Mechanical Engineering Department

Professor Patrick J. Moran
Chair

Research by faculty and midshipmen in the Mechanical Engineering Department reflects the broad interests of a diverse and highly qualified group of engineers. Research efforts in the department are promoted by faculty and midshipmen interest in studying new technologies and solving problems of interest to the U.S. Navy. This activity not only creates excitement among the research teams; it also promotes the study and introduction of new technology in the classroom. Faculty and midshipmen involvement in publication of research and invited presentations reflects credit and recognition for the individuals and the U.S. Naval Academy.

Projects active this past year included internal combustion engines, fracture mechanics, fluid mechanics of pumps, thermal systems design, materials processing and engineering, corrosion, environmentally assisted fracture, vibrations, and flow field studies. In summary, the department was involved in more than 35 different research projects. Sponsors of this work included the Office of Naval Research, Naval Surface Warfare Center, Naval Air Systems Command, Department of Energy, Air Force Office of Scientific Research, Air Force Research Laboratory, U.S. Nuclear Regulatory Commission, National Institute for Standards and Technology, Ford Foundation, and the STX Corporation. The Department is grateful for the cooperation and support of our sponsoring agencies and organizations.

Sponsored Research

Theoretical Modeling of Modulated Light Beams in Scattering Media

Researcher: Assistant Professor John A. Burkhardt
Sponsor: Naval Air Warfare Center (NAVAIR), Aircraft Division, Patuxent River

Lidar (light detecting and ranging) systems have found numerous applications for the Navy including the detection of underwater objects from both submersed and airborne platforms as well as the detection and classification of ground based and airborne objects. The success of these applications relies on the efficient transfer of light from a laser transmitter, through the intervening medium to the remote object, and back to an optical receiver. The use of modulated light beams has shown the promise of greatly increasing the efficiency of the process but is not well understood. Consequently, this research aims to provide a theoretical basis for the propagation of modulated light beams in scattering media.

Structural Testing of Missile Bodies and Surrogates

Researchers: Assistant Professor John A. Burkhardt
and Assistant Professor Peter J. Joyce
Sponsor: Naval Surface Warfare Center (NSWC), Dahlgren Division

This project's task is to perform bend-tests on both missile bodies and missile surrogates for the purpose of measuring ordinate effectiveness. Design and fabrication of a custom loading and fixture rig capable of measuring tip-deflection both in and out of the loading plane has been initiated. In total two missile bodies and two missile surrogates are to be tested, one damaged and one undamaged of each, with strain readings recorded for each.

An Investigation into the Effects of Perforations on the Heat Transfer Enhancement of Extended Surfaces

Researchers: Associate Professor Martin R. Cerza
Dr. P. T. Ireland (Oxford, England) and Mr. Juan C. Adams (Oxford, England)
Sponsors: Rolls Royce, LTD and Oxford University

In the literature there has been a large discrepancy over the enhancement effects of hole perforations on the heat transfer enhancement of extended surfaces (thin fins). Half of the investigators have claimed the perforations do enhance heat transfer, and half have claimed there is no heat transfer effect on the use of perforated surfaces. The methods employed by past investigators were not well suited for resolving small length scales, hence their investigations were clouded by gross surface effects. Through the use of liquid crystal thermography and digital image processing employed in the current investigation, it has been conclusively shown that there is a heat transfer enhancement benefit through the use of perforated surfaces. Moreover, liquid crystal thermography aided by digital image processing proved to be a very good technique for resolving small heat transfer length scales. The investigation has concluded that perforations cause a surface heat transfer enhancement by partially restarting the thermal boundary layer. The partial thermal boundary layer restart allows for a heat transfer coefficient (or Nusselt number) increase or recovery over fully developed conditions in the surface region after the perforation. Since perforations also decrease the surface area of extended surfaces, the next step would be an optimization of the trade off between the enhanced heat transfer benefit and the loss of surface area. The investigation also lends itself to the fluid dynamic wall shear friction effects caused by perforations since many heat transfer-fluid mechanic analogies show that heat transfer coefficients and friction factors behave very similarly for many flow conditions.

Effects of Alterations to the Leading Edge Extension-Delta Wing Junction on the F/A-18 E/F

Researchers: Associate Professor Karen A. Flack and
Assistant Professor Michael P. Schultz (Naval Architecture and Ocean Engineering Department)
Sponsor: Office of Naval Research (ONR)

The junction of the leading edge extension (LEX) and the delta wing on the F/A-18 E/F aircraft is a region of highly complex vortex flows interactions. The region is important not only to the performance and stability of the aircraft, but may affect cyclical loading of the tail due to vortex buffet. The geometry of the junction is also critical in the overall radar signature of the aircraft. The objective of the present research is to compare the aerodynamic forces on a model with different LEX-wing fillet configurations. Three fillet types were tested in this junction on a 1:28 scale F/A-18 E/F model in a low speed wind tunnel in the Aerodynamics/Fluids Laboratory at the United States Naval Academy. The fillets were found to have little effect on the aerodynamic forces on the model. This result is contrary to previous research on a flat plate model of a delta wing. Further tests were performed on a flat plat model of the same platform with and without a center body to compare to previous research and to investigate the accuracy of using two-dimensional models to model a three-dimensional vortex flows.

Surface Temperatures and Subsurface Velocities for Evaporation

Researchers: Associate Professor Karen A. Flack,
John Saylor (Naval Research Laboratory) and
Geoffrey Smith (Naval Research Laboratory)
Sponsor: Naval Research Laboratory (NRL), Remote Sensing Division

The surface temperature of a body of water undergoing evaporation was measured using infrared imaging techniques, demonstrating for the first time the effect of surfactant monolayers on the spatial structure of this field. Measurements were obtained from a water surface which was covered with a surfactant monolayer and also from a water surface which was nominally free of surfactants. The heat flux for these two cases was also varied by a factor of approximately 10. The presence of the surfactant increased the characteristic length scale of the temperature field for both heat flux conditions. Sub-surface velocity measurements were also obtained with a laser Doppler anemometer system. Turbulence measurements indicate that the surface shear, introduced by the surfactant, has also greatly reduced the turbulent activity near the surface. Additionally, simultaneous measurements of surface temperature and subsurface velocity were obtained to determine the spatial and temporal correlations between these two variables. This work was performed in the fluids laboratory at the U.S. Naval Academy.

UCAV Micro-acutated Surfaces

Researchers: Associate Professor Karen A. Flack and
Assistant Research Professor David B. Miklosovic (Aerospace Engineering Department)
Sponsors: Naval Air Warfare Center – Patuxent River (NAVAIR)
and Office of Naval Research (ONR)

Unmanned Combat Aerial Vehicles (UCAV) are being designed with Low Observable (LO) technology to ensure stealth capability. Conventional control surfaces which rely on large deflected flaps have a detrimental effect on LO signature. Recent research efforts have investigated the use of micro-actuators as an alternative means of LO vehicle control. The development of these control devices is of importance to the Navy for use in designing more effective future air vehicles. Micro-devices may prove to be effective in attitude control for both cruise and landing configurations. Their primary advantage is to provide increased UCAV stealth. Additionally, smaller, deployable control surfaces reduce the cruise drag penalty which would lead to increased range or loiter time. The Naval Academy will support this effort by performing additional tests using the serrated edge micro-spoiler system on other airfoil shapes (two and three-dimensional) in the 0.7 x 1.12 m sub-sonic wind tunnel in the Aerodynamics/Fluids Laboratory at the Naval Academy. Concurrent with wind tunnel tests, an extensive literature search is underway to identify other possible UCAV micro-actuator configurations that have been designed and tested by other researchers. Promising devices will be manufactured and tested in the facilities at the Naval Academy.

Advanced Concepts for Naval Nuclear Propulsion Plants

Researcher: Associate Professor Mark J. Harper
Sponsor: Knolls Atomic Power Laboratory (KAPL)

Research continued on an advanced energy delivery system that is capable of supplying power for submersibles of various sizes, from small unmanned vehicles to full-size submarines. Particular attention is paid to integration of advanced propulsion schemes with the vision outlined by the Joint Chiefs of Staff ("Joint Vision 2010") and the Department of the Navy ("Forward . . . From the Sea) documents, as well as other high level guidance from the Defense Department, including that specified in the Defense Science Board's special task force, "The Future of the Submarine."

Manpower and Technology Issues for Submarines of the Future

Researcher: Associate Professor Mark J. Harper
Sponsor: Naval Sea Systems Command, Naval Surface Warfare Center

This ongoing effort examined manning of ships in general and submarines in particular. It chronicled the history of the VIRGINIA Class SSN manpower requirements. The studies examined various methods for estimating the costs of manning submarines, and indicated that the payoffs from reducing existing manning levels are negligible. Only by incorporating the notion of reduced manning into every aspect of the submarine's design will real savings of manpower dollars be achieved. Later studies involved a series of workshops that attempted to address technology issues associated with manning future submarines. The principal finding was that the entire design philosophy and procedure must change radically in order to provide optimal manning for submarines of the future.

Fiber Damage Assessment in Carbon Fiber Tows Subjected to a Novel Fiber Spreading System

Researchers: Assistant Professor Peter J. Joyce and Associate Professor Oscar Barton, Jr.
(Mechanical Engineering Department) and Associate Professor Sarah E. Mouring
(Naval Architecture and Ocean Engineering Department)
Sponsor: Office of Naval Research (ONR)

This research seeks to evaluate the damage incurred by carbon tows subjected to fiber spreading. The current wet winding techniques of applying the exact resin content to the outer perimeter of the tow and subsequent winding under pressure results in the center of the tow not wetting out and a knock-down factor of 5-15% in the final composite. A novel fiber spreading

system, intended to improve fiber wetout and resin distribution, has been demonstrated by Adherent Technology with the intention to improve resin distribution and fiber wetout. The objective of this project is to evaluate the damage done to the fiber, if any by passing it through the spreading process. The tow tensile specimens were prepared by Adherent Technologies by first spreading the fiber tow to between ½" to 1", coated with the volumetrically correct amount of resin, rebundled to a specified band width of ¼" and vertically stacked with other tows to form a 36k tow that was then filament wound on a mandrel and cured. Three conditions were used to generate samples for the tow tensile tests: control (no spread/coating), ½" spread/coated, 1" spread/coated. A total of 30 samples were prepared for each test condition. The tow samples were tensile tested to evaluate the failure mode and load for each condition according to ASTM D4018. Based on the results to date, the effects of fiber spreading are uncertain.

Evaluation of Compression After Impact Strength of Composite Sandwich Structures

Researchers: Assistant Professor Peter J. Joyce and Associate Professor Oscar Barton, Jr.
(Mechanical Engineering Department) and Associate Professor Sarah E. Mouring
(Naval Architecture and Ocean Engineering Department)
Sponsor: Office of Naval Research (ONR)

This research seeks to evaluate the compression after impact strength of composite sandwich structures subjected to low-velocity impact. The composite sandwich specimens were fabricated and impact damaged by Northrop Grumman. Three levels of impact damage were examined 5 ft-lbs, 20 ft-lbs, and 35 ft-lbs as well ad 2 impactor diameters, 0.5 in. and 1.0 in. The specimens were then prepared by TSD for edge compression testing according to ASTM C-364. The specimens were strain gaged to evaluate the quality of each test. A major concern in compression testing is the alignment of the load train. To verify the alignment of the load train prior to testing the composite sandwich specimens a control specimen was fabricated from polycarbonate of similar structural dimensions and stiffness by the TSD. Using the screw driven 50 kip Satec load frame, the alignment was optimized using one fixed platen and one spherical seating platen. By pre-loading the platens with the retention springs removed prior to each test to achieve parallelism the load train alignment was optimized. This yielded less than 5% variation in the strains for the Lexan control specimen at loads above and beyond the failure load anticipated in the composite specimens. Edgewise compression tests of the impact damaged specimens were performed by the summer students The test results, show a clear trend of reduced residual compressive strength with increased impact energy, but little trend with respect to the diameter of the impactor.

Evaluation of the Multi-Component Resin Transfer Molding Process for Naval Aircraft Components

Researchers: Assistant Professor Peter J. Joyce,
Mr. Neil Graf and Mr. Roland Cochran (NAWCAD/PAX)
Sponsors: Naval Air Warfare Center – Patuxent River (NAVAIR)
and Office of Naval Research (ONR)

The objective of this research project was to evaluate the state of the art in resin transfer molding (RTM) process technology and examine the influence of controllable process parameters on the thermal and mechanical behavior of composites manufactured from multi-component resin systems. This research involved three thrusts, the first was to evaluate the design and performance of the automated RTM equipment designed by Northwestern University (NWU) as part of the Center for Intelligent Processing of Composites (CIPC) program. The second thrust of this research involved the selection and characterization of materials and processes for multi-component RTM of primary structural composites. The third thrust of this goal was to manufacture aerospace quality composites utilizing the selected resin systems and the NWU system to generate design allowables data for the industrial partners, principally Boeing. Tests to date with the NWU hardware have concluded that while the resin injection equipment designed by NWU has great merit in terms of the concepts being attempted and the potential for improved manufacturing reliability, is less than attractive from a manufacturing standpoint. For the materials evaluation component of this research two different resin systems have been selected. In order to evaluate the optimum process cycle for each of these material systems, thermal analysis has been used to determine the cure kinetics and the basic thermal and mechanical properties

of each resin system. Finally we are undertaking a comprehensive panel fabrication matrix using the design of experiments approach to examine the influence of *controllable* process parameters on the basic material allowables.

