Purdue University
School of Aeronautics and Astronautics
Research Report

1996-97 Academic Year

Prepared by:

John P. Sullivan
Professor and Head

October 1997

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INTRODUCTION

The School of Aeronautics and Astronautics was established on July 1, 1945, by the Board of Trustees as an independent academic unit. It's mission is to prepare men and women to be leaders in aerospace engineering by providing exceptional educational and research programs. The faculty, students, and staff are committed to honest and ethical professional conduct coupled with a teamwork focus.

The School curriculum centers around four areas of study which include Aerodynamics, Dynamics and Controls, Propulsion, and Structures and Materials. During the 1996-97 academic year, 48 students earned their Bachelor of Science degree, 30 earned Master of Science degrees, and 17 earned Doctor of Philosophy degrees.

This annual report summarizes the School of Aeronautics and Astronautics's activities for the period of July 1, 1996 through June 30, 1997.

ENROLLMENT AND DEGREES AWARDED

The School had 159 undergraduate students (excluding freshmen) beginning the Fall of 1997. Graduate enrollment was 140, with 61 students in the M. S. Program and 79 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 1996-97 academic year are summarized in the Graduate Theses section.

Degrees Awarded School of Aeronautics & Astronautics					
Year	**92-93**	**93-94**	**94-95**	**95-96**	**96-97**
B. S.	97	96	71	78	48
M. S.	45	35	35	36	30
Ph.D.	16	10	13	13	17

INDUSTRY RELATIONS

The Industrial Affiliates Program was supported this year by **The Boeing Company, Hughes Aircraft Company, Lockheed Missiles and Space Company, McDonnell Douglas Corporation, Northrop Grumman, Thiokol Corporation,** and by **TRW**. This is the 15th year for the IAP.

The Industrial Advisory Council, in its second year, continued its bi-annual meeting schedule with a meeting in October and May of this academic year. The challenge given to the Council last year was to help the School with its strategic plan.

Members of the Council include representatives from: **Aerospace Corporation, Allison Advanced Development Systems, Allied Signal, Boeing, Boeing North American**, **Hughes Space and Communications Company, Lockheed Missiles and Space Company, McDonnell Douglas Corporation, Northrop Grumman, Thiokol Corporation,** and **TRW.** **Dr. Donald Lamberson, a retired Major General for the U.S. Air Force** and now a Technical Consultant is also a member.

The **Lockheed Missiles and Space Company and Thiokol Corporation** provided financial support for the School's sophomore and senior design course awards. **Boeing North American**, formerly known as **Rockwell International**, supported a new design competition in Professor Grandt's AAE 490D Design of Aerospace Structures course.

PUBLICATIONS

Listings of books, journal articles, and other printed conference papers and reports published in calendar year 1996 are given in the "Faculty Summary" section of this report. Only documents which actually appeared in print during 1996 are listed. Note that 73 journal articles or book chapters, and 97 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 1996-97 academic year, 32 students were enrolled in the Cooperative Engineering Program with the 10 companies listed below. This popular program is limited only by the number of industry positions available.

Co-Op Companies
School of Aeronautics and Astronautics
July 1, 1996-June 30, 1997

Company	Location	Number of A&AE Co-op Students
Aerospace Corporation	Los Angeles, CA	1
Allison Gas Turbine	Indianapolis, IN	4
Hughes Aircraft Space & Comm.	Los Angeles, CA	2
McDonnell Douglas	St. Louis, MS	4
NASA-Ames-Dryden	Edwards, CA	1
NASA-Johnson Space Center	Houston, TX	6
NASA-Langley Research Center	Hampton, VA	4
Rockwell Defense Electronics	Cedar Rapids, IA	1
Structural Dynamics Research Center	Milford, OH	7
Thiokol Corporation	Ogden, UT	2

FACULTY FOR THE 1996-97 ACADEMIC YEAR

Aerodynamics

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

S. H. Collicott, Associate Professor; Ph.D., Stanford, 1991, experimental fluid mechanics, optical diagnostics, applied optics.

W. A. Gustafson, Professor and Associate Head; Ph.D., Illinois, 1956, hypersonic aerodynamics, spacecraft design.

A. S. Lyrintzis, Associate Professor; Ph.D., Cornell, 1988, computational aeroacoustics, aerodynamics, traffic flow theory.

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

J. P. Sullivan, Professor and Head; Sc.D., MIT, 1973, experimental aerodynamics, laser instrumentation, luminescent sensors for temperature and pressure measurements.

M. H. Williams, Professor; 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, Associate Professor; Ph.D., Stanford, 1983, orbit mechanics, spacecraft dynamics, control; trajectory optimization.

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

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

R. E. Skelton, Professor; Ph.D., UCLA, 1976, dynamics of aerospace vehicles, control theory.

Propulsion

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

N. L. Messersmith, Assistant Professor; Ph.D. Illinois, 1992, airbreathing propulsion, aeroacoustics, optical diagnostics.

Structures & Materials

W. A. Crossley, Assistant Professor; Ph.D., Arizona State, 1995, optimal design methods, genetic algorithms for aerospace applications, aircraft and rotorcraft conceptual design, composite and smart structure design.

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

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

T. N. Farris, Professor, 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, smart materials and structures.

T. A. Weisshaar, Professor; Ph.D., Stanford, 1971, aircraft structural mechanics, aeroelasticity,   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 is also a part owner (through the Concurrent Supercomputing Consortium) of a 512-node Intel Paragon at Caltech. An 18-node IBM SP-2 was also recently installed at Purdue University.

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, each with top of the line graphical hardware. Cluster computing, using single and dual Intel Pentium Pro 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, control and 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 in the dynamics and control area require advanced and specialized laboratory facilities. A helicopter experiment is also available for teaching control. The helicopter consists of the fuselage, the main motor (for pitch control), and the tail motor (for yaw control). The objective is to model, identify, and control the pitch and yaw axis of the helicopter. The helicopter is connected to a MAC IIsi for the purpose of driving the main and tail motors and measuring the pitch and yaw motion. The **Flight Dynamics and Control Laboratory** contains several analog computers with some nonlinear components, X-Y plotters, oscilloscopes, and signal generation devices for studying dynamic systems and evaluating feedback control laws. The **Flight Simulation Laboratory** has fixed-base, digital flight simulation capabilities with force-sensitive manipulators and CRT display for pilot-in-the-loop experiments. The simulations are controlled by a 16-bit microprocessor with a 40-mb hard disk for storing experimental data. Here, pilot/vehicle performance, workload, and vehicle dynamics are studied. An instrumented **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. The **Space Systems Control Laboratory** is located within the Institute of Interdisciplinary Engineering Studies, and involves faculty from the School of Aeronautics and Astronautics, School of Electrical Engineering, School of Mechanical Engineering, the Department of Computer Science, and the Department of Mathematics. The Space Systems Control Laboratory is a national resource for rapid analysis and design of spacecraft control systems.

PROPULSION

There are two broad categories in propulsion research: (1) devices that need air to produce thrust, and (2) devices that do not need air to produce thrust. The first category includes piston engines, turbojet engines, turbofan/propeller engines, and scramjet and ramjet engines. The second category includes various rocket engines. In the past several years, the emphasis in the School of Aeronautics and Astronautics has been on both of these types of propulsion systems.

The Rocket Propulsion Laboratory contains unique facilities for basic research on rocket propulsion. Major equipment includes a hybrid rocket engine test stand which has recently been constructed to investigate combustion and performance of these engines. A large, high pressure air supply is available for air-augmented rocket and ramjet combustion studies. A minicomputer is available for data acquisition/reduction. These facilities are housed in the Thermal Sciences and Propulsion Center.

In addition, propulsion research facilities are also housed in the Aerospace Sciences Laboratory. Facilities have been developed to investigate combustor burn-through in turbojet engines using laser sheet flow visualization, thermal paint fluorescence, and pressure paint fluorescence of a jet impinging at various angles to a plate.

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
Assistant 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

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 effect 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.

Sponsored Research Summaries

Large Eddy Simulation of a Supersonic Boundary Layer (sponsored by Purdue Research Foundation, NASA Langley Research Center, student: Evangelos T. Spyropoulos (Ph.D., graduated Fall 1996)) (Computer Resources: NAS (Cray C90), NASA LaRC (Cray YMP))

Several issues involving the large-eddy simulation (LES) of wall bounded compressible turbulent flows are investigated. A spatially evolving supersonic boundary layer is simulated using a high-order accurate finite difference scheme and the dynamic subgrid-scale model. A parametric study suggests that the finite difference scheme has a detrimental effect on the resolution of the smaller scales due to excessive numerical dissipation from the spatial differencing. Also, since the dynamic model uses the smaller resolved-scale eddies to determine the model coefficients, the predicted coefficients do not have the appropriate values. The use of higher-order schemes is found to better capture the smaller resolved scales and substantially improve the quality of the results. Future work will address the effect of discretization errors on LES.

Related Publications:

Spyropoulos, E. T. and Blaisdell, G. A., “Large-eddy simulation of a spatially evolving compressible boundary layer flow," AIAA Paper 97-0429, presented at the 35th AIAA Aerospace Sciences Meeting, Reno, Nevada, January 6-9, 1997. (Submitted to the AIAA Journal.)

Blaisdell, G. A., Spyropoulos E. T. and Qin, J. H., “The Effect of the Formulation of Nonlinear Terms on Aliasing Errors in Spectral Methods,’’ Applied Numerical Mathematics, Vol. 21, July 1996, pp. 207-219.

Spyropoulos, E. T. and Blaisdell, G. A., “Evaluation of the Dynamic Model for Simulations of Compressible Decaying Isotropic Turbulence,’’ AIAA Journal, Vol. 34, May 1996, pp. 990-998.

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.

Presentations:

“Direct Numerical Simulation of a Turbulent Axial Vortex,’’ seminar given in the Theoretical and Applied Mechanics Department, University of Illinois at Urbana-Champaign, February 27, 1997.

Simulation and Modeling of the Elliptic Streamline Flow - (Collaborator: Karim Shariff (NASA Ames Research Center), sponsored by the Center for Turbulence Research Summer Program (1994/96), and NASA/ASEE Summer Faculty Fellowship Program (1995/96); Computer Resources: PUCC (IBM SP2, Intel Paragon), NAS (IBM SP2, Intel Paragon), CACR (Intel Paragon))

Direct numerical simulations are performed for the elliptic streamline flow, which is a homogeneous turbulent flow that combines the effects of solid body rotation and strain. Simulations are run over a range of parameters in order to determine the effect of changing rotation and strain separately. For early times the nonlinear cascade is suppressed, but then is re-established at later times. The growth rate of turbulent kinetic energy agrees at early times with the trends from linear theory, but at later times the flow seems to approach an asymptotic state that is independent of the ratio of mean flow rotation rate to strain rate. A comparison with standard Reynolds stress turbulence models is made. It is found that for strong rotation rates, the models predict decay of the turbulence, while the simulations show exponential growth. Close examination of the simulation results shows that they are affected by low Reynolds numbers. Higher Reynolds number simulations are underway in order to be able to make a more quantitative evaluation of current turbulence models.

Related Publications:

Blaisdell, G. A. and Shariff, K., “Simulation and modeling of the elliptic streamline flow,’’ Proceedings of the 1996 Center for Turbulence Research Summer Program, Stanford/NASA Ames, pp. 433-446, December 1996.

Speziale, C. G., Abid, R., and Blaisdell, G. A., “On the consistency of Reynolds stress turbulence closures with hydrodynamic stability theory," Phys. Fluids, Vol. 8, pp. 781--788, 1996.

On the Development of Supersonic Jet Noise Prediction Methodology - (Collaborator: Anastasios S. Lyrintzis (Purdue, AAE), Graduate Student: Evangelos K. Koutsavdis; Computer Resources: PUCC (IBM SP2))

A new Computational Aeroacoustics (CAA) methodology for accurate prediction of supersonic jet noise from first principles will be developed. First, a three-dimensional Large Eddy Simulation (LES) code based on the dynamic subgrid scale model will be developed. Then Kirchhoff's method will be employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's 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.

Homogeneous Compressible Turbulence (sponsored by ICASE (Summer Visitor 1997), Collaborator: Ray Ristorcelli (ICASE/NASA LaRC); Computer Resources: PUCC (Intel Paragon))

Direct numerical simulations of compressible homogeneous turbulence are used to study the mechanisms of increased dissipation in compressible turbulence. Results from these simulations have been used to examine compressibility corrections to two-equation and Reynolds stress turbulence models.

Related Publications:

Ristorcelli, R. J., and Blaisdell, G. A., “Validation of a Pseudo-Sound Theory for the Pressure-Dilation in DNS of Compressible Turbulence,” to appear in the proceedings of the 11th Turbulent Shear Flows Symposium, Grenoble, France, September 8-11, 1997.

Ristorcelli, R. J. and Blaisdell, G. A., "Consistent Initial Conditions for the DNS of Compressible Turbulence," Physics of Fluids, Vol. 9, January 1997, pp. 4-6. Also, abstract published in Bulletin of the American Physical Society, Vol. 41, No. 9, p. 1745. Presented at the 49th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Syracuse, New York, Nov. 24-26, 1996.

Other Related Publications:

Hamba, F., and Blaisdell, G. A., “Toward Modeling of Inhomogeneous Compressible Turbulence Using a Two-Scale Statistical Theory,” *Physics of Fluids*, Vol. 9, pp. 2749-2768, September 1997.

Blaisdell, G. A., Coleman, G. N. and Mansour, N. N., "Rapid Distortion Theory for Compressible Homogeneous Turbulence Under Isotropic Mean Strain," Physics of Fluids, Vol. 8, October 1996, pp. 2692-2711.

STEVEN H. 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.

Publications

Collicott, S. H., Bayt, R. L., and Chambers, R., "A Small-Scale Drop-Tower for Low-Gravity Fluids Labs," *International Journal of Engrg. Education,* Vol. 12, No. 1, pp. 51-58, Jan. 1996.

