field Subsurface Temperature Measurements in Fretting," *Proceedings SEM Spring Conference on Experimental and Applied Mechanics,* pp. 437-440, Houston, TX, June 1998.

Szolwinski, M. P., Harish, G., and Farris, T. N., "The Development and Validation of Design-Oriented Metrics for Fretting Fatigue in Titanium Engine Components," *Proceedings IMECE Symposium on Mechanical Behavior of Advanced Materials,* MD 84, pp. 11-18, Anaheim, CA, Nov. 1998.

Chang, S.-H., Farris, T. N., and Chandrasekar, S., "Contact Mechanics of Superfinishing," *Proceedings IMECE Symposium on Recent Advances in Materials Processing,* MED-8, pp. 171-179, Anaheim, CA, Nov. 1998.

Sakagami, T., Szolwinski, M. P., Harish, G., and Farris, T. N., "Evaluation of the Stress Distribution Associated with Fretting Crack Nucleation Based on the Thermoelastic Temperature Measurement," *Proceedings JSME Annual Meeting,* Tokyo, April 1998.

Sakagami, T., Ogura, K., Kubo, S., and Farris, T. N., "Application of Infrared Thermography for Contact Problems," *Proceedings IUTAM Symposium on Advanced Optical Methods and Applications in Solid Mechanics,* Poitiers, France, Aug. 1998.

Rajeev, P. T., Farris, T. N., Chandrasekar, S., Andreski, B., and Brada, G., "Heat Treatment of Steels: Prediction of Microstructure, Residual Stress and Distortion," *Proceedings ASM Heat Treating Society Conference*, Rosemont, IL, Oct. 1998.

Farris, T. N., Szolwinski, M. P., and Harish, G., "Fretting in Aerospace Structures and Materials," *ASTM Conference on Fretting Fatigue, Current Technologies and Practices*, Salt Lake City, UT, Sept. 1998.

Szolwinski, M. P., Harish, G., McVeigh, P. A., and Farris, T. N., "Experimental Study of Fretting Crack Nucleation in Aerospace Alloys with Emphasis on Life Prediction," *ASTM Conf. on Fretting Fatigue: Current Technologies and Practices*, Salt Lake City, UT, Sept. 1998.

Harish, G., Szolwinski, M. P., Farris, T. N., and Sakagami, T., "Evaluation of Fretting Stresses through Full-Field Temperature Measurements," *ASTM Conf. on Fretting Fatigue, Current Technologies and Practices*, Salt Lake City, UT, Sept. 1998.

Farris, T. N., Harish, G., McVeigh, P. A., and Szolwinski, M. P., "Fretting in Aeronautical and Aerospace Structures and Materials," *Engineering Foundation Conf. on Fatigue Damage of Structural Materials II*, Cape Cod, MA, Sept. 1998.

ALTEN F. GRANDT, JR.
1979
Professor

Degrees

B.S., University of Illinois at Urbana-Champaign, General Engineering, 1968
M.S., University of Illinois at Urbana-Champaign, Theoretical and Applied Mechanics, 1969
Ph.D., University of Illinois at Urbana-Champaign, Theoretical and Applied Mechanics, 1971

Interests

Damage-tolerant structures and materials
Fatigue and fracture
Aging aircraft
Nondestructive inspection

Research Areas

Basic research is directed at developing methodology to analyze and design damage tolerant aerospace structures and materials or to evaluate the remaining safe operating life of "aging" aircraft. Emphasis is placed on employing both experimental and numerical approaches to predict the initial growth of preexistent cracks and subsequent fracture due to cyclic and/or static loads. The influence of corrosion on structural life is also of interest.

Current research is focusing on problems related to ensuring the structural integrity of older aircraft. Deterministic and probabilistic approaches are being employed to determine the influence of widespread fatigue damage on the residual strength and fatigue life of mechanically fastened joints and stiffened panels. Techniques for quantifying the effect of corrosion on structural integrity are also being investigated, along with assessment of changes in fatigue crack growth properties in structural materials that have experienced extended periods of service.

One current project involves determining the cyclic growth and coalescence of fretting induced cracks, and is part of a larger research program directed at predicting the onset of High Cycle Fatigue failures in turbine engine components. Another effort is focused on developing a fatigue specimen and test methodology to assess the cyclic performance of new aluminum alloys in aircraft joint configurations.

Other recent efforts examined the nucleation and early growth of fatigue cracks in various materials and structural configurations. In one project, high strength steel specimens were subjected to several constant and variable amplitude load histories to determine the initial growth, coalescence, and fracture of fatigue cracks that develop at notches in the specimens. Another related project evaluated the resistance to fatigue crack formation provided by new aluminum alloys, and involved subjecting large, multi-hole specimens to a given number of fatigue cycles. Those specimens were then sectioned and examined to determine the numbers and sizes of cracks that have developed at the many hole locations. A technique for monitoring the service loading of structural components by the use of pre-cracked coupons mounted to structural members has also been recently studied.

Publications

Bray, G. H., Bucci, R. J., Kulak, M., Warren, C. J., Grandt, Jr., A. F., Golden, P. J., and Sexton, D. G., "Benefits of Improved Fuselage Skin Sheet Alloy 2524-T3 in Multisite Damage Scenarios," *Light Metal Age*, Vol. 56, Nos. 11 & 12, pp. 20-28, Dec. 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Grandt, Jr., A. F., Gray, G. H., Bucci, R. J., Kulak, M., Sexton, D. G., and Golden, P. J., "A Contrast of 2024-T3 and 2524-T3 Fuselage Skin Sheet Alloy Performance in Multi-site Damage Scenarios," AeroMat -98, *9th Annual Advanced Aerospace Materials and Processes Conference and Exposition*, Tysons Corner, VA, June 15-18, 1998 (abstract only).

Grandt, Jr., A. F., Bray, G. H., Bucci, R. J., Kulak, M., Warren, C. J., Golden, P. J., and Sexton, D. G., "Benefits of Improved Fuselage Skin Sheet Alloy 2524-T3 in Multi-site Damage Scenarios," *Proceedings of the 2nd Joint NASA/FAA/DoD Conference on Aging Aircraft*, Williamsburg, VA, Aug. 31 - Sept. 3, 1998. Also published in Light Metal Age, Vol. 56, Nos. 11 & 12, pp. 20-28, Dec. 1998.

