PURDUE
UNIVERSITY

School of Aeronautics and Astronautics

Research Report
2002 – 2003
Academic Year

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TABLE OF CONTENTS

OUR MISSION

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

ACADEMIC HIGHLIGHTS

Undergraduate enrollment was 476 for the fall of 2004 indicates that enrollment has tripled since 1997. During academic year 2002-03, 95 students earned their Bachelor of Science degree, 24 earned their Master of Science degree, and 10 earned their Doctor of Philosophy degrees. The *US News and World Report* ranked our graduate program sixth in the nation and our undergraduate program sixth amongst universities that award Ph.D.s. The School continues to appear on the list of "key schools" for the major US aerospace manufacturers.

Degrees Awarded
School of Aeronautics & Astronautics

Year	**98-99**	**99-00**	**00-01**	**01-02**	**02-03**
B.S.	43	43	60	67	95
M.S.	21	35	27	42	24
Ph.D.	11	9	17	19	10

Purdue University's Program for Study Abroad Office currently offers more than 200 programs in over 40 countries around the world. The School of Aeronautics and Astronautics continues to develop relationships with international universities, and has student exchange agreements with: Bristol University, United Kingdom; Royal Melbourne Institute of Technology, Melbourne, Australia; University of New South Wales, Sydney, Australia; Ecole Superieure des Techniques Aeronautiques et de Construction Automobile (ESTACA), Paris, France; and Osaka University, Japan.

The School of Aeronautics and Astronautics, through Purdue University's Continuing Engineering Education (CEE) Program, offers graduate level courses in aerospace engineering. This opportunity to reach students through distance education, along with our history of quality education, gives us confidence that our School's participation with CEE will be a benefit to all participants.

DEVELOPMENT HIGHLIGHTS

The Boeing Company, Lockheed-Martin, Northrop Grumman and Rolls-Royce, supported the Industrial Affiliates Program (IAP) this year. The School's Industrial Advisory Council (IAC) continued its bi-annual meeting schedule, meeting both in September 2002 and April 2003. IAC members are: Dr. William Ailor III, The Aerospace Corporation; Mr. Bradley Belcher, Rolls Royce; Dr. Paul Bevilaqua, Lockheed-Martin Corporation; Ms. Nancy Carpenter, ATK Thiokol Propulsion; Ms. Andrea Chavez, Ball Aerospace; Mr. Joseph Gernand, Boeing; Dr. William Kessler, Lockheed Martin Aeronautics Co.; Dr. Andrew King, Boeing; Dr. Donald Lamberson, Major General, USAF (ret.); Mr. David McGrath, ATK Tactical Systems; Mr. G. Thomas McKane, A.M. Castle & Co.; Mr. Hank Queen, Boeing; Mr. Charles Saff, Boeing; Mr. Randal Secor, Northrop Grumman Corp.; Mr. Daniel Devitt, Vought Aircraft; and Dr. Robert Strickler.

Annual unrestricted giving continues to increase at a modest rate. The School is actively campaigning for its portion of the Multidisciplinary Engineering Building. The State of Indiana's $37.7 million commitment toward the new building, combined with $10 million in private gift funding, is well on it's way to raising the $400 million goal Purdue has set to build the engineering complex.

Mike Kennedy (B.S.A.A.E. '70, DEA '00, OAE '01) and his wife Madeline pledged $300,000 to name the Mike and Madeline Kennedy Nondestructive Evaluation Laboratory to be housed in the future Millennium Engineering Building. Mr. Kennedy was appointed Vice President for the Boeing Evolved Expandable Launch Vehicle (EELV) and Delta IV Launch Vehicle Program in 1998 and was program manager for the next generation of expendable launch vehicles. Since he retired from Boeing in May 2001, Mr. Kennedy has worked as a consultant with Boeing Missile Defense Systems developing booster rockets for the National Missile Defense System.

ALUMNI HIGHLIGHTS

The School named the following six new Outstanding Aerospace Engineers (OAEs) in the Fall of 2003. Mr. Raymond Cosner (B.S.A.A.E. '72, M.S.A.A.E. '72); Ms. Peggy P. Dedo (B.S.A.A.E. '67); Mr. Richard L. Fahrner (M.S.A.E. '61); Mr. William H. Gerstenmaier (B.S.A.A.E. '77); Dr. Ronnie K. Miller (B.S.A.A.E. '73, M.S.A.A.E. '75, Ph.D. '79); and Brigadier General David A. Wagie (Ph.D. '84).

Major General John "Jack" L. Hudson (M.S.A.E. '74) was presented the Schools of Engineering Distinguished Engineering Alumnus Award on April 25, 2003. Major General Hudson is currently Program Executive Officer and Program Director, U.S.A.F. Joint Strike Fighter Program.

Dr. Charles E. Taylor (B.S.M.E. 1946, M.S.E.M. 1948) was awarded the honorary doctorate degree during the May 2003 ceremonies. Dr. Taylor was elected to the National Academy of Engineering for his pioneering developments in three-dimensional photoelasticity and in the use of laser holography.

Dr. Mike Howse, Director-Engineering & Technology, Rolls-Royce plc, gave the 5th William E. Boeing Distinguished Lecture at 4:00 PM on September 4, 2003 in Fowler Hall.

PUBLICATIONS

Listings of books, journal articles, and other printed conference papers and reports published in calendar year 2002 are given in the "Faculty Summary" section of this report. Only documents that actually appeared in print during 2002 are listed. Note that 1 book, 39 journal articles or book chapters, and 155 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 2002-03 academic year, 75 students were enrolled in the Cooperative Engineering Program with the 22 companies listed on the following page. This popular program is limited only by the number of industry positions available. About 13 in 129 new applicants received appointments this year. Many other students gain industrial experience through internships.

Co-Op Companies
School of Aeronautics and Astronautics
July 1, 2002-June 30, 2003

Company	Location	Number of A&AE Co-op Students
Aerospace Corporation	Los Angeles, CA	1
American Trans Air Engineering	Indianapolis, IN	0
ATA Engineering Inc.	San Diego, CA	4
Atlantic Research Corporation	Knoxville, TN	0
Ball Aerospace & Tech. Corp.	Boulder, CO	10
Boeing Satellite Systems	Los Angeles, CA	4
General Electric Aircraft Engines	Cincinnati, OH	13
NASA-Dryden Flight Research Center	Edwards, CA	2
NASA-Glenn	Cleveland, OH	1
NASA-Goddard	Greenbelt, MD	2
NASA-Johnson Space Center	Houston, TX	11
NASA-Kennedy Space Center	Kennedy Space Ctr., FL	2
NASA-Langley Research Center	Hampton, VA	3
Naval Research Laboratory	Washington, DC	0
Raytheon E-Systems	Greenville, TX	0
Rockwell International Corporation	Cedar Rapids, IA	4
Rolls-Royce	Indianapolis, IN	2
Structural Analysis Engineering	Cincinnati, OH	4
United Parcel Service (Air Group)	Louisville, KY	0
United Technologies Pratt & Whitney	W. Palm Beach, FL	0
United Technologies Pratt & Whitney	East Hartford, CT	2
Wright-Patterson AFB	Dayton, OH	3

OVERVIEW OF RESEARCH AREAS AND FACILITIES

With the support of the Boeing Company and the Intel Corporation, the School was able to enhance the Design/Build/Test Laboratory. This laboratory prepares students for integrated product teams in industry. The DBT Laboratory facilitates the reduction of the build time to give students a complete design and manufacturing experience. The lab is also currently being enhanced with state-of-the-art multimedia equipment.

In addition, many workstations and personal computers are located throughout the School. High performance computing is available, using multiple IBM, Silicon Graphics, and Sun Microsystems computers. The ***High Performance Computing Cluster for Aerospace Applications*** consists of a 104-CPU Beowulf Linux cluster using 1.2 GHz AMD Athalon microprocessors allowing distributed and parallel processing. Purdue also owns a 320-CPU IBM SP supercomputer.

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; experimental measurements using laser systems; and laminar-turbulent transition in high speed boundary layers.

Experimental facilities include four wind tunnels located at the **Aerospace Sciences Laboratory** (ASL). **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 ASL. One has an 18 inch diameter test section, and the other two have test sections of 12 by 18 inches. Several small calibration tunnels are also available, along with a small water table.

Three small high-speed facilities are located in the **Boeing Compressible-Flow Laboratory**. The first is a 2-inch Mach-2.5 blowdown tunnel, and the second is a one-inch supersonic jet apparatus designed for nozzle-flow studies. Both can be operated in pressure-vacuum mode and are used primarily for teaching. The jet apparatus also includes a heater and particle filter to enable supersonic hot-wire calibrations. A 4-inch shock tube is also available.

Lastly, the Boeing Compressible-Flow Laboratory also includes two large Ludwieg tubes. The first has a 4-inch Mach-4 test section and remains quiet to a length

Reynolds number of about 400,000. The second, completed in 2001, has a 9.5-inch Mach-6 test section, but is so far quiet only at low Reynolds numbers. Instrumentation is specialized for study of laminar-turbulent instability and transition, and includes high-speed hot wires, fast-response pressure transducers, hot-film arrays and anemometers, a high-sensitivity laser-differential interferometer, a glow-discharge perturber, and a pulsed laser perturber.

DYNAMICS AND CONTROL

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

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

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

PROPULSION

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

The ***Advanced Propellants and Combustion Laboratory*** is housed at MZL, and is comprised of two test cells. The test cells are of poured, reinforced concrete design with containment steel doors and explosive rated viewing windows. These cells are classed for both Class 1.1 and 1.3 explosives and are equipped with a frangible blowout wall in case of major catastrophic events. Test Cell A currently contains a rocket thrust stand capable of handling thrust loads of up to 1000 lbf. Test Cell B is used for hybrid rocket

combustion studies and vacuum ignition studies for a variety of new nontoxic hypergolic propellants. These cells are both equipped to handle advanced storable oxidizers with emphasis on high concentration hydrogen peroxide. In local proximity is a dedicated oxidizer storage building and a dedicated explosive/propellant storage bunker, rated for Class 1.1 materials.

The ***High Pressure Laboratory***, also located at MZL is a major new facility shared with Mechanical Engineering. This facility has two 500 square-foot test cells rated for propulsion testing up to 10,000 lbf thrust levels. The airbreathing propulsion cell has a cyclic pulse detonation rig capable of simultaneous firing of up to four tubes. A 5 million sample-per-second high speed data system and associated pressure instrumentation is available in addition to a more standard suite of pressure/temperature/thrust instrumentation. A high-pressure gas turbine combustor experiment is also housed in this cell. The rocket propulsion cell has capabilities to test liquid oxygen/hydrocarbon thrust units at thrust levels up to 5000 lbf and pressures up to 5000 psi. Experiments in both the airbreathing and rocket propulsion cells are controlled remotely with a state-of-the-art data acquisition and control panel.

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

STRUCTURES AND MATERIALS

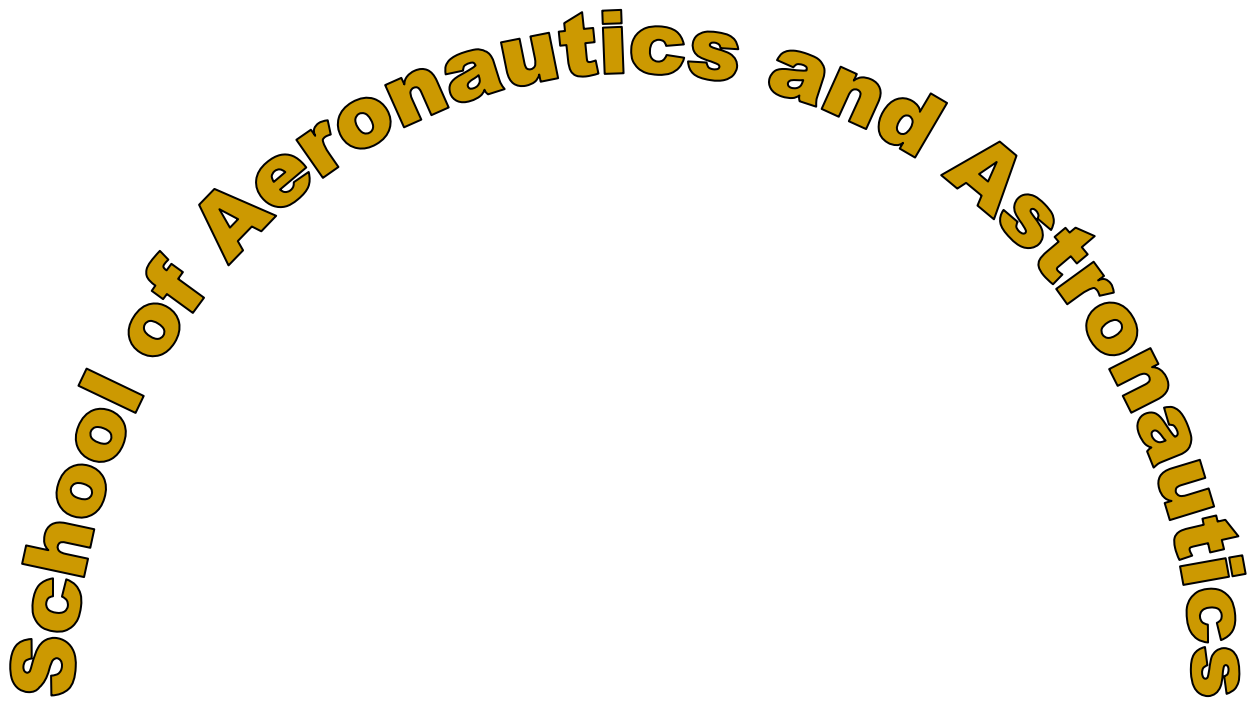
Structures and materials research includes work in composite materials, computational structural mechanics, damage tolerance analysis, experimental structural analysis, structural mechanics and aeroelasticity, tribology, manufacturing, wave propagation, smart materials and structures, and optimal design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

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

The **Fatigue and Fracture Laboratory** is well-equipped to conduct structural integrity motivated research directed at evaluating the damage tolerant properties of materials and components. Two computer-controlled electro-hydraulic test machines (11,000 and 22,000 lb. capacity), and associated equipment, are used 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, and to perform nondestructive inspections by magnetic particle and dye penetrant methods.

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.

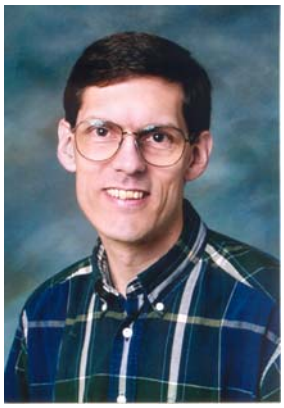
The **Tribology and Materials Processing Laboratory,** maintained jointly with the **Center for Materials Processing and Tribology** contains tribological instrumentation as well as up-to-date machines for manufacturing processes. Equipment includes a 22 kip computer-controlled electro-hydraulic test machine and associated equipment for fretting fatigue testing at room and elevated temperatures, infrared sensors for full-field temperature measurements, a friction apparatus for both low and high speed sliding indentation, lapping and polishing equipment, a vibration isolation table, micropositioning stages, a sliding wear experiment, Talysurf profilometers, phase shift interferometric profilometer, an atomic force microscope, a nanoindenter, a talysurf instrument for measurements of form, cylindricity cuts and taper, and an SEM and optical microscopes. A piezo-electric based load frame has been constructed to perform high frequency fretting fatigue experiments related to HCF of aircraft engines. Also, access is available to a variety of machine tools: a precision high speed surface grinder, a centerless grinder, and a super finishing machine, as well as associated piezoelectric force transducers.