Salyer, T. R. and Collicott, S. H., "Multiple-Source Schlieren System Noise Reduction Measurements," *AIAA Journal*, Vol. 34, No. 11, pp. 2444-2446, Nov. 1996.

Conference Proceedings, Presentations and Invited Lectures

Bayt, R. L., and Collicott, S. H., "Effects of an Elliptic End-Cap on the Ullage Bubble Stability in the Gravity Probe-B Satellite," 34th AIAA Aerospace Meeting, Reno, NV, Number AIAA-96-0596, 11 pages, Jan. 15-18, 1996.

Collicott, S. H., Schneider, S. P., and Messersmith, N. L., "Review of Optical Diagnostic Methods for Hypersonic Low-Noise Ludwieg Tube Facilities," 34th AIAA Aerospace Sciences Meeting, Reno, NV, Number AIAA-96-0851, 11 pages, Jan. 15-18, 1996.

Collicott, S. H., Chen, Y., and Heister, S. D., "Cavitating Slot Flow: 2-D Modeling and Experiments," Institute for Liquid Atomization and Sprays-Americas, San Francisco, CA, 3 pages, May 1996.

Collicott, S. H., "Hybrid Optical and Digital Measurements of Liquid Jets: Drop Sizes, Wave Shapes, and Growth Rates," invited poster presentation, International Find Particle Research Institute Annual Meeting, Champaign, IL, June 13-15, 1996.

W. A. GUSTAFSON

1960

Professor and Associate Head

Degrees

B. S., University of Illinois, Aeronautical Engineering, 1950
M. S., University of Illinois, Aeronautical Engineering, 1954
Ph.D., University of Illinois, Aeronautical Engineering, 1956

Interests

Hypersonic Aerodynamics
Spacecraft design

Current Academic Activities

Professor Gustafson has served as the School's Undergraduate Counselor for all aeronautical and astronautical students since 1981. He advises freshman students entering the School of Aeronautics and Astronautics. He also heads of our Co-op Program, and serves as the Schedule Deputy for our School.

Teaching

Courses taught during the past five years:

A&AE 333 Fluid Mechanics
A&AE 334 Aerodynamics
A&AE 451 Design I (Spacecraft)
A&AE 519 Satellite Aerodynamics and Planetary Entry

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 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 has been 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. The method is currently being extended to supersonically moving sources for HSI noise. 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), on 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 a test 2D problem was found to be very promising. We are currently investigating application of this method for 3-D unsteady Navier Stokes codes used in the prediction of helicopter aerodynamics.

Sponsored Research Summaries

Rotorcraft Impulsive Noise Prediction Using a Rotating Kirchhoff Formulation; Sponsor: Sikorsky Aircraft; Student: E. K. Koutsavdis

Rotorcraft Impulsive (i.e. High-Speed Impulsive (HSI) and Blade-Vortex Interaction (BVI)) noise for an advancing rotor is studied numerically. The unsteady transonic Full-Potential Rotor (FPR) code is used for the simulation of the near-field flow. A rotating Kirchhoff's method is used for the extension to the acoustic far-field. The formulation (Farassat's method) is extended for an advancing rotor and an observer moving with the free stream and allows a direct comparison with experiments. Results for both HSI and BVI noise are presented and compared with experimental results. Various noise parameters are identified and investigated. The rotating Kirchhoff noise has been implemented into the NASA Langley TRAC (Tiltrotor Aeroacoustic codes) system and appears to be a very valuable tool for helicopter impulsive noise prediction.

Relevant Publications:

[1] Lyrintzis, A. S., "Review: The Use of Kirchhoff's Method in Computational Aeroacoustics," *ASME Journal of Fluids Engineering*, Vol. 116, No. 4, Dec. 1994, pp. 665-676.

[2] Xue, Y., and Lyrintzis, A. S., "Rotating Kirchhoff Formulation for 3-D Transonic Blade Vortex Interaction Hover Noise," *AIAA Journal*, Vol. 32, No. 7, July 1994, pp. 1350-1359.

[3] Strawn, R. C., Biswas, R., and Lyrintzis, A. S., "Computation of Helicopter Blade-Vortex Interaction Noise with Kirchhoff Methods," *IMACS Journal of Computational Acoustics*, Vol. 4, No. 3, Sept. 1996, pp. 321-339.

[4] Lyrintzis, A. S., and Koutsavdis, E. K., "Rotorcraft Impulsive Noise Prediction Using a Rotating Kirchhoff Formulation," *AIAA Journal of Aircraft*, Vol. 33, No. 6, Nov-Dec., 1996, pp. 1054-1061.

[5] Lyrintzis, A. S., and Xue, Y., "Towards a Versatile Kirchhoff Code for Aeroacoustic Predictions," *AIAA Journal*, Vol. 35, No. 1, Jan. 1997, pp. 198-200.

[6] Lyrintzis, A. S., Koutsavdis, E. K., and Strawn, R. C., "A Comparison of Computational Aeroacoustic Prediction Methods," *American Helicopter Society Journal*, Vol. 42, No. 1, Jan. 1997, pp. 54-57.

[7] Brentner, K. S., Lyrintzis, A. S., and Koutsavdis, E. K., "A Comparison of Computational Aeroacoustic Prediction Methods for Transonic Rotor Noise," *AIAA Journal of Aircraft* , Vol. 34, No. 4, Jul.-Aug. 1997, pp. 531-538.

[8] Berezin, C., Pollack, M., Visintainer, J., Lyrintzis, A., and Koutsavdis, E., "Development and Practical Application of the Rotating Kirchhoff Method for the Prediction of HSI and BVI Noise," to be presented at the Technical Specialists' Meeting for Rotorcraft Acoustics and Aerodynamics, Williamsburg, VA, Oct. 1997.

[9] Lyrintzis, A., Koutsavdis, E., Berezin, C., Visintainer, J., and Pollack, M., "Kirchhoff Acoustic Methodology Validation and Implementation to TiltRotor Aeroacoustic Codes (TRAC)," *American Helicopter Society Journal*, Vol. 43, No. 1, Jan. 1998 (in press).

An Extended Kirchhoff Method for Rotorcraft Impulsive Noise; Sponsor: ARO; Students: E. K. Koutsavdis, A. R. Pilon

Kirchhoff's method has been employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's method allows radiating sound to be evaluated based on quantities evaluated on an arbitrary control surface, if the linear homogeneous wave equation is assumed outside the control surface. Thus, the control surface is assumed to include all the nonlinear flow effects and noise sources. Kirchhoff's method will be enhanced to include nonlinear quadrupole effects outside the control surface. The control surface can not be very far away from the blade because of the diffusion and dispersion errors of the CFD solution due to grid stretching. Thus some nonlinearities may prevail outside the Kirchhoff surface. Since the current estimate of the nonlinear sources outside the control surface is zero, it is feasible that a better estimate of them can be made, at very little additional computational cost, and possibly significant improvement in the fidelity of the radiated noise prediction. Thus, an extended Kirchhoff method for rotorcraft aeroacoustics that will include nonlinear effects outside the control surface will be developed and validated.

Relevant Publication:

[1] Pilon, A. R., and Lyrintzis, A. S., "Integral Methods for Computational Aeroacoustics," AIAA paper No. 97-0020, presented at the 35th Aerospace Science Meeting, Reno, NV, Jan. 1997.

[2] Lyrintzis, A. S., Koutsavdis, E. K., and Pilon, A. R., "An Extended Kirchhoff Method for Rotorcraft Impulsive Noise," to be presented at the Technical Specialists' Meeting for Rotorcraft Acoustics and Aerodynamics, Williamsburg, VA, Oct. 1997.

A Study of Rotorcraft Blade-Tip Shape Noise Characteristics; Sponsor: NASA Langley; Students: J. R. Jameson, E. K. Koutsavdis

Kirchhoff's method has been employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's method allows radiating sound to be evaluated based on quantities evaluated on an arbitrary control surface, if the linear homogeneous wave equation is assumed outside the control surface. Thus, the control surface is assumed to include all the nonlinear flow effects and noise sources. This methodology has been implemented recently in the NASA Langley TRAC (TiltRotor Aeroacoustic Codes) system. The method has been used for rotorcraft high-speed impulsive (HSI) and Blade-Vortex Interaction (BVI) noise prediction with very good results. Blade tip design is a very important noise parameter because noise signals are very sensitive to tip shapes. The aerodynamic behavior of various tip shapes has been studied previously at NASA Langley. We propose here the investigation of the noise characteristics of blade tip shapes. We expect to characterize several blade tip shape designs and offer ideas for possible noise reduction.

Relevant Publications:

[1] Lyrintzis, A. S., Jameson, J. R., and Koutsavdis, E. K., "A Study of Rotorcraft Blade-Tip Shape Noise Characteristics," to be presented at the Technical Specialists' Meeting for Rotorcraft Acoustics and Aerodynamics, Williamsburg, VA, Oct. 1997.

The Use of Kirchhoff's Method in Jet Noise Calculations; Sponsor: NASA Langley; Student: A. Pilon

Research in the development of an improved Kirchhoff method is described. The Kirchhoff method is a means of evaluating radiating sound from flow acoustic quantities on a computational surface. The linear, homogeneous wave equation is assumed to be valid in the propagation region, outside this surface (the Kirchhoff surface). The surface quantities are generally obtained from a computational fluid dynamics (CFD) calculation of the acoustic near--field. This work outlines the development of a Kirchhoff method for use when the linear, homogeneous wave equation is not valid in a portion of the region outside of the Kirchhoff surface. The improved method is derived through the use of a porous--surface formulation of the Ffowcs Williams--Hawkings equation. This modified integral solution allows the Kirchhoff methodology to be employed in problems with large, non--compact source regions that extend beyond the limits of the CFD calculation. Test calculations are shown to validate the method for use in jet aeroacoustics studies. However, the method is presented in a manner to make it easily applicable in cases where Kirchhoff methods have been used in the past. The method of computational aeroacoustics was also modified to account for the refraction caused by non--uniform mean flows in jet noise calculations. The corrections presented are based on simplified geometric acoustics principles. An axisymmetric, parallel shear flow is assumed for the jet mean flow which causes the refraction. The corrections are shown to qualitatively approximate the “zone of silence” observed near the axis in jet acoustics experiments.

Relevant Publications:

[1] Lyrintzis, A. S., and Mankbadi, R. R., "On the Prediction of the Far-Field Jet Noise Using Kirchhoff's Method," *AIAA Journal* , Vol. 34, No. 2, February 1996, pp. 413-416.

[2 Pilon, A., and Lyrintzis, A. S., "On the Development of a Modified Kirchhoff Method for Supersonic Jet Aeroacoustics," AIAA paper No. 96-1709, presented at the 2nd AIAA/CEAS Aeroacoustics Meeting, (17th AIAA Aeroacoustics Meeting) State College, PA, May 1996.

[3] Pilon, A. R., and Lyrintzis, A. S., "Integral Methods for Computational Aeroacoustics," AIAA paper No. 97-0020, presented at the 35th Aerospace Science Meeting, Reno, NV, Jan. 1997.

[4] Scott, J. N., Pilon, A. R., Lyrintzis, A. S., and Rozmajzl, T., "A Numerical Investigation of Noise from a Rectangular Jet," AIAA paper No. 97-0485, presented at the 35th Aerospace Science Meeting, Reno, NV, Jan. 1997.

[5] Shih, S. H., Hixon, D. R., Mankbadi, R. R., Pilon, A. R., and Lyrintzis, A. S., "Evaluation of Far-Field Jet Noise Prediction Methods," AIAA paper No. 97-0282, presented at the 35th Aerospace Science Meeting, Reno, NV, Jan. 1997.

[6] Pilon, A R., and Lyrintzis, A. S., "Refraction Corrections for the Kirchhoff Method," AIAA paper No. 97-1654 presented at the 3rd AIAA/CEAS Aeroacoustics Meeting, Atlanta, GA, May 1997.

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 will be developed. First, a three-dimensional Large Eddy Simulation (LES) code based on the dynamic subgrid scale model will be developed. Then Kirchhoff's method will be employed for the extension of Computational Fluid Dynamics (CFD) results to the far-field. Kirchhoff's 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. Kirchhoff's method will be enhanced to avoid evaluation of normal derivatives and include nonlinear effects as well as refraction effects outside the Kirchhoff surface.

Publications

Wissink, A. M., Lyrintzis, A. S., and Chronopoulos, A. T., "Efficient Iterative Methods Applied to the Solution of Transonic Flows," *Journal of Computational Physics*, Vol. 123, pp. 379-393, 1996.

Pilon, A., and Lyrintzis, A. S., "A Data-Parallel Total Variation Diminishing Method for Sonic Boom Calculations," *AIAA Journal of Aircraft*, Vol. 33, No. 1, pp. 87-92, Jan.-Feb. 1996.

Lyrintzis, A. S., and Mankbadi, R. R., "On the Prediction of the Far-Field Jet Noise Using Kirchhoff's Method," *AIAA Journal*, Vol. 34, No. 2, pp. 413-416, Feb. 1996.

Liu, G., Lyrintzis, A. S., and Michalopoulos, P. G., "Modeling of Freeway Merging and Diverging Flow Dynamics," *Applied Math. Modeling*, Vol. 20, pp. 459-469, June 1996.

Strawn, R. C., Biswas, R., and Lyrintzis, A. S., "Helicopter Noise Predictions Using Kirchhoff Methods," *IMACS Journal of Computational Acoustics*, Vol. 4, No. 3, pp. 321-339, Sept. 1996.

Wissink, A. M., Lyrintzis, A. S., and Strawn, R. C., "Parallelization of a Three-Dimensional Flow Solver for Euler Rotorcraft Aerodynamics Predictions," *AIAA Journal*, Vol. 34, No. 11, pp. 2276-2283, Nov. 1996.