Grandt, Jr., A. F., Golden, P. J., and Bray, G. H., "A Comparison of Fatigue Crack Formation at Holes in 2024-T3 and 2524-T3 Aluminum Alloy Specimens, *Fatigue Damage of Structural Materials II*, Cape Cod, MA, Sept. 7-11, 1998.

Grandt, Jr., A. F., Bray, G. H., Bucci, R. J., and Golden, P. J., "Effect of Prior Corrosion on Fatigue Performance of Toughness Improved Fuselage Skin Sheet Alloy 2524-T3," *AGARD Applied Vehicle Technology Panel Workshop 2 on Fatigue in the Presence of Corrosion*, Corfu, Greece, Oct. 7-8, 1998.

Grandt, Jr., A. F., and Wang, H. L., "Monte Carlo Analysis of Widespread Fatigue Damage in Lap Joints," *1998 USAF Structural Integrity Program Conference*, San Antonio, TX, Dec. 1-3, 1998.

Grandt, Jr., A. F., Green, S. J., Ball, D., and Doerfler, M., "Fatigue Crack Formation and Coalescence at Notches," *1998 USAF Structure Integrity Program Conference*, San Antonio, TX, Dec. 1-3, 1998.

C. T. SUN
1968
Neil A. Armstrong Distinguished Professor of Aeronautical & Astronautical Engineering

Degrees

B.S., National Taiwan University, Taiwan, Civil Engineering, 1962
M.S., Northwestern University, Theoretical & Applied Mechanics, 1965
Ph.D., Northwestern University, 1967

Interests

Composites
Fracture and Fatigue
Structural Dynamics
Smart Materials and Structures

Research Areas

Major research interests include the following areas:

Composite Materials and Structures -- Advanced fiber composites have gained wide application in aircraft and aerospace structures. However, our knowledge of these materials is still lacking, and a great deal of research is still needed. Our research covers a broad spectrum of mechanics and design of various composite materials and structures. Topics include low velocity impact response and damage analysis, ballistic impact and penetration of composite structures, design of new hybrid composites for improved impact resistance properties, development of theories for laminate failure prediction, inelastic behavior of composites, temperature-dependent properties, modeling of thick composite laminates, static and dynamic delamination crack propagation, intelligent tailoring of composite materials and structures and finite element simulation of forming of thermoplastic composites. Composite systems studies include carbon/epoxy composites, thermoplastic composites, metal-matrix composites, and ARALL laminates.

The McDonnell Douglas Composite Materials Laboratory is equipped with complete testing facilities. In addition, an autoclave and a hot press are available for composite specimen fabrication.

Fracture Mechanics -- Fracture mechanics is used to analyze failure in materials including fibrous composites. Behaviors of interfacial cracks between two dissimilar materials are of particular interest as they are pertinent to fiber debonding in composite materials and to delamination in composite laminates. Topics of research include separation of fracture modes for interfacial cracks and development of governing equations for dynamic motion of propagating interface cracks. Another major research effort concerns fracture criterion utilizing a combination of an extended J-integral for elastic-plastic materials and a crack front plastic work density to predict crack extension in ductile metals. A new research topic deals with fracture mechanics issues encountered in using composite materials to repair cracked metal structure in aging aircraft.

Smart Materials and Structures -- The use of piezoceramics as actuators in adaptive structures demands these materials to perform under increasingly high electric and mechanical loads. Durability and reliability of actuators have become important issues. Our current research aims at solving a number of fundamental problems involving cracks in piezoceramics under combined mechanical and electric loading.

Publications

Vaidya, R. S., King, J. C., and Sun, C. T., "Effect of Ply Thickness on Fracture of Notched Composite Laminates," *AIAA Journal*, Vol. 36, No. 1, pp. 81-88. 1998.

Zheng, S., and Sun, C. T., "Delamination Interaction in Laminated Structures," *Engineering Fracture Mechanics*, Vol. 59, No. 2, pp. 225-240, 1998.

Vaidya, R. S., Klug, J. C., and Sun, C. T., "Effect of Ply Thickness and Crack Tip Damage on Failure of Notched Composite Laminates," *AIAA*, Vol. 36, No. 1, pp. 81-88, 1998.

Tao, J. X., Sun, C. T., Arendt, C., and Brunner, M., "Interlaminar Shear Strength and Fracture Behavior in Aged Composite Laminates," *Journal of Thermoplastic Composite Materials,* Vol. 11, pp. 124-132, March 1998.

Klug, J., and Sun, C. T., "Large Deflection Effects on Cracked Aluminum Plates Repaired with Bonded Composites Patches," *Journal of Composite Structures*, Vol. 42, pp. 291-296, 1998.

Zhu, C. M., and Sun, C. T., "Micromechanical Characterization of Cyclic Plasticity of IM7/5260 Composite at Various Temperatures," *Journal of Reinforced Plastics and Composites,* Vol. 17, No. 3, pp. 184-204, 1998.

Lena, M. R., Klug, J., and Sun, C. T., "Composite Patches as Reinforcements and Crack Arrestors in Aircraft Structures," *Journal of Aircraft,* Vol. 35, No. 2, pp. 318-324, March-April 1998.

Qian, W., and Sun, C. T., "Methods for Calculating Stress Intensity Factors for Interfacial Cracks Between Two Orthotropic Solids," *International Journal of Solids and Structures,* 297, Vol. 35, No. 25, pp. 3317-3330, 1998.

Weeks, C. A., and Sun, C. T., "Modeling Nonlinear Rate Dependent Behavior in Figer Reinforced Composites," *Composites Science and Technology*, Vol. 58, pp. 603-611, 1998.

Wu, P. S., and Sun, C. T., "Modeling Bearing Failure Initiation in Pin-Contact of Composite Laminates," *Mechanics of Materials,* Vol. 29, pp. 325-335, 1998.