FACULTY SUMMARIES

AERODYNAMICS

Faculty Members



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

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

M. C. Jischke, University President, Ph.D., Massachusetts Institute of Technology, 1968.

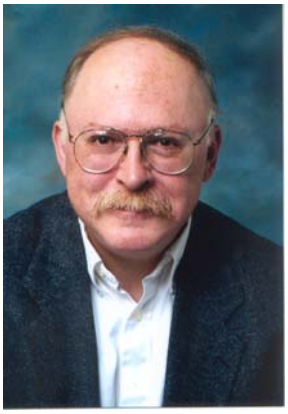
A. S. Lyrintzis, Professor, Ph.D., Cornell, 1988, computational aeroacoustics, aerodynamics for rotorcraft and jet flows.

AERODYNAMICS

Faculty Members

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

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



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

GREGORY A. BLAISDELL
1991
Associate Professor

Degrees

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

Interests

Computational fluid mechanics
Transition and turbulence

Awards and Major Appointments

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

Research Areas

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

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

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

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

Axial vortices form in many engineering systems but are of particular importance to the wake hazard problem for commercial aircraft. A previous study used direct numerical simulation (DNS) to investigate an isolated turbulent axial vortex. However, the DNS are limited to low Reynolds numbers—the DNS are at a Reynolds number that is three orders of magnitude lower than that of the wake vortices behind a typical large commercial airliner. Although LES on currently available computers will not be able to achieve full scale Reynolds numbers, it will allow the trends with increasing Reynolds numbers to be determined. This is important because Reynolds number is believed to have a significant effect on the development of turbulence within a vortex.

On the Development of Supersonic Jet Noise Prediction Methodology (Co-investigator: A. S. Lyrintzis (Purdue, AAE); Student: E. K. Koutsavdis; Sponsored by NASA Glenn; Computer resources: NPACI (Cray T90), NCSA (SGI Origin 2000), (PUCC/IBM SP2), Purdue CS (SGI Origin 2000))

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

Modeling Diesel Engine Injector Flows (Co-investigator: Stephen D. Heister (Purdue, AAE); Student: C. Xu; Sponsored by Army Research Office)

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

thereby providing an important link/methodology to reduce emissions through prudent injector design.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Koutsavdis, E. K., Uzun, A., Lyrintzis, A. S., and Blaisdell, G. A., "On the Development of a Supersonic Jet Noise Prediction Methodology," final report for NASA Glenn contract no. NAG-2095, Feb. 2002.

Uzun, A., Blaisdell, G. A., and Lyrintzis, A. S., "Recent Progress Towards a Large Eddy Simulation Code for Jet Aeroacoustics," paper no. AIAA 2002-2598, *AIAA/CEAS Aeroacoustics Conference*, Breckenridge, CO, June 17-19, 2002.

Heister, S. D., Blaisdell, G. A., Lyrintzis, A. S., and Crossley, W. A., "LINUX Cluster for High-Performance Parallel Computing," final report for ARO contract DAAD19-01-1-0439, June 2002.

STEVEN C. COLLICOTT
1991
Associate Professor

Degrees

B. S., University of Michigan, Aerospace Engineering, magna cum laude, 1983
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 cannot 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

Schmisseur, J. D., Schneider, S. P., and Collicott, S. H., "Supersonic Boundary Layer Response to Optically-Generated Freestream Disturbances," *Experiments in Fluids*, Vol. 33, No. 2, Aug. 2002, pp. 225-232.

Conference Proceedings, Presentations, Invited Lectures and Reports

Chen, Y. and Collicott, S. H., "Effects of Wicking and Spin on Bubble Position in the Gravity Probe-B Helium Tank Geometry," paper no. AIAA-2002-1004, *40th AIAA Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 2002.

Weislogel, M. M. and Collicott, S. H., "Analysis of Tank PMD Rewetting Following Thrust Resetting," paper no. AIAA-2002-0757, *40th AIAA Aerospace Sciences Meeting and Exhibit*, Reno, NV, Jan. 2002.

Salyer, T. R., Collicott, S. H., and Schneider, S. P., "A Laser Generated Thermal Spot Model for Accurate CFD Receptivity Simulation," paper no. AIAA-2002-3230, *22nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* St. Louis, MO, June 24-26, 2002.

Collicott, S. H. and Weislogel, M. M., "Modeling of the Operation of the VTRE Propellant Management Device," paper no. AIAA-2002-4140, *40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Chandra, B. W. and Collicott, S. H., "Low Gravity Propellant Slosh Prediction using Surface Evolver," paper no. AIAA-2002-3981, *40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Collicott, S. H., "A Purdue Course on Spacecraft Zero-Gravity Fluids Engineering," paper no. AIAA-2002-4189, *40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Chen, Y. and Collicott, S. H., "Investigation of the Wetting Behavior of a Vane-Wall Gap in Propellant Tanks," paper no. AIAA-2002-3986, *40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Simmons, B. D., Marchetta, J. G., Hochstein, J. I., and Collicott, S. H., "Numerical Prediction of Magnetic Cryogenic Propellant Storage in Reduced Gravity," paper no. IAC-02-J.2.05, *53rd International Astronautical Congress of the International Astronautical Federation (IAF)*, Houston, TX, Oct. 10-19, 2002.

ANASTASIOS S. LYRINTZIS
1994
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

a. The Use of Integral Techniques in Computational Aeroacoustics

Dr. Lyrintzis has made significant contributions in the use of integral techniques Computational Aeroacoustics (CAA). CAA is concerned with the prediction of the aerodynamic sound source and the transmission of the generated sound starting from the time-dependent governing equations. The goal is to improve the state-of-the-art predictive techniques, so that aircraft and rotorcraft noise can be reduced. Dr. Lyrintzis has pioneered the use of integral techniques, (i.e. the Kirchhoff method and the porous Ffowcs Williams Hawkings [FWH] equation) for describing source propagation. The methods are attractive because they utilize surface integrals (over a source region) to determine far-field acoustics, as opposed to the memory intensive volume integrals found in traditional acoustic analogy methods.

Rotorcraft Impulsive Noise: In recent years the increasing use of helicopters and the projected use of tiltrotor aircraft has drawn attention to the noise that they generate. Among the several types of helicopter and tilt rotor noise, that due to helicopter impulsive noise is the most important. Dr. Lyrintzis has introduced the application of Kirchhoff's methodology for rotorcraft impulsive noise prediction. The details of the noise mechanisms are studied extensively and analogies to other unsteady motions are drawn. Both full potential as well as Euler/Navier Stokes codes are employed for the aerodynamic near-field prediction. Dr. Lyrintzis also investigates ideas for noise reduction (e.g. blade tip shape).

Jet Noise: Jet noise prediction is a very important part of aircraft noise. Dr. Lyrintzis has employed Kirchhoff's method in jet noise prediction as well. He

introduced an important extension to the method in order to include non-linear flow regions that exist downstream of the computational Computational Fluid Dynamics (CFD) domain. Dr. Lyrintzis proved the equivalence of Acoustic Analogy methods (based on the Ffowcs Williams Hawkings [FWH] equation) and Kirchhoff's methods, as part of the extensions of the Kirchhoff method. He also added mean flow refraction corrections (downstream of the control surface) in the methodology. Currently, a new high-order accurate three-dimensional Large Eddy Simulation (LES) CFD code is being developed (with Professor Blaisdell) to provide accurate input data for the Kirchhoff and FWH equation methods. This is part of a large-scale effort in jet noise reduction in collaboration with Rolls-Royce, Indianapolis.

Dr. Lyrintzis' research demonstrates that a simple set of versatile portable Kirchhoff/Acoustic Analogy subroutines can be developed to analyze and reduce noise generation in a number of applications including fans, propellers, air-conditioning units etc.

b. Efficient Parallel Methods for Transonic Flow Calculations.

Dr. Lyrintzis is also investigating the development of efficient computational techniques for the calculation of unsteady transonic flow on parallel machines. The goal is to improve efficiency and parallelization of legacy CFD codes. Dr. Lyrintzis studies unsteady three-dimensional problems in rotorcraft aerodynamics to enhance the computational efficiency of impulsive rotorcraft noise calculations. The algorithm methodologies developed are general and can be readily applied to several existing CFD codes. This work has been funded by NASA Ames Research Center.

Sponsored Research Summaries

Development of Low Jet Noise Aircraft Engines (Project Leader: Anastasios Lyrintzis, G. Blaisdell, L. Mongeau, S. Bolton, and (W. Dalton of Rolls-Royce), Sponsored by Indiana 21st Century Research and Technology Fund)

The regional and corporate aircraft engine market's rapid expansion will be severely compromised, unless jet noise is drastically reduced. Rolls-Royce, Indianapolis, with a commanding share of 37% in this sector of the world market, may lose business to out-of-state competitors if its engines fail to meet stringent airport noise regulations. In this project experts from Purdue University and Rolls-Royce will advance the science of jet noise reduction for turbofan engines by studying the noise of internally mixed engines, where the hot core flow is mixed with the cooler fan flow inside the exhaust nozzle by lobed mixers. The turbulent mixing of these two flows and their mixing with the atmosphere causes jet noise. Although empirical methods can be used to reduce noise, optimal engine design is not possible without deeper scientific understanding. Our team of experts will synthesize computational, theoretical, and experimental techniques to generate a new level of understanding of jet noise reduction. Rolls-Royce has a plan in place for the rapid commercialization of such scientific breakthroughs. Thus the accelerated technology transfer of our new science will impact about 1200 highly skilled employees at Rolls-Royce in Indiana and also its many local suppliers.

Aerodynamic and Aeroacoustic Optimization of Airfoils via a Parallel Genetic Algorithm (Principle Investigator: H. Namgoong; Co-Principal Investigator: W. A. Crossley; Sponsored by Purdue Research Foundation)

A parallel genetic algorithm (GA) was used to generate, in a single run, a family of aerodynamically efficient, low-noise rotor blade designs representing the Pareto optimal set. The n-branch tournament, uniform crossover, genetic algorithm operates on twenty design variables which constitute the control points for a spline representing the airfoil surface. The GA takes advantage of available computer resources by operating in either serial mode or manager/worker parallel mode. The multiple objectives of this work were to maximize lift-to-drag of a rotor airfoil shape and to minimize an overall noise measure including effects of loading and thickness noise of the airfoil. Constraints are placed on minimum lift coefficient, pitching moment and boundary layer convergence. The program XFOIL provides aerodynamic analysis, and the code WOPWOP provides aeroacoustic analysis. The Pareto-optimal airfoil set has been generated and is compared to the performance of a typical rotorcraft airfoil under identical flight conditions.

Publications

Kim, H., Williams, M. H., and Lyrintzis, A. S., "An Improved Method for Rotor Wake Capturing," *AIAA Journal of Aircraft*, Vol. 39, No. 5, Sept.-Oct. 2002, pp. 794-203

Ekici, K. and Lyrintzis, A. S., "Parallelization of Rotorcraft Aerodynamics Navier-Stokes Codes," *AIAA Journal*, Vol. 40, No. 5, May 2002, pp. 887-896.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Koutsavdis, E. K., Uzun, A., Lyrintzis, A. S., and Blaisdell, G. A., "On the Development of a Supersonic Jet Noise Prediction Methodology," final report for NASA Glenn grant no. NAG-2095, Feb. 2002.

Heister, S. D., Blaisdell, G. A., Lyrintzis, A. S., and Crossley, W. A., "LINUX Cluster for High-Performance Parallel Computing," final report for ARO contract DAAD19-01-1-0439, June 2002.

Uzun, A., Blaisdell, G. A., and Lyrintzis, A. S., "Recent Progress Towards a Large Eddy Simulation Code for Jet Aeroacoustics," paper no. AIAA-2002-2598, *8th AIAA/CEAS Aeroacoustic Conference,* Breckenridge, CO, June 2002.

Namgoong, H., Crossley, W. A., and Lyrintzis, A. S., "Issues for Global Optimization in Multipoint Transonic Airfoil Design," paper no. AIAA-2002-5641, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization,* Atlanta, GA, Sept. 2002.

Lyrintzis, A. S., "From the Near-Field to the Far-Field: Integral Acoustics Methods," *CAES 6th Workshop "From CFD to CAA"*, Athens, Greece, Nov. 2002.

Lyrintzis, A. S., Blaisdell, G. A., Mongeau, L., and Bolton, S., "Development of Low Jet Noise Aircraft Engines," Quarterly Reports to the 21st Century Research and Technology Fund (9/01, 12/01, 3/02, 6/02, 9/02, 12/02).

STEVEN P. SCHNEIDER
1989
Associate Professor

Degrees

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

Interests

Experimental fluid mechanics
High-speed laminar-turbulent transition

Research Areas

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

Sponsored Research Summaries

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

To complement the expensive quiet-flow facilities under development at NASA Langley, a low-cost 4-inch Mach 4 quiet-flow Ludwieg tube was constructed at Purdue. Quiet was demonstrated to length Reynolds numbers of 400,000 (AIAA Journal, April 1995, p. 688). Localized hot-spot disturbances were repeatably generated by a pulsed Nd:YAG laser in order to generate repeatable wave packets in the flow, and surface perturbations were generated by a glow perturber. Perturbations are measured using hot wires, high-sensitivity laser differential interferometry, and arrays of surface hot films.

A new 18-inch stainless-steel Ludwieg tube is now operational with a 9.5-inch quiet-flow Mach-6 test section. Quiet-flow operation to a length Reynolds number of 13 million is projected (AIAA Paper 98-0547), although quiet-flow has so far been achieved only at low Reynolds numbers. Modern digital and optical instrumentation will enable

efficient use of the 10-second run-time, and the short duration keeps operating costs low. The larger test section enables testing with larger models and thicker boundary layers.

Publications

Schmisseur, J. D., Schneider, S. P., and Collicott, S. H., "Supersonic Boundary Layer Response to Optically-Generated Freestream Disturbances," *Experiments in Fluids,* Vol. 33, No. 2, Aug. 2002, pp. 225-232.

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Kwon, S. W. and Schneider, S. P., "Stress Analysis for the Window of the Purdue Quiet-Flow Ludwieg Tube," paper no. AIAA-2002-0309, *AIAA Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 2002.

Schneider, S. P., Skoch, C., Rufer, S., Matsumura, S., and Swanson, E., "Transition Research in the Boeing/AFOSR Mach-6 Quiet Tunnel," paper no. AIAA-2002-0302, *AIAA Aerospace Sciences Meeting and Exhibit,* Reno, NV, Jan. 2002.

Schneider, S. P., Rufer, S., Skoch, C., Matsumura, S., and Swanson, E., "Progress in the Operation of the Boeing/AFOSR Mach-6 Quiet Tunnel," paper no. AIAA-2002-3033, *22nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* St. Louis, MO, June 24-26, 2002.

Salyer, T. R., Collicott, S. H., and Schneider, S. P., "A Laser Generated Thermal Spot Model for Accurate CFD Receptivity Simulation," paper no. AIAA-2002-3230, *22nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* St. Louis, MO, June 24-26, 2002.