Lyrintzis, A. S., and Koutsavdis, E. K., "Rotorcraft Impulsive Noise Prediction Using a Rotating Kirchhoff Formulation," *AIAA Journal of Aircraft*, Vol. 35, No. 6, pp. 1054-1061, Nov.-Dec. 1996.

Lyrintzis, A. S., and Koutsavdis, E. K., "Kirchhoff Acoustic Methodology Implementation for TiltRotor Aeroacoustic Codes (TRAC)," Final Report, submitted to Sikorsky Aircraft, (28 pages), Dec. 1996.

Book

Lyrintzis, A. S., and Baysal, O., Computational Aeroacoustics, Vol. 238, presented at the ASME Fluids Engineering Conference, San Diego, CA, July 1996.

Conference Proceedings, Presentations, and Invited Lectures

Wissink, A. M., Lyrintzis, A. S., Oliher, L., Biswas, R., and Strawn, R. C., "Efficient Helicopter Aerodynamic and Aeroacoustic Predictions on Parallel Computers," AIAA paper no. 96-0153, presented at the AIAA 34th Aerospace Science Meeting, Reno, NV, Jan. 1996.

Lyrintzis, A. S., "The Use of Kirchhoff's Method in Computational Aeroacoustics," presented at the session on Direct and Inverse Problems in Aeroacoustics, Univ. of Notre Dame Symposium on Current and Future Directions in Applied Mathematics, April 1996.

Pilon, A., and Lyrintzis, A. S., "On the Development of a Modified Kirchhoff Method for Supersonic Jet Aeroacoustics," AIAA paper no. 96-1709, presented at the 2nd AIAA/CEAS Aeroacoustics Meeting, (17th AIAA Aeroacoustics Meeting) State College, PA, May 1996.

Lyrintzis, A. S., and Xue, Y., "Towards a Versatile Kirchhoff Code for Aeroacoustic Predictions," AIAA paper no. 96-1710, presented at the 2nd AIAA/CEAS Aeroacoustics Meeting, (17th AIAA Aeroacoustics Meeting) State College, PA, May 1996.

Brentner, K. S., Lyrintzis, A. S., and Koutsavdis, E. K., "A Comparison of Computational Aeroacoustic Prediction Methods for Transonic Rotor Noise," Proceedings of the 52nd AHS Annual Forum, Washington, DC, Vol. 2, pp. 1103-1114, June 1996.

Wissink, A. M., Lyrintzis, A. S., and Chronopoulos, A. T., "Parallel Krylov Solvers Applied to the Rotorcraft CFD code TURNS," presented at the 3rd Computational Aerosciences (CAS) Workshop, NASA Ames Research Center, August 1996.

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

Conventional supersonic and hypersonic wind tunnels suffer from high levels of noise radiated from the turbulent boundary layers on the wind-tunnel walls. 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 (AIAA Paper 96-2191). 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.

The existing 12-inch Ludwieg tube is being adapted for use with an 9-inch quiet-flow Mach-6 test section that is to be constructed in 1997-98. Quiet-flow operation to a length Reynolds number of 13 million is projected. A large quiet-flow Ludwieg tube with a 30-inch diameter stainless-steel driver that is 199 feet long is then to be constructed during 1998-2002. This tube is to operate a 24-inch diam. Mach-6 quiet-flow test section with a quiet length Reynolds number of 36 million. Modern digital and optical instrumentation enables efficient use of the one-second run-times typical of these facilities, and the short duration keeps operating costs low. The large test sections planned enable testing with larger models and thicker boundary layers.

Four PhD students are currently supported to continue the work described in AIAA Paper 96-2191 (from June 1996). PhD students are sought for this project, because of the 1-2 years it takes to become productive with the complex apparatus.

Publications

Alcenius, T., Schneider, S. P., Beckwith, I., White, J., and Korte, J., “Development of Square Nozzles for Supersonic Low-Disturbance Wind Tunnels,” *Journal of Aircraft*, Vol. 33, pp. 1131-1138, Nov.-Dec. 1996.

Conference Proceedings, Presentations and Invited Lectures

Schmisseur, J. D., Young, J. O., and Schneider, S. P., “Boundary-Layer Transition Measurements on the Sidewall of a Quiet-Flow Ludwieg Tube,” AIAA paper no. 96-0852, presented at the 34th AIAA Aerospace Sciences Conference, Reno, NV, 11 pages, January 1996.

Goldstein, D., Engblom, W., Ladoon, D., and Schneider, S., “Fluid Dynamics of Forward-Facing Cavity Flow,” AIAA paper no. 96-0667, presented at the 34th IAA Aerospace Sciences Meeting, Reno, NV, 16 pages, January 1996.

Schmisseur, J. D., Schneider, S. P., Salyer, T. R., and Collicott, S. H., “A Repeatable Laser-Generated Localized Perturbation for Application to Fluid Mechanics,” Eighth International Symposium on Applications of Laser Techniques to Fluid Mechanics, Lisbon, Portugal, 7 pages, July 8-11, 1996.

Schneider, S., Schmisseur, J., Ladoon, D., Randall, L., Munro, S., and Salyer, T., “Laminar-Turbulent Transition Research in the Purdue Mach-4 Quiet Flow Tube,” AIAA paper no. 96-2191, presented at the AIAA Advanced Measurement and Ground Testing Meeting, New Orleans, LA, 24 pages, June 1996.

JOHN P. SULLIVAN
1975
Professor and Head

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

Liu, T. and Sullivan, J. P., "Heat Transfer and Flow Structures in an Excited Circular Impinging Jet," *Int. J. Heat Mass Transfer*, Vol. 39, No. 17, 1996, pp. 3695-3706.

Conference Proceedings, Presentations and Invited Lectures

Campbell, B.T., Witte, G.R. and Sullivan, J.P., "Experimental Investigation of a Half-Span Boundary Layer Control Wing," AIAA 96-2422, presented at the 14th AIAA Applied Aerodynamics Conference, New Orleans, Louisiana, June 17-20, 1996.

Torgerson, S.D., Liu, T. and Sullivan, J.P., "Use of Pressure Sensitive Paints in Low Speed Flows," AIAA 96-2184, presented at the 19th AIAA Advanced Measurement and Ground Testing Technology Conference, New Orleans, Louisiana, June 17-20, 1996.

Asai, K., Kanda, H., Kunimasu, T., Liu, T., and Sullivan, J. P., "Detection of Boundary-Layer Transition in a Cryogenic Wind Tunnel by Using Luminescent Paint," AIAA 96-2185, presented at the 19th AIAA Advanced Measurement and Ground Testing Technology Conference, New Orleans, Louisiana, June 17-20, 1996.

MARC H. WILLIAMS
1981
Professor

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.

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

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 three 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.

Conference Proceedings, Presentations and Invited Lectures

Andrisani, D., "Partitioning Estimation: Application to Aerospace Problems," First International Conference on Linear Problems in Aviation & Space, Embry-Riddle Aeronautical Univ., Daytona Beach, FL, May 9-11, 1996.

Andrisani, D., and Lainiotis, D. G., "Partitioning Estimation: A Unifying Framework for Estimation Theory," First International Conference on Linear Problems in Aviation & Space, Embry-Riddle Aeronautical Univ., Daytona Beach, FL, May 9-11, 1996.

Peters, M., and Andrisani, D., "Development and System Identification of a Light Unmanned Aircraft for Flying Qualities Research," First International Conference on

Linear Problems in Aviation & Space, Embry-Riddle Aeronautical Univ., Daytona Beach, FL, May 9-11, 1996.

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

Tsiotras, P., Corless, M., and Rotea, M. A., "Counter-example to be a Recent Result on the Stability of Nonlinear Systems," *IMA Journal of Mathematical Control and Information*, Vol. 13, pp. 129-130, 1996.

Book Chapters

Corless, M., and Leitmann, G., "Control of Uncertain Systems with Componentwise Bounded Controllers," in Robust Control via Variable Structure and Lyapunov Techniques, F. Garofalo and L. Glielmo, Eds., Springer-Verlag, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Bajaj, A. K., Georgious, I. T., and Corless, M., "Dynamics of Singularly Perturbed Nonlinear Systems with Two Degrees-of-Freedom," IUTAM Symposium on Interaction between Dynamics and Control in Advanced Mechanical Systems, Eindhoven, The Netherlands, 1996.

Amato, F., Corless, M., Pironti, A., and Setola, R., "Robust Stability in the Presence of a Bounded and Bounded Rate, Time-Varying, Uncertain Parameters," 13th IFAC World Congress, San Francisco, CA, 1996.

Zenieh, S., and Corless, M., "Tracking Controllers for Flexibly Jointed Robotic Manipulators with Extreme Joint Compliance," ASME International Congress and Exposition, Atlanta, GA, 1996.

Tsiotras, P., Corless, M., and Rotea, M. A., "Optimal Control of Rigid Body Angular Velocity with Quadratic Cost," 35th IEEE Conference on Decision and Control, Kobe, Japan, 1996.

Astuti, P., Corless, M., and Williamson, D., "On the Convergence of Sampled Data Nonlinear Systems," International Conference on Differential Equations, Bandung, Indonesia, 1996.

Corless, M., and Brockman, M., "Quadratic Boundedness of Uncertain Dynamical Systems," IFAC International Workshop on Robust Control, Napa, CA, 1996.

Tu, J. F., and Corless, M., "Characterizing Tschudin Hydrodynamic Spindle," final report to Cummins Engine, 1996.

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., and Frazho, A. E., "Constructing the Schur Contraction in the Commutant Lifting Theorem," *Acta Sci. Math.*, Vol. 61, No. 1-4, pp. 425-442, 1996.

Foias, C., Frazho, A. E., Gohberg, I., and Kaashoek, M. A., "Discrete Time-Variant Interpolation as Classical Interpolation with an Operator Argument," *Integral Equation* and *Operator Theory*, Vol. 26, pp. 371-403, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Frazho, A. E., "Commutant Lifting and Unitary Systems," presentation at Vrije Universiteit, Amsterdam, Feb. 29, 1996.

Smith, M., and Frazho, A. E., “Strong Stabilization and Optimization for SISO System,” Allerton Conference on Decision and Control, Oct. 1996.

Frazho, A. E., “The Commutant Lifting Theorem and Unitary Systems,” International Workshop on Operator Theory and Applications, Indiana Univ., Bloomington, IN, June 13, 1996.

Frazho, A. E., “Time Varying Nevanlinna-Pick Interpolation,” Conference on Mathematical Theory of Networks and Systems, St. Louis, MO, June 20, 1996.

KATHLEEN C. HOWELL
1982
Associate 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

Howell, K. C., "Introducing Cooperative Learning into a Dynamics Lecture Class," *Journal of Engineering Education*, Vol. 85, No. 1, pp. 69-72, Jan. 1996.

Ely, T. A., and Howell, K. C., "Long Term Evolution of Artificial Satellite Orbits Due to Resonant Tesseral Harmonics," *Journal of the Astronautical Sciences,* Vol. 44, No. 2, pp. 167-190, 1996.

Hiday-Johnston, L. A., and Howell, K. C., "Impulsive Time-Free Transfers Between Halo Orbits," *Celestial Mechanics and Dynamical Astronomy*, Vol. 64, No. 4, pp. 281-303, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Howell, K. C., "Trajectory Design Strategies in the Vicinity of the Sun-Earth Libration Points," Department de Matematica Aplicada I Analisi, Universitat de Barcelona, Barcelona, Spain, January 1996.

Howell, K. C., "Application of Dynamical Systems Theory to Support Trajectory Design for the FIRE/PSI and Suess-Urey Mission Proposals," Libration Point Trajectory Design Workshop, Jet Propulsion Laboratory, Pasadena, CA, Feb. 1996.

Howell, K. C., "Using Invariant Manifold Theory to Support Trajectory Design with Application to Libration Point Missions," University of Cincinnati, Cincinnati, OH, March 1996.

Howell, K. C., and Wilson, R. S., "Trajectory Design in the Sun-Earth-Moon System Using Multiple Lunar Gravity Assists," Proceedings of the AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, pp. 630-640, July 1996.

Barden, B. T., Howell, K. C., and Lo, M. W., "Application of Dynamical Systems Theory to Trajectory Design for a Libration Point Mission," Proceedings of the AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, pp. 268-281, July 1996.

Lo, M. W., Howell, K. C., and Barden, B. T., "Mission Design for the FIRE and PSI Missions," Proceedings of the AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, pp. 282-286, July 1996.

Ely, T. A., and Howell, K. C., "Tesseral Resonance Overlap Including the Effects of Luni-Solar Perturbations," Proceedings of the AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, pp. 119-129, July 1996.

Howell, K. C., "ACRP: Dynamical Systems and Trajectory Design," Jet Propulsion Laboratory, Pasadena, CA, Sept. 1996.

JAMES M. LONGUSKI

1988

Associate 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

Tsiotras, P., and Longuski, J. M., "Analytic Solution of Euler's Equations of Motion for an Asymmetric Rigid Body," *Journal of Applied Mechanics*, Vol. 63, No. 1, pp. 149-155, March 1996.

Sims, J. A., Staugler, A. J., Longuski, J. M., and Williams, S. N., "Non-Earth Flyby Options for Pluto Express (2002)," Technical Report prepared for Jet Propulsion Laboratory, 16 pages, March 1996.

Tragesser, S. G., and Longuski, J. M., "Saturn Gravity Field Modeling Accuracy," Progress Report prepared for Jet Propulsion Laboratory by Purdue University, JPL contract number 960620, 50 pages, November 1996.

Conference Proceedings, Presentations, and Invited Lectures

Sims, J. A., Longuski, J. M., and Staugler, A. J., "Trajectory Options for Low-Cost Missions to Asteroids," IAA-L-0206, Second IAA International Conference on Low-Cost Planetary Missions, Laurel, MD, April 16-19, 1996.