Sun, C. T., and Tao, J. X., "Prediction of Failure Envelopes and Stress/Strain Behavior of Composite Laminates," *Composites Science and Technology*, Vol. 58, pp. 1125-1136, 1998.

Thiruppukuzhi, S., and Sun, C. T., "Testing and Modeling High Strain Rate Behavior of Polymeric Composites," *Composites Part B,* Vol. 29B, pp. 535-546, 1998.

Tao, J. X., and Sun, C. T., "Influence of Ply Orientation on Delamination in Composite Laminates," *Journal of Composite Materials,* Vol. 32, No. 1, pp. 1933-1947, 1998.

Guo, C., and Sun, C. T., "Dynamic Mode I Crack Propagation in a Carbon/Epoxy Composite," *Composites Science and Technology,* Vol. 58, No. 9, pp. 1405-1410, 1998.

Wu, P. S., and Sun, C. T., "Bearing Failure in Pin Contact of Composites," *AIAA Journal,* Vol. 36, No. 11, pp. 2124-2129, Nov. 1998.

Qian, W., and Sun, C. T., "A Frictional Interfacial Crack Under Combined Shear and Compression," *Composites Science and Technology,* Vol. 58, pp. 1753-1761, 1998.

Book

Sun, C. T., Mechanics of Aircraft Structures, John Wiley & Sons, New York, NY, 1998.

Conference Proceedings, Presentations, Invited Lectures and Reports

Beaumont, M., Sun, C. T., and Li, H. H., "Multiaxial Creep Behavior of Indalloy 227," *Proceedings of the 6th Intersociety on Thermal and Thermomechanical Phenomena in Electronic Systems ITHERM 1998,* Seattle, WA, pp. 201-204, May 27-30, 1998.

Sun, C. T., "Analysis of Interfacial and Delamination Cracks," *Proceedings of the First Korea-U. S. Seminar on Composite Materials,* Seoul National University, Seoul, Korea, pp. 185-195, Sept. 7-11, 1998.

Yang, Z., and Sun, C. T., and Wang, J., "Fracture Mode Separation for Delamination Cracks in Plate-like Composite Structures," *Proceedings of the 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Long Beach, CA, pp. 2666-2676, Apr. 20-23, 1998.

Sun, C. T., "Testing and Modeling of Inelastic Behavior in Polymeric Composites," in Mechanics of Composite Materials, ed. by C. A. Mota Soares, C. M. Mota Soares, and M. J. M. Freitas, *Proceedings of the NATO Advanced Study Institute*, Tro′ia, Portugal, pp. 181-192, July 12-24, 1998.

Sun, C. T., Characterization of Strain Rate-Dependent Behavior in Polymeric Composites," in Mechanics of Composite Materials, ed. by C. A. Mota Soares, C. M. Mota Soares, and M. J. M. Freitas, *Proceedings of the NATO Advanced Study Institute*, Tro′ia, Portugal, pp. 183-202, July 12-24, 1998.

Sun, C. T., and Qian, W., "A Treatment of Interfacial Cracks in the Presence of Friction," in Mechanics of Composite Materials, ed. by C. A. Mota Soares, C. M. Mota Soares, and M. J. M. Freitas, *Proceedings of the NATO Advanced Study Institute*, Tro′ia, Portugal, pp. 203-224, July 12-24, 1998.

Hasebe, R. S., and Sun, C. T., "Performance of Sandwich Structures with Composite Face Sheets and Composited Reinforced Core," *Proceedings of the 13th Annual American Society for Composites Technical Conference on Composite Materials,* Baltimore, MD, pp. 1797-1809, Sept. 21-23, 1998.

Ninan, L., and Sun, C. T., "High Strain Rate Characterization of Off-axis Composites Using Split Hopkinson Pressure Bar," *Proceedings of the 13th Annual American Society for Composites Technical Conference on Composite Materials,* Baltimore, MD, pp. 1732-1745, Sept. 21-23, 1998.

Sun, C. T., and Kim, W. D., "Stress Recovery Behavior of a Polymeric Composite During Unloading," (abstract only), *13th U. S. National Congress of Applied Mechanics,* Gainesville, FL, June 21-26, 1998.

Kwon, S. W., and Sun, C. T., "Characteristics of 3-D Stress Field in Cracked Flat Plates," (abstract only), *13th U. S. National Congress of Applied Mechanics,* Gainesville, FL, June 21-26, 1998.

Sun, C. T., and Tsai, J., "Mixed Mode Dynamic Delamination Crack Propagation in Polymeric Composites," (abstract only), *13th U. S. National Congress of Applied Mechanics,* Gainesville, FL, June 21-26, 1998.

Sun, C. T., and Jiang, L. Z., "Domain Switching Induced Stress at the Tip of a Crack in Piezoceramics," *Proceedings of the 4th European Conference on Smart Structures and Materials,* Harrogate, UK, pp. 715-722, July 6-8, 1998.

Sun, C. T., "Interfacial Cracks in the Presence of Friction," (abstract only), *The TMS (The Minerals, Metals, and Materials Society) Fall Meeting '98,* Chicago, IL, Oct. 11-15, 1998.

Sun, C. T., and Zhu, C., "Effect of Deformation-Induced Change of Fiber Orientation on Nonlinear Behavior of Polymeric Composite Laminates," *1998 International Mechanical Engineering Congress and Exposition*, Annaheim, CA, Nov. 15-20, 1998.

Sun, C. T., Adams, D. S., and Han, C., "Behavior of Brittle Materials in the Presence of Confinement and Prestresses," *Proceedings of the 3rd International Symposium on Impact Engineering*, Singapore, Dec. 7-9, 1998.

TERRENCE A. WEISSHAAR
1980
Professor

Degrees

B.S., (highest distinction), Northwestern University, Mechanical Engineering, 1965
S.M., Massachusetts Institute of Technology, Aeronautics & Astronautics, 1966
Ph.D., Stanford University, Aeronautics & Astronautics, 1971

Interests

Aircraft structural mechanics
Aeroelasticity
Integrated Design

Research Areas

Primary research areas include optimization of structural concepts for smart aeroelastic structures and efficient multidisciplinary design. Currently, two primary areas are of interest:

- *Aeroelastic tailoring and active flexible wings.* This includes using conventional articulated surfaces such as ailerons and leading edge devices for roll control, as well as using smart materials to change the camber of advanced wing concepts for aircraft control. Objectives also include aeroelastic design for reduced drag and optimization of smart wing flutter suppression systems for micro-air vehicles. We are also developing innovative techniques with advanced composite structure design to find optimal designs and reduce time to develop new concepts.