Sakaue, H., Matsumura, S., Schneider, S. P., and Sullivan, J. P., "Anodized Aluminum Pressure Sensitive Paint for Short Duration Testing," paper no. AIAA-2002-2908, *AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* St. Louis, MO, June 24-26, 2002.

Schneider, S. P., "Laminar-Turbulent Transition Research in the Boeing/AFOSR Mach-6 Quiet Tunnel," Arizona State Univ., Tempe, AZ, Feb. 15, 2002.

Schneider, S. P., "Hypersonic Laminar-Turbulent Transition," TRW/Space Park, Redondo Beach, CA, July 2, 2002.

JOHN P. SULLIVAN
1975
Professor

Degrees

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

Interests

Experimental aerodynamics
Laser instrumentation
Luminescent sensors for temperature and pressure measurements

Research Areas

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

1. High lift systems
2. Suction/blowing airfoils

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

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

Conference Proceedings, Presentations and Invited Lectures

Sakaue, H., Matsumura, S., Schneider, S. P., and Sullivan, J. P., "Anodized Aluminum Pressure Sensitive Paint for Short Duration Testing," paper no. AIAA-2002-2908, *AIAA Aerodynamic Measurement Technology and Ground Testing Conference,* St. Louis, MO, June 24-26, 2002.

Gregory, J. W., Sakaue, H., Sullivan, J. P., "Unsteady Pressure Measurements in Turbomachinery using Porous Pressure Sensitive Paint," paper no. AIAA 2002-0084, *40th Aerospace Sciences Meeting and Exhibit*, Reno, NV, Jan. 14-17, 2002.

Huang, C.-Y., Sakaue, H., and Sullivan, J. P., "Molecular Sensors for MEMS," paper no. AIAA 2002-0256, *40th Aerospace Sciences Meeting and Exhibit*, Reno, NV, Jan. 14-17, 2002.

Gregory, J., W., Sakaue, H., and Sullivan, J. P., "Fluidic Oscillator as a Dynamic Calibration Tool" paper no. AIAA 2002-2701, *22nd Aerodynamic Measurement Technology & Ground Testing Conference*, St. Louis, MO, June 24-26, 2002.

Sullivan, J., Gregory, J. W., Huang, C.-Y., Sakaue, H., "Flow Visualization Applications of Luminescent Paints," Keynote Paper F0452, *10th International Symposium on Flow Visualization*, Kyoto, Japan, Aug. 26-29, 2002.

MARC H. WILLIAMS
1981
Professor and Associate Head

Degrees

B. S., University of Pittsburgh, Aeronautical Engineering,
magna cum laude, 1969
M. A., Princeton University, Aerospace & Mechanical Sciences, 1971
Ph.D., Princeton University, Aerospace & Mechanical Sciences, 1975

Interests

Aerodynamics
Computational fluid Mechanics

Research Areas

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

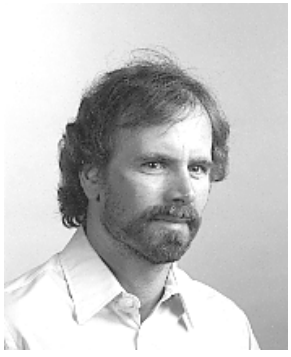
Much of this work has been done for advanced propfan applications. These engines are intended for use on medium range commercial transports, which operate at low transonic Mach numbers. In order to maintain high operating efficiency and low noise, the blades are very thin and flexible. Therefore, they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

DYNAMICS AND CONTROL

Faculty Members

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

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



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

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

DYNAMICS AND CONTROL

Faculty Members

J. L. Garrison, Assistant Professor, Ph.D., University of Colorado, 1997, satellite navigation, GPS, and remote sensing.

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

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

DOMINICK ANDRISANI II
1980
Associate Professor

Degrees

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

Interests

Estimation
Control
Dynamics
Flight Aircraft Flying Qualities

Research Areas

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

Publications

Kim, E. T. and Andrisani II, D., "Robust Tracker Design Method Based on Multi-Trajectories of Aircraft," *The Korean Society for Aeronautical and Space Sciences International Journal* [in English], Vol. 3, No. 1, May 2002, pp. 39-49.

Ryu, S. and Andrisani II, D., "Longitudinal Flying Qualities Prediction for Nonlinear Aircraft," *Journal of Guidance, Control, and Dynamics*, Vol. 26, No. 3, May 2003, p. 474-482.

Conference Proceedings, Presentations, Invited Lectures and Reports

Andrisani II, D., "Fundamentals of Strapdown Inertial and GPS-Aided Navigation," *Tactical Imagery Geopositioning Workshop*, Chantilly, VA, Mar. 12, 2002.

Bethel, J., van Gelder, B., Mikhail, E., Braun, A., Mulyana, A., Andrisani II, D., and Hoshizaki, T., “Motion Imagery Modeling Study,” final report, submitted to Sarnoff Corporation, Apr. 15, 2002.

MARTIN CORLESS
1984
Professor

Degrees

B. E., University College, Dublin, Ireland, Mechanical Engineering, (1st honors), 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

Corless, M., Swei, S.-M., and Rotea, M. A., "System Order Reduction in the Stabilization of Multi-Block Uncertain Systems," *International Journal of Control,* Vol. 75, No. 2, 2002, pp. 69-79.

Sultan C., Corless M., and Skelton R. E., "Symmetrical Reconfiguration of Tensegrity Structures," *International Journal of Solids and Structures*, Apr. 2002.

Sultan, C., Corless, M., and Skelton R. E., "Linear Dynamics of Tensegrity Structures," *Journal of Engineering Structures*, May 2002.

Acikmese, A. B. and Corless M., "Robust Output Tracking for Uncertain/Nonlinear Systems Subject to Almost Constant Disturbances," *Automatica*, Vol. 36, No. 11, 2002, pp. 1919-1926.

Conference Proceedings, Presentations, Invited Lectures and Reports

Acikmese, A. B. and Corless, M., "Constant Output Tracking and Disturbance Rejection for Systems with Lipschitz Nonlinearities," *15th IFAC World Congress*, Barcelona, Spain, 2002.

Bengea, S., DeCarlo, R., Rizzoni, G., Yurkovich, S., and Corless, M., "A Polytopic System Approach for Gain Scheduled Control of a Diesel Engine," *15th IFAC World Congress*, Barcelona, Spain, 2002.

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

Frazho, A. E. and Kaashoek, M. A., "A Band Method Approach to a Positive Expansion Problem in a Unitary Dilation Setting," *Integr. Equation Operator Theory,* Vol. 42, 2002, pp. 311-371.

Foias, C., Frazho, A. E., and Kaashoek, M. A., "Relaxation of Metric Constrained Interpolation and a New Lifting Theorem," *Integr. Equation Operator Theory,* Vol. 42, 2002, pp. 253-310.

Foias, C., Frazho, A. E., and Kaashoek, M.A., "Contractive Liftings and the Commutator," *C.R. Acad. Sci. Paris,* Ser. I **335** (2002), pp. 431-436.

Conference Proceedings, Presentations, Invited Lectures and Reports

Frazho, A. E. and Kaashoek, M.A., *MTNS Conference at Notre Dame*, Invited Talk, Aug. 2002.

Frazho, A. E., Yagci, B., and Sumalik, A., "A Note on Sinusoid Estimations in Non-Stationary Noise," *Allerton Conference on Control*, Oct. 2002, 10 pages.

JAMES L. GARRISON
Assistant Professor
2000

Degrees

B.S. Rensselaer Polytechnic Institute, Troy, NY, Aeronautical Engineering, 1988
M.S. Stanford University, Stanford, CA, Aeronautics and Astronautics 1990
Ph.D. The University of Colorado, Aerospace Engineering Sciences, 1997

Interests

Satellite navigation
GPS
Remote sensing

Publications

Garrison, J. L., Komjathy, A., Zavorotny, V., and Katzberg, S., "Wind Speed Measurement from Forward Scattered GPS Signals," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 40, No. 1, Jan. 2002, pp. 50-65.

Conference Proceedings, Presentations, Invited Lectures and Reports

Garrison, J. L., Bertuccelli, L., and Moreau, M., "GPS Code Tracking in High Altitude Orbiting Receivers," *IEEE Position Location and Navigation Symposium (PLANS)*, Palm Springs, CA, Apr. 15-18, 2002.

Garrison, J. L. and Bertuccelli, L., "Model Function Development for GPS Reflection Measurements," *2002 IEEE International Geoscience and Remote Sensing Symposium*, Toronto, Canada, June 23-28, 2002.

KATHLEEN C. HOWELL
1982
Professor

Degrees

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

Interests

Orbit mechanics
Spacecraft dynamics, control
Trajectory optimization

Research Areas

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

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

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

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

Conference Proceedings, Presentations, Invited Lectures and Reports

Howell, K. C., "Dynamics Around the Libration Points: Transfers to L_1 and L_2 using Lunar Gravity," *International Conference on Libration Point Orbits and Applications*, Parador d'Aiguablava, Girona, Spain, June 10-14, 2002.

Howell, K. C., "The Timing Condition and Trajectory Design," *SPACE DAYS: Space Mission Design and Dynamical Systems,* Univ. of Paderborn, Germany, Sept. 30-Oct. 1, 2002.

JAMES M. LONGUSKI
1988
Professor

Degrees

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

Interests

Spacecraft Dynamics
Orbit Mechanics
Control
Orbit decay and reentry

Awards and Major Appointments

NOVA (Notable Organizational Value-Added) Award from Jet Propulsion Laboratory

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) the current goal is to develop 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 gravity-assist problem in terms of identifying potential trajectories (such as the Voyager Grand Tour, the Galileo VEEGA, and the Europa Orbiter Tour) and optimizing the launch energy and propellant requirements for these missions.

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

Strange, N. J. and Longuski, J. M., "Graphical Method for Gravity-Assist Trajectory Design," *Journal of Spacecraft and Rockets*, Vol. 39, No. 1, Jan.-Feb. 2002, pp. 9-16.

Heaton, A. F., Strange, N. J., Longuski, J. M., and Bonfiglio, E. P., "Automated Design of the Europa Orbiter Tour," *Journal of Spacecraft and Rockets,* Vol. 39, No. 1, Jan.-Feb. 2002, pp. 17-22.

Johnson, W. R. and Longuski, J. M., "Design of Aerogravity-Assist Trajectories," *Journal of Spacecraft and Rockets,* Vol. 39, No. 1, Jan.-Feb. 2002, pp. 23-30.

Okutsu, M. and Longuski, J. M., "Mars Free Returns via Gravity Assist from Venus," *Journal of Spacecraft and Rockets,* Vol. 39, No. 1, Jan.-Feb. 2002, pp. 31-36.

Johnson, W. R., Longuski, J. M., and Lyons, D. T., "Pitch Control During Autonomous Aerobraking for Near-Term Mars Exploration," *Journal of Spacecraft and Rockets,* Vol. 40, No. 3, May 2003, pp. 371-379.

McConaghy, T. T., Debban, T. J., Petropoulos, A. E., and Longuski, J. M., "Design and Optimization of Low-Thrust Trajectories with Gravity-Assists," *Journal of Spacecraft and Rockets,* Vol. 40, No. 3, May 2003, pp. 380-387.

Conference Proceedings, Presentations, Invited Lectures, and Reports

McConaghy, T. T., Longuski, J. M., and Byrnes, D. V., "Analysis of a Broad Class of Earth-Mars Cycler Trajectories," paper no. AIAA-2002-4420, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Chen, K. J., McConaghy, T. T., Okutsu, M., and Longuski, J. M., "A Low-Thrust Version of the Aldrin Cycler," paper no. AIAA-2002-4421, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Chen, K. J., Landau, D. F., McConaghy, T. T., Okutsu, M., Longuski, J. M., and Aldrin, B., "Preliminary Analysis and Design of Powered Earth-Mars Cycling Trajectories," paper no. AIAA-2002-4422, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Byrnes, D. V., McConaghy, T. T., and Longuski, J. M., "Analysis of Various Two Synodic Period Earth-Mars Cycler Trajectories," paper no. AIAA-2002-4423, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Jokic, M. D. and Longuski, J. M., "Design of a Tether Sling for Human Transportation Systems Between Earth and Mars," paper no. AIAA-2002-4642, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Jokic, M. D., Daniel, W. J. T., and Longuski, J. M., "3-D Modeling of an Elastic Tether using a Dissipative Time-Stepping Algorithm," paper no. AIAA-2002-4643, *AIAA/AAS Astrodynamics Specialist Conference*, Monterey, CA, Aug. 5-8, 2002.

Debban, T. J., McConaghy, T. T., and Longuski, J. M., "Design and Optimization of Low-Thrust Gravity-Assist Trajectories to Selected Planets," paper no. AIAA-2002-4729, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

Johnson, W. R., Longuski, J. M., and Lyons, D. T., "High-Fidelity Modeling of Semi-Autonomous Attitude Control During Aerobraking," paper no. AIAA-2002-4909, *AIAA/AAS Astrodynamics Specialist Conference,* Monterey, CA, Aug. 5-8, 2002.

MARIO A. ROTEA
1990
Professor

Degrees

Electronic Engineering Degree, 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

Algorithms for estimation and control under uncertainty
Algorithms for large-scale optimization and on-line optimization
Modeling, optimization, and control of mechanical and aerospace systems

Awards and Major Appointments

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

Research Areas

Active Projects

Analysis and Design of Multivariable Extremum Seeking Algorithms, NSF, September 2000—August 2004

Parameter Estimation for Airdrop System, Fleet and Industrial Supply Center, July 2000—September 2003

Colorimetric Modeling using Robust Parameter Estimation, Xerox, August 2001—July 2004

Mission Design and Analysis Involving Formation Flying Near Libration Point Orbits, NASA (PI: K. Howell), July 2003—June 2006

Air Traffic Management for the 21st Century and Beyond, e-Enterprise Center & VP for Research (with D. Andrisani, A. Chaturvedi, T. Carney, M. Nolan), July 2003—June 2004

Publications

Corless, M., Swei, S-M,., and Rotea, M. A., "System Order Reduction in the Stabilization of Multi-block Uncertain Systems," *International Journal of Control*, Vol. 75, No. 2, 2002, pp. 69-79.

Conference Proceedings, Presentations, Invited Lectures, and Reports

Rotea, M. A. and D'Amato, F., "New Tools for Analysis and Optimization of Mistuned Bladed Disks," paper no. AIAA-2002-4041, *38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Viassolo, D. E. and Rotea, M. A., "Design of Multirate Output Controllers with an Engineering Application," *IFAC 15th World Congress*, Barcelona, Spain, July 2002.

Rotea, M. A. and D'Amato, F., "Efficient Algorithms for Mistuning Analysis in Turbomachinery," *IFAC 15th World Congress*, Barcelona, Spain, July 2002.

Rotea, M. A., "Semidefinite Programming: Applications in Systems and Control," graduate seminar series, Univ. of Minnesota, Aerospace Engineering and Mechanics Dept., Jan. 2002.

Rotea, M. A. and Kothandaraman, G., "Parameter Estimation for Airdrop System," Report, Contract N00244-01-P-2540, Aug. 2002, 48 pages.