Tragesser, S. G., and Longuski, J. M., "The Effect of Parameter Uncertainties on the Aerobraking Tether," AIAA Paper no. 96-3597, 1996 AIAA/AAS Astrodynamics Conference, San Diego, CA, July 29-31, 1996.

Sims, J. A., Staugler, A. J., and Longuski, J. M., "Trajectory Options to Pluto via Gravity Assists from Venus, Mars, and Jupiter," AIAA paper no. 96-3614, AIAA/AAS Astrodynamics Conference, San Diego, CA, July 29-31, 1996.

Tsiotras, P., and Longuski, J. M., "Comments on a New Parameterization of the Attitude Kinematics," AIAA paper no. 96-3627, 1996 AIAA/AAS Astrodynamics Conference, San Diego, CA, July 29-31, 1996.

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 and identification

Awards and Major Appointments

NSF Young Investigator Award

Research Areas

Basic research in systems and controls is aimed at developing methods and tools for:

1. controller design with multiple performance and robustness specifications, and
2. the real-time implementation of dynamical systems with time and amplitude quantizations.

Professor Rotea supervises the Control System Design Laboratory (CSDL) in our School. The research at the CSDL is focused on the development of new results and methodologies, and the application of these to challenging practical problems.

Publications

Khargonekar, P. P., Rotea, M. A., and Baeyens, E., "Mixed H_2 / H_∞ Filtering," *International Journal of Robust and Nonlinear Control*, Vol. 6, pp. 313-330, May 1996.

Rotea, M. A., and Prasanth, R. K., "An Interpolation Approach to Multiobjective H_∞ Design," *International Journal of Control*, Vol. 65, No. 4, pp. 699-720, Nov. 1996.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Rotea, M. A., "Third Annual NSF-YIA Progress Report, grant #ECS-93-58288, May 1996.

Rotea, M., Randall, L., Song, G., and Schneider, S., "Model Identification of a Kulite Pressure Transducer," AIAA paper no. 96-2278, presented at the AIAA Advanced Measurement and Ground Testing Meeting, New Orleans, LA, 10 pages, June 17-20, 1996.

Prasanth, R. K. and Rotea, M. A., "Interpolation with Multiple Norm Constraints," 1996 Symposium on the Mathematical Theory of Networks and Systems-MTNS96, St. Louis, MO, June 24-28, 1996.

Lu, J., and Rotea, M. A., "Robust Stabilization for Systems with Rank-one Uncertainty Structure," 34th Annual Allerton Conference on Communication, Control, and Computing, Monticello, IL, 10 pages, Oct. 1996.

Iwasaki, T., Hara, S., and Rotea, M. A., "Computational Complexity Reduction in the Globally Optimal Scaled H_∞ Synthesis," International Workshop on Robust Control, Napa, CA, June 1996.

ROBERT E. SKELTON
1975
Professor

Degrees

B.S.E.E., Clemson University, 1963
M.S.E.E., University of Alabama-Huntsville, 1970
Ph.D., UCLA, Mechanics and Structures, 1976

Interests

Dynamics of aerospace vehicles
Control theory

Research Areas

Professor Skelton's research is focused on the integration of the modeling and control problems in the analysis and design of dynamic systems, in search of a theory for design (selection of the physical system's parameters and the parameters of the controller). This activity includes identification (open loop and closed loop), flexible structure control, sensor/actuator selection, covariance control (a particular parameterization of the class of all stabilizing controllers), and digital control using finite precision computers.

Publications

Grigoriadis, K., and Skelton, R. E., “Alternating Convex Projection Methods for Discrete Time Covariance Control,” *Journal Optimization Theory and Applications* (JOTA), Vol. 89, No. 2, May 1996.

Books

Skelton, R.E., Iwasaki, T., and Grigoriadis, K., A Unified Algebraic Approach to Linear Control Design, ISBN 07484-0592-5, Taylor & Francis, London, 1996.

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. Most recently, we have coupled the boundary element solutions with an integral method treatment of the boundary layer in order to investigate viscous effects in high-speed jets. In addition, a fully three-dimensional code is in development and should be completed in mid-1997. 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. Hybrid Rocket Combustion Experiments - This effort involves the use of the Purdue University Rocket Propulsion Lab (PURPL); a facility housed at the Thermal Sciences and Propulsion Center. Currently, lab scale motors are being fired to assess basic combustion phenomena in hybrid rockets. We currently utilize hydrogen peroxide and polyethylene as oxidizer and fuel, respectively. Over 100 firings of this propellant combination have been conducted during the past three 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 PURPL facility.

3. Diesel Engine Injector Modeling - This project, funded by **Cummins Engine Company** and **NSF**, 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. The model is currently being upgraded to improve efficiency and to ultimately extend capabilities to address 3-D flows. In addition, 2-D simulations are underway to calibrate the tool against flowfield measurements being obtained by Professor Collicott's research group.

Publications

Hilbing, J. H., and Heister, S. D., "Droplet Size Control in Liquid Jet Breakup," *Physics of Fluids*, Vol. 8, No. 6, pp. 1574-1581, 1996.

Chen, Y., and Heister, S. D., "Modeling Cavitating Flows in Diesel Injectors," *Atomization and Sprays*, Vol. 6, pp. 709-726, 1996.

Heister, S. D., HYROCS - A Computer Code for Hybrid Rocket Sizing and Preliminary Design, Technical Description and User's Guide, 133 pages, Jan. 1996.

Conference Proceedings, Presentations, and Invited Lectures

Hilbing, J. H., Heister, S. D., Rump, K. M. "Recent Advances in Nonlinear Modeling of Atomization Processes, ILASS-96 Conference Proceedings, 1996.

Murray, I. F., and Heister, S. D., "Modeling Acoustically-Induced Oscillations of Droplets," ILASS-96 Conference Proceedings, 1996.

Caravella, J. R., Heister, S. D., and Wernimont, E. J., "Characterization of Fuel Regression in a Radial Flow Hybrid Rocket," AIAA 96-3096, 32nd AIAA Joint Propulsion Conference, Lake Buena Vista, FL, 1996.

Wernimont, E. J., and Heister, S. D., "Progress in Hydrogen Peroxide Oxidized Hybrid Rocket Experiments," AIAA 96-2696, 32nd AIAA Joint Propulsion Conference, 1996.

NATHAN L. MESSERSMITH
1992
Assistant Professor

Degrees

B.S., University of Illinois at Urbana-Champaign, Mechanical Engineering with an International Minor in Germanic Studies, Honors, 1985
M.S., University of Illinois at Urbana-Champaign, Mechanical Engineering, 1987
Ph.D., University of Illinois at Urbana-Champaign, Mechanical Engineering, 1992

Interests

Airbreathing propulsion
Aeroacoustics
Optical Diagnostics

Awards and Major Appointments

Member of AIAA Airbreathing Propulsion Technical Committee, 1994-1997
Chairperson, Central Indiana Professional Section, 1994-1996
AAE Nominee, Murphy Undergraduate Teaching Award, 1995

Research Areas

Primary research interests encompass experimental gas dynamics, combustion, air-breathing propulsion and optical diagnostics.

Research is being conducted in several areas:

- Study of the energy transport within organized vortex flows. Impingement heat transfer studies have shown that peak temperatures greater than the jet stagnation temperature can be achieved on the impingement surface. The underlying reasons are not known, but the separation of energy within the jet stream and mixing layer due to well organized vortex motion is a suspected mechanism. Investigations are proceeding to capture the evolution of the energy field within a convecting vortex by using phased locked velocity and temperature measurements. Also surface measurements of the average temperature field are being conducted using temperature sensitive fluorescent paints, and will be correlated to the vortex dynamics.

- Investigations of the aeroacoustics of free and impinging sonic and supersonic jets to help reduce jet engine noise. Aeroacoustic feedback mechanisms have been observed to enhance the formation of large vortex structures in jet impingement flows. Understanding the natural and forced frequencies responsible for the formation of such vortex structures will aid in control of these processes. Several fluidic control concepts are being developed to possibly reduce far being conducted.

- Ballistic Earth to orbit launch capabilities of ram accelerators. An analytical study of the muzzle requirements of a ram accelerator are being studied to find optimal launch conditions for ballistic Earth to orbit capabilities. Consideration of optimal trajectories and its impact on projectile design and payload fraction are being currently studied. Earlier results suggest an optimal launch altitude exists between 300 km and 1000 km, that will lead to either reduced launch costs or greater launch payloads per projectile.

Publications

Messersmith, N. L., and Dutton, J. C., "Mie Scattering Measurements of Scalar Probability Density Functions in Compressible Mixing Layers," *Experiments in Fluids,* Vol. 21, No. 4, pp. 291-301, 1996.

Messersmith, N. L., and Dutton, J. C., "Characteristic Features of Large Structures in Compressible Mixing Layers," *AIAA Journal*, Vol. 34, No. 9, pp. 1814-1821, 1996.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Messersmith, N. L., and Reeb, A. B., "Analysis of Ram Projectile Acceleration and Unstart Using Oblique Detonation Theory," AIAA 96-2947, 32nd Joint Propulsion Conference, Orlando, FL, July 1-3, 1996.

Messersmith, N. L., and Murthy, S. N. B., "Thermal and Mechanical Loading on a Fire Protection Shield Due to a Combustor Burn-Through," presented at the AGARD Propulsion and Energetics Panel 88th Meeting on Aircraft Fire Safety, Dresden, Germany, Oct. 14-18, 1996.

Messersmith, N. L., "Studies of Internal and External Ram Accelerator Ballistics," seminar at the French-German Research Institute at Saint-Louis, France, Oct. 17, 1996.

Messersmith, N. L., "Correlation Between the Aerodynamics and Aeroacoustics of the E^3 Mixer Nozzles," General Electric Aircraft Engines Summer Faculty Research Report, 60 pages, Aug. 1996.

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

Genetic Algorithms (GA) are a relatively new class of search and optimization methods that mimic the idea of natural selection displayed by biological populations. The idea of "fitness" is analogous to an objective function in a more traditional optimization method. GA can use this idea of fitness to find solutions to optimal design problems that are difficult or impossible to solve using calculus-based methods. Research is being conducted to apply GA to a wide range of aerospace-related problems and to develop appropriate GA schemes for multiobjective and constrained optimization.

The abilities of genetic algorithms also allow them to perform as automated design methodologies. Combining selection and sizing tasks for rotorcraft conceptual design in a GA-based approach has demonstrated the ability of the genetic algorithm to generate designs for helicopters in much the same manner as human designers. Work is continuing to increase the applicability of this automated design approach to both rotorcraft and fixed-wing aircraft.

Recent investigation of smart materials and structures has displayed the potential for these concepts to be applied to aircraft in a variety of ways. Preliminary investigation of smart structures for adaptive rotor systems to improve primary rotor performance is beginning. Design techniques for these smart structures in aerospace systems are being developed.

Genetic Algorithm Applications for Aerospace Design and Optimization

Design of Composite Structures using Discrete, Integer and Continuous Variables. Composite structures present challenging design problems for aerospace engineering applications. Laminates are generally best represented by a combination of discrete, integer and continuous variables. The ply orientation angles are generally restricted to a set of discrete values as a matter of manufacturing practicality. Laminate thickness is restricted to a multiple of each ply thickness; the number of plies is an integer value. Finally, dimensions like length and width are continuous. The genetic algorithm is well suited for solving a design problem with this combination of variable types. Research in this area has included studies of stiffened composite panels (including stiffener cross-section and material selection as discrete variables) for buckling resistance and for energy absorption. Professor William Crossley, investigator.

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. To demonstrate this new design method, blades will be designed for a prop-rotor, like that for the envisioned Short Haul Civil Tiltrotor. Professor William Crossley, investigator; 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 whose configurations may be significantly different than current aircraft, such as V/STOL aircraft, unmanned (UAV) and remotely piloted vehicles (RPV). Professor William Crossley, investigator; Gregory Roth, graduate student. Currently sponsored by Purdue Research Foundation.

Using Cost as an Objective Function in Conceptual Design of Transport Aircraft. The current practice for commercial aircraft design has been to design for minimum weight or maximum performance. One reason for this is the inability to easily model the Direct Operating Cost (DOC) of an aircraft, including ownership costs. This research effort is exploring new options for predicting the cost of commercial transport aircraft. These schemes will then be applied to the conceptual design process which uses cost as an objective in place of and/or in addition to cost and performance. It is envisioned that configurations for minimum cost airliners may be different than those designed for maximum performance or minimum weight. To fully investigate this hypothesis, a genetic algorithm will be used to generate near-optimally sized configurations for short range transport aircraft. Professor William Crossley, investigator; Tamaira Ross, 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. Professor William Crossley, co-investigator (with Professor Steven Heister); Philip Schoonover, graduate student.

Genetic Algorithm Operator Development for 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 constellations. One of the issues that often arises when using the genetic algorithm is problem dependence. Slightly different versions of the GA may have dramatically different performance on a given problem. This problem dependence will require investigation of several versions of the operators for the GA to determine which set of operators provides the best performance for the constellation design problems. Professor William Crossley, investigator; Edwin Williams, undergraduate student; sponsored by The Aerospace Corporation and by the NASA/Indiana Space Grant Consortium.

Genetic Algorithm Methodology Development

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 are the development of new selection operators and of new ways to construct the fitness function to find designs which 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. To date, a rotor system has designed for both minimum power and minimum weight subject to several constraints; discrete, integer and continuous design variables were used. Professor William Crossley, investigator; sponsored in part by Purdue Research Foundation.