- *Design methodology. - developing new methods and algorithms to improve the ability of a design team to generate innovative, creative concepts for aerospace vehicles.* This includes examining how the external aerodynamic and internal structural topology of lifting surfaces can be addressed simultaneously in the design process. This also includes introducing manufacturing concerns and decisions early in the design process and creating, through the early use of finite element models, more feed-forward/feed-back paths.

We have been examining how to use new modeling software to generate and present accurate, useful information to designers by displaying load paths and theoretically optimal designs. This leads to an improved conceptual design process for airplane structures that begins with a few participants and quickly proceeds to a high level with diverse technical groups represented. We are involved in the creation of an object-oriented system, using Adaptive Modeling Language (AML), to provide a natural, integrated, virtual environment for modeling, linking and simulating the aircraft design process from its earliest conceptual phase into preliminary design. When completed, this system will allow an integrated product team access to a virtual environment that scientifically simulates the iterative, collaborative process required to design an airplane in a short amount of time.

Conference Proceedings, Presentations, Invited Lectures and Reports

Weisshaar, T. A., Nam, C. H., and Batista-Rodrigues, A., "Aeroelastic Tailoring for Improved UAV Performance," *39th AIAA/ASME Structures, Structural Dynamics and Materials Conference,* Long Beach, CA, Apr. 1998.

Blair, M., Hill, S., Taylor, R., and Weisshaar, T. A., "Rapid Modeling with Innovative Structural Concepts," *39th AIAA/ASME Structures, Structural Dynamics & Materials Conference,* Long Beach, CA, April 1998.

Komarov, V., and Weisshaar, T. A., "Aircraft Structural Design – Improving Conceptual Design Fidelity," AIAA paper 98-4885, St. Louis, MO, Sept. 1998.

Weisshaar, T. A., "Breakthrough Technologies and Long Term Research Goals in Aeronautics and Space Transportation," National Research Council, 1998, (prepared for NASA, T. Weisshaar prepared section of structures, materials and design methods).

Weisshaar, T. A., "The Air Force Roadmap to an Increased Presence in Space," U. S. Air Force Scientific Advisory Board, Dec. 1998 (T. Weisshaar authored sections on Expendable Launch Vehicle Requirements and Funding as well as a section on long term materials needs).

ACTIVE RESEARCH PROJECTS
JULY 1, 1998 to JUNE 30, 1999

RESEARCH AND OTHER SCHOLARLY ACTIVITIES

In the areas of Aerodynamics, Dynamics and Controls, Propulsion, and Structures and Materials, $4.1 million in expenditures were realized between July 1, 1998 and June 30, 1999.
These expenditures represent significant funding from Boeing, GE Aircraft Engines, United Technologies, Alcoa, Raytheon, Cummins, Caterpillar, Lockheed Martin, Ball Aerospace, Procter & Gamble, Physical Acoustics and Advanced Refractory Technologies indicating that industry is developing greater appreciation for the School's research. For the first time, the School organized a research day to establish interaction with Rolls-Royce Allison. Industry day will be held on October 1, 1999 as an opportunity to continue increasing research interactions with industry.

The externally funded research for the 1998-99 year was obtained from the following sources.

SOURCE OF SPONSORED RESEARCH FOR 1998-1999	
Source	**Percentage of Total**
Department of Defense	42%
NASA	29%
National Science Foundation	18%
Industrial	9%
Other	2%
Total	100.0%

SPONSORED RESEARCH PROJECTS
ACTIVE DURING THE PERIOD JULY 1, 1998 TO JUNE 30, 1999

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
NASA	Indiana Space Grant Consortium Program Grant	03/01/91-02/28/01	$1,634,500	Andrisani
Res. & Dev. Labs	Validation of a Large Eddy Simulation Code & Development of Commuting Filters for LES	01/01/98-06/30/99	$25,000	Blaisdell
Sceee Services Corp.	National Defense Science & Engineering Grad. Fellowship	08/01/98-07/31/99	$22,795	Blaisdell
NASA	High Reynolds Number Experiments on Bypass Duct and Strut Flows	07/14/95-10/31/99	$288,441	Collicott Co-PI: Sullivan
NSF	Career: Experimental Investigation of the Internal Structures in Atomizing Orifice Flows	08/01/95-07/31/00	$341,678	Collicott
United Technologies	United Technologies/Pratt & Whitney	04/01/95-12/31/75	$18,000	Collicott
Cummins Engine	NSF Matching	01/01/97-12/31/99	$50,000	Collicott
Allied Signal	Special Progams	05/01/98-12/31/75	$2,800	Collicott
NASA	Indiana Space Grant Consortium	06/01/98-05/31/99	$5,305	Collicott
NSF	A Proposal to Establish an Engineering Research Center for Collaborative Manufacturing	10/1/95-09/30/99	$17,869	Corless
Boeing	Adaptive Control of Milling Machines: Stability Analysis	04/01/98-06/30/99	$34,569	Corless
NSF	A Proposal to Establish an Engineering Research Center for Collaborative Manufacturing	10/1/97 09/30/98	$19,954	Crossley
NASA	Topology Design of Rotor Blades for Aerodynamic and Structural Consideration	07/01/97-06/30/00	$66,000	Crossley
NASA	Genetic Algorithm Approaches for Actuator Placement	12/09/98-12/31/99	$20,581	Crossley
NASA	Improved Aircraft Conceptual Design Using A Genetic Algorithm Based Approach	07/01/98-06/30/99	$32,000	Crossley
ONR	An Experimental Computational Investigation of Inelasticity in Nanostructured and Layered Materials	06/01/97-05/30/00	$337,000	Espinosa
NSF	Tribo-Mechanics of Nanostructured Materials	07/01/96-06/30/00	$280,000	Espinosa
Raytheon	Elastic Property Identification of a Mems Switch	07/01/98-06/30/99	$25,000	Espinosa
AFOSR	An Investigation on High Temperature Behavior of Laminate and Nanostructured Composite Materials	10/15/97-10/14/99	$198,219	Espinosa
NSF	Effect of Grain Size, Second Phases and Texture in the Dynamic Failure of Ceramics	09/15/95-08/31/99	$150,293	Espinosa