PROPULSION

Faculty & Staff Member

W. E. Anderson, Assistant Professor, Ph.D., 1996, Pennsylvania State University, combustor design, combustion stability, atomization, and combined cycle propulsion.

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

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

Scott Meyer, Senior Engineer, MSAE 1991, Purdue Univ.

WILLIAM E. ANDERSON
2001
Assistant Professor

Degrees

B. S., Arizona State Univ., Chemistry, 1979
M. S., Univ. of Arizona, Chemical Engrg., 1984
Ph.D., The Pennsylvania State University, Mechanical Engrg., 1996

Interests

Combustor design
Combustion stability
Atomization
Combined cycle propulsion

Sponsored Research Summaries

Rocket Combustor Design – The a priori analysis of rocket combustor performance, heat transfer, and life are difficult because the extreme environments of the combustor make direct measurements and prediction difficult. Improved methodologies for preliminary injector design analysis and combustor life prediction are being developed using subscale approaches combined with relatively simple analysis. The injector design projects emphasize measurements in representative high-pressure rocket combustors (>1000 psia) and concurrent determination of one-dimensional energy release profiles. The life prediction work looks to develop innovative subscale test approaches for life cycle testing, including the acquisition of validation data for thermostructural models, life data on advanced materials in prototypical combustor configurations, identification of failure modes, and definition of long-life design concepts. This work is sponsored by NASA Marshall Space Flight Center.

Rocket-Based Combined Cycle Combustors – Combined cycle systems offer potential cost and performance benefits over all-rocket systems, yet they present design challenges due to added system complexities. Work is underway to develop a prototype thruster that will be used in a flight experiment to develop an operational baseline for future flight tests of RBCC systems. This work is sponsored by NASA Dryden Flight Center.

Non-Toxic Propellants – It is imperative to find safe replacements for highly toxic storable propellants. Before new propellant combinations can be used, reliable design databases must be developed. Experimental combustion data are being generated for hydrogen peroxide and dimethylethylamidoazide, two propellants that are significantly less toxic than storable propellants currently in use. The experiments include both realistic combustor conditions and geometries and measurements of propellant drop vaporization and chemical reaction in optically accessible chambers. Work is also

underway to develop improved field test methods for the determination of the stability margin of hydrogen peroxide. Sponsors include NASA Marshall Space Flight Center and Stennis Space Center, and the Army Space and Missile Defense Command.

Conference Proceedings, Presentations, Invited Lectures and Reports

Mok, J.-S., Helms, J., and Anderson, W., "Decomposition and Vaporization Studies of Hydrogen Peroxide," paper no. AIAA 2002-4028, Indianapolis, IN, July 8-10, 2002.

Fitzpatrick, S., Prater, D., and Anderson, W., "A Design, Build, Test Course in Rocket Combustors," paper no. AIAA 2002-4186, Indianapolis, IN, July 8-10, 2002.

Anderson, W. and Meyer, S., "Propulsion Test Facilities at Purdue University," paper no. AIAA 2002-4280, Indianapolis, IN, July 8-10, 2002.

Long, M. R., Anderson, W. E., and Humble, R. W., "Bi-Centrifugal Swirl Injector Development for Nontoxic Hypergolic Bipropellants," paper no. AIAA 2002-4026, Indianapolis, IN, July 8-10, 2002.

STEPHEN D. HEISTER
1990
Professor

Degrees

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

Interests

Rocket propulsion
Liquid propellant injection systems
Two-phase and capillary flows

Sponsored Research Summaries

1. Atomization modeling - Under **AFOSR** sponsorship, a number of atomization models have been developed to study the unsteady evolution of liquid jets and droplets. These simulations utilize boundary element methods to provide high-resolution of very large surface distortions and atomization processes. In fact, a number of the models can carry out calculations beyond atomization events. Currently, we are developing a more comprehensive model to treat the entire spray formed by a high-speed injection process. This model incorporates detailed drop dynamics including collisions and secondary atomization of droplets in the spray. Current models track upwards of 2,000,000 droplets simultaneously in a parallel-processing approach.

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

3. Diesel Engine Injector Modeling - This project, funded by **Cummins Engine Company**, **NSF**, and **ARO** is aimed at developing computational tools for use in simulating internal flows in diesel injector passageways. Due to the high injection pressures, cavitation is a crucial feature, which must be incorporated in the modeling. To this end, we have developed a new cavitation treatment capable of addressing hydrodynamic nonequilibrium effects in a fully viscous calculation. Two-dimensional simulations have been compared to experimental measurements from Professor Collicott's research group with favorable results. A full 3-D model has recently been

developed making use of advanced parallel processing schemes in a LINUX computing environment. The model shows complex unsteady flow behavior under cavitating conditions. Presently, a turbulence model is being incorporated in the 2-D codes.

Publications

Mailhe, L. and Heister, S. D., "Design of a Hybrid Chemical/Electric Propulsion Orbital Transfer Vehicle," *Journal of Spacecraft and Rockets*, Vol. 39, No.1, 2002, pp. 131-139.

Xu, C., Heister, S. D., and Field, R., "Modeling Cavitating Venturi Flows," *Journal of Propulsion and Power*, Vol. 18, No. 6, 2002, pp. 1227-1234.

Conference Proceedings, Presentations, Invited Lectures and Reports

Remson, A. E., Crossley, W. A., and Heister, S. D., "Consumable Satellite Structures for Apogee Insertion Applications," paper no. AIAA-2002-3574, *38th AIAA/ASME/ SAE/ASEE Joint Propulsion Conference and Exhibit*, July 2002.

Heister, S. D., Blaisdell, G. A., Lyrintzis, A. S., and Crossley, W. A., "LINUX Cluster for High-Performance Parallel Computing," final report for ARO contract DAAD19-01-1-0439, June 2002.

Pham, T. L. and Heister, S. D., "Spray Modeling using Lagrangian Droplet Tracking in a Homogeneous Flow Model," *Atomization and Sprays*, 2002.

Xu, C., Heister, S. D., and Field, R., "Model Cavitating Venturi Flows," *Journal of Propulsion and Power*, 2002.

Kim, B-D. and Heister, S. D., "Two-Phase Modeling of Hydrodynamic Instabilities in Coaxial Injectors," *Journal of Propulsion and Power*, 2002.

Xu, C., Blaisdell, G. A., and Heister, S. D., "Modeling of Turbulent Cavitation Flows," *Journal of Fluids Engineering*, 2002.

Xu, C., Heister, S. D., and Blaisdell, G. A., "Simulation of Cavitated Flow in Orifices Fed by a Manifold," *Atomization and Sprays*, 2002.

Yoon, S. S. and Heister, S. D., "Analytic Solutions for Computing Velocities Induced from Potential Vortex Ring," *AIAA Journal*, 2002.

Yoon, S. S. and Heister, S. D., "A Fully Nonlinear Model for Atomization of High-Speed Jets," *Engineering Analysis with Boundary Elements*, 2002.

Yoon, S. S. and Heister, S. D., "Categorizing Linear Theories for Atomizing Jets," *Atomization and Sprays*, 2002.

Yoon, S. S. and Heister, S. D., "Fully Nonlinear Primary Atomization Model," ILASS-02 Conference, 2002.

Austin, B. L. and Heister, S. D., "Characterization of Pintle Engine Performance for Nontoxic Hypergolic Bipropellants," *5th International Hydrogen Peroxide Propulsion Conference,* 2002.

Martin, T. N., Edwards, J. M., Heister, S. D., and Meyer, S. E., "A Device to Investigate Peroxide Reactivity at Elevated Pressures," *5th International Hydrogen Peroxide Propulsion Conference,* 2002.

Remson, A., Crossley, W., and Heister, S.D., "Consumable Satellite Structures for Apogee Insertion Applications," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Kim, B. and Heister, S., "Two-Phase Modeling and Hydrodynamic Instability Study of Shear Coaxial Injector Flow," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Xu, C., Heister, S., Collicott, S., and Yeh, C., "Modeling Cavitating Venturi Flows," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Shimo, M., Meyer, S., Heister, S., and Gore, J., "Initial Results from Pulse Detonation Engine Experiments at Purdue University," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Kowalkowski, M., Heister, S., and Bulathsinghala, I., "Trajectory Control of Agile Land Mines," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Bulathsinghala, I., Kowalkowski, M., and Heister, S., "Propulsion for Agile Landmines II, Dynamic Simulations and Experiments," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Beutien, T., Heister, S., Rusek, J., and Meyer, S., "Cordierite-Based Catalytic Beds for 98% Hydrogen Peroxide," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Miller, K., Martin III, T., Edwards, J., Heister, S., and Meyer, S., "Immersion Test Apparatus for Studying Monopropellant Decomposition with Various Catalysts," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Weinstock, V. and Heister, S., "Modeling Oil Flows in Engine Sumps: Drop Dynamics and Wall Impact Simulation," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Shimo, M. and Heister, S., "Modeling Oil Flows on Seal Runners and Engine Sump Walls," *38th AIAA Joint Propulsion Conference and Exhibit,* Indianapolis, IN, July 2002.

Austin, B., Matthews, J., and Heister, S., "Development of Pintle and Splash Plate Injectors for Nontoxic, Storable, Hypergolic Bipropellants," *38th AIAA Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Funk, J., Rusek, J., and Heister, S., "Reaction Zones for Impinging Jets and Sheets," *38th AIAA Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Kwon, T. and Heister, S., "Modeling Droplet Impact on Dry and Wet Walls," *38th AIAA Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Yoon, S. and Heister, S., "A Fully Nonlinear Primary Atomization Model," *38th AIAA Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

Heister, S. and Rusek, J., "Development of a Design/Build/Test Course in Rocket Propulsion," *38th AIAA Joint Propulsion Conference and Exhibit*, Indianapolis, IN, July 2002.

SCOTT MEYER
2001
Sr. Engineer

Degrees

B.S.A.A.E., Purdue University, School of Aeronautics & Astronautics, 1990
M.S.A.A.E., Purdue University, School of Aeronautics & Astronautics, 1992

Scott Meyer is a Senior Propulsion Engineer at Purdue University for the Departments of Mechanical Engineering and Aeronautics and Astronautics. He joined the Purdue staff in 2001 to direct propulsion testing operations and to develop the test facilities for the Indiana Propulsion and Power Center of Excellence.

From 1998 to 2001, Mr. Meyer worked at Beal Aerospace in Frisco, Texas as a senior propulsion engineer. In this role, he defined test programs to support the development of the BA2-C launch vehicle stages and rocket engines. He wrote test plans and coordinated test planning with the engine test facilities including mechanical and fluid system interfaces and instrumentation and control requirements. He directed the procurement, manufacture, and assembly activities for the construction of rocket engines and wrote engine assembly and catalyst preparation procedures. He directed testing operations, wrote test procedures, supervised the installation of test hardware, defined requirements for and performed system calibrations, and performed rocket engine tests. Following testing he wrote test and analysis reports and was responsible for the validation and analysis of test data including engine and stage performance and data reduction methodologies.

From 1993 to 1998 Mr. Meyer worked at Arnold Engineering Development Center in Tullahoma, Tennessee as a project engineer in the Propulsion Wind Tunnel Facility. There he directed multi-million dollar propulsion integration wind tunnel tests for contractors on the F-22 and F/A-18 fighter aircraft and the X-33 SSTO launch vehicle. As such his responsibilities included providing instrumentation specifications and hardware design requirements, managing testing operations, and performing project cost estimation and fiscal management.

Mr. Meyer is a co-patent holder for a hybrid rocket engine ignition device.

Conference Proceedings, Presentations, Invited Lectures and Reports

Anderson, W. and Meyer, S., “Propulsion Test Facilities at Purdue University,” paper no. AIAA 2002-4280, Indianapolis, IN, July 8-10, 2002.

JOHN J. RUSEK
1998
Adjunct Assistant Professor

Degrees

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

Interests

Energy Conversion
Chemical and Physical Propulsion
Power Generation

Awards and Major Appointments

- Who's Who in the World
- Who's Who in America

Research Areas

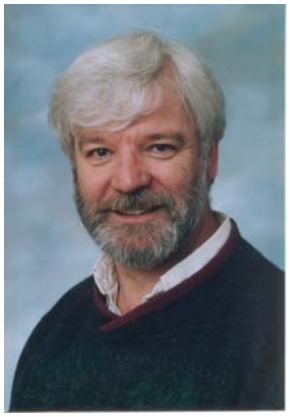
Current research is directed towards obtaining a fundamental understanding of hydrogen peroxide decomposition via heterogeneous and homogeneous catalysis for use in rocket propulsion and power generation. Major focus concerns the synthesis, characterization, and testing of these novel catalysts in rocket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

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

STRUCTURES AND MATERIALS

Faculty Members

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



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

T. N. Farris, Professor and Head, Ph.D., Northwestern, 1986, tribology, manufacturing processes, fatigue and fracture.

A. F. Grandt, Jr., Professor, Ph.D., Illinois, 1971, damage-tolerant structures and materials, fatigue and fracture, and aging aircraft.

STRUCTURES AND MATERIALS

Faculty Members

P. K. Imbrie, Assistant Professor, Freshman Engineering, Ph.D., Texas A&M, 2000, educational research, solid mechanics, experimental mechanics, and nonlinear materials characterization.

H. Kim, Assistant Professor, Ph.D., University of California-Santa Barbara, 1998, composites, impact, stability, and adhesive joining.

C. T. Sun, Professor, Ph.D., Northwestern, 1967, composites, fracture and fatigue, and structural dynamics.

Terrence A. Weisshaar, Professor, Ph.D., Stanford, 1971, aircraft structural mechanics, aeroelasticity, integrated design.

WILLIAM A. CROSSLEY
1995
Associate Professor

Degrees

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

Interests

Optimization
Rotorcraft and aircraft design
Structure design

Research Areas

Professor Crossley's major research interests are in the area of design methodologies and optimization, with emphasis on techniques like the GA that will allow optimization-like methods to be applied in the conceptual design phase, which traditionally has been dominated by qualitative or subjective decision making. Significant contributions have been made in applications to discrete actuator placement, topology design, and satellite constellation design.

Sponsored Research Summaries

Topology Design of Rotor Blades for Aerodynamic and Structural Concerns. This computational research effort strives to develop a rotor blade design strategy with the potential to improve the aerodynamic, structural, and dynamic performance of advanced rotorcraft. This work investigates the Genetic Algorithm (GA) as a 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 multi-disciplinary approach combining structural and aerodynamic concerns for optimal topology design of rotor blades provides potential benefit to the rotorcraft design process. The aerodynamic optimization portion of this research was cited in the technical research highlights of the NASA Ames Research Center, Rotor Aeromechanics Branch for 1999. Contributions in the structural portion of the research have demonstrated capabilities for discrete (on/off) topology; most notably handing connectivity issues and performing design of sections under combinations of bending and torsion that several authors had previously claimed were not possible.

Genetic Algorithm Issues for Optimal Smart Actuator Placement. This research is investigating approaches for smart actuator placement to provide aircraft maneuverability without requiring hinged flaps or other control surfaces. The effort supports many of the goals of the Multidisciplinary Design Optimization focus efforts in NASA's Aircraft

Morphing program. Computational studies are being conducted to allow comparison and selection of appropriate techniques for posing and solving an actuator placement problem. The work began with a geometrically simple wing model, but the approaches identified during this research have been applied to complete aircraft configurations. The problem statement and algorithm application are being used at NASA Langley by researchers working on the Aircraft Morphing Program. Research in this area has been cited twice as technical highlights for the NASA Langley Multidisciplinary Optimization Branch; once in 1998 and again in 1999.