Constitutive Modeling of Inert HTPB Binder Material

Researcher: Assistant Professor Peter J. Joyce
Sponsor: Naval Surface Warfare Center (NSWC), Indian Head Division

This research was initiated in order to better understand the pre-ignition mechanical response of the high explosive (HE) materials currently used in Navy warheads. Modern warhead design has resulted in plastic bonded explosive materials serving as structural components. The use of plastic bonded high explosives (PBX) as load-bearing members requires the assessment of the state of stress and strain in these components, necessitating a thorough understanding of the mechanical behavior of the materials in question. Most highly filled polymers such as high explosives and solid propellants exhibit nonlinear viscoelastic behavior. The viscoelastic response of the HTPB binder material is measured in order to develop a micromechanics model of the PBX. A literature review of PBX materials modeling was undertaken to determine the level of understanding in the HE community. Several efforts to model the viscoelastic response of PBX materials were uncovered. A model incorporating the cumulative damage approach was selected to fit the PBX N-110 data provided by NSWC/Indian Head Division. Test data for the inert HTPB binder was also provided by Department of Energy (DoE) personnel at the Los Alamos National Laboratory. The test program conducted at the U.S. Naval Academy (USNA) involved quasi-static compression testing of the HTPB binder material at various strain rates over a range of temperatures from -65º F to 150º F. Several interesting results have emerged from the preliminary test data produced at USNA. An unexpected failure mode occurred because of the end-constraints used during the quasi-static compression testing. The stress-state which produced this failure mode is still under investigation at the Naval Academy.

R&D for Metallurgical/Microstructural Evaluation of Structural Damage and Damage Mapping of Corroded Structures

Researcher: Assistant Professor Michelle G. Koul
Sponsor: Air Force Research Laboratories (AFRL), Wright Patterson Air Force Base

This effort will help to provide tools to depot persons responsible for selecting environmentally benign corrosion maintenance procedures for aircraft. The evolving maintenance philosophy of “predict and manage” requires additional corrosion maintenance protocols for the depot maintainers. This philosophy is aimed at replacing the “find-and-fix” approach that requires the removal of all corrosion when detected during planned depot maintenance. AFRL and/or their contractors will provide corroded specimens for evaluation at U.S. Naval Academy (USNA). Prior to providing the specimens to USNA, the corrosion damage will be evaluated using the non-destructive evaluation (NDE) technology being developed as a separate part of this program. The primary objectives of the work to be performed at USNA are:

1. Characterize the types of corrosion damage observed in as a function of alloy, exposure environment and corrosion protection technology.
2. Analyze the corrosion damage within the context of the provided sample history, previous corrosion damage evaluations and repairs, and the NDE results.
3. Evaluate the incorporation of this data into structural integrity and lifetime predication models.

Dynamic Fracture Toughness Evaluation of Naval Structural Alloys

Researcher: Associate Professor Richard E. Link
Sponsor: Naval Surface Warfare Center, (NSWC), Carderock Division, Fatigue and Fracture Branch

Experimental techniques for determining the dynamic fracture toughness of tough naval alloys have been developed over the past 20 years. The rapid loading rates are achieved through impact loading of the fracture specimen using a drop tower. The experimental procedure requires that the test be stopped abruptly after a predetermined displacement (on the order of 0.1

inches) to prevent the test specimen from being completely fractured. This is typically achieved by having the falling mass from the drop tower contact rigid stops, leading to sudden and severe shock in the drop tower. The drop tower is not designed to withstand this abuse and is frequently damaged by this procedure. The falling mass is designed to slowly arrest by contacting a spring-damper system to smoothly decelerate the mass. The objective of this research project is to develop a collapsible test fixture for dynamic fracture toughness testing. The fixture can be triggered to collapse below the falling weight at any specified displacement level. Once the fixture begins collapsing, no further force is applied to the specimen and there is ample room for the falling mass to be decelerated on the spring-damper system.

Cooperative Ferromagnetic Hysteresis in Transition Metals

Researchers: Associate Professor Richard E. Link and
Professor Carl S. Schneider (Physics Department)
Sponsor: Naval Surface Warfare Center, (NSWC),Carderock Division,
Fatigue and Fracture Branch

Ferromagnetic hysteresis is of interest to the Navy in controlling ship magnetic signatures as well as in developing magnetoelastic transducers. Existing models do not have the accuracy to represent more details than B(H) curves using parameters without explicit physical meaning. Ferromagnetic domains have been explained using the Curie-Weiss molecular field, but variations in the slope of B(H) curves, essentially the material susceptibility, have been assumed to be due to a distribution of material reluctances such as residual stresses and crystalline anisotropy. Our model of hysteresis includes a cooperative interaction of domains through a domain field proportional to the magnetization and susceptibility itself, consistent with observed exponential increases in susceptibility with magnetization.

Current experimental methods for measuring the magnetization and susceptibility of alloys do not have sufficient accuracy or resolution to describe subtle changes in susceptibility necessary to fully investigate this new model. The objective of my research was to develop an interactive computer program capable to permit experimental measurements of the magnetic properties of alloys with improved accuracy and precision.

Fracture Analysis of Surface Cracks in Shells Under Explosive Loading

Researcher: Associate Professor Richard E. Link
Sponsor: Naval Surface Warfare Center, (NSWC),Carderock Division,
Fatigue and Fracture Branch

Welded structures often contain crack-like defects that can be a result of fabrication, hydrogen cracking or fatigue due to service loading. Surface and submarine combatants contain many welded structural elements that must be able to withstand explosive loads without failing prematurely. This investigation is designed to quantify the driving force for fracture in spherical shell elements containing surface cracks subjected to static and explosive loads. Non-linear, three dimensional finite element models are being used to analyze typical structural details. The results of this investigation will support predictions of experiments which will be conducted on representative welded structural elements containing surface cracks.

CFD Analysis of the Flow Distribution in the Oily Waste Ultrafiltration System

Researcher: Associate Professor Steven M. Miner
Sponsor: Mr. Larry Murphy at Naval Surface Warfare Center (NSWC), Carderock Division

Computational Fluid Dynamics (CFD) is used to analyze the distribution of flow in the filter of an oily waste ultrafiltration system. The purpose is to determine how uniform the distribution of flow is within the filter. Several different combinations of filter media are considered.

Ceramic Matrix Composites and High Temperature Materials

Researchers: Associate Professor Angela L. Moran and
Dr. Matthew C. Osborne (ONR Post-Doctoral Fellow)
Sponsor: Department of Energy/Office of Naval Research

Materials for high temperature applications are required for the Department of Energy as well as for the Navy. This project involves analyzing the validity of computer codes developed to predict the properties of ceramic composites. SiC/SiC composites are being experimentally tested to determine mechanical properties, density and uniformity. This test data has been utilized to evaluate and compare the results of analytical codes developed by a number of institutions and agencies to predict elastic stress states for different composite architectures. Materials have been acquired from commercial sources and are being fabricated in-house.

High Temperature Copper Alloys for the Automotive Industry

Researcher: Associate Professor Angela L. Moran
Sponsor: Ford Research Laboratory

Spot welding electrodes deteriorate very rapidly when used for welding of aluminum automotive components. This is due to the formation of a low melting point eutectic phase at the interface of the copper electrode and the aluminum, dissolving away the surface of the electrode. This project involves developing novel electrode compositions which suppress the formation of low melting point phases, thereby increasing electrode life. Advanced manufacturing methods such as laser cladding, ion implantation and spray deposition are being utilized.

Failures Analysis and Performance Evaluation of Sprinkler Heads

Researcher: Associate Professor Angela L. Moran
Sponsor: Consumer Products Safety Commission

As a result of a Consumer Products Safety Commission ongoing investigation into the performance of sprinkler heads, the Naval Academy was tasked with testing of sprinklers produced by a number of different manufacturers. Standardized test methods were developed to measure the response of the heads to pressure and temperature. Visual inspection and pressure testing have been conducted on samples provided. Metallurgical examination of samples has also been conducted as required to understand the mechanisms involved in the failure of certain heads.

Multi-functional Coatings for Military Applications

Researchers: Associate Professor Angela L. Moran
and Dr. Brian Connolly (ONR Post-Doctoral Fellow)
Sponsor: Air Force MURI Program

This effort, in conjunction with researchers at the University of Virginia seeks to identify the next generation military coating system to provide improved performance from the standpoint of mission safety, corrosion protection, and environmental compatibility. The goal was to create a metallic cladding that is easily field applied and has a range of functions to improve corrosion performance, coating adhesion, and provide active corrosion protection. This is accomplished through implementation of thermal spray technology and the use of nanocrystalline or amorphous matrix metallic glasses such as the Al-transition metal (TM)- rare earth (RE) glasses. Aluminum based metals are thermally sprayed in air from wire, ribbon, or powder stock using several thermal spray techniques such as hand-held arc spraying and plasma spraying. Control claddings are compared to newer compositions aimed at multi-functionality. Fatigue life at several stress values is determined. Electrochemical inhibition of pitting and other forms of local corrosion, known to reduce fatigue lifetimes, can be distinguished from reductions in purely mechanically-driven fatigue processes by conducting tests in air, in benign solutions and in corrosive solutions. Mechanistic factors improving the fatigue resistance of high strength Al alloys are also obtained.

Characterization and Remediation of Thorium Contaminated Soils at Sites Within Kirtland Air Force Base

Researchers: Professor Martin E. Nelson and Associate Professor Mark J. Harper
Sponsor: Naval Research Laboratory (NRL)

Eight sites at Kirtland Air Force Base (KAFB) were intentionally contaminated with Th-232 compounds in order to provide realistic training scenarios for Department of Defense personnel. In response to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), KAFB has initiated an Installation Remediation Program (IRP) for complete environmental restoration. Before remediation can commence it is necessary to fully characterize the contaminated soil, with particular emphasis on geophysical analysis and relationships between soil grain size and radionuclear content. Following this analysis, various remediation methods were proposed. Several publications were generated from this research.

Neutron Induced Charge Deposition: An Integral Part Of Navy SLBM System Radiation Hardened Microelectronics Design

Researchers: Professor Martin E. Nelson and
LCDR Gene Canfield, Strategic Systems Programs (SSP)
Sponsor: Strategic Systems Programs (SSP)

This research examined the need for the determination of neutron induced charge deposition in the design of radiation induced microelectronics utilized in Navy Submarine Launched Ballistic Missile (SLBM) systems. The research to date has examined trends in the commercial and radiation hardened microelectronic industries. Next an investigation has been performed on specific neutron interactions and their effects on microelectronics. In the next phase of the research, a model will be developed and integrated into Radiation hardened Technology Computer Aided Design (RHTCAD) tools. Finally, experiments are planned in order to confirm model predictions.

Measurement Of Neutron Fluxes Due To Cosmic Rays

Researchers: Professor Martin E. Nelson and
Visiting Professor James F. Ziegler (Physics Department)
Sponsor: International Business Machines (IBM)

Terrestrial cosmic rays, consisting of neutrons and other charged particles, cause soft errors in semiconductor devices such as SRAMs. Recent data indicates that the low energy neutrons, including thermal neutrons, dominate the soft error rate (SER) of memory chips. Additionally, published data indicates that the neutron flux can vary by over an order of magnitude, depending on the local ground environmental and shielding factors, such as building materials. The objective of this research is to design, construct an instrument which can measure these neutrons. It is then planned to take this instrument into the field to make measurements in various types of buildings and environments, and then model the observed variations so that flux in most locations can be predicted.

Sample Handling Effects on Particulate Measurement In Gas Turbine Engines

Researcher: Assistant Professor Paulius V. Puzinauskas
Sponsors: Naval Air Systems Command (NAVAIR)
and Office of Naval Research (ONR)

The adverse environmental effects of engine-particulate-matter emissions have been investigated for over 30 years, but recent evidence from the medical and health industry combined with the changing character of modern-engine-particulate emissions have significantly escalated the concern in recent years. Attention is now being focused on significantly smaller particles as well as particle composition. Recent particulate-matter mutagenic and pathological studies indicate ultrafine (<100nm) particles composed of materials previously considered benign can cause negative health effects. Adding to the concern is that current and near-term-future particulate-matter mitigation techniques tend to significantly increase the number of ultrafine particles composed of volatile compounds that are known carcinogens.

To better quantify the effect of particulate emissions on human health and the environment, traditional time-averaged mass-based measurements will have to be replaced with measurements that provide time-resolved mass, number and size information. When focusing on ultrafine particles, the results of such measurements are highly dependant on sample-handling conditions. The objective of this study is to examine the effects of sample temperature, dilution ratio and humidity on measurement results. It is being accomplished by building a mini-dilution tunnel capable of accurately varying and controlling the sample conditions and quantifying their effect on particulate measurements from an internal combustion engine as they are varied through their range of interest.

Dynamic Characterization of Urethane Damping

Researcher: Associate Professor Colin P. Ratcliffe
Sponsor: Naval Surface Warfare Center (NSWC), Carderock Division

Reinforced urethane is becoming recognized as an important composite material. It has reasonable structural characteristics, while having excellent (high) vibrational damping. NSWC is continuing to fund a project to characterize this material, which is being used in a variety of military structures. An early study found that the material properties of the reinforced urethane changed with the thickness of the specimen. This project continues the process of quantifying the performance of the reinforced urethane material system. The primary experimental method is modal analysis.

Damage Detection in Bridges

Researcher: Associate Professor Colin P. Ratcliffe
Sponsor: Naval Surface Warfare Center (NSWC), Carderock Division

There are hundreds of existing small road bridges that are close to the end of their life expectancy. The University of Delaware has designed a 100% composite bridge that was installed near Newark, Delaware. As part of this program, the U. S. Naval Academy has conducted an extensive experimental vibration analysis of the deck. The results of the vibration analysis were used a) to verify finite element models and b) to look for damage and other structural irregularities in the bridge. This is the third year the bridge has been surveyed and vibration data obtained. Using this data, experimental methods of using broadband vibration data to locate structural irregularities have been developed.