Empirically-Derived Population Size and Mutation Rate Guidelines for a Genetic Algorithm with Uniform Crossover. The Genetic Algorithm (GA) is used by different users to solve many problems; however, many challenges and issues surround the appropriate form and parameter settings of the genetic algorithm. One of the more troubling of these issues is the conflict between theory and experiment regarding the crossover operator. Experimental results suggest that the uniform crossover can provide better results for optimization, so many users wish to employ this approach. Unlike for the traditional single-point crossover GA, no established set of guidelines exist to assist users in choosing appropriate population sizes and mutation rates when using the uniform crossover. This research involved an empirical study to determine a set of these guidelines by examining various parameter combinations on four mathematical functions and one engineering design problem. Values for the population size and mutation rates were based on the string length of the binary chromosomes used for each problem. For each set of parameters, a test problem was solved 100 different times, to help minimize the effect of probabilistic noise. This process was repeated for all five test problems, which ranged from a 2-D unimodal mathematical minimization problem to a stiffened composite panel design problem with combined discrete, integer and continuous variables. The resulting guidelines appear to be valid over this range of test problems. Professor William Crossley, investigator; Edwin Williams, undergraduate student.

Techniques for Constraint Handling in Genetic Algorithm-Based Optimization. Constrained optimization via the Genetic Algorithm (GA) is often a challenging endeavor, as the GA is most directly suited to unconstrained optimization. Traditionally, external penalty functions have been used to convert a constrained optimization problem into an unconstrained problem for GA-based optimization. This approach requires the somewhat arbitrary selection of penalty draw-down coefficients. In this research, several potential approaches are presented that utilize adaptive penalty functions that change the value of the draw-down coefficients during a run of the genetic algorithm. A simple one-dimensional constrained problem and a more complex two-dimensional constrained problem were solved using the adaptive penalty strategies. Then, a stiffened composite panel was optimized for minimum weight, subject to several constraints using the adaptive penalty methods to provide insight to how the approaches perform on an engineering problem. Based on these problem solutions, conclusions were drawn regarding the efficacy of adaptive penalty functions for constrained optimization. Professor William Crossley, investigator; Edwin Williams, undergraduate student.

Publications

Crossley, W. A., and Laananen, D. H., “Conceptual Design of Helicopters via Genetic Algorithm,” *Journal of Aircraft*, Vol. 33, No. 6, pp. 1062-1070, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Crossley, W. A., and Laananen, D. H., "Generic Algorithm-Based Optimal Design of Stiffened Composite Panels for Energy Absorption," Proceedings of the 52nd Annual Forum of the American Helicopter Society, Washington, DC, pp. 1367-1376, June 4-6, 1996.

Crossley, W. A., "Genetic Algorithm Approaches for Multiobjective Design of Rotor Systems," AIAA paper 96-4026, Proceedings of the 6th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, pp. 384-394, Sept. 4-6, 1996.

Crossley, W. A., "Aircraft Conceptual Design via Genetic Algorithm," Wright Laboratories, Wright-Patterson Air Force Base, OH, Dec. 10, 1996.

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.

Publications

Danial, A. N., Rizzi, S. A., and Doyle, J. F., "Dynamic Response of Folded Plate Structures," *Journal of Vibration and Acoustics*, Vol. 118, pp. 591-598, 1996.

Doyle, J. F., and Farris, T. N., "Structural Mechanics Modeling of the Impact of a Double Cantilever Beam," *International Journal of Fracture*, Vol. 76, pp. 311-326, 1996.

Martin, M. M., and Doyle, J. F., "Impact Force Identification from Wave Propagation Responses, *International Journal of Impact Engineering*, Vol. 18, pp. 65-77, 1996.

Martin, M. M., and Doyle, J. F., "Impact Location in Frame Structures," *International Journal of Impact Engineering*, Vol. 18, pp. 79-97, 1996.

Book

Doyle, J. F., Wave Propagation in Structures, Springer-Verlag, New York, 1989, 2nd edition, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Bilodeau, B. A., and Doyle, J. F., “Acoustic Wave Propagation in Complex Structures,” American Acoustical Society, Indianapolis, IN, May 1996.

Doyle, J. F., “Wave Propagation through Joints and Other Structural Discontinuities,” SEM Proceedings, Nashville, TN, June 1996.

Kannal, L. E., and Doyle, J. F., “Combining Spectral Super-Elements, Genetic Algorithms, and Massive Parallelism for Computationally Efficient Flaw Detection in Complex Structures *IUTAM Conf. on Damage Mechanics*, Dublin, Ireland, 1996.

Doyle, J. F., “Crack Detection in Complex Structures,” Army Mechanics Conference, Myrtle Beach, SC, Oct. 1996.

HORACIO D. ESPINOSA
1992
Assistant 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.

- **Related Journal Publications**:

- H.D. Espinosa, G. Raiser, R.J. Clifton and M. Ortiz, "Experimental Observations and Numerical Modeling of Inelasticity in Dynamically Loaded Ceramics," *J. of Hard Materials*, Vol 3, No. 3-4, pp. 285-313, 1992.

- H.D. Espinosa, G. Raiser, R.J. Clifton and M. Ortiz, ``Performance of the Star-Shaped Flyer in the Study of Brittle Materials: Three Dimensional Computer Simulations and Experimental Observations," *J. Appl. Phys.*, Vol 72, No. 8, pp. 3451-3457, 1992.

- H.D. Espinosa, ``On the Dynamic Shear Resistance of Ceramic Composites and its Dependence on Applied Multiaxial Deformation", *Int. J. of Solids and Structures*, Vol. 32, No. 21, pp. 3105-3128, 1995.

- H.D. Espinosa, and N.S. Brar, ``Dynamic Failure Mechanisms of Ceramic Bars: Experiments and Numerical Simulations," *J. of the Mechanics and Physics of Solids*, Vol. 43, No. 10, pp. 1615-1638, 1995.

- H.D. Espinosa, ``Dynamic Compression-Shear Loading with In-Material Interferometric Measurements," *Rev. Sci. Instr.*, Vol. 67, No. 11, pp.3931-3939, 1996.

- H.D. Espinosa, M. Mello, and Y.Xu, ``A Variable Sensitivity Displacement Interferometer with Application to Wave Propagation Experiments", *J. Applied Mechanics*, Vol. 64, pp.123-131, 1997.

- H.D. Espinosa, Y. Xu, and N.S. Brar, ``Micromechanics of Failure Waves in Glass: Experiments", *J. Am. Cer. Soc.*, Vol. 80, No. 8, pp. 2061-2073, 1997.

- H.D. Espinosa, Y. Xu, and N.S. Brar, ``Micromechanics of Failure Waves in Glass: Modeling", *J. Am. Cer. Soc.*, Vol. 80, No. 8, pp. 2074-2085, 1997.

- H.D. Espinosa, M. Mello, and Y. Xu, ``A Desensitized Displacement Interferometer Applied to Impact Recovery Experiments," *Applied Physics Letters*, Vol. 69, No. 21, pp. 3161-3163, 1996.

- H.D. Espinosa, Y. Xu, and H-C. Lu ``Inelastic Behavior of Fiber Composites Subjected to Out-of-Plane High Strain RateShearing," to appear in *Acta Materialia*, 1997.

- H.D. Espinosa, H-C. Lu, and Y. Xu, ``A Novel Technique for Penetrator Velocity Measurement and Damage Identification in Ballistic Penetration Experiments," to appear in *J. of Composite Materials*, 1997.

- H.D. Espinosa, P.D. Zavattieri, and G.L. Emore, ``Adaptive FEM Computation of Geometric and Material Nonlinearities with Application to Brittle Failure," to appear in special issue of *Mechanics of Materials*, 1997.

- H.D. Espinosa, ``Recent Developments in Velocity and Stress Measurements Applied to the Dynamic Characterization of Brittle Materials," to appear in special issue of *Mechanics of Materials*, 1997.

- H.D. Espinosa, S. Dwivedi, P.D. Zavattieri, and G. Yuan, ``Numerical Investigations of Penetration in Multi-Layered Structure/Systems"submitted to *Int. J. Solids and Structures*, 1997.

- H.D. Espinosa, P.D. Zavattieri, and S. Dwivedi, ``A Finite Deformation Continuum/ Discrete Model for the Description of Fragmentation and Damage in Brittle Materials," submitted to *J. of the Mechanics and Physics of Solids*, 1997.

Publications

Espinosa, H. D., "Dynamic Compression-Shear Loading with In-material Interferometric Measurements," *Rev. Sci. Instr*., Vol. 67, No. 11, pp. 3161-3939, 1996.

Espinosa, H. D., Mello, M., Xu, Y., "A Desensitized Displacement Interferometer Applied to Impact Recovery Experiments," *Appl. Phys. Lett*er, Vol. 69, No. 21, pp. 3161-3163, Nov. 1996.

Conference Proceedings, Presentations, and Invited Lectures

Espinosa, H. D., "Micromechanics of Failure Waves in Glass," 1996 ASME Mechanics and Materials Conference, The John Hopkins Univ., Baltimore, MD, June 1996

Brar, N. S., and Espinosa, H. D., "Micromechanics of Failure Waves in Glass," Int. Conf. on Shock Waves in Condensed Matter, St. Petersburg, Russia, Sept. 1996.

Espinosa, H. D., "Tribomechanics of Nanostructured Materials," poster presented at NSF-IMM Young Investigator Conference, sponsored by Boeing Co., Seattle, WA, Oct. 1996.

Espinosa, H. D., "A Novel Experiment for Failure Identification During Ballistic Penetration," 14th U. S. Army Symposium on Solid Mechanics, Myrtle Beach, SC, Oct. 1996.

Espinosa, H. D., Lu, H-C., and Xu, Y., "A Novel Technique for Penetrator Velocity Measurements in Ballistic Penetration Studies," in Advances in Failure Mechanisms in Brittle Materials, edited by R. J. Clifton and H. D. Espinosa, ASME Winter Annual Meeting, Atlanta, GE, pp. 23-47, Nov. 1996.

Espinosa, H. D. Zavattieri, P. D., and Emore, G. L., "Computational Modeling of Geometric and Material Nonlinearities with Application to Impact Damage in Brittle

Failure," in Advances of Failure Mechanisms in Brittle Materials, edited by R. J. Clifton and H. D. Espinosa, ASME Winter Annual Meeting, Atlanta, GE, pp. 115-158, Nov. 1996.

Espinosa, H. D., "Modeling Failure Waves in Brittle Materials," in Fourth International Conference on Structures under Shock and Impact IV, edited by N. Jones, C. A. Brebbia, and A. J. Watson, Computational Mechanics Publications, Southampton, UK, pp. 449-458, 1996.

Espinosa, H. D., "Experimental/Numerical Analysis of Brittle Failure," Purdue Univ., Mechanical Engrg. Dept., W. Lafayette, IN, Fall 1996.

THOMAS N. FARRIS

1986

Professor

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 force and slip amplitude. 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 if fretting on multi-site damage nucleation and growth in the aging aircraft problem. Additional theoretical work is directed at application of spectral analysis to the rough surface contact problem.

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

Ahn, Y., Chandrasekar, S., and Farris, T. N., "Determination of Surface Residual Stresses in Machined Ceramics using Indentation Fracture," *ASME Journal of Manufacturing Science & Engineering,* Vol. 118, No. 4, pp. 483-489, 1996.

Madhavan, V., Farris, T. N., Chandrasekar, S., and Craig, L., "FEM Comparison of Ball and Roller Bullgears," *STLE Tribology Transactions,* Vol. 39, No. 2, pp. 286-295, 1996.

Farris, T. N., "Effect of Overlapping Wheel Passages on Residual Stress in Rail Corners," *Wear,* Vol. 191, No. 1-2, pp. 226-236, 1996.

Ju, Y., and Farris, T. N., "Spectral Analysis of Two-Dimensional Contact Problems," *ASME Journal of Tribology*, Vol. 118, No. 2, pp. 320-328, 1996.

Blair, K. B., Krousgrill, C. M., and Farris, T. N., "Non-linear Dynamic Response of Shallow Arches to Harmonic Forcing," *Journal of Sound and Vibration*, Vol. 194, No. 3, pp. 355-367, 1996.

Szolwinski, M. P., and Farris, T. N., "Mechanics of Fretting Fatigue Crack Formation," *Wear,* Vol. 198, pp. 93-107, 1996.

Book Chapters

Madhavan, V., Chandrasekar, S., and Farris, T. N., "Mechanistic Model of Machining as an Indentation Process," Materials Issues in Machining and the Physics of Machining Processes III, eds. D. A. Stephenson and R. Stevenson, TMS, pp. 187-208, 1996.

Farris, T. N., Tribology, Rules of Thumb for Mechanical Engineers, Gulf, pp. 226-237, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Farris, T. N., Grandt, A. F., Harish, G., and Wang, H. L., "Analysis of Widespread Fatigue Damage in Structural Joints," 41st SAMPE Symposium, Las Vegas, March 1996.

Farris, T. N., Harish, G., McVeigh, P. A., and Szolwinski, M. P., "Fretting Fatigue in Aging Aircraft," Euromech 341 - Fretting Fatigue, Oxford, England, March 1996.

Woodard, P. R., Farris, T. N., Chandrasekar, S., and Yang, H. T., "Effect of Cylinder Diameter on Quenching Induced Residual Stress," Trans. North American Manufacturing Research Inst. of SME, XXIV, pp. 205-210, 1996.

Farris, T. N., Grandt, A. F., Harish, G., McVeigh, P. S., Szolwinski, M. P., and Wang, H. S., "Fretting Fatigue Crack Nucleation and Propagation in Structural Joints," Proc. Air Force 4th Aging Aircraft Conference, Colorado Springs, CO, July 1996.

Farris, T. N., Harish, G., McVeigh, P. A., and Szolwinski, M. P., "The Role of Fretting Crack Nucleation in the Onset of WFD: Analysis and Experiments," Proc. FAA-NASA Symp. on Continued Airworthiness of Aircraft Structures, Atlanta, GA, pp. 585-596, Aug. 1996.

Ju, Y., Farris, T. N., and Chandrasekar, S., "Heat Partitioning and Temperatures in Grinding," ASME MED, Vol. 4, Manufacturing Science and Engineering, Atlanta, GA, pp. 259-266, Nov. 1996.