Improved Satellite Constellation Design and Optimization. Improving satellite constellation design is of great interest to any users of satellite communication (e.g. cellular phones, television), location (e.g. global positioning system) and/or observation (e.g. weather). Many of today's satellite constellation designs rely on the "Walker Constellations," a series of designs developed in 1970, which have rarely been improved upon. These constellations make use of symmetric constellations with circular orbits. Using the genetic algorithm to search the constellation design space has begun to yield constellation designs not previously envisioned but with performance equal to or greater than comparable Walker or "streets of coverage" constellations. Research is ongoing for sparse coverage constellations, constellation build-up problems, multiobjective constellation concerns and elliptic orbit constellations. The Aerospace Corporation performs satellite constellation design for its US Air Force customers using the design techniques developed as part of this research. In one of these studies, a multiobjective GA approach was able to generate constellation designs that outperformed constellations that had been under development for several months. The GA was able to do this in a matter of days.

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. Because the GA-based approach to conceptual design helps to reduce the number of qualitative decisions needed from the design team, this appears to have great potential for application to aircraft design. 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 underway for fixed-wing aircraft. The Systems Analysis Branch at NASA Langley Research Center supports this research.

Methods to Assess Commercial Aircraft Technologies. Increasing competition in the commercial aircraft industry requires that airframe manufacturers be judicious with technology research and development efforts. Currently, technology development strategies for commercial aircraft appear to be lacking; this research presents a methodology to assess new technologies in terms of both cost and performance. This methodology encompasses technologies that can be applied to the aircraft design and technologies that improve the development, manufacturing, and testing of the aircraft. This differs from past studies that focused upon a small number of performance-based technologies. The method is divided into two phases. The first phase evaluates technologies based on cost measures alone. The second phase redesigns an aircraft with

new technologies, assesses the relative importance of performance-based technologies, and recognizes technology interactions using Taguchi's Design of Experiments. For a wide-body transport aircraft example, the methodology identifies promising technologies for further study. Recommendations and conclusions about the methodology are made based on the results. This work was done in collaboration with the Configuration Engineering and Analysis group at Boeing Commercial Aircraft.

Response Surface Methods as Approximation Models for Optimization. Approximation techniques, particularly the use of response surfaces (RS), have achieved wide popularity in engineering design optimization, especially for problems with computationally expensive analyses. The chief aims of using RS is to lower the cost of optimization and to smooth out the problem (e.g., for analyses solved iteratively, with a convergence tolerance). In one part of this research effort, an investigation of RS methods to minimize drag of a turbofan nacelle is being pursued in conjunction with engineers at Allison Advanced Development Company. This approach can improve the nacelle design practices at AADC by providing a formalized optimization framework for this CFD-based design exercise. The use of RS raises practical questions about the solution accuracy and computational expense. In particular, building response surfaces may involve a prohibitively large number of high-fidelity function evaluations, depending on problem dimensionality. In another part of this research effort, a computational study to address questions of expense and accuracy was undertaken with researchers in the Multidisciplinary Optimization Branch at NASA Langley Research Center. Important observations about the impact of constructing and using response surfaces for moderately high-dimensional problems were made. NASA researchers are using the RS models constructed during this portion of the research to further investigate techniques to manage approximation models in engineering optimization.

Publications

Fanjoy, D. W. and Crossley, W. A., "Topology Design of Planar Cross-Sections with a Genetic Algorithm: Part 1 – Overcoming the Obstacles," *Engineering Optimization,* Vol. 34, No. 1, Jan. 2002, pp. 33-48.

Fanjoy, D. W. and Crossley, W. A., "Topology Design of Planar Cross-Sections with a Genetic Algorithm: Part 2 – Bending, Torsion and Combined Loading Applications," *Engineering Optimization,* Vol. 34, No. 1, Jan. 2002, pp. 49-64.

Hassan, R. A. and Crossley, W. A., "Multi-objective Optimization for Communication Satellites with a Two-branch Tournament Genetic Algorithm," *Journal of Spacecraft and Rockets*, Vol. 40, No. 2, Mar. 2003, p. 266-272.

Conference Proceedings, Presentations, Invited Lectures and Reports

Martin, E. T. and Crossley, W. A., "Empirical Study of Selection Methods for Multiobjective Genetic Algorithm," paper no. AIAA-2002-0177, *40th AIAA Aerospace Sciences Meeting and Exhibit,* Jan. 2002.

Raymer, D. P. and Crossley, W. A., "A Comparative Study of Genetic Algorithm and Orthogonal Steepest Descent for Aircraft Multidisciplinary Optimization," paper no. AIAA-2002-0514, *40th AIAA Aerospace Sciences Meeting and Exhibit*, Jan. 2002.

Hassan, R. A. and Crossley, W. A., "Multiobjective Conceptual Design of a Geostationary Communication Satellite," paper no. AIAA-2002-1323, *43rd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Denver, CO, Apr. 2002.

Hassan, R. A. and Crossley, W. A., "Conceptual Satellite Design using Uncertain Reliability Values via a Genetic Algorithm with Population-based Sampling," paper no. AIAA-2002-1683, *4th Non-Deterministic Approaches Forum* at the *43rd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Denver, CO, Apr. 2002.

Remson, A. E., Crossley, W. A., and Heister, S. D., "Consumable Satellite Structures for Apogee Insertion Applications," paper no. AIAA-2002-3574, *38th AIAA/ASME/ SAE/ASEE Joint Propulsion Conference and Exhibit*, July 2002.

Heister, S. D., Blaisdell, G. A., Lyrintzis, A. S., and Crossley, W. A., "LINUX Cluster for High-Performance Parallel Computing," final report for ARO contract DAAD19-01-1-0439, June 2002.

Prock, B. C., Weisshaar, T. A., and Crossley, W. A., "Energy as an Objective for Airfoil Shape Change Optimization," paper no AIAA-2002-5401, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, Sept. 2002.

Martin, E. T., Hassan, R. A., and Crossley, W. A., "Comparison of Multiobjective Genetic Algorithm Approaches for *N* Objectives," paper no. AIAA-2002-5430, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, Sept. 2002.

Peters, C., Roth, B., Crossley, W. A., and Weisshaar, T. A., "Use of Design Methods to Generate and Develop Missions for Morphing Aircraft," paper no. AIAA-2002-5468, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, Sept. 2002.

Namgoong, H., Crossley, W. A., and Lyrintzis, A. S., "Issues for Global Optimization in Multipoint Transonic Airfoil Design," paper no. AIAA-2002-5641, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, Sept. 2002.

Raymer, D. P. and Crossley, W. A., "Variations of Genetic Algorithm and Evolutionary Methods for Optimal Aircraft Sizing," paper no. AIAA-2002-5839, *2nd AIAA Aircraft Technology, Integration, and Operations (ATIO) 2002 Forum*, Los Angeles, CA, Oct. 2002.

Roth, B., Peters, C., and Crossley, W. A., "Aircraft Sizing with Morphing as an Independent Variable: Motivation, Strategies and Investigations," paper no. AIAA-2002-5840, *2nd AIAA Aircraft Technology, Integration, and Operations (ATIO) 2002 Forum*, Los Angeles, CA, Oct. 2002.

Martin, E. T. and Crossley, W. A., "Multiobjective Aircraft Design to Investigate Potential Geometric Morphing Features," *2nd AIAA Aircraft Technology, Integration, and Operations (ATIO) 2002 Forum*, Los Angeles, CA, Oct. 2002.

Thom, M. A., Crossley, W. A., and Thom, J. M., "The Application of Structured Engineering Design Methodologies to Engineering Curriculum Development," *IEEE Frontiers in Education Conference*, Boston, MA, Nov. 6-9, 2002.

Crossley, W.A., "Preliminary performance and Sizing of Morphing Air Vehicles," *In-Flight Reconfigurable Aircraft Workshop*, Dec. 10-11, 2002.

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) 2-D Fast Fourier Transforms.

Publications

Adams, R. and Doyle J. F., "Multiple Force Identification for Complex Structures," *Experimental Mechanics,* 2002. **42**(1), pp. 25-36.

Doyle, J. F., "Reconstructing Dynamic Events from Time-limited Spatially Distributed Data," *Numerical Methods in Engineering*, 2002, **53**, pp. 2721-2734.

Doyle J. F., "Inverse Methods in Experimental Mechanics," in *Advances in Experimental Mechanics*, Kluwer, The Netherlands, 2002.

Conference Proceedings, Presentations, Invited Lectures and Reports

Doyle, J. F., "Force Identification using Dynamic Photoelasticity," *Numerical Methods in Engineering*, submitted 2002.

Doyle, J. F., "Impact Force Identification for Nonlinear Structures," *Impact Engineering*. submitted 2002.

Doyle J. F., "Inverse Methods in Experimental Mechanics I: partially specified problems," *Congress of Applied Mechanics*, Blacksburg, June 2002.

Doyle J. F., "Inverse Methods in Experimental Mechanics II: partially specified problems," *Congress of Applied Mechanics*, Blacksburg, June 2002.

THOMAS N. FARRIS
1986
Professor and Head

Degrees

B. S., Rice University, Mechanical Engineering, cum laude, 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

Awards and Major Appointments

General Chair of 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Seattle WA, April 2001

Research Areas

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

Manufacturing process research includes experimental and analytical work on grinding, turning, 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 and tempering 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.

Publications

Madhavan, V., Chandrasekar, S. and Farris, T. N., "Direct Observations of the Chip-Tool Interface in the Low Speed Cutting of Pure Metals," *ASME Journal of Tribology*, Vol. 124, No. 3, 2002, pp. 617-626.

Goryacheva, I. G., Murthy, H. and Farris, T. N., "Contact Problem with Partial Slip for the Inclined Punch with Rounded Edges," *International Journal of Fatigue*, Vol. 24, 2002, pp. 1191-1202.

Rajeev, P. T. and Farris, T. N., "Numerical Analysis of Fretting Contacts of Dissimilar Isotropic and Anisotropic Materials," *Journal of Strain Analysis*, Vol. 37, No. 6, 2002, pp. 503-517 [PE Publishing Award].

Conference Proceedings, Presentations, Invited Lectures and Reports

Rajeev, P. T. and Farris, T. N., "Load History Effects in Fretting of Dissimilar Contacting Materials," *Proceedings of the 42nd AIAA/ASME/ASCE/ASC Structures, Structural Dynamics and Materials Conference*, Denver, CO, Apr. 2002.

Murthy, H., Farris, T. N., and Okane, M., "Investigation of Fretting Characteristics of Turbine Materials at Higher Temperatures," *Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, Denver, CO, Apr. 2002.

Farris, T. N., Murthy, H., and Matlik, J. F., "Fretting Fatigue of Contacts between Engine Alloys of Dissimilar Elastic Properties," *Proceedings of the 7th National Turbine Engine High Cycle Fatigue (HCF) Conference*, W. Palm Beach, FL, May 2002.

Murthy, H., Rajeev, P. T., and Farris, T. N., "Fretting Fatigue of Ti6A14V/Ti6A14V and Ti6A14V/In718 Subjected to Blade/Disk Contact Loading," *Fatigue 2002 the 8th International Fretting Fatigue Congress*, Stockholm, Sweden, June 2002.

Rajeev, P. T., Murthy, H., and Farris, T. N., "Load History Effects on Fretting Contacts of Isotropic Materials," paper no. GT 2002-30297, *Proceedings of ASME Turbo Expo 2002*, Amsterdam, June 2002.

Hwang, J., Kompella, S., Chandrasekar, S., and Farris T. N., “Direct Measurement of Workpiece Temperature Field in Surface Grinding,” *Abrasives Magazine*, Apr./May 2002, pp. 15-18.

ALTEN F. GRANDT, JR.
1979
Raisbeck Engineering Distinguished Professor for Engineering and Technology Integration

Degrees

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

Interests

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

Research Areas

General technical interests deal with assuring the safe operation of aerospace and other complex structures through damage tolerance analyses and nondestructive inspection. Particular emphasis is on basic research to predict critical and subcritical crack growth under static and cyclic loads (i.e. fracture and fatigue). The influence of corrosion on structural integrity is also of interest. This research may be characterized by several overlapping categories.

Aging aircraft research is aimed at determining and/or extending the remaining life of structures that have seen extended periods of service, and focuses on determining the effect of multiple site damage on residual strength, and on evaluating the influence of corrosion on fatigue life.

Evaluation of new materials and manufacturing processes includes characterization of new materials in simple coupon or mechanical joint scenarios, analysis of fatigue resistant fastening systems, and evaluation of damage tolerant aspects of unitized construction. Research in this category also includes development of devices to monitor the severity of aircraft loading and has led to one patent.

Crack growth research is directed at predicting crack formation by fretting, corrosion, or cyclic loading, and as well as characterization of fatigue crack growth under complex variable amplitude and/or elevated temperature load histories.

Stress intensity factor analyses are aimed at obtaining solutions to evaluate complex two- and three-dimensional crack configurations common to aerospace structures (e.g. cracked fastener holes, dovetail joints, etc.).

Publications

Yang, X., Liu, C. R., and Grandt, Jr. A. F., "An Experimental Study on Fatigue Life Variance, Residual Stress Variance, and Their Correlation of Turned and Ground Ti 6A1-4V Samples," *Journal of Manufacturing Science and Engineering*, Transactions of the ASME, Vol. 124, No. 4, 2002, pp. 809-819.

Conference Proceedings, Presentations, Invited Lectures and Reports

Golden, P. J. and Grandt, Jr., A. F., "Crack Growth Predictions of Ti-6A1-4V Fretting Fatigue Tests," *7th National Turbine Engine High Cycle Fatigue (HCF) Conference*, Palm Beach Gardens, FL, May 14-17, 2002.

Garcia, D. B. and Grandt, Jr., A. F., "Fractographic Examination of Fretting Induced Cracks in Ti-6A1-4-V, *7th National Turbine Engine High Cycle Fatigue (HCF) Conference*, Palm Beach, FL, May 14-17, 2002.

Grandt, Jr., A. F., and Kim, J., "Modeling Three-Dimensional Crack Growth in Damage Containment Features," AeroMat 2002, *ASM International 13th Advanced Aerospace Materials and Processes Conference ad Exposition*, Orlando, FL, June 10-13, 2002.

Zonker, H. R., Yeh, J.R., Bray, G. H., Bucci, R. J., Wang, H. T., Grandt, Jr., A. F., and Par, C. Y., "Improving the Performance of Mechanically Fastened Joints Through the Use of New Fatigue Resistant Aluminum Alloys," AeroMat 2002, *ASM International 13th Advanced Aerospace Materials and Processes Conference ad Exposition*, Orlando, FL June 10-13, 2002.

Grandt, Jr., A. F., and Kim, J., "Three-Dimensional Crack Growth Experiments," *4th Boeing Unitized Structure Technical Interchange*, San Francisco, CA, Sept. 16, 2002.

Grandt, Jr., A. F. and Park, C. Y., "Analysis of Fatigue Crack Growth from Countersunk Fastener Holes," *FAA 2nd Annual Centers of Excellence Meeting*, Oct. 21-24, 2002, Wichita, KS.