Boundary Layer Separation and Transition Control under Low-Pressure Turbine Conditions

Researcher: Assistant Professor Ralph J. Volino
Sponsor: NASA Glenn Research Center

Boundary layer behavior is currently being investigated under modern low-pressure turbine airfoil conditions. The flow over the trailing section of the suction side is subject to an adverse pressure gradient, which tends to cause boundary layer separation. The adverse pressure gradient also tends to promote transition to turbulent flow. Transition often leads to reattachment of the boundary layer. Boundary layer separation causes a degradation of performance, particularly if the boundary layer does not reattach. The problem is most severe in aircraft engines under cruise conditions, where the lower density at altitude results in lower Reynolds numbers and increases the likelihood of separation. The interaction between separation and transition is complex, and the inability to accurately predict the flow is a limitation to designers. To provide a better understanding of the flow, detailed experimental documentation is needed. A single passage turbine cascade with geometry and pressure distribution matching a modern low pressure turbine has been constructed and installed in a low speed wind tunnel. Extensive velocity measurements have been acquired using hot-wire anemometry at five different Reynolds numbers and two different free-stream turbulence levels. The locations of boundary layer separation, transition, and reattachment are being documented and compared to results obtained in earlier work at the NASA Glenn Research Center. These baseline cases have been followed with modifications to the test section directed at flow control. Efforts are being made to alter the state of the boundary layer and prevent separation from occurring.

Intelligent Computer Aided Instruction (ICAI)

Researchers: Professor Chih Wu and Associate Professor Kenneth L. Tuttle
Sponsor: Office of Naval Research (ONR)

The Mechanical Engineering Department at the United States Naval Academy is currently evaluating a new teaching method that implements the use of computer software. Utilizing the thermodynamic based software CyclePad, Intelligent Computer Aided Instruction (ICAI) is incorporated in a basic Engineering Thermodynamics course (EM319) for engineering major students and an advance Energy Conversion Course (EM443) for mechanical engineering students. The use of the CyclePad software enhances lectures and aids students in visualization and design.

The contents of undergraduate thermodynamics courses was established long before computers existed. Problem assignments appearing in popular textbooks have been developed with an understanding that students will work them by hand. Interesting practical problems which are difficult to solve or which involve parametric studies are usually not assigned because the long calculation would require an unreasonable time investment by the students. CyclePad allows users to concentrate on the fundamental engineering design principles without being distracted by the tedious computation and wrong input design data. As a consequence, students can do more comprehensive design and cover more material without necessarily devoting more study time to the course.

CyclePad introduces students to the concept of design as an open-ended process involving synthesis, analysis, and choices among design alternatives. It provides a valuable design aid by giving visualization of the schematic combination of a variety of thermodynamic cycles. This visualization allows the students easily to explode the effects that changing design parameters have on the behaviour of a cycle. The approach of the CyclePad makes the learning of thermodynamic cycle design more exciting and results in more effective training of future designers.

CyclePad has been in use for six semesters now at the Naval Academy for design homework and project. The experience has been a positive one. The future version of the software will incorporate modifications suggested by users.

Independent Research

Inverse Ultrasonic Radiative Transfer

Researcher: Assistant Professor John A. Burkhardt

A comprehensive research program is being executed which will develop new modeling, computational and experimental techniques necessary for the application of time-dependent diffuse ultrasonic backscatter as a materials characterization tool. The proposed method is based on inverse solutions of the ultrasonic radiative transfer equation (URTE). Both explicit inverse techniques, based on a diffusion approximation of the URTE, as well as implicit inverse technique, based on Monte Carlo simulations of the URTE, are being developed. An experimental research effort for the purpose of corroborating the developed inverse techniques will also be pursued utilizing manufactured scattering samples composed of glass beads suspended in agarose. For confirmation with the explicit inverse technique, based on plane-wave illuminations, an elaborate ultrasonic interrogation technique will be developed which will allow comparison with backscattered results using directional transducers.

CFD Analysis of the Flow and Forces in a Centrifugal Pump Impeller

Researcher: Associate Professor Steven M. Miner

In this project both potential flow and viscous flow analysis techniques are being used to predict the flow field within the impeller of a centrifugal flow pump. The viscous flow results are generated using the “locked rotor” technique. The resulting velocity and pressure fields are used to calculate the pressure and momentum forces acting on the impeller. The potential and viscous flow results are then compared to each other and to experimental data available for the impeller geometry considered. Studies are first done for the impeller centered in its volute and then repeated for the impeller orbiting within the volute.

Pollution from Ship Stack Emissions

Researcher: Associate Professor Kenneth L. Tuttle

The purpose of this research is to determine whether stack emissions from ships can be effectively reduced by modifications to the combustion process or by add on end of pipe devices and whether the exhaust emissions should be regulated either nationally or internationally. Written input has been submitted to the Environmental Protection Agency (EPA) in attempt to convince the United States not to regulate ship exhaust emissions and especially not Navy ships, as they burn low sulfur fuel already and most have engines that produce low oxides of nitrogen. Results of this research have been presented to the Society of Naval Architects and Marine Engineers (SNAME), and to the American Society of Naval Engineers (ASNE). One paper is in *Ship Design and Operation in Harmony with the Environment*, a SNAME publication. A second paper is in the *SNAME Transactions* and was presented at the SNAME Annual Conference. This paper is the result of a joint effort that has been developed between SNAME and ASNE. One paper is in the *Proceedings of the Maritime Environmental Symposium '95*, the American Society of Naval Engineers and another in the *Proceedings of Marine Environmental Stewardship for the 21st Century*. Experimentation planned for the future is for engine exhaust emissions to determine the effect of turbocharging and other parameters on NO_x emissions from compression ignition engines.

Combustion of Shipboard Solid Wastes

Researcher: Associate Professor Kenneth L. Tuttle

This research is one in which the researcher has the most expertise and experience. He was appointed to the Naval Studies Board of the National Research Council to study the disposal of solid wastes from ships. This research investigates incineration to destroy shipboard trash rather than dumping combustible wastes, solid or liquid, at sea. Most ships use burning to destroy shipboard combustible wastes. The questions are how to use the incinerators effectively and how to improve incinerator design to make incineration compatible with ships and emissions regulations. The author has published data on the emissions from the combustion of solid waste fuels. Papers have been presented to the International Conference on Solid Waste Technology and Management, to the Solid Waste Division of ASME and to the International Air Pollution Control Association. One paper is in the Journal of the Association. The author has several related publications and one U.S. Patent on the subject of solid fuels, combustion and gasification of solid fuels and combustion generated emissions and helped innovate wood gasification, pulverized wood combustion and environmentally sound wood fired boiler combustion. Additional publications are in progress or planning. Biomass, including wood, is still the predominant fuel used in the world by individuals and homes, and is gaining attention in the United States. Most recently, the Turkish National Committee on Solid Wastes invited this researcher to become a member of the International Advisory Board for the ISWA 2002 World Congress-Istanbul.

Boundary Layer Transition Under Turbine Airfoil Conditions

Researchers: Assistant Professor Ralph J. Volino and
Assistant Professor Michael P. Schultz (Naval Architecture & Ocean Engineering Department)

Boundary layer transition is an important phenomenon for the flow over gas turbine airfoils. When transition occurs, heat transfer rates and skin friction can increase significantly. To accurately predict the flow through an engine, which is necessary for improved designs, transition must be predicted accurately. Transition under engine conditions is complicated by high background turbulence, strong pressure gradients, and surface curvature. Although the problem has been studied extensively, the importance of curvature is still not completely understood. Many experiments and numerical simulations are carried out on flat plates, under the assumption that curvature effects are secondary under high free-stream turbulence conditions. Other studies suggest, however, that curvature effects may be significant. An experimental study was conducted in which velocity measurements were made in the boundary layer on both a flat plate and a surface with strong concave streamwise curvature. Free-stream turbulence level, Reynolds number, and streamwise pressure gradient were the same for both cases and were representative of the flow over the pressure side of a gas turbine airfoil. The curved surface had curvature similar to that on the concave side of an airfoil. Data from the cases showed that curvature does have a significant effect on transition and the wall shear stress. The transition location was farther upstream in the curved wall case, and skin friction coefficients were about 40% higher for the curved wall case. A scheme for separating the laminar and turbulent zone data in the transitional boundary layer was developed and applied.

Research Course Projects

Failure Investigation of Composite Vaulting Poles

Researcher: Midshipman 1/C William M. Dull, USN
Adviser: Associate Professor Oscar Barton, Jr.

Composite materials have become the materials of choice for structural and non-structural applications in a diverse engineering community. Consider the application of carbon fiber reinforced plastics (CFRP) used to strengthen deteriorating beams and support columns in aging bridges in the civil engineering industry or the use of graphic fiber reinforced plastics (GrFP) for body panels in the automotive industry. Interest in its use has increased in the sporting arena with the development of composite tennis rackets, composite biking gear, and hockey sticks. The track and field area too has adopted the use of composite materials producing composite vaulting poles. Too often, however, the design of these vaulting poles have been based upon static analysis, not taking into consideration the impact loading and the fatigue effects which are generated from continued use.

In this research, the failure of analysis of a composite vaulting poles is undertaken. More specifically, an investigation of the mode of failure, failure mechanism, and a failure criteria is considered. To accomplish this task, a series of composite vaulting poles will be subjected to cyclic and impact loading to understand the degradation in material performance. A failed composite vaulting pole provide the means of micro-structure evaluation and analysis.

Analysis of SiC-AL Composite Box Beams

Researcher: Midshipman 1/C Clinton A. Cornell, USN
Adviser: Associate Professor Oscar Barton, Jr.

In this research, the relative capabilities of metal matrix composite (MMC) box beams fabricated by welding and brazing techniques are explored. The metal matrix composite system consist of silicon carbide fibers and T6061 aluminum matrix with the laminate stacking sequence of $[0, \pm 45, 0]_s$. To assess the potential, the resulting beams are examined using optical microscopy exploring both welded and brazed joint characteristics, hardness tested to generate hardness profile through the joined sections, and sectioned across the both the brazed and welded section producing tensile properties. Tensile test specimens were also machined from the flanges and web sections of the box structure and will provide needed mechanical response information. A final comparison comes through the free vibration dynamic analysis comparing fundamental frequencies of the beams. The four box beams were hot formed using two C shell sections. Each C section was fabricated using preformed, plasma sprayed composite metal sheets. These unidirectional sheets were arranged in the desired orientations and formed against a steel male mold producing a section which is 2 in x 4 in x 48 in. Subsequently, two C sections were joined to form four-foot long box beam structures. The C-sections were either welded using conventional welding techniques or alternatively brazed with the webs configured in a stepped-lap configuration.

Passive Control of Structural Noise Using Shunted Piezoelectric Elements

Researcher: Midshipman 1/C Vytenis Benetis, USN
Advisers: Assistant Professor John A. Burkhardt and CAPT Owen G. Thorp, USNR

A passive noise control technique using shunted piezoelectric elements is explored experimentally. Experimental configurations using commercially available piezoelectric ceramics and films as well as in-house fabricated PVDF elements will be explored. The suitability and limitations of each material system as passive noise control elements will be determined.

Passive Solar Water Heater

Researcher: Midshipman 1/C Devin J. Langguth, USN
Adviser: Associate Professor Karen A. Flack

A passive solar water heater was developed for use in laboratories and demonstrations in the senior level heat transfer course, EM415. The water heater employs multi-passes of copper tubing on a copper plate, painted black, and enclosed in a shallow box with a glass cover. The apparatus is instrumented with thermocouples for experimental data collection. The experimental data will be compared to calculations involving the theory of solar radiation and convection.

Creep Properties of Sn-Ag Solder Materials

Researcher: Midshipman 1/C Monica R. Hurley, USN
Advisers: Associate Professor Angela L. Moran
and Dr. Matthew C. Osborne (ONR Post-Doctoral Fellow)

The objective of this study was to determine if Tin-Silver (SnAg) solder is an appropriate substitute for Lead-Tin solder (PbSn). Various properties of the SnAg materials were compared to those for PbSn in an effort to determine if the tin-silver would be an acceptable alternative. Until recently PbSn has been used extensively for all kinds of soldering applications, however increasing environmental concerns have necessitated the need to find another material. Degradation of disposed electronics and other components containing the solder can result in leaking of lead metal into the groundwater. Because of this concern, new solders are being tested to determine an appropriate replacement. Another concern with the PbSn solder is that it is being used at temperatures well above its melting temperature. This results in poor solder performance in certain applications. So in addition to an environmentally safe solder, the search is also for a solder that has a higher melting point. One promising alternative is the SnAg solder that is the focus of this study.

Ceramic Matrix Composites, From Bend Tests to Tensile Tests

Researcher: Midshipman 1/C Michael B. Moore, USN
Advisers: Associate Professor Angela L. Moran
and Dr. Matthew C. Osborne (ONR Post-Doctoral Fellow)

Mechanical property testing is difficult to perform on brittle, anisotropic ceramic and ceramic matrix composite materials. This research involved the establishment of a method to convert 3 or 4 point bend test results to uni-axial tensile test results. Bend tests are a proven method for developing some tensile data from less ductile materials, but they do not provide the complete information required for design. Once the test method was established, simple bend tests were used to analyze ceramic matrix composites at various temperatures and then the results were converted to uni-axial data, such as ultimate strength which is the information required by designers for real components.