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
AFOSR	Instrumentation for Full Field Measurement with Nanosecond Resolution	04/01/97-12/31/98	$312,288	Espinosa
Univ. Dayton Res. Inst.	Advanced High Cycle Fatigue Life Assurance Methodologies	04/01/99-03/31/00	$60,210	Farris (Co-P.I. Grandt)
Advanced Refractory Tech. Inc.	The Effect of Processing on Mechanical Properties Fiber Reinforced Aluminum Alloys	01/01/99-12/31/99	$50,000	Farris
ARO	National Defense Science & Engrg. Graduate Fellow	08/1/94 - 08/31/98	$96,354	Farris
NSF	A Proposal to Establish an Engineering Research Center for Collaborative Manufacturing	09/01/97 – 09/30/99	$497,360	Farris
GE Aircraft Engines	Fretting Fatigue Feature Testing	03/15/97-12/14/98	$75,394	Farris
NSF	Use of Polishing Process Model as an Example for Manufacturing System Design	09/15/97-08/31/00	$194,801	Chandrasekar (Co-P.I. Farris, Compton)
Univ. Dayton Res. Inst.	Fretting Fatigue of Flat, Titanium Surfaces	03/01/98-06/30/99	$203,000	Farris (Co-P.I. Grandt)
GE Aircraft Engines	Titanium Fretting Fatigue Life Modeling	03/15/98-12/15/98	$30,000	Farris
GE Aircraft Engines	Forward Outer Seal/Rabbet Edge-of-Contact Testing	06/01/98-12/31/99	$74,675	Farris
Cummins	Mapping of a Residual Stress	10/01/97-09/30/98	$22,317	Farris
Caterpillar	Process Performance Model for Hard Turning	01/15/97-12/31/98	$91,713	Chandrasekar (Co-P.I: Farris)
NASA	New H_2 / H_∞ Control Synthesis for the F-18	07/01/95-07/31/98	$47,650	Frazho
AFOSR	Analysis of Widespread Fatigue Damage in Aircraft Structures	02/15/98-11/30/98	$210,000	Grandt (Farris, Hillberry, Co-P.I.'s)
Lockheed Martin	Crack Coalescence Analysis Methods Development	01/01/97-12/31/98	$66,947	Grandt
ALCOA	Durability of Aircraft Joints	06/01/99-12/31/01	$210,000	Grandt
AFOSR	Modeling Dense Sprays in Liquid Rocket Engines	01/01/99-10/31/99	$79,905	Heister
Procter & Gamble	Electrostatic Atomization Research	04/25/97-99/99/99	$46,385	Sojka (Heister, Co-P.I.)
KB Sciences /Ballistic Missile Defense	Advanced, Non-toxic, Divert and Boost Bipropellant Rocket Thrusters Using Hypergolic Miscible Liquid Propellants	07/26/98-5/31/99	$15,000	Heister

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
AFOSR	Modeling Primary Atomization Processes	07/01/96-11/30/98	$211,552	Heister
IBM	Nonlinear Modeling of Droplet Atomization Processes	08/01/96-7/31/98	$25,000	Heister
ARO	Modeling Diesel Engine Injector Flows	05/20/98-02/14/00	$105,000	Heister Co-PI: Blaisdell
Allied-Signal	Special Program	05/01/98-12/31/75	$2,000	Heister
NASA	Trajectory Design Strategies for Libration Point Missions that Incorporate Invariant Manifolds	08/01/96-07/31/99	$66,000	Howell
NASA	Dynamic Systems Theory, Numerical Methods, Optimization Strategies and their Application to Trajectory Design and Mission Analysis Involving Lissajous and Halo Orbits	08/01/98-07/31/99	$100,189	Howell
NASA	Application of Dynamical Systems Theory to the Design and Development of Spacecraft Trajectories	08/19/96-08/19/98	$125,000	Howell
JPL	Analysis of Transfer Trajectories from Earth to Sun-Earth L_2 Lissajous Orbits	05/01/95-09/30/99	$179,445	Howell
NASA	Indiana Space Grant	06/01/98 – 05/31/99	$3,682	Longuski
NASA	Theory of Maneuvers for Small Autonomous Spacecraft	08/15/97-08/14/99	$44,000	Longuski
JPL/NASA	Low-Thrust and Gravity-Assist Trajectory Design for Planetary Missions	11/03/97-12/31/99	$125,000	Longuski
NASA	On the Development of Supersonic Jet Noise Prediction Methodology	11/25/97-11/24/99	$68,105	Lyrintzis Co-PI: Blaisdell
NSF	National Science Foundation Young Investigator Award	10/01/93-03/01/00	$295,000	Rotea
United Tech. Research Ctr.	Robust Control Analysis and Synthesis	09/01/98-99/99/99	$37,500	Rotea
AFOSR	Laminar-Turbulent Transition in Hypersonic Boundary Layers: Development of a High-Reynolds Number Mach-6 Quiet-Flow Testing	03/01/98-11/30/99	$206,600	Schneider
AFOSR	Laminar-Turbulent Transition in High-Speed Compressible Boundary Layers: Continuation of Elliptic-Cone Research	11/15/96-11/14/99	$349,378	Schneider Co-PI: Collicott
NASA	Boundary-layer Transition Detection in Cryogenic Wind Tunnel using Fluorescent Paints	01/23/96-01/31/99	$153,758	Sullivan
NASA	Pressure and Temperature Measurement of Rotating Machinery Using Flourescent Paints	04/16/96-10/15/99	$225,000	Sullivan