Grandt, Jr., A. F., "A Tribute to Dr. J. W. Lincoln – How a Real Life Hero Surpassed Hollywood," 2002 USAF Structural Integrity Program Conference, Savannah, GA, Dec. 10-12, 2002.

PETER K. IMBRIE
Freshman Engineering
Assistant Professor

Degrees

B.S.A.E., Texas A&M University, May 1980
M.S.A.E., Texas A&M University, May 1985
Ph.D., Texas A & M University, August 2000

Interests

Solid mechanics
Experimental mechanics
Nonlinear materials characterization
Microstructural evaluation of materials
Mechanics of composites
Engineering materials
Constitutive modeling
Experiment and instrument design
Educational research

Research Areas

Current research interests include, educational research, solid mechanics, experimental mechanics, nonlinear materials characterization, microstructural evaluation of materials, and experiment and instrument design. He has been involved with various research projects sponsored by NSF, NASA, and AFOSR, ranging from education related issues to traditional research topics in the areas of elevated temperature constitutive modeling of monolithic super alloys and environmental effects on titanium based metal matrix composites.

HYONNY KIM
2001
Assistant Professor

Degrees

B. S., University of California, Santa Barbara, Mechanical Engineering, 1993
M. S., Stanford University, Mechanical Engineering, 1994
Ph.D., University of California, Santa Barbara, Mechanical Engineering, 1998

Interests

Composites
Impact
Stability
Adhesive Joining

Research Areas

Adhesive Joining

Current research projects in adhesive joining are focused on (i) buckling stability driven disbonding of bonded composite structures, and (ii) developing nonlinear analysis techniques to predict failure in lap joints.

There exists features in high-performance structures of bonded composite construction that are of minimum gage thickness, or that rely on adhesive bonds to maintain structural stability. When these features develop partial disbonds, they become susceptible to buckling if compressive and/or shear loads are applied. Henceforth they are critical safety concerns, particularly if additional disbonding ensues. Conditions for which buckling initiates, and for which further disbond growth can occur are being investigated. Theoretical models have been developed to predict buckling initiation and the threshold for disbond growth. These models identify which are the critical parameters governing these phenomena. Sub-element level experiments of partially-disbonded splice-jointed sandwich panels are being used to validate the capabilities of these models, and to observe the interplay between buckling and disbond growth. This research addresses important safety issues related to the tolerance of bonded composite airframes to disbonds, particularly if these disbonds are not easily detected by pre-flight ground checks or basic maintenance inspections.

Theoretical models predicting the complex nonlinear behavior, and ultimately failure, of adhesively bonded joints are being developed. In order to predict failure, these models incorporate the highly nonlinear constitutive behavior of adhesives. A current focus is to understand the phenomena of plastic strain localization which develops in a highly concentrated zone at the outer overlap-ends of a bonded joint, near the interface between the adhesive and the adherend. These zones are where fracture initiates, and cracks propagating inwards from these zones ultimately result in failure of the joint.

Impact Simulation

A research project is underway investigating the numerical simulation of high-velocity hailstone impacts on composite structures. Hail ice ingestion in aero-engines is a realistic concern for engines having composite, as well as metallic, fan blades. A key component of this project is the material response of the ice projectile during the impact event: the ice transitions between an elastic-like solid into a fluid-like powder. A material model that accounts for various parameters, principally strain rate and hydrostatic pressure, on the rupture of ice projectiles is being developed based on available experimental data.

Publications

Kim, H. and Kedward, K.T., "The Design of In-Plane Shear and Tension Loaded Bonded Composite Lap Joints," *Journal of Composites Technology and Research*, Vol. 24, No. 2, 2002, pp. 297-307. Invited paper to special issue in honor of Don Oplinger.

Kim, H., Kedward, K. T., and Welch, D. A., "Experimental Investigation of High Velocity Ice Impacts on Woven Carbon/Epoxy Composite Panels," *Composites Part A*, in press – submitted June 2002.

Kim, H., "The Influence of Adhesive Bondline Thickness Imperfections on Stresses in Composite Joints," *Journal of Adhesion*, in press – submitted Sept. 2002.

Conference Proceedings, Presentations, Invited Lectures and Reports

Kim, H. "The Buckling Stability of Disbonds in Composite Adhesive Lap Joints," *Proceedings of the 43rd AIAA/ASME/ASCE/AAHS/ASC Structures, Structural Dynamcis, and Materials (SDM) Conference*, Denver, CO, Apr. 22-25, 2002.

Lee, J., Kim, H., "The Prediction of Failure in In-Plane Shear Loaded Composite Bonded Joints," *Proceedings of the 17th Annual ASC Technical Conference on Composite Materials*, West Lafayette, IN, Oct. 21-23, 2002.

Tomblin, J., Seneviratne, W., Kim, H., and Lee, J., "Characterization of In-Plane Shear Loaded Adhesive Lap Joints: Experiments and Analysis," FAA Final Report, submitted Dec. 2002.

Sun, C. T. and Kim, H., *Proceedings of the American Society for Composites 17th Technical Conference*, West Lafayette, IN, Oct. 21-23, 2002.

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
Nano-structured Materials

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

Sun, C. T. and Wang, C. Y., "A New Look at Energy Release Rate in Fracture Mechanics," *International Journal of Fracture* Vol. 113, 2002, pp. 295-307.

Kim, W. and Sun, C. T., "Modeling Relaxation of a Polymeric Composite During Loading and Unloading," *Journal of Composite Materials*, Vol. 36, No. 6, 2002, pp.647-672.

Bodily, B. H. and Sun, C. T., "Structural and Equivalent Continuum Properties of Single-Walled Carbon Nanotubes," *International Journal of Nano Technology*, Vol. 18, No. 4/5/6, 2003, pp.381-397.

Wang, Z.-P. and Sun, C. T., "Modeling Micro-inertia in Heterogeneous Materials Under Dynamic Loading," *Wave Motion* Vol.36, No. 4, 2002, pp. 473-485.

Sun, C. T., Tao, J., and Kaddour, A. S., "The Prediction of Failure Envelopes and Stress/Strain Behavior of Composite Laminates: Comparison with Experimental Results," *Composites Science and Technology*, Vol. 62**,** 2002, pp. 1673- 1682.

Conference Proceedings, Presentations, Invited Lectures and Reports

Sun, C. T. and Kim, H., *Proceedings of the American Society for Composites 17th Technical Conference*, Oct. 21-23, 2002, West Lafayette, IN.

Achuthan, A. and Sun, C. T., "Modeling Nonlinear Piezoelectric Behavior," *Spie's 9th Annual International Symposium on Smart Structures and Materials*, Vol. 4699, 2002.

Kalyanam, C. and Sun, C. T., "Domain Switching Near the Crack Tip in Single Crystal Piezoceramics," *Spie's 9th Annual International Symposium on Smart Structures and Materials*, Vol. 4699, 2002.

Cho, J. and Sun, C. T., "Multi-step Bonding Cycles for Lowering Thermal Residual Stresses in Composite Patch Repairs," paper no. AIAA-2002-1725, *43rd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* Denver, CO, Apr. 22 - 25, 2002.

Zhang, H. and Sun, C. T., "Semi-Continuum Model for Plate-Like Nanomaterials," paper no. AIAA-2002-1316, *43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* Denver, CO, Apr. 22 - 25, 2002.

Wang, Z. and Sun, C. T., "A Micro-Inertia Model for Heterogeneous Solids Under Dynamic Loading," *Proceedings of International Conference on New Challenges in Mesomechanics*, Aalborg University, Denmark, Aug. 26-30, 2002.

Park, J. and Sun, C. T., "Effect of Contiguity on the Mechanical Behavior of Co-continuous Ceramic Metal Composites," *Proceedings of the 10th US-Japan Conference on Composite Materials*, Stanford University, Sept. 16-18, 2002.

Sun, C. T. and Tsai, J. L., "Strain Rate Effect on Compressive Strength of Polymeric Composites," (abstract only), *14th US National Congress of Applied Mechanics*, Virginia Tech, June 23-28, 2002.

Sun, C. T. and Tsai, J. L., "The Effect of Platelet Distribution on the Modulus of Nanoclay Composites," (abstract only), 14th US National Congress of Theoretical and Applied Mechanics, Virginia Tech, June 23-28, 2002.

Rangarajan, B. and Sun, C. T., "A Study on the Use of Cohesive Model in Ductile Fracture," (abstract only), 14th US National Congress of Theoretical and Applied Mechanics, Virginia Tech, June 23-28, 2002.

Tsai, J. L. and Sun, C. T. "The Effect of Platelet Dispersion on the Load Transfer Efficiency in Nanoclay Composites," *Proceedings of the 17th Technical Conference, American Society for Composites*, Oct. 21-23, 2002, Purdue University, West Lafayette, IN.

Cho, J. and Sun, C. T. "Analysis of Cylindrically Orthotropic Plates," *Proceedings of the 17th Technical Conference, American Society for Composites*, Purdue University, West Lafayette, IN, Oct. 21-23, 2002.

Zeng, Q. and Sun, C. T., " Modeling of Ballistic Impact on Composite Laminates Using a Meshless Method," *Proceedings of the 17th Technical Conference, American Society for Composites*, Purdue University, West Lafayette, IN, Oct. 21-23, 2002.

Adams, D.S. and Sun, C. T., " Static and Dynamic Strength of Brittle Materials Under Self-induced Confining Stress Produced Using Filament Wound Advanced Composites," *Proceedings of the 17th Technical Conference, American Society for Composites*, Purdue University, West Lafayette, IN, Oct. 21-23, 2002.

Sun, C. T. and Achuthan, A., "Modeling of Nonlinear Behavior of PZT Piezoceramics Based on Microstructures," (Abstract only) 1st World Congress on Biomimetics and Artificial Muscles, Albuquerque, NM, Dec. 6-8, 2002.

Tsai, J.L. and Sun, C. T., "Measuring Dynamic Fracture Toughness in Polymeric Composites," *Proceedings of the International Symposium on Experimental Mechanic*s, Taipei, Taiwan, Dec. 28-30, 2002.

Hu, H. and Sun, C. T., "Creep Testing of Physical Aging in Polymeric Composites Under Temperature and Moisture Conditions," *Proceedings of the International Symposium on Experimental Mechanic*s, Taipei, Taiwan, Dec. 28-30, 2002.

Sun, C. T. "Modeling High Strain Rate response and Failure in Polymeric Fiber Composites," (Plenary lecture) Proceedings of the 2nd International Conference on Structural Stability and Dynamics, Singapore, Dec. 16-18, 2002.

TERRENCE A.WEISSHAAR
1980
Professor

Degrees

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

Interests

Aircraft structural mechanics
Aeroelasticity
Integrated Design

Research Areas

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

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

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

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

preliminary design. When completed, this system will allow an integrated product team access to a virtual environment that scientifically simulates the iterative, collaborative process required to design an airplane in a short amount of time.

Conference Proceedings, Presentations, Invited Lectures and Reports

Prock, B. C., Weisshaar, T. A., and Crossley, W. A., "Energy as an Objective for Airfoil Shape Change Optimization," paper no. AIAA-2002-5401, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization,* Atlanta, GA, Sept. 2002.

Peters, C., Roth, B., Crossley, W. A., and Weisshaar, T. A., "Use of Design Methods to Generate and Develop Missions for Morphing Aircraft," paper no. AIAA-2002-5468, *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization,* Atlanta, GA, Sept. 2002.

Taylor, R. M., Weisshaar, T. A., and Sarukhanov, V., "Structural Design Process Improvement using Evolutionary Finite Element Methods," accepted by the *Journal of Aircraft*, Aug. 2002.

Weisshaar, T. A. and Taylor, R. M., "Improved Structural Design using Evolutionary Finite Element Modeling," *Symposium on Reduction of Military Acquisition Time and Cost Through Advanced Modeling and Virtual Product Simulation*, North Atlantic Treaty Organization, Research & Technology, Paris, France, Apr. 2002.

Weisshaar, T. A. and Lee, D-H, "Aeroelastic Tailoring of Joined-wing Configurations," paper no. AIAA 2002-1207, *43rd AIAA/ASME/ASCE/AHS Structural Dynamics and Materials conference*, Denver, CO, Apr. 2002.

Bowman, J., Sanders, B., and Weisshaar, T. A., "Evaluating the Impact of Morphing Technologies on Aircraft Performance," paper no. AIAA-2002-1631, *43rd AIAA/ASME/ ASCE/AHS Structural Dynamics and Materials conference*, Denver, CO, Apr. 2002

Bowman, J., Sanders, B., and Weisshaar, T. A., "Identification of Military Morphing Aircraft Missions and Morphing Technology Assessment," *AIAA/MDO Conference*, Atlanta, GA, Sept. 2002.

Prock, B., Weisshaar, T. A., and Crossley, W. A.,"Morphing Airfoil Shape Change Optimization with Minimum Actuator Energy as an Objective," *AIAA/MDO Conference*, Atlanta, GA, Sept. 2002.

ACTIVE RESEARCH PROJECTS

July 2002 to June 2003

RESEARCH AND OTHER SCHOLARLY ACTIVITIES

In the areas of Aerodynamics, Dynamics and Controls, Propulsion, and Structures and Materials, $5.1 million in research expenditures were realized between July 1, 2002 and June 30, 2003. Several faculty were recognized for research as is detailed in the "Faculty Highlights" section. The research expenditure for the 2002-2003 year was attributed to the following sources.

SOURCE OF SPONSORED RESEARCH FOR 2002-2003	
Source	**Percentage of Total**
Department of Defense	32.8%
NASA	30.5%
National Science Foundation	3.0%
Industry	5.8%
Indiana 21st Century R & D	24.4%
Other	3.5%
Total	100.0%

SPONSORED RESEARCH PROJECTS
ACTIVE DURING THE PERIOD JULY 1, 2002 TO JUNE 30, 2003

U.S. GOVERNMENT

AFOSR

T. Farris	Fundamentals of Fretting Applied to Anisotropic Materials
S. Heister	Modeling Dense Sprays in Liquid Rocket Engines
S. Heister	Modeling Liquid Rocket Engine Atomization and Swirl/Coaxial Injectors
S. Schneider & H. Reed ASU	Mechanisms of Hypersonic Boundary-Layer Transition on Generic Scramjet Forebody
S. Schneider	Mechanisms of Hypersonic Boundary Layer Transition on Two Generic Vehicle Geometries
J. Sullivan	Active Control of Secondary Flow in Engine Inlets
C.T. Sun	Development of Composites Reinforced with Short Wavy Fibers
C.T. Sun	Prediction of Ductile Fracture of Thin-walled Cylinders Subjected to Localized Intense Heat

AFRL

S. Heister	Non-Catalytic Ignition of Advanced Monopropellants
T.A. Weisshaar	Improved Methodology for Advanced Aircraft Design

AFRL/OHIO STATE UNIVERSITY FOUNDATION

A. Grandt	AFRL Visiting Scientist Program

ARMY SPACE & MISSILES DEFENSE

S. Heister & W. Anderson	Space and Missile Propulsion Using Advanced Propellants

ARO

C.T. Sun, J. Doyle, A. Espinosa, J. Bolton & K. Trumble	Lightweight Layered Materials/Structures for Damage Tolerant Armor

DARPA

T.A. Weisshaar	IPA Agreement

ERC, INC.