Feasibility of a New Power Generation Cycle

Researcher: Midshipman 1/C Adam K. Hruby, USN
Adviser: Assistant Professor Ralph J. Volino

A new combined cycle for power generation has been investigated. Exhaust from a gas turbine engine is fed into a fluidized bed coal combustor which provides heat for a steam power plant. The gas turbine exhaust replaces air which would normally be used for the coal combustion. Because gas turbines operate with excess air for combustion, the gas turbine exhaust contains sufficient oxygen for combustion of the coal in the fluidized bed. The steam plant would operate continuously as a base load plant, and the gas turbine would be used only for peak load conditions. In a more conventional situation, the steam plant and gas turbine would be operated independently of each other. When the two systems are combined, the high temperature of the exhaust entering the coal combustor raises the possibility of reducing the amount of coal consumption needed for the fluidized bed. Technical advice and the idea for the project have been provided by a senior engineer with a large utility. A computer model of the new system has been developed, and the model indicates that coal consumption could be reduced by about 30% compared to a conventional system producing the same net power.

Trident Scholar Projects

Investigation Of A Flat Plate Capillary Pumped Loop System (CPL) Employing A Shell And Tube Condenser For Shipboard Cooling Use

Researcher: Midshipman 1/C Richard C. Herron, USN
Advisers: Associate Professor Martin R. Cerza
and Associate Professor Mark J. Harper
Sponsor: Department of Energy (DoE)

Electronic cooling is quickly becoming a topic of paramount concern in the computer, aerospace and electronic industries. As computer chips and circuit boards get smaller, while their power generation increases, very high heat fluxes have to be dealt with. Since most devices operate below 120F, the cooling of such devices is a major issue. The U.S. Navy is also facing the issue of cooling demand for it's electronic packages that are used for shipboard use, such as weapons control systems, reactor and propulsion plant control and diagnostic systems, navigation systems, etc. This investigation looks into the use of capillary pumped loop systems as a viable method to cool electronic packages. A capillary pumped loop (CPL) system is essentially similar to heat pipe systems, the difference being that a heat pipe is a small, hermetically sealed device that employs a working fluid which undergoes phase changes to transport thermal energy over a distance. A capillary pumped loop system is a heat pipe that has been broken up into components so that it can be used in places where there are greater distances between the heating source, such as an electronic package, and the sink required to cool that package. The present investigation utilizes a shipboard condenser as the cooling sink, and a simulated electronic package as the heat source. A capillary pumped loop evaporator was designed to complete the cooling system. Results show that a CPL system is a viable alternative to cooling electronic packages. During this investigation, the effects of seawater temperature on CPL performance were evaluated.

Optimizing the Strength and Stress Corrosion Cracking Resistance of Aluminum Alloys Used for Refurbishing Aging Aircraft

Researcher: Midshipman 1/C Charles P. Ferrer, USN
Advisers: Associate Professor Angela L. Moran
and Assistant Professor Michelle G. Koul

The focus of this Trident Research project was on the mechanical and corrosion properties of high-strength aluminum alloys. Aluminum alloy 7075, a common material in the aerospace industry, is susceptible to stress-corrosion cracking (SCC) in the T6, or peak-aged temper. The susceptibility of this temper to SCC is alleviated through the use of the T73, or overaged temper. This temper exhibits significantly better SCC resistance, but at a 10-15% strength loss compared to the T6 temper. Cina and Ranish patented a new heat treatment known as retrogression and reaging (RRA) in 1974. Experimental test results indicated that the RRA heat treatment reduces the traditional trade-off between T6 strength and T73 SCC resistance. However, the short time heat treatment limits the applicability of RRA to thin sections of material. The primary goal of this research was to determine if lower retrogression temperatures could be used in the RRA process to extend the applicability of this heat treatment to thick sections. Tensile, fatigue, fracture toughness, and hardness tests were conducted to characterize the mechanical properties of the T6, T73, and various RRA tempers. Alternate immersion and double-cantilever beam tests were conducted to evaluate the corrosion properties of the different tempers.

Development of an Inverse Ultrasonic Radiative Transfer

Researcher: Midshipman 1/C Kevin D. V. Smith, USN
Adviser: Assistant Professor John A. Burkhardt

A novel material characterization technique was proposed which employs multiply scattered ultrasound in contrast to customary single scattering techniques. The technique was enabled by modeling the multiply scattered ultrasound using a radiative transfer formulation that ignored all phase information. An experimental program was undertaken to test the proposed technique.

Publications

Journal (Refereed) Manuscripts

AUNAPU, Nicole V. (Trident Scholar, Class of 1999), VOLINO, R.J., Assistant Professor, FLACK, K.A., Associate Professor, and Stoddard, R.M., "Measurements in a Gas Turbine Cascade Passage with Endwall Flow Modification," *American Society of Mechanical Engineers Journal of Turbomachinery*, Vol. 122, pp. 651-658.

A flow modification technique is introduced in an attempt to allow increased turbine inlet temperatures. A large-scale two half-blade cascade simulator is used to model the secondary flow between two adjacent turbine blades. Various flow visualization techniques and measurements are used to verify that the test section replicates the flow of an actual turbine engine. Two techniques are employed to modify the endwall secondary flow, specifically the path of the passage vortex. Six endwall jets are installed at a location downstream of the saddle point near the leading edge of the pressure side blade. These wall jets are found to be ineffective in diverting the path of the passage vortex. The second technique utilizes a row of 12 endwall jets whose positions along the centerline of the passage are based on results from an optimized boundary layer fence. The row of jets successfully diverts the path of the passage vortex and decreases its effect on the suction side blade. This can be expected to increase the effectiveness of film cooling in that area. The row of jets increases the aerodynamic losses in the passage, however. Secondary flow measurements are presented showing the development of the endwall flow, both with and without modification.

AUNAPU, Nicole V. (Trident Scholar, Class of 1999), VOLINO, R.J., Assistant Professor, and FLACK, K.A., Associate Professor, "Surface Flow Visualization of a Scaled-Up Turbine Blade Passage," *Measurement Science and Technology*, Vol. 11, pp. 987-991.

Surface Flow visualization results are presented for the endwall and suction-side blade of a turbine blade passage. The passage consists of two adjacent blades with inlet flow control to model a multi-blade cascade. Flow visualization was performed with established methods utilizing ink dots and solvent, and oil and black powder. The flow features captured using these techniques include the horseshoe vortex and its migration across the passage to impinge on the neighbouring blade, endwall cross flow and the endwall saddle point. The methodology for using these techniques in a low-speed wind tunnel is discussed.

BARTON, Oscar, Jr., Associate Professor, MOURING, S. E., Associate Professor and SIMMONS, D. Kevin (Trident Scholar, Class of 1999), "Reinforced Concrete Beams Externally Retrofitted with Advanced Composites," *Advanced Composites Materials Journal*, in press.

This study investigates the effect of externally bonded carbon fiber reinforced polymer (CFRP) laminates on the ductility of reinforced concrete beams used in the repair of damaged bridge structures. Reinforced concrete structures deteriorate over time due to environmental aging, fatigue, excessive loading, chemical attack, and other factors. Strengthening and rehabilitating these concrete structures by externally bonding carbon laminates is one of many economical engineering solutions. Eight rectangular beams with varying internal steel reinforcement were retrofitted with CFRP strips on the tension faces and tested under four-point bending. The beams were instrumented to monitor strains, deflection, and curvature over the entire spectrum of loading, and determine the structural response of the beams. An existing analytical model using the discrete yield and ultimate values of the load-deflection and moment-curvature curves was modified to an energy-based model, and used to predict the ductility of the beams. Numerical results indicated an increase in strength, a decrease in ductility, and validated the analytical model. Ultimately, this study will aid in the development of design guidelines governing the use of CFRP.

CERZA, Martin R., Associate Professor, "Infrared Photographs of a Gas Loaded Heat Pipe," *American Society of Mechanical Engineers Journal of Heat Transfer*, Vol. 122, n 3, p 428, 2000.

A large gas loaded flat heat pipe, 1.22m x 0.305m x 0.127m, fabricated from Monel 400 sheet metal and Monel 400 screens was videographed at horizontal and vertical orientations with an infrared video camera. The heat pipe evaporator section consisted of a 0.305m x 0.305m area (one heated side only) while the side opposite the heated section was insulated. The remaining area of the heat pipe served as the condenser. In the horizontal orientation, the heated section was on the bottom. In the vertical orientation, the evaporator was aligned below the condenser. The sequence of photographs depicts heat inputs ranging from 200W to 800W, and the effect of the non-condensable gas on heat pipe operation for both orientations. For the horizontal orientation, the non-condensable gas is seen to recede into the fill pipe as the heat input is increased. For the vertical orientation, the non-condensable gas is seen to sink down in the central portion of the heat pipe, while water vapor rises up the edges of the heat pipe. Also shown in the vertical orientation is a time sequence which leads to transient oscillations caused by the buoyancy effects of the air and water vapor.

FLACK, K. A., Associate Professor, Saylor, J.R., and Smith, G.B., "Infrared Imaging of Free Surface Turbulence, Damped by a Spreading Film of Immiscible Liquid," *Physics of Fluids*, Vol. 12, pp. 597-602, 2000.

The effect of a spreading surfactant film on the surface turbulence at and air/water interface is investigated by means of infrared thermal imaging. This rapidly spreading film was used as a tool to quickly change the boundary condition of a water surface from one which is shear-free, to a boundary condition which supports shear. The turbulence is significantly damped by the spreading film, leaving a less active turbulent region within the film. Ahead of the front, significant variations at large and small spatial scales are evident, while behind the front the small scale structures are eliminated. Measurements of the spreading rate, surface temperature and images of the spreading process are included.

FLACK, K. A., Associate Professor, Saylor, J.R., and Smith, G.B., "An Experimental Investigation of the Surface Temperature Field during Evaporative Convection," *Physics of Fluids*, Vol. 13, pp. 428-439, 2001.

Measurements of the surface temperature field are presented for a water surface undergoing evaporation. Experiments were conducted for water surfaces with and without a surfactant monolayer. A statistical analysis of the data is presented which shows the effect of heat flux and surfactants on the root mean square and skewness of the field. Temporal power spectra are presented which reveal the role of heat flux and surfactants on the temporal evolution of the surface temperature field.

JOYCE, J. A., Professor, Gao, X., Dodds, R.H., and Tregoning, R.L., "Prediction of the T_o Shift Between Specimens of Different Constraints Using the T-stress based σ - Functions," *International Journal of Fracture,* 104, pp. L3-L8, 2000.

This work applies the T-stress based σ - functions to predict the T_o shift between types of specimens exhibiting different in-plane constraint levels at cleavage fracture. The analytical model predicts accurately the shift of the T_o values estimated using fracture toughness data measured with deep-notch SE(B) specimens and C(T) specimens, and the shift of the T_o values from deep and shallow cracked SE(B) specimens.

JOYCE, J.A., Professor and Tregoning, R.L., "Development of the T_o Reference Temperature from Precracked Charpy Specimens," *Engineering Fracture Mechanics*, 68, pp. 861-894, 2001.

The Master Curve approach specified within the new ASTM E1921 Test Standard is a significant advance in defining an indexing temperature, T_o, the median fracture toughness, and associated failure probability bounds for ferritic steels in the ductile-to-brittle transition regime. An objective in developing this standard test procedure has been that it should, if possible, allow the use of precracked Charpy-size specimens to measure T_o and the associated fracture performance. However, the supporting technical basis document for E1921 presents no experimental evidence which demonstrates the accuracy of T_o estimates from precracked Charpy specimens.

There was also little independent experimental verification presented to support the limiting deformation criterion (M=30) contained in the standard. Computational and analytical support in of the deformation criterion for precracked Charpy specimens is also lacking. The most applicable recent computational work by Ruggieri and Dodds supports a deformation criterion that is almost twice as stringent as the E1921 standard to ensure that constraint loss does not occur. Historically, constraint loss has been evaluated for individual specimens, while E1921 implicitly only requires that constraint loss does not significantly alter the median toughness.

This work experimentally evaluates the use of precracked Charpy specimens to estimate T_o by comparing results obtained on both precracked Charpy and 1T (or larger) fracture toughness measurements. The data demonstrate that the Charpy-size specimens tend to have a non-conservative bias, even when the data fall within the allowable E1921 deformation criterion. This effect may be a function of the degree of crack tip constraint loss, which strongly depends on the material flow properties. An attempt is made to correct for any constraint loss in the Charpy-size specimen and remove any bias in the measured T_o using a simple constant stressed volume cleavage failure criterion. While this method does decrease the difference between T_o values measured using Charpy and conventional 1T specimens, more detailed cleavage initiation models which can be independently calibrated will be required to rigorously account for any constraint differences between Charpy and larger specimens.

KOUL, Michelle G., Assistant Professor, and Scully, John R., "Hydrogen Desorption Mechanisms in Metastable Beta Ti-3Al-8V-6Cr-4Mo-4Zr," *Journal of the Electrochemical Society*, accepted for publication in Sept/Oct 2001.

The mechanisms by which hydrogen desorbs from Ti-3Al-8V-6Cr-4Mo-4Zr in the presence of a native oxide film under vacuum were examined over a range of temperatures using thermal desorption spectroscopy (TDS) and x-ray photoelectron spectroscopy (XPS). Hydrogen release was extremely limited and not measured below 260°C owing to the thermal stability of the surface oxide. XPS experiments indicate that hydrogen release is not observed until after the oxide film is completely dissolved in vacuum. However, in the temperature range of 325-490°C, TDS measurements indicate that hydrogen desorption is bulk diffusion controlled with a high desorption activation energy (135-144 kJ/mol). XPS measurements in conjunction with H desorption measurements indicate a slow, but measurable desorption rate following oxide dissolution with the presence of a high O content (25-50%) at within the metallic surface. H desorption is rationalized to be diffusion-limited by a high O content surface layer at these temperatures. Surface recombination controlled desorption was observed by TDS at temperatures exceeding 490°C. XPS results indicate that the transition from metallic diffusion control to surface recombination control (and an increased desorption rate) is likely coincident with a reduction of the surface O content in the alloy to below 25 at.%. Qualitative desorption simulation results indicate agreement with a model that includes H egress by diffusion and surface recombination coupled in series. However, quantitative agreement cannot be obtained without accounting for the effect of the high O surface layer on bulk H diffusion parameters.