Hucker, S. A., Mann, J. B., Farris, T. N., and Chandrasekar, S., "Thermal Aspects of Grinding with Superabrasives: Part I," Abrasives Magazine, pp. 24-27, Oct./Nov. 1996.

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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

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 predicting the initial growth and subsequent fracture of preexistent cracks due to cyclic and/or static structural loads, and both experimental and numerical approaches are employed. The influence of corrosion on structural life is also of interest.

Recent research has examined development and growth of small cracks in aluminum alloys which have been produced to various initial quality levels. Other recent projects have characterized thermal-mechanical fatigue crack growth in metal matrix composites, analyzed fatigue cracks which originate in complex rotor-craft components or at dovetail joints in turbine disks, and studied three-dimensional aspects of fatigue crack closure.

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 multiple-site damage on the residual strength and fatigue life of mechanically fastened joints. 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 which have experienced extended periods of service usage.

Sponsored Research Summaries

Validation of Widespread Fatigue Damage Models (sponsored by Alcoa, students: Darren Sexton and Pat Golden)

The goal of this project is to quantify the improved resistance to both the occurrence and consequences of wide spread fatigue damage provided by the new 2524-T3 aluminum alloy. Currently used in the Boeing 777 aircraft, the 2524-T3 alloy was designed for fuselage skin sheet as a replacement for 2024-T3, the industry standard since the DC-3 aircraft. Alloy 2524 has superior fatigue crack growth resistance and fracture toughness and equivalent tensile properties. This research will develop testing protocols and computational tools for evaluating the performance of 2024-T3 and 2524-T3 sheet under widespread damage scenarios that could develop in older aircraft. Three types of tests are being conducted: (1) residual strength tests to assess the effect of MSD on residual strength in a cracked panel; (2) panel fatigue tests to assess the effect of MSD on fatigue performance of cracked panels; and (3) multi-hole coupon fatigue tests to define the size and distribution of naturally occurring MSD at holes with and without corrosion.

Crack Coalescence Analysis Methods Development (sponsored by Lockheed-Martin Tactical Aircraft Systems, student: Steven Green)

The objective of this research program is to characterize the initiation and early growth of fatigue cracks that develop at notches in high strength steels. The long term goal is to develop a fracture mechanics based model for the early stages of fatigue in notched components. High strength steel (D6-ac) specimens with semi-circular edge notches are being examined with a crack replicating technique. Crack formation and growth is recorded by pressing an acetate tape into the notch to form a replica that is then examined under a microscope. This microscopic examination determines the crack development sites and the initial growth and link-up of individual cracks.

Residual Strength of Panels Containing MSD (sponsored by Air Force Office of Scientific Research URI, student: M. B. Heinimann)

Although aircraft structures are designed to resist failure from relatively large cracks, one of the major concerns with older aircraft deals with the potential for small fatigue cracks that develop at multiple sites (MSD) to compromise the original damage tolerance. Previous work on this problem led to a numerical model for predicting the initiation, growth, and coalescence of multiple cracks located along a row of open holes in an unstiffened sheet. That analysis is being extended here to consider the effects of stiffeners oriented perpendicular to that direction of crack growth. Although such stiffeners provide a means to arrest lead cracks, this damage tolerance ability can be defeated by small MSD cracks which are located on the opposite side of the stiffener from the lead crack. The influence of stiffeners on crack growth in thin panels is being investigated with both analytical and experimental approaches.

Widespread Fatigue Analysis of Structural Joints (sponsored by Air Force Office of Scientific Research URI, student: H. L. Wang)

The objective of this project is to evaluate the influence of widespread fatigue cracking in a structural joint. A numerical model has been developed to determine the load transfer through individual fasteners in joints with multiple rows of fasteners. The analysis includes the effects of fastener material, diameter, and spacing as well as sheet thickness and material. The influence of crack growth at a given fastener on the load transfer at other locations is also considered. The results of the load transfer model are then incorporated into a fracture mechanics analysis of multiple-site damage to predict the life and residual strength of a joint that contains cracking at several fastener holes. Current work is considering the effect of interference-fit fasteners, and experimental evaluation of the numerical analysis is underway. Long term plans are to include a probabilistic treatment of various input parameters on structural performance.

A Fracture Mechanics Based Approach for Quantifying Corrosion Damage (sponsored by Air Force Office of Scientific Research URI, student: J. N. Scheuring)

The goal of this project is to develop a fracture mechanics based approach to quantify the influence of initial corrosion damage on structural integrity. The approach assumes that corrosion can be approximated by a geometric structural change consisting of a general thickness reduction combined with a localized stress concentration that may be treated as an equivalent initial crack size distribution. These two parameters enable fracture mechanics techniques to quantify corrosion damage with respect to the remaining fatigue life. By determining the influence of the state of corrosion on remaining life, it is possible to give a quantitative definition for the extent of corrosion in the context of the structure of interest. Several numerical calculations based on this approach have been completed. A facility for artificially corroding specimens has been developed, and an experimental verification program is under way.

Fatigue Crack Cage for Individual Aircraft Testing (sponsored by Air Force Office of Scientific Research URI, student: M. D. Gates)

This project is directed at developing a fatigue "crack gage" for individual Aircraft Tracking purposes. The goal is to provide a simple device that will monitor the cyclic loads encountered in service, and assess the potential for fatigue crack growth damage in structural components. By monitoring individual aircraft in this manner, it would be possible to schedule maintenance on the basis of the severity of fatigue loading actually experienced in service. The approach employed here is to attach a small precracked coupon (crack gage) to the structural member of interest. Structural loads are transferred to the coupon and result in measurable crack growth in the coupon. Fracture mechanics techniques enable one to relate crack growth in the coupon with extension of an assumed structural crack. Thus, the crack gage provides a simple technique to assess the potential for fatigue crack growth damage in the structural member of interest. This project extends prior work with the crack gage technique, and is focused on developing a side-grooved gage geometry which will minimize potential thickness effects caused by variable amplitude fatigue crack growth.

Description of the total aging aircraft URI Project:

Materials Degradation and Fatigue in Aerospace Structures (sponsored by the Air Force Office of Scientific Research)

The Purdue University Schools of Engineering and Science have formed an interdisciplinary research team to address basic research issues associated with aging aircraft. The program is supported by the USAF Office of Scientific Research, with Professor A. F. Grandt, Jr. from the School of Aeronautics and Astronautics as the Principal Investigator. Other Purdue University faculty include: Professors T. N. Farris and C. T. Sun from the School of Aeronautics & Astronautics, Professor E. P. Kvam from the School of Materials Science, Professor B. M. Hillberry from the School of Mechanical Engineering, and Professor G. P. McCabe from the Department of Statistics. These faculty are supported by a research team of approximately 20 Purdue graduate students. The objective of the **Purdue Aging Aircraft Program** is to solve fundamental problems that limit the safe operation of aircraft beyond their original design or current lifetimes. The general program goals fall into the following four categories.

- **Damage Development** goals are focused on determining how service induced damage develops in older aircraft through corrosion, fatigue crack formation, and fretting. A series if interrelated projects deal with understanding how corrosion of aircraft materials causes stress risers and material loss which leads to crack formation, on quantifying the influence of corrosion on the remaining fatigue life of a structure, and with understanding fretting fatigue as a mechanism for crack development.
- **Crack Growth and Interaction** goals deal with predicting the growth of service induced cracks and the impact of widespread fatigue damage (WFD) on residual strength and fatigue life. These projects include testing specimens from retired aircraft to quantify the fatigue crack growth resistance of “aged” materials and determining the development and consequences of WFD at mechanically fastened joints in stiffened panels.
- **Failure Prevention** goals focus on extending the operational life of “older” aircraft by delaying service induced damage, repairing cracked structure, and employing fleet tracking methods to prioritize maintenance actions within a fleet of aircraft. Projects in this task deal with developing adhesive bonded composite patches to repair cracks in metal structure, examining the ability of corrosion inhibitors to improve the stress corrosion cracking resistance of aluminum alloys, and developing simple monitoring techniques for assessing the potential for service induced damage.
- **Advanced Analysis Methods** are being developed to characterize crack growth in ductile materials, and to perform risk analyses to achieve the above general life analysis goals.

Publications

Grandt, Jr., A. F., Moukawsher, E. J., and Neussel, M. A., “Fatigue of Panels with Multiple Site Damage,” Journal of Aircraft, Vol. 33, No. 5, pp. 1003-1013, Sept.-Oct. 1996.

Grandt, Jr., A. F., Moukawsher, E. J., and Heinimann, M., "Residual Strength of Panels with Multiple Site Damage," Journal of Aircraft, Vol. 33, No. 5, pp. 1014-1021, Sept. - Oct. 1996.

Grandt, Jr., A. F., Heinimann, M. B., and Doerfler, M. T., "Analysis of Cracks at Deep Notches," Engineering Fracture Mechanics, Vol. 55, No. 4, pp. 605-616, 1996.

Grandt, Jr., A. F., Rifani, A. I., "A Fracture Mechanics Analysis of Fatigue Crack Growth in a Complex Cross Section," Engineering Failure Analysis, Vol. 3, No. 4, pp. 249-265, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Watkins, W. A., and Grandt, Jr., A. F., "Teaching Engineering and Technology Students in a TWM (Teamwork) Environment," presented at Design/Design Manufacturing in Aerospace Engineering Education session of the June 1996 ASEE Annual Meeting, Washington, DC.

Heinimann, M. B., and Grandt, Jr., A. F., "Analysis of Stiffened Panels with Multiple Site Damage," Proc. of 1996 USAF Structural Integrity Program Conference, San Antonio, TX, 28 pages, Dec. 3-5, 1996.

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

Klug, J., Wu, X. X., and Sun, C. T., "Efficient Modeling of Postbuckling Delamination Growth in Composite Laminates," *AIAA Journal*, Vol. 34, No. 1, pp. 178-206, Jan. 1996.

Sun, C. T., Klug, J., and Arendt, C., "Analysis of Cracked Aluminum Plates Repaired with Bonded Composite Plates," *AIAA Journal*, Vol. 34, No. 2, pp. 369-374, Feb. 1996.

Sun, C. T., and Potti, S. V., "A Simple Model to Predict Penetration of Thick Composite Laminates Subjected to High Velocity Impact," accepted for publication in *International Journal of Impact Engineering*, Vol. 18, No. 2, pp. 339-353, 1996.

Sun, C. T., and Vaidya, R. S., "Prediction of Composite Properties from a Representative Volume Element," *Composites Science and Technology*, Vol. 56, No. 2, pp. 171-179, 1996.

Wang, C., Sun, C. T., and Gates, T. S., "Elastic/Viscoplastic Behavior of Fiber-Reinforced Thermoplastic Composites," *Journal of Reinforced Plastics and Composites*, Vol. 15, pp. 360-377, April 1996.

Sun, C.T., and Zheng, S., "Delamination Characteristics of Double-Cantilever Beam and End-Notched Flexure Composite Specimens," *Composites Science & Technology*, Vol. 56, pp. 451-459, 1996.

Liao, W. C., and Sun, C. T., "The Determination of Mode III Fracture Toughness in Thick Composite Laminates," *Composites Science & Technology*, Vol. 56, pp. 489-499, 1996.

Morris, S. R., and Sun, C. T., "Analysis of Forming Loads for Thermoplastic Composite Laminates," *Composites Part A - Applied Science & Manufacturing*, Vol. 27A, pp. 633-640, 1996.

Pandey, R. K., and Sun, C. T., "Deformation of Thermoplastic Composite Laminates under Processing Conditions," *Mechanics of Composite Materials and Structures,* Vol. 3, No. 3, pp. 183-200, 1996.

Gates, T. S., Chen, J. L., and Sun, C. T., "Micromechanical Characterization of Nonlinear Behavior of Advanced Polymer Matrix Composites," *ASTM STP 1274*, pp. 295-319, 1996.

Pandey, R. K., and Sun, C. T., "Calculating Strain-Energy Release Rate in Cracked Orthotropic Beams," *Journal of Thermoplastic Composite Materials*, Vol. 9, pp. 381-395, Oct. 1996.

Tao, J. X., and Sun, C. T., "Effect of Matrix Cracking on Stiffness of Composite Laminates," *Mechanics of Composite Materials and Structures*, Vol. 3, pp. 225-239, 1996.

Sun, C. T., and Wu, X. X., "On the J-Integral in Periodically Layered Composites, *International Journal of Fracture*, Vol. 78, No. 1, pp. 67-87, 1996.

Wu, C. L., and Sun, C. T., "Low Velocity Impact Damage in Composite Sandwich Beams," *Composite Structures*, Vol. 34, pp. 21-27, 1996.

Su, X. M., and Sun, C. T., "On Singular Stress at the Crack Tip of a Thick Plate under In-Plane Loading," *Internatl. Journ. Fracture*, Vol. 82, pp. 237-252, 1996.

Sun, C. T., Luo, J., and McCoy, R. W., "Analysis of Wave Propagation in Thick-Section Composite Laminates Using Effective Moduli," *Composites Engineering*, Composites Part B, Vol. 27B, pp. 613-621, 1996.

Zhang, X. D., and Sun, C. T., "Formulation of an Adaptive Sandwich Beam," *Smart Materials & Structures,* Vol. 5, pp. 814-823, 1996.

Conference Proceedings, Presentations, and Invited Lectures

Tao, J. X., and Sun, C. T., "A Simplified Method for Predicting Onset of Open-Mode Free Edge Delamination," Proceedings of the 37th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Salt Lake City, Utah, pp. 2479-2485, Apr. 15-17, 1996.

Vaidya, R. S., and Sun, C. T., "Fracture Criterion for Notched Thin Composite Laminates," Proceedings of the 37th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Salt Lake City, Utah, pp. 331-338, Apr. 15-17, 1996.

Klug, J. C., and Sun, C. T., "Large Deflection Effects of Cracked Aluminum Plates Repaired with Bonded Composite Patches," Proceedings of the First International

Conference on Composite Science and Technology, Durban, South Africa, June 18-20, 1996.