W. Anderson	Fundamental Studies of Peroxide Decomposition
W. Anderson	Proposal for Lectures and Analyses of Main Chamber Injectors for the Oxidizer-Rich Staged Combustion Cycle
S. Heister	Advanced Fuels Testing Using Hydrogen Peroxide as Oxidizer

FAA

A. Grandt	Analysis of Fatigue Crack Growth from Countersunk Fastener Holes

FLEET & INDUSTRIAL SUPPLY CENTER

M. Rotea	Parameter Estimation for Airdrop Systems

JPL/NASA

J. Longuski	Trajectory Analysis and Design in Support of Planetary and Interplanetary Missions
J. Longuski	Interplanetary Mission Design

NASA

W. Anderson	2nd Generation RLV Systems Engineering and Risk Reduction – Phase I Risk Reduction for the ORSC Main Chamber Injectors and Cooling
W. Anderson	Design, Fabrication, and Testing of a Rocket Based Combined Cycle Flight Experiment
W. Anderson	Development of a Partial Design Database for Advanced Hydrogen Peroxide Engines
W. Anderson	Direct-Connect Testing of a Rocket-Based Combined Cycle Flight Experiment
W. Anderson	Field Test Methods for Hydrogen Peroxide Stability Margin
W. Anderson	Improved Preliminary Design Analysis Process for High-Pressure Rocket Combustion
W. Anderson	Study of Long-Life Thruster
S. Collicott	Zero-Gravity Validation of Surface-Tension Propellant for Rocket-Grade Hydrogen Peroxide

W. Crossley & T. Weisshaar	Design Methods and Optimization for Morphing Aircraft
J. Garrison	Autonomous Navigation for Alternate Access to the International Space Station
J. Garrison	Investigation of the Fundamental Properties of Forward Scattered GPS Signals for Oceanographic Remote Sensing
J. Garrison	Model Function Development for the Retrieval of Ocean Surface Properties from Scattered GPS Signals
J. Garrison	Model Improvement and Validation for GPS Code Tracking in High Earth Orbits (HEO)
S. Heister	Improved Modeling of Cavitating Venturi Flows
K. Howell	Applications of Dynamical Systems Theory, Control Methods, and Optimization Strategies to Trajectory Design & Mission Analysis Involving Formation Flying at Libration Points for GSFC Missions
K. Howell	Dynamical Systems Theory, Numerical Methods, Optimization Strategies and their Application to Trajectory Design Mission Analysis Involving Lissajous and Halo Orbits at the Goddard Space Flight Center (GSFC) Guidance, Navigation, and Control Center (GNCC)
H. Kim	Bucking Stability of Disbonded Composite Structures
J. Longuski	Low-Thrust Gravity-Assist Trajectory Design
S. Schneider	Cold-Wire Measurements in the Body-Flap Cavity of an X-38 Model
S. Schneider	Mechanisms of Boundary-Layer Transition on Reusable Launch Vehicles
J. Sullivan	Unsteady Pressure Measurement in Turbomachinery Using Porous Pressure Sensitive Paint
C.T. Sun	Modeling of Nano Materials

NSF

M. Rotea	Analysis and Design of Multivariable Extremum Seeking Algorithms

S. Schneider	Collaborative Research: Mechanisms of Hypersonic Boundary-Layer Transition on Reentry Vehicles
C.T. Sun	Interlaminar and Compressive Properties of Composites – A Subcontract to Tuskegee Univ. for the Establishment of a Center for Innovative Manufacturing of High Performance Composite Materials

ONR

C.T. Sun	Dynamic Modeling of Composite Materials and Structures
C.T. Sun	Applications of Nanomaterials in Polymeric Composites for Marine Structures

INDUSTRIAL AND OTHER PROGRAMS

AEROJET

S. Meyer	Advanced Reusable Rocket Engine Uni-Element Tri-Fluid Injector
S. Meyer	Advanced Nontoxic Propellant Propulsion
S. Meyer	Hydrogen Peroxide Catalyst Testing

ALLISON ADVANCED DEVELOPMENT

S. Heister	Purdue, West Lafayette Budget for Propulsion and Power Center of Excellence
S. Heister	University Technology Center in High Mach Propulsion

A.T.C. INCORPORATED

J. Sullivan	ATC, Inc.

BALL AEROSPACE & TECHNOLOGIES CORPORATION

C.T. Sun	Development of Damaged Length Model for Mixed Mode Fracture

BOEING

W. Crossley	Investigation of Structured Design Methods Using an Unmanned Aerial Vehicle Launch and Recovery System

CUMMINS ENGINE

S. Collicott	NSF Matching

GENERAL ELECTRIC AIRCRAFT ENGINES

T. Farris	Mechanics of Blade/Disk Contacts

INDIANA 21ST CENTURY RESEARCH AND TECHNOLOGY FUND

A. Lyrintzis, G. Blaisdell, L. Mongeau, & J. Bolton	Development of Low Jet Noise Aircraft Engines
J. Sullivan, S. Nof, & S. Wereley	Intelligent MEMS-based Flow Sensors and Controllers

LSP TECHNOLOGIES

T. Farris and A. Grandt	Fretting Fatigue Testing for LSP Technologies Inc

METRON

D. Andrisani II	Intent Inference Algorithm

MIDE TECH CORP.

W. Crossley	Self Consuming Spacecraft

NORTHROP GRUMMAN SPACE TECHNOLOGIES

S. Meyer	Purdue University's High Pressure Facility

N.S. GOWADIA

S. Meyer	Static and Free Jet Inlet Testing

ODYSSIAN TECHNOLOGY

H. Kim	Multifunctional Composite Structure

ORBITAL SCIENCES

W. Anderson	Upper Stage Flight Experiment (USFE) Injector Calibration and HTP Flow-test

OTHER/MULTISPONSPRED

T. Farris	Materials Processing and Tribology Research Group

PHYSICAL ACOUSTICS CORPORATION

C.T. Sun	Composite Armor Material Characterization

PRATT & WHITNEY

S. Meyer	Advanced Hydrogen Peroxide Catalyst Testing

PRECISION COMBUSTION, INC.

S. Meyer	2-inch Diameter 90% H_2O_2 Gas Generator Testing for Precision Combustion, Inc.

RAISBECK ENGINEERING

J. Sullivan	Design/Build/Test Laboratory

ROCKWELL COLLINS

D. Andrisani II	Portable Data Acquisition and Control System

ROLLS-ROYCE

S. Collicott & S. Heister	Dynamics of Engine Oil Sumps and Drains
T. Farris	Fretting Fatigue Modeling

SANDIA NATIONAL LABS

S. Schneider	Aerothermodynamic Predictions for Hypersonic Reentry Vehicles
S. Schneider	Effect of Roughness on Boundary-Layer Transition for Re-entry Vehicles: Quiet Tunnel Experiments
S. Schneider	Validation Experiments for Boundary-Layer Transition Caused by Second Mode Instability on a Blunt Cone at Zero Angle of Attack

SCIENCES APPLICATIONS INTERNATIONAL

S. Heister	Alternative Schemes for Controlling Thrust Vector
S. Heister	Trajectory Control Through Thrust Vector Rotation

STAR ENTERPRISES, INC.

S. Collicott	Zero-gravity Control for Bio-fluids

SWIFT ENTERPRISES LTD.

S. Meyer	Modify 72% H_2O_2 Test Stand Apparatus for Testing
S. Meyer	72% Monoprop Hydrogen Peroxide Gas Generator Testing

UNITED TECHNOLOGIES RESEARCH CENTER

S. Collicott	United Technologies/Pratt & Whitney
H. Kim	Modeling Hail Impacts on Aero-Engine Structures
M. Rotea	Robust Control Analysis and Synthesis

UNIVERSITY OF ALABAMA, HUNTSVILLE

S. Heister	Combustion Instability and Film Cooling Studies for Hydrocarbon Engines

UNIVERSITY OF DAYTON RESEARCH INSTITUTE

T. Farris & A. Grandt	Advanced High Cycle Fatigue Life Methodologies

XEROX CORPORATION

M. Rotea	University Award from Xerox Foundation

YANKEE SCIENTIFIC INC./DARPA

S. Heister	Cycle Analysis for Liquid Rocket Engines Using Scrull Compressor/Expander Technology

GRADUATE THESES

July 2002 to June 2003

MASTER'S THESES

Student/ ***Major Professor***	**Thesis Title**	**Degree** **Date Granted**
Aratama, Shigeki *C. T. Sun*	"The Static and Fatigue Characteristics of a Notched Hybrid Composite Laminate"	M.S. August 2002
Lamb, Gregory John *A. F. Grandt, Jr.*	"Fatigue Performance of an Advanced Fastener Hole Cold Working Method"	M.S. August 2002
Martin, Eric Thomas *W. A. Crossley*	"Multiobjective Optimization Using Genetic Algorithms with Applications for Aircraft Design"	M.S. August 2002
Prock, Brian C. *T. A. Weisshaar*	"Energy Based Design for Morphing Aircraft Wings"	M.S. August 2002
Remson, Andrew E. *S. D. Heister*	"The Non-Catalytic Ignition of High-Performance Monopropellants"	M.S. August 2002
Canino, James *S. D. Heister*	"Characterization of the Turbulent Windage in an Annulus and it's Incorporation Into Two Sump Design Codes"	M.S. December 2002
Gregory, James W. *J. P. Sullivan*	"Unsteady Pressure Measurements in a Turbocharger Compressor Using Porous Pressure-Sensitive Pain"	M.S. December 2002
Kothandaraman, Govindarajan *M. A. Rotea*	"Parameter Estimation of the G-12 Parachute"	M.S. December 2002
Swanson, Erick O. *S. P. Schneider*	"Mean Flow Measurements and Cone Flow Visualization at Mach 6"	M. S. December 2002
VanMeter, Michael G. *S. D. Heister*	"Low-Frequency Combustion Instabilities in Labscale Hybrid Rockets"	M. S. December 2002
Fitzpatrick, Shannon L. *S. H. Collicott*	"Study of Hydrogen Peroxide Low-Gravity Control in a Propellant Management Device"	M. S. May 2003
Koenigs, Michael R. *W. A. Crossley*	"Numerical Methods for Modeling Gas Turbine Combustors"	M.S. May 2003
Rodrian, Jeffrey E. *A. F. Grandt, Jr.*	"Incorporating Real World Engineering Experiences into Aeronautical and Astronautical Engineering Education"	M.S. May 2003

Roth, Brian D. *W. A. Crossley*	"Aircraft Sizing with Morphing as an Independent Variable: Motivation, Strategy & Investigation"	M.S. May 2003

DOCTORAL THESES

Student/ ***Major Professor***	**Thesis Title**	**Degree** **Date Granted**
Choi, Seung-Woo *J. F. Doyle*	"Impact Failure Mechanisms of Layered Structures"	Ph.D. May 2002
Lee, Dong-Hwan *T. A. Weisshaar*	"Aeroelastic Tailoring and Structural Optimization of Joined-Wing Configuration"	Ph.D. May 2002
Acikmese, Ahmet *M. J. Corless*	Stabilization, Observation, Tracking and Disturbance Rejection for Uncertain/Nonlinear and Time Varying Systems"	Ph.D. December 2002
Johnson, Wyatt *J. M. Longuski*	"Analysis and Design of Aeroassisted Interplanetary Missions"	Ph.D. December 2002
Kang, Un-Taik *J. F. Doyle*	"Inverse Method for Static Problems Using Optical Data"	Ph.D. December 2002
Kim, Byoung-Do *S. D. Heister*	"Study of Hydrodynamic Instability of Shear Coaxial Injector Flow in a Recessed Region"	Ph.D. December 2002
Yoon, Suk Goo *S. D. Heister*	"A Fully Nonlinear Model for Atomization of High Speed Jets"	Ph.D. December 2002
Kwon, Tae-Jun *S. D. Heister*	"Simulating Collisions of Droplets with Walls and Films Using a Level Set Method"	Ph.D. May 2003
Park, Jae Seong *C. T. Sun*	"Effect of Contiguity on the Mechanical Behavior of Co-Continuous Ceramic Metal Composites"	Ph.D. May 2003
Turaga, Umamaheswar *C. T. Sun*	"A Study of Sandwich T-Joints and Composite Lap Joints"	Ph.D. May 2003

COLLOQUIUM SERIES

July 2002 to June 2003

Colloquium Series – Fall 2002

DATE/TIME	TOPIC	SPEAKER
August 29, 2002 4:00 p.m. Grissom 166	The Founding of the Aerojet Engineering Corporation and its CALCIT Connection	**Chuck Ehresman** Professor Emeritus of Mechanical Engrg. Purdue University
September 5, 2002 4:00 p.m. Grissom 166	Building Low-Cost, Reliable Launch Vehicles: The Plan for Space Exploration Technologies, a New Rocket Company Headquartered in El Segundo, CA	**Elon Musk,** CEO **Thomas Mueller** VP Propulsion Space Exploration Company
September 26, 2002 4:00 p.m. Grissom 166	Prediction of Fatigue Performance in Gas Turbine Blades after Foreign Object Damage	**Dr. David Nowell** Dept. of Engineering Science Univ. of Oxford
September 27, 2002** 4:00 p.m. Grissom 160	Propagating Instabilities in Solids	**Stelios Kyriakides** Professor Univ. of Texas @ Austin
October 10, 2002 4:30 p.m. Grissom 280	Past, Present, and Future of Propulsion Technology at Pratt & Whitney	**Nathan Messersmith** VAATE Program Manager Pratt & Whitney Advanced Military Engine Programs
October 17, 2002 4:00 p.m. Grissom 166	Electric Propulsion Overview	**Frank Curran** Manager, Technologies Decision Division SAIC
October 18, 2002* 4:00 p.m. Stewart Hall	Fluid Mechanics in Small Devices	**Howard Stone** Professor Harvard University
November 1, 2002 4:30 p.m. Grissom 166	NASA Propulsion – Present Activities and Future Plans	**Robert Sackheim** Asst. Dir. & Chief Engr. Propulsion NASA Marshall Space Flt. Ctr.