LINK, R. E., Associate Professor and MINER, S. M., Associate Professor, "Complementary Usage of Mathematica and IDEAS in Mechanism Design," *ASEE Computers in Education Journal*, Vol. 10, No. 3, pp 14-21, July 2000.

All mechanical engineering majors at the U.S. Naval Academy are required to take a course in Computer Aided Design during their senior year. The underlying philosophy of the course is to use the computer to solve problems that would be impractical to solve by hand. The vehicle used to illustrate this is the design of four bar mechanisms. During the first part of the course the students write programs using Mathematica to perform synthesis, position, velocity, acceleration, and force analyses for the complete range of motion of a four bar mechanism. Using Mathematica helps the students develop an understanding of the equations being solved, as well as, develop an appreciation for the progression of the solution from synthesis through force analysis. In the second part of the course the students are introduced to the IDEAS solid modeling software package. Using IDEAS they build physically realistic models of the mechanisms including animation of the complete range of motion. The position, velocity, acceleration, and force analyses are repeated within IDEAS by means of menu picks. The only part of the design process that IDEAS cannot be used for is the synthesis of the mechanism. The use of Mathematica enhances the students understanding of the mechanism design process, while the use of IDEAS gives the students an appreciation for the ease with which physically realistic models can be generated using high end solid modeling packages.

MINER, S.M., Associate Professor and LINK, R.E., Associate Professor, "A Project -Based Introduction to the Finite Element Method," *ASEE Computers in Education Journal*, Vol.10, No. 3, pp. 9-13, July 2000.

All mechanical engineering majors at the naval Academy are required to take a course in Computer Aided Design during their senior year. The underlying philosophy of the course is to introduce students to computer based solution techniques that are currently used in engineering practice. To emphasize the utility of the computer the problems selected for solution are ones that would be difficult to solve by hand. In particular, students are introduced to the finite element method through a project requiring the design of a bracket that must meet size, load, and deflection requirements. In addition, the strength to weight ratio of the bracket is to be optimized. The students are given a brief introduction to the fundamentals of the finite element method, including basic theory and practical guidelines for modeling. Then design teams are formed to design and build the brackets. The brackets are tested to check the performance against the design requirements, to compare the teams predicted results to actual performance, and to see which team achieves the highest strength to weight ratio. The IDEAS software package is used to generate the geometry of the bracket and to perform the finite element analysis. Design teams have developed brackets with strength to weight ratios of 6000 and have been able to predict failure loads to within 10% of the measured value. This project-based approach to the finite element method gives the students an appreciation for how powerful the method can be in performing structural analysis.

MINER, S. M., Associate Professor, "Evaluation of Blade Passage Analysis using Coarse Grids," *American Society of Mechanical Engineers Journal of Fluids Engineering*, Vol. 122, No. 2, pp. 345-348, June 2000.

This paper presents the results of a study using coarse grids to analyze the flow in the impellers of an axial flow pump and a mixed flow pump. A commercial CFD code (FLOTRAN) is used to solve the 3-D Reynolds Averaged Navier Stokes equations in a rotating cylindrical coordinate system. The standard k-e turbulence model is used. The meshes for this study use 22,000 nodes and 40,000 nodes for the axial flow impeller, and 26,000 nodes for the mixed flow impeller. Both models are run on a SPARCstation 20. This is in contrast to typical analyses using in excess of 100,000 nodes. The smaller mesh size has advantages in the design environment. Stage design parameters for the axial flow impeller are, rotational speed 870 rpm, flow coefficient 0.13, head coefficient 0.06, and specific speed 2.97 (8101 US). For the mixed flow impeller the parameters are, rotational speed 890 rpm, flow coefficient 0.116, head coefficient 0.094, and specific speed 2.01 (5475 US). Evaluation of the models is based on a comparison of circumferentially averaged results to measured data for the same impeller. Comparisons to measured data include axial and tangential velocities, static pressure, and total pressure. A comparison between the coarse and fine meshes for the axial flow impeller is included. Results of this study show that the computational results closely match the shapes and magnitudes of the measured profiles, indicating that coarse CFD models can be used to accurately predict performance.

MINER, S. M., Associate Professor, "3-D Viscous Flow Analysis of a Mixed Flow Pump Impeller," *International Journal of Rotating Machinery*, Vol. 7, No. 1, pp. 53-63, 2001.

This paper presents the results of a study using a coarse grid to analyze the flow in the impeller of a mixed flow pump. A commercial computational fluid dynamics code (FLOTRAN) is used to solve the 3-D Reynolds Averaged Navier Stokes equations in a rotating cylindrical coordinate system. The standard k-e turbulence model is used. The mesh for this study uses 26,000 nodes and the model is run on a SPARCstation 20. This is in contrast to typical analyses using in excess of 100,000 nodes that are run on a super computer platform. The smaller mesh size has advantages in the design environment. Stage design parameters are, rotational speed 1185 rpm, flow coefficient j = 0.116, head coefficient y = 0.094, and specific speed 2.01 (5475 US). Results for the model include circumferentially averaged results at the leading and trailing edges of the impeller, and analysis of the flow field within the impeller passage. Circumferentially averaged results include axial and tangential velocities, static pressure, and total pressure. Within the impeller passage the static pressure and velocity results are presented on surfaces from the leading edge to the trailing edge, the hub to the shroud, and the pressure surface to the suction surface. Results of this study are consistent with the expected flow characteristics of mixed flow impellers, indicating that small CFD models can be used to evaluate impeller performance in the design environment.

MORAN, Angela, Associate Professor and OSBORNE, M. C., ONR Post-Doctoral Fellow, "Stress Pattern Analysis by Thermal Emission of Plain Weave Carbon Fiber-Epoxy Iosipescu Specimens with Three Different Notch Angles," *Journal of Test and Evaluation*, accepted for publication.

Iosipescu specimens were developed to examine the shear properties of isotropic materials. In the past decade, there has been much effort made to analyze this specimen configuration for measuring anisotropic materials particularly laminated and woven composites. Authors have used notch angles ranging from 90° to 110° in these materials and other authors performed finite element analysis (FEA) to determine that the best notch angle would be 100° based on the ratio of elastic moduli. The object of this study is to verify the preferred angle through the use of Stress Pattern Analysis by Thermal Emission (SPATE), which is a technique that can image the hydrostatic stress state in a material under load. SPATE images were collected for various specimens at different notch angles (90°, 100° and 110°) and different weave lay-ups. Mean load was held constant while the SPATE image was collected but later increased to examine the stress state of the Iosipescu specimens at high loads. The results indicate that for a plain woven graphite-epoxy composite, the 100° notched specimen is the best specimen of the three conditions examined due to the delay in occurrence of damage and the large size of the pure shear zone.

NELSON, M.E., Professor, SARLESE, J.A., MIDN 1/C, USN, ZIEGLER, J.F., Visiting Professor, Muhlfeld, H., Peterson, R. J., Campbell, A., Melinger, J. S., Clark, K., and Thompson, A. K., "Cosmic Ray Induced Soft Error Rates of Commercial 16 Mb and 64 Mb DRAMS at Aircraft Altitudes," *Journal of Radiation Effects*, accepted for publication.

The soft error rate (SER) for commercial-off-the shelf (COTS) 16 Mb and 64 Mb memory devices has been estimated at different worldwide locations and altitudes from different commercial vendors. The chips were irradiated with neutrons, protons, and pions, whose energy ranged from thermal (,025 eV) to 280 MeV. The SER for these devices was then calculated at various altitudes for a given longitude and latitude using results from an atmospheric particle flux model. The results show that the 16 Mb chips have a much wider variation than the 64 Mb chips in their SER between vendors. In addition, the 64 Mb chips were found on average to have a smaller SER cross section (fails/unit particle fluence/bit) than the 16 Mb chips. A flight experiment needed to confirm these predictions is described.

RATCLIFFE, C.P., Associate Professor, "A Frequency and Curvature Based Experimental Method for Locating Damage in Structures," *American Society of Mechanical Engineers Journal of Vibrations and Acoustics*, JVA V122, Issue 3, pp. 324-329, 2000.

This paper presents a method for locating structural damage using experimental vibration data. The method uses measured frequency response functions to obtain displacement as a function of frequency. The displacement functions are converted to curvature functions, which are further processed to yield a damage index, displayed on a plot of position versus frequency. The method can be applied when there is no a priori knowledge about the undamaged structure, and it is suitable for automation. This paper details the theory of the broadband method, and the results of an experimental demonstration in which a steel beam was damaged with a narrow slot. It is shown that this proposed damage detection method is highly sensitive, and can locate a very small amount of damage. For example, the narrow slot was correctly located when there was only a 0.8% reduction in thickness in the beam. Traditionally, damage causes a change in natural frequencies, but at this small level of damage the frequency changes were within experimental error. Other published methods failed to locate the slot until it was significantly deeper.

TUTTLE, Kenneth L., Associate Professor, "Oxides of Nitrogen Emissions from Burning Wood," *Journal of Solid Waste Technology and Management*, (Widener University and University of Pennsylvania), accepted for publication.

Oxides of nitrogen, NO_x emissions, are one of the most carefully monitored contributors to air pollution in metropolitan areas. NO_x is known to contribute to smog and ground level ozone as well as having the potential to make rain more acidic. Any fuel burned in air can be expected to produce NO_x although some sources are much worse than others. The NO_x emissions data presented in this paper show the effects of several combustion parameters in a boiler burning wood. The wood fuel burned in the United States is generally waste wood and is burned in boilers that use grates. The wood wastes vary in particle size, moisture content and bark content; however, in a single

boiler the species is usually fairly constant. The energy content is affected mostly by moisture content and the combustion is affected mostly by fuel particle size and air distribution. This paper presents variables such as excess air, combustion air distribution, fuel moisture, fuel size and fuel combustion rate and their effect on the production of nitric oxide during the combustion of wood fuel. The results should apply to many other biomass fuels including agricultural wastes, industrial solid wastes, shipboard solid wastes and municipal solid wastes fired under similar conditions.

VOLINO, R. J., Assistant Professor and Hultgren, L.S., "Measurements in Separated and Transitional Boundary Layers under Low-Pressure Turbine Airfoil Conditions," *American Society of Mechanical Engineers Journal of Turbomachinery*, Vol. 123, pp. 189-197.

Detailed velocity measurements were made along a flat plate subject to the same dimensionless pressure gradient as the suction side of a modern low-pressure turbine airfoil. Reynolds numbers based on wetted plate length and nominal exit velocity were varied from 50,000 to 300,000, covering cruise to takeoff conditions. Low and high inlet free-stream turbulence intensities (0.2% and 7%) were set using passive grids. The location of boundary-layer separation does not depend strongly on the free-stream turbulence level or Reynolds number, as long as the boundary layer remains non-turbulent prior to separation. Strong acceleration prevents transition on the upstream part of the plate in all cases. Both free-stream turbulence and Reynolds number have strong effects on transition in the adverse pressure gradient region. Under low free-stream turbulence conditions transition is induced by instability waves in the shear layer of the separation bubble. Reattachment generally occurs at the transition start. At Re = 50,000 the separation bubble does not close before the trailing edge of the modeled airfoil. At higher Re, transition moves upstream, and the boundary layer reattaches. With high free-stream turbulence levels, transition appears to occur in a bypass mode, similar to that in attached boundary layers. Transition moves upstream, resulting in shorter separation regions. At Re above 200,000, transition begins before separation. Mean velocity, turbulence and intermittency profiles are presented.

VOLINO, R. J., Assistant Professor and Simon, T.W., "Spectral Measurements in Transitional Boundary Layers on a Concave Wall under High and Low Free-Stream Turbulence Conditions," *American Society of Mechanical Engineers Journal of Turbomachinery*, Vol. 122, pp. 450-457.

The relationship between free-stream turbulence and boundary layer behavior has been investigated using spectral measurements. The power spectral densities of turbulence quantities in transitional and fully-turbulent boundary layers were computed and compared to the power spectra of the same quantities measured in the free-stream. Comparisons were made using the "transfer function". The transfer function is the ratio of two spectra at each frequency in the spectra. Comparisons were done in flows with low (0.6%) and high (8%) free-stream turbulence intensities. Evidence was gathered which suggests that relatively low frequency, large scale eddies in the free-stream buffet the boundary layer, causing boundary layer unsteadiness at the same low frequencies. These fluctuations are present in both transitional and fully-turbulent boundary layers. They are seen under both high and low free-stream turbulence conditions, although they are stronger in the high-turbulence case. Examination of the turbulent shear stress suggests that the low-frequency fluctuations enhance transport in the boundary layer but they are not so effective in promoting eddy transport as are turbulent eddies produced and residing within the boundary layer. In the fully-turbulent boundary layer, higher-frequency fluctuations are added to the low-frequency unsteadiness. These higher-frequency fluctuations, not seen in the transitional boundary layer, are associated with turbulence production in the boundary layer and appear to not be directly related to free-stream unsteadiness.

WU, Chih, Professor, "Intelligent Computer Aided Simulation, Design and Improvement of a Heat Pump," *Simulation*, Vol 74, n 1, pp. 18-27, 2000.

This paper describes the use of an intelligent computer aided software in simulation, design and possible refinements of vapor heat pumps. Historical evolution and several differently arranged Rankine heat pump cycles are demonstrated. Objectives for improvements, constraints, and consequently design which cannot be easily accomplished using conventional methods, are empasized. Using the software increases engineers' interest and design ability in the vapor heat pumps.

WU, Chih, Professor, "A Combined Law Power Optimized Open Joule-Brayton Heat Engine Cycle With a Fixed-finite Thermal Reservoir," *International Journal of Power and Energy Systems*, Vol 20, n1, pp.1-6, 2000.