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
NASA	Laser Spot Heating System for Transition Detection in Cyrogenic Wind Tunnels	07/01/98-06/30/00	$100,000	Sullivan
Raytheon	Pressure and Temperature Paint Systems for Flight Testing	07/01/98-06/30/00	$133,000	Sullivan
NASA	Pressure and Temperature Sensitive Paint Measurements on Rotors	05/01/97-04/30/99	$40,000	Sullivan
Boeing	Pressure and Temperature Paint Laser Scanning System	05/01/97-12/31/99	$85,428	Sullivan
ARO	Lightweight Layered Materials/Structures for Damage Tolerant Armor	09/01/96-11/30/99	$1,489,348	Sun (Co-PI's: Doyle, Espinosa)
ONR	Dynamic Constitutive and Failure Modeling of Composite Materials and Structures	02/01/96-09/30/99	$454,720	Sun
NSF	Design, Analysis, and Manufacture of Connectors Joining Components of Advanced Composite Materials	07/15/98-05/30/99	$101,000	Sun
NSF	Fracture and Fatigue of Piezoceramics Under Combined Mechanical and Electrical Loading	09/15/98-08/31/01	$272,727	Sun
Univ. California	Testing and Modeling of Strain-Rate Dependent Constitutive Properties of Composite Fan Blade	10/01/96-10/31/98	$50,000	Sun
ONR	Development of Lightweight Multi-Core Composite Structures for Surface Ship Hull Applications	06/01/97-12/31/99	$100,440	Sun
McDonnell Douglas	Viscoplastic Modeling for HSCT Candidate Composite Materials	06/15/95-09/03/00	$163,214	Sun
Tuskegee Univ./NSF	Interlaminar and Compressive Properties of Composites – A Subcontract to Tuskegee Univ. for the Establishment of a Center for Innovative Manufacturing of High Performance Composite Materials	09/01/97-08/3199	$80,808	Sun
AFOSR	Characterizing and Modeling Physical Aging in Polymeric Composites	12/0197-11/30/99	$188,635	Sun
AFOSR	Modeling and Lowering Residual Stresses in Bonded Composite Patch Repairs of Metallic Aircraft Structures	02/01/98-10/31/99	$82,498	Sun
Ball Aerospace	Testing and Analyzing Mixed Mode Fracture of Steel Tubular Steel Structures	07/15/98-12/31/98	$45,000	Sun
Air Force Res. Lab	Intergovernmental Personnel Act with Wright Patterson Air Force Base	05/17/99-07/30/99	$126.057	Weisshaar
Boeing	A Proposal to Investigate the Active Flexible Wing Concept for Design of Light-Weight Advanced Concept Structures	12/16/97-09/15/98	$45,302	Weisshaar
Raytheon	Structural Optimization for Low Cost Manufacturing	07/01/98-06/30/00	$133,000	Weisshaar
Technosoft	Air Vehicle Technology Modeling and Simulation	01/01/99-12/31/99	$50,000	Weisshaar

GRADUATE THESES
JULY 1998- JUNE 1999

MASTER'S THESES

Student/ ***Major Professor***	**Thesis Title**	**Degree Date Granted**
Erqausquin, Richard *J. P. Sullivan*	"Cyrogenic Temperature and Pressure-Sensitive Fluorescent Paints"	M. S. December 1998
Green, Stephen *A. F. Grandt, Jr.*	"Crack Coalescence Analysis Methods Development"	M. S. December 1998
Hasebe, Ryoichi Sergio *C. T. Sun*	"Performance of Sandwich Structures with Composite Reinforced Core"	M. S. December 1998
Hua, Yuan *C. T. Sun*	"Effective Crack Growth Model and Pseudo Three Dimensional Analysis of Composite Laminates"	M. S. May 1999
Jones, Brian R. *W. A. Crossley* *A. S. Lyrintzis*	"Aerodynamic and Aeroacoustic Optimization of Rotor Airfoils Via Parallel Genetic Algorithm"	M. S. December 1998
Kompella, Sridhar *T. N. Farris*	"Techniques for Rapid Characterization of Grinding Wheel-Workpiece Combinations"	M. S. August 1998
Ninan, Lal *C. T. Sun*	"High Strain Rate Characterization of Off-Axis Composites Using Split Hopkinson Pressure Bar"	M. S. May 1999
Norris, Stephen *D. Andrisani, II*	"Longitudinal Equilibrium Solutions for a Towed Aircraft"	M. S. August 1998
Patanella, Alejandro *H. D. Espinosa*	"A Novel Experimental Technique for Dynamic Friction Studies"	M. S. December 1998
Reimann, William J. *T. N. Farris*	"Three Dimensional Form Generation During Infeed Centerless Grinding"	M. S. August 1998
Roeder, Blayne A. *C. T. Sun*	"Impact of Thermally Confined Alumina/Aluminum Laminates: Experiments and Modeling"	M. S. May 1999
Sanchez, Paul K. *S. H. Collicott*	"Rigorous Investigation of Cavitation of a 2-D Slot Orifice"	M. S. May 1999

Tsai, Jia-Lin *C. T. Sun*	"Dynamic Delamination Crack Propagation in Polymeric Composites"	M. S. December 1998
Vandenboom, Michael *S. D. Heister*	"A Thermostructural Analysis of a Lined Composite Rocket Nozzle"	M. S. December 1998