November 14, 2002 4:30 p.m. Grissom 280	Aircraft Design – the Process to the Product	**Robert Sandusky** NASA Langley Res. Ctr**.**
November 15, 2002** 4:00 p.m. Grissom 276	Mechanics in the New Biology from DNA Packing to Molecular Motors	**Rob Phillips** Professor Mech. Eng. & Applied Physics California Inst. Technology
November 18, 2002*** 4:00 p.m. Fowler Hall	Life, the Universe and the JSF Program	**Major Gen. John L. Hudson** Program Executive Officer & Program Director Joint Strike Fighter Program
November 21, 2002 4:30 p.m. Grissom 280	The Lockheed Martin Atlas V-Program, First Launch, and Future	**William Green** Director, Dept. Test **Gail Ryan** Sr. Mgr. Tech. Dev. Lab. Lockheed Martin

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*Jointly sponsored by the School of Aeronautics & Astronautics and the Student American Institute of Aeronautics and Astronautics Chapter

**Jointly sponsored by the School of Aeronautics & Astronautics and the Mechanical Engineering Dept.; Midwest Mechanics Seminar

***William E. Boeing Distinguished Lecture sponsored by the School of Aeronautics and Astronautics

Colloquium Series – Spring 2003

DATE/TIME	TOPIC	SPEAKER
January 23, 2003* 6:30 p.m. East Faculty Lounge, PMU	Changing the Shape of Aeronautics – the Case for Autonomous Morphing Aircraft	**Terrence A. Weisshaar** DARPA Program Mgr. and Purdue AAE Professor
February 14, 2003 2:30 p.m. GRIS 274	Designing Precision Pointing Spacecraft at Lockheed-Martin	**Dr. Jeff Fisher** Lockheed-Martin
February 20, 2003 4:30 p.m. GRIS 280	The Stability of Disconnected Capillary Surfaces	**Dr. Lev Slobozhanin** Case Western Reserve Univ.
February 24, 2003 3:30 p.m. GRIS 160	MEMS Microvalve for Harsh Environment	**Dr. Charles E. Seeley** General Electric Global Research Center
February 26, 2003 4:00 p.m. Heav Hall 128	Tracing the History of the Hartmann Tube Motivated by Present Day Applications	**Dr. Ganesh Raman** Mechanical & Aerospace Engr. Illinois Inst. of Technology
April 8, 2003 2:00 p.m. GRIS 280	Review of Hypersonic Quiet Tunnels and Experiments at NASA Langley	**Dr. Stephen P. Wilkinson** NASA Langley Research Ctr.
April 25, 2003** 4:00 p.m. ME 256	Paradoxical Behaviour Associated with Rolling of Rigid Bodies	**Dr. Keith Moffatt** Ecole Normale Superieure France
May 1, 2003 3:30 p.m. GRIS 276	High-Order Computational Methods for Multi-disciplinary Simulation	**Dr. Miguel R. Visbal** Air Force Research Lab WPAFB

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**Jointly sponsored by the School of Aeronautics & Astronautics and the Mechanical Engineering Dept.; Midwest Mechanics Seminar

HIGHLIGHTS & AWARDS

July 2002 to June 2003

FACULTY HIGHLIGHTS

Our faculty continues to be feted for the outstanding work they do in the classroom and in the laboratory.

The School welcomed two new faculty. Dr. Ivana Hrbud is joined our faculty from NASA's Marshall Space Flight Center in the propulsion area. Dr. Charles L. Merkle joined our faculty as well as the Mechanical Engineering faculty, from the University of Tennessee as part of the Renewal Energy and Power Systems Signature Area.

Professor Terrence Weisshaar began his second year on sabbatical at DARPA where he directs the Morphing Program.

Several faculty continue their visible service as Editors and on various visiting committees.

Other highlights include:

- Professor William Crossley was awarded the 2003 Bruhn Best Teaching Award.
- Professor Tom Farris and P. T. Rajeev were selected by the Editorial Board of the Journal of Strain Analysis for the 2002 Professional Engineering Publishing Award.
- Professor Kathleen Howell was named one of the "50 most important women in science" by Discover Magazine in November 2002.
- Professor Hyonny Kim was selected to participate in the ASEE/NASA Faculty Fellowship program during the summer 2003.
- Professor Anastasios Lyrintzis was awarded the 2003 Gustafson Teaching Award.
- Professor Anastasios Lyrintzis is a member of the TiltRotor Aeroacoustics (TRAC) Systems Development Team and was presented the prestigious Howard Hughes Award.
- Professor Anastasios Lyrintzis was named fellow of ASME.

STUDENT HIGHLIGHTS

There are four student organizations with a relationship with the School. They are the Aeronautics and Astronautics Engineering Student Advisory Council (AAESAC); American Institute of Aeronautics and Astronautics (AIAA); Students for the Exploration and Development of Space (SEDS); and Sigma Gamma Tau (SGT). AIAA, SGT, and SEDS conducted the 7th annual Fall Space Day. SGT hosted "Professor Pizzas," an opportunity for students to interact one-on-one with an AAE professors and visiting dignitaries. Several student groups continue to perform well in national design competitions.

Student Awards

Congratulations to the following students who have earned top honors

Winners of the AAE 251 ATK Thiokol Propulsion SP.A.C.E. Awards Fall 2002

First Place Team: **Andrew Beam, Mike Carpenter, Mark French, George Pollock, Zade Shaw, and Charles Weaver**

2002 - Purdue Engineering Foundation Outstanding Student Award **Paul Brower**

2003 - Herbert F. Rogers Scholarship – **John Gedmark** and **Kristen Gina Pieri**

2003 - Koerner Scholarships **- Michael Grant, Debanik Barua, Jayleen Gustromson, Michael Shockling,** and **Melanie Silosky.**

2003 - Magoon Graduate Teaching Award **- Ajit Achthan, Michael Koenigs, Shin Matsumura, Christopher Patterson,** and **Stephanie VanY.**

2003 - Elmer F. Bruhn Undergraduate Research Assistantship **– Lucia Capdevila and Yen Ching Yu**

2003 - Outstanding Senior Award – **Gina Pieri**

2003 - Outstanding Graduate Student Award **- Jeff Rodrian**

2003 - Hsu Lo Fellowship – **Hai-Yang Qian**

2003 - John and Patricia Rich Scholarship – **David Berger, Jr., John Gedmark, Ryan Irwin, and Ryan Whitley**

Presentation of Awards at the 2003 Society of Women Engineers Brunch

Congratulations to:

Jayleen Guttromson for being named the Outstanding Junior, General Motors

Allison Bahnsen on a merit award from Alumnae

Heather Pawley on a merit award from Alumnae

Gina Pieri on a merit award from Alumnae

Melanie Silosky on a merit award from United Technologies

Elizabeth Newsome on a merit award from Aerospace & Technologies Corp.

Angela Long on a merit award from the Boeing Company

Jeri Metzger on a merit award from the Boeing Company

Dawn Gordon on a merit award from Delphi Delco

Jackie Jaron on a activity and leadership award from Shirley McCarty Award

Rebecca Karnes on a activity and leadership award from Tree, Limb and Activity Award

OUTREACH HIGHLIGHTS

In its **seventh** year, Fall Space Day '02 was a rousing success with more than **270** third through eighth graders, and 85 plus strong volunteer crew attending. Astronaut Colonel **John H. Casper** was the featured speaker. Additionally, the children participated in many interactive lessons, which reinforced basic science and math principles. Purdue Fall Space Day was sponsored by the Indiana Space Grant Consortium; Pratt & Whitney; Students for the Exploration and Development of Space, and students in the American Institute of Aeronautics and Astronautics and the School of Aeronautics and Astronautics.

Several faculty gave presentations to local schools. The inherent excitement of aerospace leads to these invitations and generates great responses from the students.

CURRICULUM & COURSE OFFERINGS

July 2002 to June 2003

CURRICULUM AND COURSE OFFERINGS

Course enrollments and summarized class enrollment statistics are listed below:

Course Enrollments
School of Aeronautics and Astronautics
2002-2003 Academic Year

A&AE Course	Most Recent Title	Cr.	Fall 2002		Spring 2003	
			Enroll-ment	Instructor	Enroll-ment	Instructor
203-1	Aeromechanics I	3	76	Garrison	64	Garrison
203-2	Aeromechanics I	3	74	Corless		
204-1	Aeromechanics II	3	43	Imbrie	54	Kim
204-2	Aeromechanics II	3			53	Grandt
204L	Aeromechanics II Lab.	1	40	Doyle	102	Doyle
251	Intro. Aerosp. Design	3	62	Crossley	94	Sullivan
333	Fluid Mechanics	3	85	Lyrintzis	53	Lyrintzis
333L	Fluid Mechanics Lab.	1	77	Collicott	40	Collicott
334	Aerodynamics	3	39	Blaisdell	67	Williams
334L	Aerodynamics Lab.	1	24	Collicott	36	Collicott
340	Dynamics & Vibration	3	77	Longuski	56	Howell
352	Structural Anal. I	3	81	Farris	38	Sun
352L	Struct. Anal. I Lab.	1	16	Doyle	36	Doyle
364	Control System Analy.	3	50	Frazho	81	Acikmese
364L	Control Systems Lab.	1	72	Rotea	49	Rotea
372	Jet Propl. Power Plt.	3			84	Heister
412	Intro. Comp. Fluid Dyn.	3	31	Blaisdell		
416	Viscous Flows	3	19	Schneider		
421	Flt. Dyn. Control	3	57	Andrisani II	51	Corless
439(1) (2)	Rocket Propulsion	3	29 39	Anderson Anderson		
440	Spacecr. Attitude Dyn.	3			46	Howell
450	Spacecraft Design	3	3	Williams	34	Longuski
451	Design I (Aircraft Design Spr. 01 Sem)	3	22	Andrisani II	34	Crossley
453	Matr. Meth. Aerosp. Struc.	3			28	Doyle
454	Design Aerosp. Struct.	3	14	Grandt		

A&AE Course	Most Recent Title	Cr.	Fall 2002		Spring 2003	
			Enroll-ment	Instructor	Enroll-ment	Instructor
490A	Flight Testing	3			27	Andrisani II
490D	Intro. To Labview	3			1	Filmer
490E	Intro. Satellite Sys.	3	26	Heister		
490F	Engr. Syst. Analysis	3	56	Frazho	49	Frazho
490G	Zero Grav. Flt. Exper.	3	14	Collicott		
490S	Satellite Design	3			15	Crossley
490T	Design Build Test	3			38	Sullivan
507	Principles of Dynam.	3	30	Longuski		
511	Intro. Fluid Mech.	3	21	Blaisdell		
514	Intermediate Aerodyn.	3			32	Lyrintzis
519	Hypersonic Aerotherm	3			9	Schneider
520	Experimental Aerody.	3			30	Sullivan
532	Orbit Mechanics	3	34	Howell		
537	Hypersonic Propulsion	3	42	Heister		
539	Adv. Rocket Prop.	3			34	Heister
546	Aero Struct Dyn Stab.	3	9	Doyle		
547	Exper. Stress. Analy.	3			10	Doyle
550	Multidisciplinary Des. Opt.	3	53	Crossley		
553	Elasticity Aerosp. I	3	29	Sun		
554	Fatigue Struct. & Matrl.	3	46	Grandt		
555	Mechanics Comp. Matl.	3			34	Kim
556	Aeroelasticity	3			18	Weisshaar
558	Finite Element Meth. In Aerospace Structures	3	32	Kim		
559	Mechanics Friction & Wear	3			14	Farris

A&AE Course	Most Recent Title	Cr.	Fall 2002		Spring 2003	
			Enroll-ment	Instructor	Enroll-ment	Instructor
564	System Anal. & Synth.	3	31	Corless		
565	Guidance Aerospace Veh.	3			6	Andrisani II
567	Intro. Appl. Stoch. Proc.	3			21	Frazho
590A	Rocket Combuster DBT	3			25	Anderson
590D	Intro. to Labview	3			6	Filmer
590E	Satellite Design	3			5	Crossley
590F	Des. Thes. Meth. Aerosp. Sys.	3	24	Crossley		
590G	Intr. Satellite Nav. & Posit.	3	15	Garrison		
590T	Design Build Test	3			5	Sullivan
607	Vari. Princ. Of Mech.	3			15	Longuski
615	Aeroacoustics	3	19	Lyrintzis		
626	Turb. & Turb. Modeling	3			29	Blaisdell
654	Fracture Mechanics	3			16	Sun
666	Nonlin. Dyn. Syst. Cont.	3			18	Corless
690A	Injector Des. & Analy.	3			7	Heister
696	Theory/Pract. Multi. Ctrl.	3	12	Rotea		
698	M.S. Thesis Research	--				
699	Ph.D. Thesis Research	--				

Aerospace Engineering Requires a Multidisciplinary Curriculum

Required Introductory 251-Introduction to Aerospace Design; 203 Aeromechanics I (statics/dynamics)

Aerodynamics	*Dynamics and Control*	*Propulsion*	*Structures and Materials*
Required Undergraduate			
333-Fluid Mechanics & Lab. 334-Aerodynamics and Lab	340-Dynamics and Vibrations 364-Controls and Lab 421-Flight Dynamics or 440-Spacecraft Att. Dynamics	372-Jet Propulsion or 439-Rocket Propulsion	204-Aeromech. II (Str of Mat.) and lab 352-Structural Analysis & Lab
Undergraduate Electives			
412-Intro to CFD 414-Compressible Aero 416-Viscous Flows	421-Flight Dynamics or 440-Spacecraft Att. Dynamics 490A Flight Testing	372-Jet Propulsion or 439-Rocket Propulsion	453-Matrix Methods in Struct.
415-Aerodynamic Design	490R-Control Systems Design	590C Propulsion Design	454-Structural Design

Required Capstone Design 450 Spacecraft Design or 451 Aircraft Design

Multidisciplinary Electives 490E-Introduction to Satellite Systems; 490F Engineering Systems Analysis; 490S-Satellite Design

Undergraduate/ Graduate Electives			
511-Intro. to Fluid Mech.	507-Basic Mechanics	536-Adv Energy Conversion	546-Struct. Dyn and Stability
512-Computational Aero	508-Optimization in Aero. Eng.	537-Hypersonic Propulsion	547-Experimental Stress Anal.
514-Intermediate Aero	531-Flight Mechanics	538-Air Breathing Propulsion	550-MDO
515-Rotorcraft Aerodynamics	532-Orbit Mechanics	539-Adv. Rocket Propulsion	551-Design Th and Methods
518-Low Gravity Fluid Mech.	564-Systems Anal. and Control	630-Stability of Free Surfaces	552-NDE of Struct and Mat.
519-Satellite Aerodynamics	565-Guidance and Control	637-Future Prop Concepts	553-Elasticity in Aero. Eng
520-Experimental Aero.	567-Intro to Stochastic Proc.		554-Fatigue in Struct. and Mat.
613-Viscous Flow Theory	574-Digital Flight Control Sys.		555-Mech. of Composite Mat.
615-Aerocoustics	590G-Satellite Nav and Pos		556-Aeroelasticity
626-Turbulence	632-Adv Orbital Dynamics		558-Finite Element Methods
	660-Operator Methods		559-Mech. of Friction & Wear
	666-Nonlinear Dynamics		646-Elastic Wave Propagation
	696-Multivariate Control		654-Fracture Mechanics
			655-Adv Topics in Composites

Summarized Class Enrollment Statistics
for the 2002-2003 Academic Year

Semester	Statistic	Three-Credit Courses				One-Credit Laboratory Courses
		100, 200, 300, 400, Levels	500 Levels	600 Level	All Levels	
Fall of 2002	No. of classes offered	25	12	2	39	5
	Total Enrollment	925	355	31	1311	229
	Average number of students per class	37	30	16	34	46
Spring of 2003	No. of classes offered	25	13	5	43	5
	Total enrollment	979	227	85	1291	227
	Average number of students per class	39	17	17	39	45

(does not include AAE 490, 590, 698 and 699)

STAFF FOR THE 2002-2003 ACADEMIC YEAR

Administrative Assistants
Linda Flack, Terri Moore

Business Office
Stephanie Stewart, Joan Jackson, Michelle Kidd, Sherry Wagner

Clerical
Paula Kerkhove, Sharon Wise

Director of Communications and Development
Tim Bobillo

Communications Administrator
Ann Broughton

Professional/Technical
Madeline Chadwell, Lisa Crain, Ivan Ellis, Gerald Hahn, Joe Kline, Scott Meyer, David Reagan, Robin Snodgrass, Jim Younts