Optimum power expressions for the open irreversible Brayton and open Joule Brayton heat engine cycles are obtained through the concurrent employment of the first and second laws of thermodynamics. The results are applicable to finite reservoir configurations where the value of the source inlet and outlet temperatures are fixed during the power optimization of the working substance temperatures.

WU, Chih, Professor, "Intelligent Computer Aided Simulation of a Thermodynamic Cycle," *International Journal of Modeling and Simulation*, Vol 20, n 4, pp. 308-312, 2000.

In the design and operation of a thermodynamic power system, significant resources must be utilized in order to maximize the system thermal efficiency. The traditional cycle simulation is a long and tedious process. This paper describes the use of an Intelligent computer software to obtain the simulation of the thermodynamic cycle quickly and accurately with a coaching facility.

WU, Chih, Professor, "Finite-time Exergoeconomic Performance Bound for a Quantum Stirling Engine," *International Journal of Engineering Science*, Vol 38, n 2, pp. 239-247, 2000.

The finite-time exergoeconomic optimal performance for a quantum Stirling engine is studied. The maximum exergoeconomic profit, the optimal thermal efficiency and the optimal power output of the quantum Stirling engine are obtained.

WU, Chih, Professor, "Method of Thermoeconomical Optimization of Energy Intensive Systems with Linear Structure on Graphs," *International Journal of Energy Research*, Vol 24, pp. 615-623, 2000.

In the design and operation of energy intensive systems, the problem of improving efficiency is very important. The main way for solving this problem is optimization. This paper describes the general approach for thermoeconomical optimization systems with linear structure. A method based on the building and analysis of a special graph of thermoeconomical expenditure is suggested.

WU, Chih, Professor, "Analysis on the Performance of a Thermoelectric Generator," *American Society of Mechanical Engineers Journal of Energy Resources Technology*, Vol 122, n 2, pp. 61-63, 2000.

An externally and internally irreversible heat engine model of thermoelectric generator is used to analyze the so-called device-design parameter introduced by Ozkaynak et al. The simple expression of the parameter is given and its physical meaning is expounded. Moreover, the optimal range of the parameter is determined and the problems relative to the maximum power output and maximum efficiency are discussed. Some meaningful results are obtained.

WU, Chih, Professor, "Gas Turbine Design for Large Naval Ships Using Intelligent Computer Design Software," *Naval Engineers Journal*, Vol 112, n 6, pp. 41-48, 2000.

This paper explodes the possibility of combining the Brayton and Ericsson cycles to produce a high efficiency gas turbine cycle for use onboard large Navy vessels. The advantages would be quick startup, decreased manning and less space requirements. Efficiencies were found to equal and surpass those of a typical Rankine cycle. Analysis is done using CyclePad, an intelligent computer aided design program.

WU, Chih, Professor, "Ground Heat Exchanger for GSHP System," *International Journal of Power and Energy Systems*, Vol 20, n 3, pp. 119-122, 2000.

The design process and features of a vertical double-spiral coil ground heat exchanger for a ground source heat pump systems are described in this paper. The heat absorption rate per unit of ground surface area occupied by the

ground heat exchanger is shown to be eighteen times greater than a single-pipe heat horizontal exchanger. The COP of the ground heat exchanger heat pump system shows a 21% improvement over that of a single-pipe heat horizontal exchanger heat pump system.

WU, Chih, Professor, "Thermoeconomic Analysis on the Performance Characteristics of a Multi-stage Irreversible Combined Heat Pump System," *American Society of Mechanical Engineers Journal of Energy Resources Technology*, Vol 122, n 4, pp. 212-216, 2000.

A cycle model of a multi-stage combined heat pump system which includes the irreversibility of finite rate heat transfer across finite temperature differences and the irreversibilities inside the working fluid is established and used to investigate the influence of these irreversibilities on the performance of the system. The profit of operating the heat pump system is taken as an objective function for optimization. The maximum profit is calculated for a given total heat transfer area or total thermal conductance of heat exchangers. The COP, heating load, and power input at the maximum profit is determined.

WU, Chih, Professor, "Optimization of Irreversible Magnetic Stirling Cryocoolers," *International Journal of Engineering Science*, 39(4), pp. 361-368, 2001.

This paper presents a model of irreversible magnetic Stirling crycooler using paramagnetic material as the working substance. The relation between optimal cooling load and the COP, the maximum cooling load and the corresponding COP, as well as the maximum COP and the corresponding cooling load of an irreversible magnetic Stirling cryocooler is derived.

WU, Chih, Professor, "Optimum Distribution of Heat Exchanger Inventory for Power Density Optimization of an Endoreversible Closed Brayton Cycle," *Journal of Physics D: Applied Physics*, Vol 34, n 3, pp. 422-427, 2001.

The power density is taken as the objective for performance optimization of an endoreversible closed Brayton cycle coupled to constant- or variable-temperature heat reservoirs. The optimum heat conductance distribution corresponding to the optimum power density of the hot- and cold-side heat exchangers for a fixed heat exchanger inventory is analyzed.

WU, Chih, Professor, "Performance of Heat Transfer Irreversible Regenerated Brayton Refrigerators," *Journal of Physics D: Applied Physics*, Vol 34, n 5, pp. 830-837, 2001.

The performance of an externally and internally irreversible regenerated Brayton refrigerator is analyzed. Analytical relationships between cooling load and pressure, as well as between coefficient of performance and pressure ratio of a real closed irreversible regenerated Brayton refrigerator coupled to constant- or variable-temperature heat reservoirs are derived.

WU, Chih, Professor, "Measurement Performance of a Solar-ground Source Heat Pump with Vertical Double Spiral Coil Ground Heat Exchanger," *International Journal of Ambient Energy*, Vol 22, n 1, pp. 3-11, 2001.

The experimental study was performed for a solar-ground source heat pump with vertical double spiral coil ground heat exchanger. The heating mode of the system is alternated between a solar energy source heat pump and a ground source heat pump using a low grade energy utilization system.

WU, Chih, Professor, "Energy Analysis for a Braysson Cycle," *Energy International Journal*, Vol 1, n 1, pp. 52-57, 2001.

An energy analysis has been carried out for an irreversible Braysson cycle. The analytical formula of power output and energy efficiency are derived. The influence of various parameters on the energy performance are analyzed by numerical calculations.

WU, Chih, Professor, "Effect of Heat Transfer on the Performance of Thermoelectric Heat Pumps," *Journal of Non-Equilibrium Thermodynamics*, Vol 26, n 1, pp.41-51, 2001.

The performance analysis of thermoelectric heat pumps is performed using the combined method of finite time thermodynamics and non-equilibrium thermodynamics. The heating load and COP expressions for the thermoelectric heat pump are derived with the consideration of heat transfer irreversibility in the heat exchangers between the heat pump and the surroundings as well as the other internal irreversibilities. Numerical examples are provided. The effects of heat transfer, the number of elements, and other design parameters on the performance of the heat pump are analyzed.

WU, Chih, Professor, "Theoretical Analysis and Experimental Confirmation of the Performance of a Thermoelectric Refrigerator," *Journal of Non-Equilibrium Thermodynamics*, Vol 26, n1, pp. 85-92, 2001.

The cooling load and COP expressions for a thermoelectric refrigerator are derived with the consideration of heat transfer irreversibility in the heat exchangers between the refrigerator and the surroundings. Experimental data are taken. The theoretical results are compared and confirmed with experimental results.

WU, Chih, Professor, "Power Density Analysis of an Endo-reversible Closed Brayton Cycle," *International Journal of Ambient Energy*, Vol 22, n 2, pp. 95-104, 2001.

The power density is maximized for an endo-reversible closed Brayton cycle coupled to constant temperature heat reservoirs in the view point of finite time thermodynamics or entropy generation minimization. The effect of heat transfer and engine size were included in the analysis.

WU, Chih, Professor, "Power Density Analysis and Optimization of a Regenerated Closed Variable Temperature Heat Reservoir Brayton Cycle," *Journal of Physics D: Applied Physics*, Vol 34, n 11, pp.1727-1739, 2001.

The power density of an endo-reversible regenerated closed Brayton cycle coupled to constant temperature heat reservoirs in the view point of finite time thermodynamics or entropy generation minimization. The analytical formulae between the power density and pressure ratio is derived with the heat resistance losses in the hot- and cold-side heat exchangers and the regenerator, the irreversible compression and expansion losses in the compressor and turbine, the pressure drop losses at the heater, cooler and regenerator as well as in the piping, and the effect of the finite thermal capacity rate of the heat reservoirs.

WU, Chih, Professor, "Recent Advances in Finite-time Thermodynamics and its Future Application," *International Journal of Energy, Environment and Economics*, 2001, in press.

Recent advances in finite-time thermodynamics including the theory of irreversible engines, refrigerators and heat pumps, analysis of regenerated systems, characters of heat-engine-like plants, and theory of generalized thermodynamic optimization are described. Potential future developments in finite-time thermodynamics are discussed.

WU, Chih, Professor, "Accoustically Controlled Heat Transfer of Ferromagnetic Fluids," *International Journal of Heat and Mass Transfer*, 2001, in press.

The accoustically controlled heat transfer enhancement of a ferromagnetic fluid in an external magnetic field is studied. The analytical expression for the effective thermal diffusivity is obtained. The numerical analysis and experimental results are discussed.

WU, Chih, Professor, "The Specific Heats of Gases in an Arbitrary Process," *International Journal of Mechanical Engineering Education*, 2001, in press.

The specific heats of gases in an arbitrary process is investigated and a general expression is obtained. The expression is used to derive the specific heats of ideal and real gases, which are subject to the different equations of state, along an arbitrary process and some specific paths. The results obtained here can give not only the relevant contents in thermodynamics textbooks but also some new useful conclusions, so they are of general theoretical significance and practical application value.

WU, Chih, Professor, "Heating Load Versus COP Characteristics for Irreversible Air Heat Pumps," *International Journal of Power and Energy Systems*, Vol 24, n 2, 2001, in press.

The effect of heat resistance on the performance of an air heat pump is analyzed. This work extends the recent flurry of publication in heat pump performance by incorporating nonisentropic compression and expansion. Relationships between heating load and pressure ratio, and between COP and pressure ratio for the heat pump are derived.

Conference Proceedings

BARTON, Oscar, Jr., Associate Professor, Cornell, C. and Lenoe, E., "Analysis of SiC-2/Aluminum Composite Box Beams," *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.*

In this paper the relative capabilities of metal matrix composite (MMC) box beams fabricated by welding and brazing techniques are explored. The metal matrix composite system consist of silicon carbide fibers and T6061 aluminum matrix with the laminate stacking sequence of [0,"ð45, 0]$_s$. To assess the potential, the resulting beams are examined using optical microscopy exploring both welded and brazed joint characteristics, hardness tested to generate hardness profile through the joined sections, and sectioned across the both the brazed and welded section producing tensile properties. Tensile test specimens were also machined from the flanges and web sections of the box structure and will provide needed mechanical response information. A final comparison comes through the free vibration dynamic analysis comparing fundamental frequencies of the beams. The four box beams were hot formed using two C shell sections. Each C section was fabricated using pre-formed, plasma sprayed composite metal sheets. These unidirectional sheets were arranged in the desired orientations and formed against a steel male mold producing a section which is 2 in x 4 in x 48 in. Subsequently, two C sections were joined to form four-foot long box beam structures. The C-sections were either welded using conventional welding techniques or alternatively brazed with the webs configured in a stepped-lap configuration.

CERZA, M.R., Associate Professor, BOUGHEY, B., Lieutenant (USN) and LINDLER, K.W., Professor, "A Flat Heat Pipe for Use as a Cold Side Heat Sink," Heat Pipes and Capillary Pumped Loops, *Proceedings of the 35th Intersociety Energy Conversion Engineering Conference*, Las Vegas, NV, July 24-28, 2000.

Heat pipe technology can effectively meet the demand for an isothermal emitter in a thermophotovoltaic (TPV) energy system as it utilizes near isobaric phase changes to transfer heat at a uniform temperature. A flat heat pipe offers many advantages over the conventional cylindrical design, such as increased surface to volume ratio and the ability to stack or layer the energy conversion system on both sides of the flat heat pipe to utilize available energy. Flat heat pipes present unique engineering demands and are also difficult to construct. This paper details the design, construction and analysis of a low temperature flat heat pipe as part of the thermal sink in order to determine the feasibility of implementing flat heat pipes into TPV energy conversion systems. Theoretical and experimental data are compared.

CERZA, M.R., Associate Professor, "The Effects of Air Infiltration on a Large, Flat Heat Pipe at Horizontal and Vertical Orientations," Heat Pipes and Capillary Pumped Loops for Electronic Cooling, *Proceedings of the 34th National Heat Transfer Conference*, Pittsburgh, PA, August 20-22, 2000.

A large flat heat pipe, 1.22m x 0.305m x 0.0127m, fabricated from 50 mil Monel 400 sheet metal and Monel 400 screens was videographed at horizontal and vertical orientations with an infrared video camera. The heat pipe evaporator section consisted of a 0.305m x 0.305m area (one heated side only) while the side opposite the heated section was insulated. The remaining area of the heat pipe served as the condenser. In the horizontal orientation, the heated section was on the bottom. In the vertical orientation, the evaporator was aligned below the condenser. The sequence of photographs depict heat inputs ranging from 200W to 800W, and the effect of air infiltration on heat pipe operation for both orientations. For the horizontal orientation, the air is seen to recede towards the small fill pipe as the heat input is increased. For the vertical orientation, the air and water vapor seem to exhibit a buoyant interaction. The effects presented in this paper are primarily qualitative.