DOCTORAL THESES

Student/ ***Major Professor***	**Thesis Title**	**Degree** **Date Granted**
Chang, Shih-Hsiang *T. N. Farris*	"Basic Study of Superfinishing of Hardened Steels"	Ph.D. December 1998
Chao, Chien-Chi *S. D. Heister*	"Boundary Element Modeling of 2-D and 3-D Atomization"	Ph.D. May 1999
Ladoon, Dale *S. P. Schneider*	"Wave Packets Generated by a Surface Glow Discharge on a Cone at Mach 4"	Ph.D. December 1998
Lu, Hung Cheng ***H. D. Espinosa***	"Ballistic Penetration of GRP Composites: Identification of Failure Mechanisms and Modeling"	Ph.D. December 1998
Qin, Jim Hongxin *G. A. Blaisdell*	"Numerical Simulations of a Turbulent Axial Vortex"	Ph.D. December 1998
Szolwinski, Matthew *T. N. Farris*	"The Effect of Manufacturing Process Parameters on Fretting Fatigue in Riveted Lap Joint Structure"	Ph.D. August 1998
Spyropoulos, John T. *A. S. Lyrintzis*	"A New Scheme for the Navier-Stokes Equations Employing Alternating-Direction Operator Splitting and Domain Decomposition"	Ph.D. May 1999
Sultan, Cornel *M. J. Corless*	"Modeling, Design, and Control Tensegrity Structures with Applications"	Ph.D. May 1999
Wang, Hsing-Ling *A. F. Grandt, Jr.*	"Evaluation of Multiple Site Damage in Lap Joint Specimens"	Ph.D. December 1998
Wilson, Roby S. *K. C. Howell*	"Trajectory Design Using Multiple Lunar Gravity Assists"	Ph.D. December 1998
Yen, Chih-Chieh *N. Messersmith*	"Investigation of Axisymmetric Jet Instabilities and Acoustic Radiation"	Ph.D. December 1998

Colloquium Series
1998 - 1999

Colloquium Series - Fall 1998

DATE/TIME	TOPIC	SPEAKER
August 26, 1998	Hypersonic Boundary Layer Transition	**Mr. Ken Stetson** Retired from Air Force Wright Aeronautical Lab
September 4, 1998	Fracture Mechanics of Bonded Repairs to Aircraft	**Dr. L. R. Francis Rose** Aeronautical & Maritime Res. Lab Melbourne, Australia
September 24, 1998 Dept.	Active Control of Cavity Flows Using Pulsed Jet Actuators	**Dr. Ndaona Chokani** Mechanical & Aerospace Engrg. North Carolina State Univ.
*September 25, 1998	The Level Set Method for Multiphase Flow	**Professor Stanley Osher** UCLA
October 22, 1998	Smart Materials and Adaptive Aerostructures	**Professor Ron Barrett** Auburn University
October 29, 1998	Where is the Air Force Going in Space?	**Dr. Dan Hastings** Chief Scientist USAF Washington, DC
November 5, 1998 Programs	Innovative Space Concepts for the Future	**Mr. Iven Bekey** Former Director-Advanced NASA Office of Space Flight
*November 6, 1998 Jr. Processing of Technology Tech	Length Scales and Evolution of Structure in Solids	**Professor David McDowell** Regents' Prof. & Carter N. Paden, Distinguished Chair in Metals Georgia Institute
December 1, 1998	Topics in Satellite Contamination: Simulation and Analysis	**Dr. Michael Woronowicz** Swales Aerospace
December 3, 1998	The "Tuned Absorber" in Compressor Rotors	**Dr. Sriram Srinivasan** Pratt & Whitney

____

*Midwest Mechanics Seminar, co-sponsored by the Schools of Aeronautics and Astronautics and Mechanical Engineering Departments

Colloquium Series - Spring 1999

DATE/TIME	TOPIC	SPEAKER
January 22, 1999	Imperfections, Fatigue and Symmetry Arguments in Jet Engines	**Mr. Benjamin Shapiro** California Institute of Technology
**January 27, 1999	Full-scale Static and Durability Testing of the Boeing 777 Airframe	**Mr. Art Braun** MTS Systems Corporation
*February 19, 1999	Micromechanics of Particle-Toughened Thermoplastics	**Professor David Parks** Massachusetts Institute of Technology
March 4, 1999	Biefield Brown Effect	**Mr. Hector Luis Serrano** President, Gravitech and Fusion Tech., Inc.
March 29, 1999	ASUS at Lab: Student Projects	**Dr. Helen Reed** Mechanical & Aerospace Engrg. Arizona State University
April 8, 1999	The Evolution of Fighter Aircraft	**Dr. Richard Bradley, Jr.** Former Director Lockheed Martin Tactical Aircraft Systems
*April 2, 1999	MEMS and Micro Fluid Dynamics	**Dr. Chih-Ming Ho** Ben Rich/Lockheed Martin Professor Mechanical & Aerospace Engrg. UCLA
April 21, 1999	Noise Abatement System	**Mr. James Raisbeck** Chief Executive Officer Raisbeck Engineering
April 22, 1999	Shaping the Role of Air Power for the 21st Century	**Mrs. Natalie W. Crawford** Vice Pres. & Director, Project Air Force Rand Corporation, and Co-chair U.S.A.F. Scientific Advisory Board
*April 23, 1999	Dynamic Shear-Dominated Intersonic and Supersonic Crack	**Professor Ares J. Rosakis** California Institute of Technology
April 29, 1999	Unsteady Disturbances in Annual Swirling Flows	**Dr. Hafiz M. Atassi** University of Notre Dame

*Midwest Mechanics Seminar, co-sponsored by the School of Aeronautics & Astronautics and the Mechanical Engineering Departments

**Co-sponsored seminar by the School of Aeronautics & Astronautics and the Student Chapter of the American Society for Testing Materials

FACULTY HIGHLIGHTS

Professor Thomas Farris assumed the role as Head of the School of Aeronautics and Astronautics on July 1, 1998, while Professor Marc Williams was named Associate Head of the School. Professor John Rusek joined the propulsion group and comes with more than 10 years of experience in industry and more than 10 years of experience in government.

Other highlights include:

- Professor William Crossley was named the recipient of the W. A. Gustafson Teaching Award
- Professor James Doyle was awarded the prestigious Hetenyi award by SEM
- Professor Horacio Espinosa spent the academic year on sabbatical at Harvard University
- Professor Thomas Farris was awarded the ASME/Boeing Structures and Materials Award
- Professor Kathleen Howell was named to the Purdue's Teacher Wall of Fame
- Professor Stephen Heister was promoted to full professor, received the Elmer F. Bruhn Teaching Award, and was named a University Faculty Scholar
- Professor Lyrintzis spent part of summer '99 at NASA Glenn Research Center (at Cleveland)
- Professor C. T. Sun was named to the Purdue's Teacher Wall of Fame
- Professor Terrence Weisshaar received the USAF Decoration for Exceptional Civilian Service award for serving on the Scientific Advisory Board

STUDENT HIGHLIGHTS

There are five student organizations with a relationship with our School. They are the Aeronautics and Astronautics Engineering Student Advisory Council (AAESAC), American Helicopter Society (AHS), American Institute of Aeronautics and Astronautics (AIAA), Students for the Exploration and Development of Space (SEDS), and Sigma Gamma Tau (SGT) Highlights from the organizations for this past academic year include the establishment of AAESAC, whose goal is to facilitate communication between the students, faculty, and administrators of the School. AIAA, SGT, and SEDS worked on the third Annual Fall Space Day. Additionally, SEDS hosted their annual Open Forum Discussion. SGT hosted "Professor Pizzas," an opportunity for students to interact one-on-one with an AAE professor, and also organized the AAE Fall Banquet.