Sun, C, T., and Su, X., "Effect of Crack Interactions on Ductile Fracture," Proceedings of the FAA/NASA Symposium on Continued Airworthiness of Aircraft Structures, Atlanta, GA, Aug. 28-30, 1996.

Tao, J., Sun, C. T., Arendt, C., and Brunner, M., "Interlaminar Shear Strength and Fracture Behavior in Aged Composite Laminates," 11th Technical Conference, American Society for Composites, Atlanta, GA, pp. 625-634, Oct. 7-9, 1996.

Guo, C., and Sun, C. T., "Dynamic Delamination Crack Propagation in Unidirectional Fiber Composite," 11th Technical Conference, American Society for Composites, Atlanta, GA, pp. 467-475, Oct. 7-9, 1996.

Thiruppukuzhi, S., and Sun, C. T., "High Strain Rate Characterization of Unidirectional Fiber and Woven Glass Composites," 11th Technical Conference, American Society for Composites, Atlanta, GA, pp. 201-210, Oct. 7-9, 1996.

Sun, C. T., and Qian, W., "The Role of Friction in the Fracture of Interfacial Cracks," Proceedings of the 14th U. S. Army Solid Mechanics Symposium, Myrtle Beach, SC, Oct. 16-18, 1996.

Su, X. M., and Sun, C. T., "A Plane Strain Core Model for Crack Growth in Ductile Materials," Proceedings of the ASME Aerospace Division, AD- Vol. 52, pp. 217-226, 1996.

Tao, J., and Sun, C. T., "Influence of Ply Orientation on Delamination in Composite Laminates," Proceedings of the ASME Aerospace Division, AD-Vol. 52, pp. 51-60, 1996.

Qian, W., and Sun, C. T., "Calculation of Mode Mixing for Delamination Cracks in Composite Laminates under In-plane Loading," in Advances in Failure Mechanisms in Brittle Materials, presented at the 1996 International Mechanical Engineering Congress and Exposition, Atlanta, GA, M-Vol. 75 (also AMD-Vol. 219) pp. 15-22, Nov. 17-22, 1996.

Sun, C. T., "Selection of Scale in Modeling Composite Materials and Laminates," in Progress in Advanced Materials and Mechanics, Proceedings of International Conference on Advanced Materials, Beijing, China, pp. 53-62, Aug. 12-15, 1996.

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

Currently, visible interfaces exist between structural design and active control design. The active control system is often an add-on feature to cure a perceived deficiency of the structural system, i.e., fatigue life extension or flutter suppression. In such a case, a judgment has been made that the increased complexity of an automatic control system is a lesser price to pay than increased weight required to increase flutter speed or improve fatigue life. The optimization or quest for the best add-on control system focuses almost entirely upon the control law design and regards the structure as untouchable. This lack of integration is not likely to be the case with future competitive aerospace designs, for which integration is a must.

Integrated Structures and Control Design (ISCD) research design seeks to combine a variety of components and subsystems, of differing form and function, into a single advantageous interplay of performance related design objectives. In this case, interfaces become transparent. At the heart of ISCD is to attempt to treat the active control design and structural stiffness design in parallel, that is, both are to be considered simultaneously in the design process.

Of the many promising uses of integration currently under consideration we may look forward to: reduced factors of safety because of greater load control on flexible structures; integrated design of lateral control systems involving control placement and sizing together with structural stiffness optimization; aeroservoelastic tailoring of laminated structures for flutter prevention; and perhaps even astroservoelastic tailoring of flexible satellites to increase controllability and damping. These efforts can only be fruitful if teams of individuals rather than one single individual exert leadership initiatives.

At Purdue research interests have focused upon creating optimally tailored advanced composite structures to passively control flutter and creating optimal configurations consisting of control systems and structures to enhance aircraft maneuverability. Related issues have included new structural modeling techniques and efficient analytical representation of structural behavior. This research area requires a strong capability and interest in optimization techniques, unsteady aerodynamics, aeroelasticity and structural dynamics.

Publications

Nam, C., Kim, Y., and Weisshaar, T. A., "Optimal Sizing and Placement of Piezo-Actuators for Active Flutter Suppression," *Smart Materials and Structures*, Vol. 5, pp. 216-224, Nov. 1996.

Conference Proceedings, Presentations, and Invited Lectures

Weisshaar, T. A., "The Future of UAV's," SAB Report to the Secretary of the Air Force, Dec. 1996.

ACTIVE RESEARCH PROJECTS JULY 1, 1996 to JUNE 30, 1997

RESEARCH AND OTHER SCHOLARLY ACTIVITIES

The 1996-97 academic year realized $2,942,231 of externally funded research. A detailed listing of all outside sponsored research projects that were active during the period July 1, 1996 to June 30, 1997, is given in the Active Research Projects section. Please note that students and faculty are involved in many other research efforts which are not sponsored by external funds. The externally funded research for the 1996-97 year was obtained from the following sources.

SOURCE OF SPONSORED RESEARCH FOR 1996-1997	
Source	**Percentage of Total**
Department of Defense	44%
NASA	30%
National Science Foundation	14%
Industrial	5%
Other	7%
Total	100.0%

Professor C.T. Sun is the Principal Investigator for a new research project, funded by the **U.S. Army**. The $3 million dollar research grant involves three faculty members from the School, two faculty members from the School of Materials Engineering, and three researchers from the University of Dayton Research Institute. The multidisciplinary research initiative, which will continue the School's long standing tradition of advanced structure research started by our founder, **Elmer Bruhn**, will investigate lightweight layered materials and structures for damage tolerant armor.

"Materials Degradation and Fatigue in Aerospace Structures," a University research initiative directed by Professor Grandt completed its final year. Support for this research was received through the **U.S. Air Force**.

SPONSORED RESEARCH PROJECTS
ACTIVE DURING THE PERIOD JULY 1, 1996 TO JUNE 30, 1997

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
NASA	Indiana Space Grant Consortium Program Grant	03/01/91-09/30/97	$1,045,812	Andrisani
NASA	A Proposal to Establish the NASA Academy in Aeronautics	01/01/97-12/31/97	$34,234	Andrisani
NASA	National Space Grant College and Fellowship Program	03/01/97-02/28/98	$205,000	Andrisani
IBM	Numerical Simulation of Turbulent Axial Vortices Using an IBM SP2 Parallel Computer	07/01/96-06/30/97	$24,574	Blaisdell
NASA	High Reynolds Number Experiments on Bypass Duct and Strut Flows	07/14/95-10/31/97	$194,748	Collicott Co-Pi: Sullivan
NSF	Career: Experimental Investigation of the Internal Structures in Atomizing Orifice Flows	08/01/95-07/31/98	$209,978	Collicott
United Technologies	United Technologies/Pratt & Whitney	04/01/95-12/31/75	$8,000	Collicott
NASA	Indiana Space Grant Consortium	03/01/91-06/30/97	$2,280	Collicott
NSF	Presidential Young Investigator Award	08/15/90-01/31/97	$207,500	Corless
NSF	A Proposal to Establish an Engineering Research Center for Collaborative Manufacturing	10/1/94-08/30/97	$23,576	Corless
NASA	Indiana Space Grant	03/01/91-6/30/97	$4,452	Crossley
Aerospace Corp.	Genetic Algorithms	06/01/97-08/31/97	$3,000	Crossley
NASA	Application of the Spectral Element Method to Interior Noise Problems	08/11/95-08/10/97	$52,027	Doyle
ONR	An Experimental Computational Investigation of Inelasticity in Nanostructured and Layered Materials	06/01/97-05/31/00	$420,000	Espinosa
NSF	Micromechanical Study of Inelasticity in Brittle and Amorphous Materials	07/15/93-07/14/96	$100,000	Espinosa
NSF	Tribo-Mechanics of Nanostructured Materials	07/01/96-06/30/00	$210,000	Espinosa
NSF	Effect of Grain Size, Second Phases and Texture in the Dynamic Failure of Ceramics	09/15/95-08/31/98	$148,790	Espinosa
ARO	Development of a Microcracking Multiple-plane Model for Ballistic Impact	05/01/96-10/31/96	$20,000	Espinosa
Air Force	Instrumentation for High Temperature Testing of Advanced Materials	08/15/95-08/14/96	$64,560	Espinosa
NSF	Presidential Young Investigator Award	09/01/90 - 08/31/96	$312,500	Farris
ARO	National Defense Science & Engrg. Graduate Fellow	08/1/94 - 01/31/98	$96,540	Farris

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
NIST	Mechanics of Ceramic Machining	9/15/94-9/14/96	$90,300	Farris
NSF	A Proposal to Establish an Engineering Research Center for Collaborative Manufacturing	10/01/94-09/30/97	$219,545	Farris
GE Aircraft	Fretting Fatigue Feature Testing	03/15/97-12/14/97	$75,394	Farris
Caterpillar	Process Performance Model for Hard Turning	01/15/97-01/14/98	$90,400	Chandrasekar (Co-PI: Farris)
NASA	New H_2 / H_∞ Control Synthesis for the F-18	07/01/95-07/31/98	$66,000	Frazho
Air Force	Materials Degradation and Fatigue in Aerospace Structures	07/01/93-07/31/97	$3,209,473	Grandt (Farris, Hillberry, McCabe, Sun, Co-P.I.'s)
ALCOA	Validation of Widespread Fatigue Damage Models	07/01/96-06/30/97	$53,378	Grandt
Lockheed Martin	Crack Coalescence Analysis Methods Development	01/01/97-05/31/98	$66,947	Grandt
AFOSR	Modeling Primary Atomization Processes	07/01/96-11/30-97	$87,103	Heister
IBM	Nonlinear Modeling of Droplet Atomization Processes	08/01/96-7/31/97	$25,000	Heister
NASA	Indiana Space Grant Consortium Program Grant	03/01/92-06/30/97	$4,022	Heister
NASA	Trajectory Design Strategies for Libration Point Missions that Incorporate Invariant Manifolds	08/01/96-07/31/97	$22,000	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	050/1/95-09/30/97	$122,600	Howell
NASA	Delta-V Gravity-Assist Trajectory Design: Theory and Practice	08/01/93-12/31/96	$66,000	Longuski
JPL	Saturn Gravity Field Modeling Accuracy	06/01/96-09/30/97	$20,000	Longuski
JPL	Trajectory Options to Pluto via Gravity Assists from Venus, Mars, and Jupiter	08/01/96-12/31/96	$20,000	Longuski
NASA	Theory of Maneuvers for Small Autonomous Spacecraft	08/19/96-08/18/97	$22,000	Longuski
NASA	Indiana Space Grant	03/01/91-06/30/97	$4,049	Longuski
NASA	The Use of Kirchhoff's Method in Jet Aeroacoustics	12/15/94-07/14/97	$84,400	Lyrintzis

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
Sikorsky	Kirchhoff Acoustic Methodology Implementation and Validation for TiltRotor Aeroacoustic Codes (TRAC)	01/13/95-03/31/97	$40,000	Lyrintzis
ARO	An Extended Kirchhoff Method for Rotorcraft Impulsive Noise	03/01/97-08/31/97	$20,000	Lyrintzis
NASA	A Study of Rotorcraft Blade-tip Shape Noise Characteristics	01/15/97-08/31/97	$25,000	Lyrintzis
NSF	National Science Foundation Young Investigator Award	10/01/93-09/30/97	$212,500	Rotea
United Technologies	Industrial Match to NSF Young Investigator Award	11/01/96-12/31/75	$20,000	Rotea
AFOSR	Laminar-Turbulent Transition in High-Speed Compressible Boundary Layers with Curvature: Controlled Receptivity and Extent-of-Transition Experiments	11/15/93-11/14/96	$233,572	Schneider Co-Pi: Collicott
Air Force	Laminar-Turbulent Transition in High-Speed Compressible Boundary Layers with Curvature: Non-zero Angle of Attack Experiments	07/01/94-06/30/97	$145,364	Schneider
AFOSR	Laminar-Turbulent Transition in High-Speed Compressible Boundary Layers: Continuation of Elliptic-Cone Research	11/15/96-11/14/97	$165,378	Schneider Co-Pi: Collicott
NSF	Design of Controllable Civil Engineering Structures	10/1/94-09/30/97	$159,999	Skelton
NASA	Indiana Space Grant Consortium Program Grant	03/01/93-06/30/97	$10,000	Skelton
TRW	Space Systems Research	12/23/92-12/31/75	$1,000	Skelton
NASA	High-Lift Aerodynamics	06/01/93-08/31/97	$179,783	Sullivan Co-Pi: Schneider
NASA	Laser Scanning Pressure and Temperature Sensitive Paints	02/01/95-08/31/96	$18,098	Sullivan
NASA	Boundary-layer Transition Detection in Cryogenic Wind Tunnel using Fluorescent Paints	01/23/96-01/22/98	$132,011	Sullivan
Air Force	Luminescent Paints for Pressure Measurements on Rotation Machine	10/1/94-09/30/96	$89,879	Sullivan
Boeing	Portable Laser Scanning System	05/01/96-09/06/96	$26,700	Sullivan
NASA	Pressure and Temperature Measurement of Rotating Machinery using Fluorescent Paints	04/16/96-04/15/97	$75,000	Sullivan
NASA	Pressure and Temperature Sensitive Paint Measurements on Rotors	05/01/97-04/30/98	$40,000	Sullivan
ARO	Lightweight Layered Materials/Structures for Damage Tolerant Armor	09/01/96-02/28/97	$862,625	Sun Co-Pi's: Doyle, Espinosa