FLACK, K.A., Associate Professor and SCHULTZ, M.P., Assistant Professor, "Experimental Investigation of Lift Modification on Double Delta Wings using Fillets," *AIAA Applied Aerodynamics Conference*, Anaheim, CA, June 2001.

The junction of the leading edge extension (LEX) and the delta wing on the F/A-18 E/F aircraft is a region of highly complex vortex flows interactions. The region is important not only to the performance and stability of the aircraft, but may affect cyclical loading of the tail due to vortex buffet. The geometry of the junction is also critical in the overall radar signature of the aircraft. The objective of the present research is to compare the aerodynamic forces on a model with different LEX-wing fillet configurations. Three fillet types were tested in this junction on a 1:28 scale F/A-18 E/F model in a low speed wind tunnel in the Aeronautics Laboratory at the United States Naval Academy. The fillets were found to have little effect on the aerodynamics forces of the model. This result is contrary to previous research on a flat plate model of a delta wing.

JOYCE, P.J., Assistant Professor, Violette, M. G., and Moon, T. J., "Finite Element Analysis of Unidirectional Composite Compression Test Specimens: A Parametric Study," *ASTM STP 1416: Composite Materials: Testing, Design, and Acceptance Criteria*, Phoenix, AZ, March 26-27, 2001, accepted for publication.

Compression testing of unidirectional composites has long been a very active field. Because of the difficulties associated with compression testing of unidirectional composites, a great deal of effort has been devoted to the problem of determining what type of test configuration is best. Several testing methods have been standardized, each optimized for a particular loading method and specimen configuration. Recently, several investigators have proposed combined shear/end loading of the specimen as a way of obtaining improved compressive strength from unidirectional laminate coupons. Comparing the various compression test techniques, whether experimentally, or numerically, has often been confounded by the peculiarities of each technique. This research undertakes a comprehensive parametric study of the Combined Loading Compression (CLC) test fixture from Wyoming Test Fixtures (WTF) using numerical analysis to evaluate various test parameters associated with compression testing of unidirectional test specimens.

A two-dimensional finite element analysis of the WTF CLC fixture was used to identify loading conditions and tabbing configurations that minimized the peak axial, shear, and through-thickness stress concentrations in the test specimen. Combined shear and end loading appears to offer a good compromise between reducing the tab tip stress concentrations inherent in shear loading, and avoiding premature failure by end brooming associated with end loading. Thin, tapered tabs made of compliant materials were found to have the smallest stress concentrations at the tab tip. Specimens with these tab configurations should yield higher measured compressive strengths since premature failure at the tab tip is less likely to occur. Partial debonding of the tab tip was found to increase the stress concentration compared to the fully-bonded case, but to move its location away from the gage section of the specimen. Tab tip debonding should be avoided for compressive strength testing.

KOUL, Michelle G., Assistant Professor, and Scully, John R., "Hydrogen Desorption Mechanisms in Metastable Beta Ti-3Al-8V-6Cr-4Mo-4Zr," Oxide Films, K.R. Hebert, R.S. Lillard, B. R. MacDougall, eds., *Symposium Proceedings from the 197th Meeting of the Electrochemical Society*, Toronto, Canada, Spring 2000.

The mechanisms by which hydrogen desorbs from Ti-3Al-8V-6Cr-4Mo-4Zr in the presence of a native oxide film under vacuum were examined using a thermal desorption spectroscopy technique. Hydrogen release was extremely limited and not measured below 300°C owing to the thermal stability of the surface oxide. In the temperature range of 325-490°C, hydrogen release was diffusion controlled and not observed until the oxide film was dissolved. Surface recombination controlled desorption was observed at temperatures exceeding 490°C with apparent activation energies similar to the theoretical value of $2E_{sol}$, where E_{sol} is the energy of hydrogen solution. The transition from diffusion control to surface recombination control was coincident with a reduction of the surface O content to ~25%.

LINDLER, K.W., Professor, "A Flat Heat Pipe for Use as a Cold Side Heat Sink" in Heat Pipes and Capillary Pumped Loops, *Proceedings of the 35th Intersociety Energy Conversion Engineering Conference*, Las Vegas, NV, July 24-28, 2000.

Heat pipe technology can effectively meet the demand for an isothermal emitter in a thermophotovoltaic (TPV) energy system as it utilizes near isobaric phase changes to transfer heat at a uniform temperature. A flat heat pipe offers many advantages over the conventional cylindrical design, such as increased surface to volume ratio and the ability to stack or layer the energy conversion system on both sides of the flat heat pipe to utilize available energy. Flat heat pipes present unique engineering demands and are also difficult to construct. This paper details the design, construction and analysis of a low temperature flat heat pipe as part of the thermal sink in order to determine the feasibility of implementing flat heat pipes into TPV energy conversion systems. Theoretical and experimental data are compared.

MORAN, Angela, Associate Professor, SCHROEDER, J. A., MIDN 1/C, USN and D. R. White, "Improvements in Copper Welding Electrodes Via Powder Metallurgy Processing," in Advances in Powder Metallurgy and Particulate Materials 2000, *Metal Powder Industries Federation*, NJ, July 2000, pp.12-19.

As an alternative to conventional materials, welding electrodes made from copper alloys with very high melting temperature refractory metals, such as molybdenum, niobium, and chromium, have been fabricated via several powder metallurgy processing methods. This effort was aimed at increasing the life of copper electrodes used in the resistance welding of aluminum work pieces employed in the automotive and aerospace industries. When the copper and aluminum make contact at the interface, there is some undesirable mixing which results in the formation of a copper-aluminum eutectic phase. The welding temperature is high enough to melt the aluminum, but the eutectic phase has a lower melting temperature than either pure copper or pure aluminum. During subsequent welds the eutectic melts away, causing the copper to degrade rapidly and the electrode lifetime to be shortened. Since the refractory metals additions were not readily soluble in copper, it was necessary to use powder processing techniques to produce electrodes of uniform composition. These techniques included spray forming, plasma processing, laser cladding, and mechanical alloying which allowed for a higher concentration and a more uniform distribution of the refractory metal, as confirmed by metallurgical analysis involving optical and electron microscopy. The electrodes were tested for homogeneity, conductivity and welding lifetime. Recommendations are provided concerning alloy selection and processing methods for improved electrode performance.

MORAN, Angela, Associate Professor, OSBORNE, M.C., ONR Post-Doctoral Fellow, Antenucci, A. and Lauten, F., "Formation of C/SiC Composites from a Commercially Available Pre-ceramic Polymer," in Advances in Ceramic Matrix Composites VI, *Ceramic Transactions*, Vol. 124, 2000, pp. 53-64.

The physical and mechanical properties of ceramic matrix composites (CMC's) are greatly affected by different fabrication techniques. Density, interphase strength, matrix cracking stress and ultimate strength can be tailored to fit the application by varying the composite's fiber lay-up and the conditions under which the pre-form is filled. Two common ways of producing SiC as the matrix in a CMC are by chemical vapor infiltration (CVI) and by polymer pre-cursor pyrolization. With the interface controlling the failure mode of the CMC, the matrix unifor-

mity and consistency controls the repeatability (statistical distribution) of these failure modes. This study examined the physical property changes of a C/SiC CMC formed by the polymer conversion method. Converted Ceraset™CMC's with graphite fibers were produced for this study at the USNA. Homogeneity and porosity distribution were examined via optical microscopy. Density measurements were made via immersion in ethyl alcohol. A TGA was used to measure mass loss during heat-up. Results indicate that Ceraset loses 25% of its mass on heating to 2000°F under a N_2 and CH_4 atmosphere. The distribution of densities in the composite plate varied ±10% around the mean density of 1.68 g/cc. The majority of the porosity was open which allows continuing impregnation of the polymer into the composite. Therefore, dense, uniformly porous, composite plates were produced which should have repeatable failure characteristics.

PUZINAUSKAS, P.V., Assistant Professor, Willson, B.D., and Evans, K.H., "Optimization of Natural-Gas Combustion in Spark-Ignited Engines Through Manipulation of Intake-Flow Configuration," *Society of Automotive Engineers Conference*, Paper # 2000-01-1947, 2000.

An investigation was performed to try to quantify the relative importance of large-scale mixing and turbulence in a multi-valve spark-ignited automotive engine converted to use natural-gas fuel. The role of mixing was examined by comparing single-point versus multi-point combustion performance at several operating conditions. The fuel-air mixture passed through a static mixer prior to entering the intake manifold in the single point case. This configuration was assumed to produce a well-mixed charge entering the combustion chamber. The fuel was delivered just upstream of the intake port in the multi-point configuration. The charge was assumed to be stratified in this case. The results showed a significant degradation in combustion stability and maximum power but little-to-no difference in ignition delay and fully-developed burn duration using multi-point injection.

The relative role of turbulence was examined by altering the intake-flow configuration to create three levels of inlet swirl. A thermodynamic model was used to characterize the effect of the altered flow on mean flow and turbulence. The engine was then tested using each intake-flow configuration. Inlet swirl typically improved combustion stability and decreased fully-developed burn duration, but consistently increased ignition delay. The differences were generally most dramatic at lower engine speeds.

PUZINAUSKAS, P.V., Assistant Professor, Hutcherson, G.H., and Willson, B.D., "Analysis of In-Cylinder Heat Transfer in Large-Bore Engines," *Pipeline and Compressor Research Council*, Paper # 2000-102, 2000.

One cylinder of the large-bore test engine at the Engines and Energy Conversion Laboratory at Colorado State University was instrumented with fast-response surface thermocouples (FRT) for heat-transfer analysis. Probes were installed at several locations progressively farther from the ignition source and their outputs were recorded along with combustion pressure using a high-speed data-acquisition system. The engine was operated with two different ignition methods and the manifold boost pressure and cylinder jacket-water temperature were varied. The recorded surface-temperature data were processed to calculate in-cylinder heat transfer.

Combustion initiated with a screw-in type pre-combustion chamber resulted in significantly different heat-flux characteristics than that initiated by a conventional spark plug. The differences in the peak value could likely be attributed to flame quench distance. Differences in other portions of the cycle could have been caused by significantly increased flame velocities associated with the pre-chamber jet. Increasing boost pressure from 25 to 54 kPa decreased peak heat-flux values about 20-30% and steady-state values about 13%. Increasing jacket-water temperature 14 K had an insignificant effect on heat flux and combustion pressure.

RATCLIFFE, C. P., Associate Professor, "Correcting A Significant Bias Error In The Modal Damping Determined Using Transient Vibration Data," *American Society of Mechanical Engineers, Noise Control and Acoustics Division*, NCA-V27, pp. 379-384, 2000.

This paper investigates the experimental vibration technique of impact excitation when used to determine modal damping. Current practices introduce a consistent bias error in the derived modal damping estimates. The error can be significant, with levels of damping being wrongly predicted by a factor of three or more. This paper

identifies the source of the error, and derives a simple correction to be applied to the observed modal damping estimates. The procedure is demonstrated by experiment and the results of a round robin exercise.

RATCLIFFE, C. P., Associate Professor, Gillespie, Jr., J. W., Heider, D., Eckell, II, D. A. and Crane, R. M., "Monitoring and Defect Detection of an All-Composite Road Bridge," *American Society of Mechanical Engineers, Noise Control and Acoustics Division,* NCA-Vol. 27, pp. 399-406, 2000.

This paper presents the results of an ongoing investigation into the use of broadband vibration data to monitor the structural integrity and health of an all-composite road bridge. Bridge 1-351 on Business Route 896 in Glasgow, Delaware, was replaced with one of the first state-owned all-composite bridges in the nation in the fall of 1998. The bridge consists of two E-Glass/vinyl ester sandwich core sections (13-ft x 32 ft) joined by a longitudinal joint in the traffic direction. Each sandwich core section consists of a 28-inch deep core and 0.4-0.7-inch thick facesheets.

Vibration data were obtained from the upper and lower surfaces of the bridge using a mesh of 1050 test points. From the modal information and the visualization of the data, several aspects of the structural behavior of the bridge were obtained. These characteristics include the interactions between the bridge and abutments; the effectiveness of the longitudinal joint to couple the deck sections; the effectiveness of the core to couple the face sheets; and the structural integrity and dynamic consistency of the entire structure. Mode shapes and natural frequencies were determined and are correlated with theoretical calculations and vibration analyses conducted for this bridge.

A novel algorithm using the vibration data is being developed that enables local perturbations sensitive to the state of the material (e.g., manufacturing defects, material degradation or service damage) to be detected and spatially located in the bridge. This technique has been successfully validated for locating damage in 1-D beam structures and is being extended to the 3-D sandwich configuration of the bridge. By coupling this damage detection algorithm with the more conventional modal technique, the quality assurance/quality control and health monitoring of large composite bridge can be obtained.

RATCLIFFE, C. P., Associate Professor, Yoon, M. K., Heider, D., Gillespie, Jr., J.W., and Crane, R. M., "Local Damage Detection Using A Global Fitting Method On Mode Shape Data," *The Society for Experimental Mechanics, International Modal Analysis Conference IMAC-19,* V, Orlando 2001, pp. 231-237.

Damage in a structure alters its dynamic characteristics such as frequency response functions and modal parameters. This study expands 'gapped smoothing method' for identifying the location of structural damage in a beam by introducing a 'globally optimized smooth shape' with an analytic mode shape function. The procedure uses only the mode shapes from the damaged structure without a priori knowledge of the undamaged structure. The developed damage algorithm is tested with a finite element analysis (FEA) and validated with experiments on notched steel beam. The present method can detect local stiffness losses associated with local thickness reduction of less than 1 % in the case of both narrow damage (13 mm) and wide damage (126 mm) with FEA. The damage detection ability is enhanced by the summation of normalized damage indexes. The present method shows improved resolution on location and size of damage in the beam.