ALUMNI HIGHLIGHTS

Alumni Relations

The School continued hosting new graduate receptions for its December and May graduates. Also, during Homecoming and Gala Weekend we hosted "Breakfast with the Professors." Additionally, an alumni reception in St. Louis, Missouri, was held in March during the AIAA Structures and Materials Conference. The School newsletter, now in its third consecutive year, was published in the summer and in the winter. This continues to be the best source we have for communicating regularly with all our alumni.

The proposed establishment of the Outstanding Aerospace Engineer award to acknowledge the achievements of our alumni was approved by President Beering. The inaugural OAE event will be held October 21, 1999. Additionally, President Beering appointed the School to be the Administrator of the William E. Boeing Lecture Series. The inaugural lecture will be on September 30, 1999. Mr. Mike Sears, Vice President, The Boeing Company, and President of the Military Aircraft and Missile Systems Group is the guest lecturer.

OUTREACH HIGHLIGHTS

In its third year, Fall Space Day '99 was a rousing success with more than 200 third through eighth graders, and 50 plus teachers and chaperones. Astronaut Mark Brown was the featured speaker. Additionally, the children participated in many interactive lessons, which reinforced basic science and math principles. Students for the Exploration and Development of Space and students in the American Institute of Aeronautics and Astronautics and Sigma Gamma Tau supported this project.

The Indiana Space Grant Consortium, now in its 10th year, has 13 affiliates. IUPUI and the Lafayette Imagination Station are the newest members. The affiliates of ISGC reflect community, education, government, and industry involvement in the space program. Some highlights of activities of the ISGC for this academic year include sponsoring the second annual Indiana Aerospace Symposium at Rose Hulman Institute of Technology, the creation of an advisory, awarding two fellowships for graduate study at Purdue, sending three Indiana students to the NASA Academies, and funding five mini-grant proposals to faculty and students at Purdue.

CURRICULUM & COURSE OFFERINGS

190-Introduction to Aerospace Engineering

Math | Chemistry | Physics | Communications | Economics | Liberal Arts

Thermodynamics | Electrical Circuits | Computer Skills/Programming

251-Introduction to Aerospace Design			
Aerodynamics	*Dynamics and Control*	*Propulsion*	*Structures and Materials*
Required Undergraduate			
333-Fluid Mechanics & Lab.	203-Aeromech.I(statics/dyn)	372-Jet Propulsion	204-Aeromech. II (Str of Mat.) & Lab
334-Aerodynamics and Lab	340-Dynamics and Vibrations 421-Flight Dynamics & Lab 464-Control System Analysis		352-Structural Analysis & Lab
Undergraduate Electives			
412-Intro to CFD 414-Compressible Aero 416-Viscous Flows 490G-Low Gravity Exp.	361-Intro to Random Variables 474-Exp. Flight Mechs.	439-Rocket Propulsion	453-Matrix Methods in Structure
Design Electives			
415-Aerodynamic Design	490r-Control Systems Design	490p- Propulsion Design	454 Design of Aerospace Structure

451-Capstone Design (Aircraft or Spacecraft)			
Undergraduate/ Graduate Electives			
511-Intro. to Fluid Mech. 512-Computational Aero	507-Principles of Dynamics 508-Optimization in Aero. Eng.	538-Air Breathing Propulsion 539-Adv. Rocket Propulsion	546-Aero. Structural Dyn. & Stability 547-Experimental Stress Anal.
513-Transonic Aero. 514-Intermediate Aerodynamics	531-Flight Mechanics 532-Orbit Mechanics		552-Nondestructive Eval. of Str.&Matrl. 553-Elasticity in Aero. Eng
515-Rotorcraft Aerodynamics 517-Unsteady Aerodynamics 518-Low Gravity Fluid Mech. 519-Satellite Aerodyn. & Planet. Entry 520-Experimental Aerodynamics	540-Spacecraft Attitude Dyn. 564-Systems Anal. and Control 565-Guid. & Contrl. Aerosp. Veh 567-Intro to Stochastic Proc. 574-Digital Flight Control Sys.		554-Fatigue in Struct. and Mat. 555-Mech. of Composite Mat. 556-Aeroelasticity 558-Finite Element Meth. Aero. Struct. 559-Mech. of Friction & Wear 590e-Damage & Elas. In Adv Mat. 590f-Multidisciplinary Design Opt.
Graduate Electives		603 -Theoretical Methods	
611-Principles of Fluid Mech. 613-Viscous Flow Theory 615-Aeroacoustics 626-Turbulence & Turbulence Model.	607-Var.Prin. of Mechanics 630-Stability of Free Surfaces 632-Advanced Orbital Dynamics 660-Operator Methods on Crtl. Sup. 664-Uncertain Dyn. Systems 666-Nonlinear Dyn, Systems, Control 684-Design of Dyn.Systems.	630-Stability of Free Surfaces 690a-Future Prop. Conc. 690e- Optimal Trajectories 690g-Astro.Nav.&Guidance 690r-Multi-Feedback Control	646-Elastic Wave Propagation 652-Theory of Plates & Shells 654-Fracture Mech 655-Composite Matrls. & Struct. .
Cooperative Education Courses			
241-Industrial Practice I	341-Industrial Practice III	442-Industrial Practice V	642-Graduate Professional Practice
242-Industrial Practice II	342-Industrial Practice IV 390-Professional Internship		