SPONSOR	PROJECT TITLE	PROJECT PERIOD	AWARD AMOUNT	P. I.
NASA	Modeling Damage Progression in Composite Laminated Structures	08/01/91-05/31/97	$279,865	Sun
ONR	Dynamic Constitutive and Failure Modeling of Composite Materials and Structures	02/01/96-09/30/97	$190,000	Sun
Univ. California	Testing and Modeling of Strain-Rate Dependent Constitutive Properties of Composite Fan Blade	10/01/96-09/30/97	$30,000	Sun
ONR	Development of Lightweight Multi-Core Composite Structures for Surface Ship Hull Applications	06/01/97-05/31/00	$100,400	Sun
McDonnell Douglas	Viscoplastic Modeling for HSCT Candidate Composite Materials	06/15/95-06/14/97	$103,214	Sun
ONR	Dynamic Response and Failure in Thick-Section Composite Cylindrical Shells Subjected to a Dynamic Pressure Wave	06/01/93-05/31/96	$73,118	Sun
Army	Development of Novel Multi-Layered Composite Structures for Ballistic Impact	07/01/94-12/31/97	$84,724	Sun
NASA	Interactive Aircraft Flight Control and Aeroelastic Stabilization	05/01/81-04/30/97	$808,392	Weisshaar

GRADUATE THESES
JULY 1996 - JUNE 1997

MASTER'S THESES

Student/ *Major Professor*	**Thesis Title**	**Degree Date Granted**
Bucci, Gregory S. *J. P. Sullivan*	"Modeled High Lift Wake Flows at High Reynolds Number"	MS December 1996
Caravella, Joseph R. *S. D. Heister*	"Investigation of Combustion in a Radial Flow Hybrid Rocket Engine"	MS August 1996
D'Amato, Fernando J. *M. A. Rotea*	"Control of Uncertain Lightly Damped Systems"	MS May 1997
Emore, Gordon L. *H. D. Espinosa*	"Computational Modeling of Geometric and Material Nonlinearities with Applications to Impact Dynamics"	MS December 1996
Ganapathy, Harish *T. N. Farris*	"Modeling of Plate/Fastener Contact: Application to Fretting Fatigue"	MS August 1996
Gates, Matthew D. *A. F. Grandt, Jr.*	"A Crack Gage Approach to Monitoring Flaw Growth Potential in Aircraft"	MS May 1997
Kannal, Lance *J. F. Doyle*	"Spectral Super-Elements for Wave Propagation"	MS December 1996
Koutsavdis, Evangelos *A. S. Lyrintzis*	"An Investigation of Kirchhoff Methodologies for Computational Aeroacoustics"	MS May 1997
Munro, Scott E. *S. P. Schneider*	"Effects of Elevated Driver Tube Temperature on the Extent of Quiet Flow in the Purdue Ludwieg Tube"	MS December 1996
Murray, Ian *S. D. Heister*	"Modeling Acoustically Induced Oscillations of Droplets"	MS August 1996
Rump, Kurt *S. D. Heister*	"Modeling the Effect of Unsteady Chamber Conditions on Atomization Processes"	MS December 1996
Viassolo, Daniel E. *M. A. Rotea*	"Implementation of Digital Controllers"	MS August 1996
Zink, Jonathan *M. J. Corless*	"Motion Control Experiments with Flexibly Jointed Robots"	MS December 1996

DOCTORAL THESES

Student/ ***Major Professor***	**Thesis Title**	**Degree Date Granted**
Davidson, John B. *D. A. Andrisani, II*	"Lateral-Directional Eigenvector Flying Qualities Guidelines and Gain Weighted Eigenspace Assignment Methodology"	Ph.D. May 1997
Ely, Todd A. *K. C. Howell*	"Dynamics and Control of Artificial Satellite Orbits with Multiple Tesseral Resonances"	Ph.D. December 1996
Heinimann, Markus *A. F. Grandt, Jr.*	"Analysis of Stiffened Panels with Multiple Site Damage"	Ph.D. May 1997
Hilbing, James H. *S. D. Heister*	"Nonlinear Modeling of Atomization Processes"	Ph.D. August 1996
Huang, Wen-Liang *M. H. Williams*	"Unsteady Aerodynamics of Ducted Fans"	Ph.D. August 1996
Ju, Yongqing *T. N. Farris*	"Thermal Aspects of Grinding for Surface Integrity"	Ph.D. May 1997
Kim, Hong-on *C. T. Sun*	"Elastic-Plastic Fracture Analysis for Small Scale Yielding"	Ph.D. August 1996
Kolonay, Raymond *H. T. Yang*	"Unsteady Aeroelastic Optimization in the Transonic Regime"	Ph.D. December 1996
Leeks, Tamara *T. A. Weisshaar*	"Active Aeroelastic Panels with Optimum Self-Straining Actuators"	Ph.D. May 1997
McCoy, Robert *C. T. Sun*	"Dynamic Stress Analysis of a Submerged Thick-Section Composite Cylinder"	Ph.D. December 1996
Qian, Wenqi *C. T. Sun*	"Fracture Mechanics in Interface Cracks with or without Friction"	Ph.D. May 1997
Sims, Jon A. *J. M. Longuski*	"Delta-V Gravity-Assist Trajectory Design: Theory and Practice"	Ph.D. December 1996
Spyropoulos, Evangelos *G. A. Blaisdell*	"On Dynamic Subgrid-Scale Modeling for Large-Eddy Simulation of Compressible Turbulent Flows"	Ph.D. December 1996

Su, Xuming *C. T. Sun*	"Three-Dimensional Effects in Elastic-Plastic Fracture"	Ph.D. December 1996
Vaidya, Rajesh S. *C. T. Sun*	"Failure Criterion for Notched Fiber Dominated Composite Laminates"	Ph.D. May 1997
Zhang, Xiaodong *C. T. Sun*	"Adaptive Sandwich Structures"	Ph.D. December 1996

Colloquium Series
1996 - 1997

Colloquium Series - Fall 1996

DATE/TIME	TOPIC	SPEAKER
September 12, 1996	Aircraft Structural Design - Towards New Horizons	**Dr. Terrence A. Weisshaar** Professor, School of Aeronautics and Astronautics, Purdue Univ.
September 17, 1996	The Origins & Future of Flight (A Paleoecological, Multidisciplinary Perspective)	**Dr. John McMasters** Sr. Principal Engr. Boeing Commercial Airplane Group
September 26, 1996 .	Solid Propellant Rocket Motor Failures	**Dr. Ellis M. Landsbaum** The Aerospace Corporation
October 10, 1996	Industrial Strength Problems, Systems & Education	**Professor Charles Boppe** Dept. of Aeronautics and Astronautics, MIT
October 17, 1996	Orbit Selection & Satellite Constellation Design	**Mr. Hans Karrenberg** The Aerospace Corporation
*October 24, 1996	Tiltrotor - Past, Present, & Future	**Mr. Tommy H. Thomason** Vice Pres. - Small Aircraft Engines Allison Engine Co.
November 7, 1996	Control-Oriented Identification and Model Validation	**Prof. Kameshwar Poola** Univ. of California-Berkeley
November 14, 1996	NASA High Angle of Attack Research Vehicle (HARV) Propulsion System Study Results	**Dr. William Steenken** General Electric Aircraft Engines
**November 15, 1996	Exact Solutions in Compressible Finite Elasticity	**Prof. Michael M. Carroll** Dean, Schools of Engineering Rice University

*Jointly hosted by School of Aeronautics and Astronautics and the Student Chapter of the American Helicopter Society

**Midwest Mechanics Seminar, sponsored jointly by the Schools of Aeronautics and Astronautics and Mechanical Engineering

Colloquium Series - Spring 1997

DATE/TIME	TOPIC	SPEAKER
*January 24, 1997	Progress in Large Eddy - Simulation of Turbulent Flows	**Professor Parviz Moin** Professor, Mechanical Engrg. Stanford University
February 6, 1997	Temperature Measurement on Contact Surface by Infrared Thermography	**Professor Takahide Sakagami** Dept. of Mechanical Engineering Osaka University
*March 7, 1997	MIDWEST MECH. SEMINAR	**Professor Herbert E. Huppert** Cambridge University
March 20, 1997	Advanced Composite Design	**Paul Lagace** Massachusetts Institute of Tech.
March 27, 1997	Aerodynamic Considerations in Design of Nacelles for Transport Aircraft	**Mr. Tom Wynosky** Pratt & Whitney Aircraft Engines
April 4, 1997	Materials for the Future	**Valery Vasiliev** Virginia Polytechnic Institute and State University
**April 9, 1997	National Rotorcraft Technology Center: A Technology Partnership Between Government, Industry and Academia	**Dr. John Shaw** Chief Scientist Boeing Defense & Space Group
*April 18, 1997	Saint-Venant End Effects in Composite Structures	**Professor Cornelius Horgan** Univ. of Virginia
April 23, 1997	Aerospace R & D in the Former Republics of the Soviet Union	**Dr. Mark S. Maurice** Wright Laboratory
May 7, 1997	Swept-wing Boundary-Layer Stability and Receptivity	**Yuri S. Kachanov** Institute of Theoretical and Applied Mechanics, Novosibirsk, Russia
May 15, 1997	Optical Diagnostic of Shock Tube Flows using Differential Interferometry	**Mr. Alfred George** French-German Research Inst.

*Midwest Mechanics Seminar, jointly hosted by the School of Aeronautics & Astronautics and the Mechanical Engineering Department

**Jointly hosted seminar by the School of Aeronautics & Astronautics and the Student Chapter of the American Helicopter Society

FACULTY ACCOMPLISHMENTS

The accomplishments of our faculty are important and enhance our student and industry interaction. Of particular note this year:

•**Professor Dominick Andrisani** spent the Fall Semester on sabbatical at Wright Patterson Air Force Base.

•**Professor Horacio Espinosa** was awarded a National Science Foundation CAREER grant for his "Tribo-Mechanics of Nanostructured Materials" research project. (Of the eligible faculty members at the School, nearly 50% have received this prestigious award.) He also earned the Office of Naval Research Young Investigator Award.

•**Professor Alten Grandt** was awarded the 1997 Elmer F. Bruhn Teacher Award and became a Fellow in the American Institute of Aeronautics and Astronautics.

•**Professor Steven Heister** spent the Spring semester on sabbatical at TRW, California.

•**Professor James Longuski** was nominated for the Murphy Outstanding Undergraduate Teaching Award 1996-97.

•**Professor Anastasios Lyrintzis** was admitted to the grade of Associate Fellow of American Institute of Aeronautics and Astronautics.

•**Professor Mario Rotea** spent the Summer at the United Technologies Research Center in East Hartford, Connecticut.

•**Professor C.T. Sun** was awarded the 1997 American Institute of Aeronautics and Astronautics Structures, Structural Dynamics and Materials Award for outstanding recent technical or scientific contribution in aerospace structures, structural dynamics, or materials.

STUDENTS ACCOMPLISHMENTS

Awards

The Sigma Gamma Tau Outstanding Senior Award recipient was Senior **R. Sergio Hasebe** and **Scott Schoenherr** was awarded the Herbert F. Rogers Scholarship. The 1997 Magoon Award for Outstanding Teaching Assistants went to: **Eric Campbell, David Fanjoy,** and **Stephen Norris**. Mr. **Daniel Bodony, Derek Liechty, Daniel Javorsek, Craig Williamson,** and Ms. **Kerrie Benish** and **Lisa Brilliant** received the William Koerner Scholarships.

Junior **Dwayne Bevis** was the first recipient of the Elmer F. Bruhn Undergraduate Research Assistantship, which was made possible by a generous donation from Lloyd and Rosalene Hackman.

Ph.D. candidate **Markus Heinimann** received the Best Student Paper Presentation Award at the May 1996 American Society for Testing and Materials (ASTM) E-08 commitee meeting held in St. Louis.

American Helicopter Society (AHS)

The Purdue Chapter of the American Helicopter Society, dedicated to promoting and advancing student involvement within the rotorcraft industry, completed its second year. Led by President **Jason Myers** and Chapter Advisor **Professor William Crossley**, the society has received funding from Allied Signal and United Technologies for research and development of the Human Powered Project. **Professors William Crossley** and **Anastasios Lyrintzis**, and A&AE students, set up a display booth at the 53rd Annual American Helicopter Society Forum in Virginia Beach, VA, April 29-May 1, 1997.

American Institute of Aeronautics & Astronautics (AIAA)

The Purdue Chapter of the American Institute of Aeronautics and Astronautics was led this year by: President **Greg Roth**. The Purdue Chapter has 275 members.

AIAA hosted or co-sponsored numerous special events including a reception for Astronaut **John Blaha**, who just returned from his MIR mission, and professional opportunities with speakers from industry. **Professor Marc Williams** was the AIAA Advisor.

Sigma Gamma Tau

Sigma Gamma Tau, the Aerospace Engineering Honor Society, has 60 members and was led this year by President **Tamiara Ross**. **Professor Martin Corless** is the Chapter Advisor.

Activities this year for Sigma Gamma Tau included maintaining the graduate photo board, selling A&AE baseball caps, and hosting industry speakers.

Students for Exploration and Development of Space (SEDS)

Established in 1994, SEDS members are dedicated to promoting the exploration and development of space by educating people about the benefits of space. SEDS coordinated the first annual Fall Space Day, which was an educational event for 3rd through 12th graders. More than 175 students and 25 chaperones attended the event. Astronauts **Gary Payton** and **Don Williams** were featured speakers. AIAA and Purdue Engineering Student Council also helped with this event. **Professor James Longuski** is the SEDS Advisor.

American Society for Testing and Materials (ASTM)

The Purdue ASTM Student Chapter was founded in the Fall of 1996 by an interdisciplinary group of graduate students involved primarily in fatigue and fracture research. The goal of the organization is to promote the exchange of information and expertise in the areas of materials research and testing on the Purdue campus. Student officers for the 1996/97 academic year included: president, Matthew Szolwinski (AAE); treasurer, Pamela McVeigh (AAE). Professors **A. F. Grandt** from the School of Aeronautics and Astronautics and B. M. Hillberry from the School of Mechanical Engineering serve as faculty co-advisors.

CURRICULUM & COURSE OFFERINGS