RATCLIFFE, C. P., Associate Professor, Yoon, M. K., Heider, D., Gillespie, Jr., J.W., and Crane, R. M., "Damage Localization using the Two-Dimensional Gapped Smoothing Method," *46th International SAMPE Symposium/Exhibition,* Long Beach, CA, May 6-10, 2001, pp. 752-764.

Dynamic characteristics of structures are sensitive to manufacturing defects and service damage. Several methods exist to locate damage in a structure with modal parameters. Unfortunately, these methods require a-priori data of the undamaged structure to enable detection of changes in the modal parameters. Ratcliffe has successfully applied a one-dimensional procedure for beam-like geometry that uses only the mode shape from the damaged structure. The study reported here has been generalized to plate-like structures by introducing a two-dimensional gapped smoothing method. The procedure is demonstrated using a two-dimensional finite element model of a plate. The new method locates damage by calculating damage index, which is formed by fitting a smoothed curvature surface to the measured modal curvature surface. The damage index at each point on the structure is the difference between the smoothed surface and the measured curvature at that point. The method can detect very

small, localized stiffness reductions. A case study is included for large composite structures such as ground vehicle hull components.

TUTTLE, Kenneth L., Associate Professor and WU, Chih, Professor, "Intelligent Computer Assisted Instruction in Thermodynamics at the U.S. Naval Academy," *Proceedings of the American Association for Artificial Intelligence*, Qualitative Reasoning Workshop, San Antonio, TX, 17-19 May 2001, pp. 105-112.

Since 1996, the Mechanical Engineering Department of the U.S. Naval Academy has evaluated and incorporated Intelligent Computer-Assisted Instruction, ICAI, into the thermodynamics curriculum. The ICAI takes advantage of a new software package called CyclePad. CyclePad has been tested in three course and a forth course is scheduled for fall term 2001. Two other courses are in planning stages. The three courses to use CyclePad thus far include: EM319, Engineering Thermodynamics, a first term course for engineering students, EM443, Advanced Energy Conversion, an elective for mechanical engineers and EM300, Naval Engineering II, a core thermodynamics course for non-engineers. Testing the software in these courses has caused improvements to be made to the software as well as evaluating student receptiveness of a computer-based approach to thermodynamics. This testing judged compatibility of the course material with the ICAI approach. Improvements included increasing user friendliness of CyclePad. This effort was concurrent between Computer Science Professor Kenneth D. Forbus and the software development group at Northwestern University and Peter D. Whalley at Oxford University and Professor Chih Wu at the U.S. Naval Academy. These efforts successfully integrated CyclePad into the classroom as a tool for design and research as well as teaching. This paper describes the courses, students targeted, logic of planning approach and long-range goals at the U.S. Naval Academy. The paper presents a study of effectiveness of CyclePad and also current and planned course developments.

VOLINO, R. J., Assistant Professor and SCHULTZ, M.P., Assistant Professor, "Effects of Concave Curvature on Boundary Layer Transition Under High Free-Stream Turbulence Conditions," *2001 American Society of Mechanical Engineers International Gas Turbine Conference*, paper 2001-GT-0191, New Orleans, LA, June 2001.

An experimental investigation has been carried out on a transitional boundary layer subject to high (initially 9%) free-stream turbulence, strong acceleration (K as high as $9x10^{-6}$), and strong concave curvature (boundary layer thickness between 2% and 5% of the wall radius of curvature). Mean and fluctuating velocity as well as turbulent shear stress are documented and compared to results from equivalent cases on a flat wall and a wall with milder concave curvature. The data show that curvature does have a significant effect, moving the transition location upstream, increasing turbulent transport, and causing skin friction to rise by as much as 40%. Conditional sampling results are presented which show that the curvature effect is present in both the turbulent and non-turbulent zones of the transitional flow.

VOLINO, R. J., Assistant Professor, SCHULTZ, M.P., Assistant Professor and PRATT, C.M., MIDN 1/C, USN, "Conditional Sampling in a Transitional Boundary Layer Under Hign Free-Stream Turbulence Conditions," *2001 American Society of Mechanical Engineers International Gas Turbine Conference*, paper 2001-GT-0192, New Orleans, LA, June 2001.

Conditional sampling has been performed on data from a transitional boundary layer subject to high (initially 9%) free-stream turbulence and strong (K as high as $9x10^{-6}$) acceleration. Methods for separating the turbulent and non-turbulent zone data based on the instantaneous streamwise velocity and the turbulent shear stress were tested and found to agree. Mean velocity profiles were clearly different in the turbulent and non-turbulent zones, and skin friction coefficients were as much as 70% higher in the turbulent zone. The streamwise fluctuating velocity, in contrast, was only about 10% higher in the turbulent zone. Turbulent shear stress differed by an order of magnitude, and eddy viscosity was three to four times higher in the turbulent zone. Eddy transport in the non-turbulent zone was still significant, however, and the non-turbulent zone did not behave like a laminar boundary layer. Within each of the two zones there was considerable self-similarity from the beginning to the end of transition. This may prove useful for future modeling efforts.

WU, Chih, Professor, "Discussion on Intelligent Computer Aided Optimization of Power and Energy Systems," *Proceedings of the Institute of Mechanical Engineers, Part A, Journal of Power and Energy*, Vol 214, n A3, pp. 287-289, 2000.

Discussion on intelligent computer aided optimization of power and energy systems is made. An innovative Braysson cycle which is made of a Brayton cycle and an Ericsson cycle is employed to illustrate the optimization method.

WU, Chih, Professor, "Cooling and Heating Rate Limits of a Reversed Reciprocating Ericsson Cycle at Steady State," *Proceedings of the Institute of Mechanical Engineers, Part A, Journal of Power and Energy*, Vol 214, n A1, pp. 75-85, 2000.

The optimal cooling and heating rates for the reversed reciprocating Ericsson cycle with ideal regeneration are determined for heat pump operations. These limiting rates are based on the upper and lower thermal reservoir temperature bounds and are obtained using time and entropy minimization procedures from irreversible thermodynamics. Using the Second law and time symmetry, the cycle time is minimized. This optimally allocates the thermal capacitances of the cycle and minimizes internal cycle entropy generation. Although primarily a theoretical work, a very practical and extensive parametric study using several environmentally friendly working fluids (neon, nitrogen and helium) is included. This study evaluates the relative contributions of various system parameters to rate-optimized design.

Books

TUTTLE, Kenneth L., Associate Professor and WU, Chih, Professor. Thermodynamics: A Computer Based Approach, Kendall/Hunt, Dubuque, 2001, in press.

Thermodynamics: A Computer Based Approach is a textbook written to enable the U.S. Naval Academy to develop courses featuring Intelligent Computer-Assisted Instruction (ICAI). This text was written specifically for two courses, one exists as a lab course for non-engineering majors. For it a further step is required before this text will support special sections or a special version for several sections of non-engineers. The other course is new, still in development and will be the first course in thermodynamics taught anywhere using full immersion in ICAI using a sophisticated software package, CyclePad, that may be downloaded from the web. This course is an elective for all engineering majors, except those who already take a second term of thermodynamics, EM320. The course, EM485D, and the textbook are applied in nature, instruct in English units to satisfy needs of the navy and provide instruction in heat transfer, heat exchangers and incompressible fluid flow for those students who have not had a course covering these topics. Thermodynamics: A Computer Based Approach covers the full range of thermodynamics topics from basic theory to cycle analysis for heat engines and heat pumps. This text includes many examples worked using CyclePad and features homework problems designed for solving on CyclePad.

Technical Reports, Book Reviews and Book Chapters

JOYCE, J.A., Professor and Tregoning, R.L., "Development of Consistent Size Criteria for ASTM Combined Fracture Mechanics Standards," Fatigue and Fracture Mechanics: 30th Volume, ASTM STP 1360, ASTM West Conshohocken, PA, 2000, pp. 357-376.

Recent ASTM E08.08 Subcommittee activities have concentrated on the development of fracture test standards that allow the evaluation of K_{Ic}, J_{Ic}, δ_i, and a resistance curve like the J-R curve from fracture toughness tests from a single test specimen. A parallel effort has been undertaken on the international stage under the auspices of the International Standards Institute (ISO). Many technical changes have been made to allow this process to go forward, but one area in which progress has not been made is in clarifying the various specimen size requirements that were part of the earlier standards. Instead, the size requirements in the new toughness testing standard E1820 have been extracted from the earlier standards, like ASTM E399 and ASTM E813 and extended to the new standard without change, in spite of their clear inconsistency.

A review of the development of the E399 size criteria seems to make it clear that the E399 size criterion was meant by its originators only to represent a requirement which allowed the 0.95 secant offset method to adequately evaluate a consistent measure of crack initiation. The later J integral based size criteria of E813, E1152, E1737, E1820, and the recent T_o Reference Temperature standard E1921 is based on finite element analysis which ensures that a minimal deviation from small scale yielding (SSY) occurs. This generates consistent crack tip constraint as the specimen size decreases or the crack length increases.

In this work, specimens have been machined from three materials, a 6061-T651 Aluminum, a 6V-4Al Titanium alloy, and a 4340 steel alloy to investigate what the proper size criteria should be for a combined fracture mechanics test standard. Larger specimens have been machined from each material and tested to obtain K_{Ic} values meeting the stringent size criteria of ASTM E399. Smaller specimens of each material were also prepared to intentionally fail the E399 size criteria, but still satisfy the less stringent criteria of ASTM E813 and E1820. The unloading compliance method has been used in the testing of the smaller specimens so that an estimate of the true crack initiation point on the specimen load displacement record can be measured.

The fracture toughness at the onset of ductile crack extension is measured in terms of the J integral and converted to an equivalent stress intensity K_J value using the standard relationship. The fracture toughness at this crack initiation point can then be compared with the K_Q obtained using the 0.95 secant offset initiation point specified by the E399 K_{Ic} procedure, and the validity of the various measures of initiation toughness can be determined with respect to the different size criteria.

JOYCE, J.A., Professor and Tregoning, R.L., "Application of Master Curve Technology to Biaxial and Shallow Crack Fracture Data for A533B Steels," Effects of Radiation on Materials: 19th International Symposium, ASTM STP 1366, M.L. Hamilton, A/S. Kumar, S.T. Rosinski, and M.L. Grossbeck, Eds., West Conshohocken, PA, 2000, pp 177-203.

The Master Curve approach has recently been proposed by Wallin to define the expected toughness of ferritic steels in the ductile-to-brittle transition. This method has been standardized in ASTM E1921-98 using deeply cracked fracture toughness specimens tested quasistatically in the lower transition regime. However, the commercial nuclear power industry will often use this method to infer structural performance where the critical crack of interest is shallow, rather than deep, and the loading is biaxial rather than uniaxial. Research has been funded by the U.S. Nuclear Regulatory Commission (NRC) and conducted at the Oak Ridge National Laboratory (ORNL), the U.S. Naval Academy (USNA), and the Naval Surface Warfare Center (NSWC) to address potential shortcomings of the present ASTM Standard Master Curve method for such applications.

Low-constraint specimens of A533B steel were tested to measure performance under more realistic crack tip constraint conditions, and results were analyzed using the Master Curve approach. The A533B steel plate was heat treated to simulate the elevation of the material yield strength and reduction in toughness which results from extended aging due to neutron irradiation. ORNL conducted shallow crack (a/W = 0.1), uniaxially and biaxially-loaded cruciform specimen testing, while USNA performed shallow crack (a/W = 0.1), uniaxially-loaded SE(B) testing. Both laboratories also utilized additional deeply cracked (a/W > 0.5) specimens to fully characterize the A533B steel plate tested as per ASTM E1921. ORNL conducted 1/2T C(T) specimens, while USNA tested both 1/2T C(T) and 1T SE(B) specimens. The standardized master curve approach has been used for analysis in most cases, but this technique was augmented with the maximum likelihood, multi-temperature method when data at a single temperature was sparse.

Results indicate that larger variability in K_{Jc} (fracture toughness at onset of cleavage initiation) is present in the shallow cracked specimens compared with deeply cracked specimens tested at the same temperature. This result is expected due to interaction between the gross section and crack-tip plasticity which lowers constraint and reduces the opening mode stress magnitude within the crack-tip process zone. Surprisingly, however, the 1T SE(B) shallow crack specimens exhibited a distinct reduction in the median K_{Jc} in comparison with the deeply cracked specimens tested using the same material. This trend is counter to historical short-crack data which exhibits an increase in the median K_{Jc}.

Stereo-Section fractography was performed to reveal the microstructure near the cleavage crack initiation sites of several shallow and deeply cracked A533B specimens. More intense carbide bands are present in the USNA shallow cracked SE(B) specimens than in the other specimens tested. This implies that the *local* carbon content

and hardness is higher in these specimens and lead to the low median K_{Jc}. This effect has recently been more rigorously quantified. The variation of the carbide band density in the A533B material tested is a cause of considerable concern. The ability of surrogate, surveillance capsule specimens to accurately capture the reduced toughness due to banding is questionable in light of the relatively small amount of material available for testing, the highly localized nature of the banding, and the inability to predict where it will occur.

MORAN, Angela, Associate Professor, HURLEY, M., MIDN 1/C, USN, and OSBORNE, M.C., ONR Post-Doctoral Fellow, U.S. Naval Academy Report EW-01-01 "Materials Evaluation of SnAg Alternatives to PbSn Solders," June 2001.

Creep tests measure the resistance of a material to deformation and failure when subjected to a static load below the yield strength at an elevated temperature, or to a constant temperature at a varying stress. The temperature at which creep becomes significant is generally considered to be approximately 0.4 T_m where T_m is the absolute temperature so for lower melting point materials such as lead –tin solders, creep can become an issue at room temperature.

The experimental tests described in this paper were designed to give quantitative results which allow students to see room temperature changes in a commonly used material. This experiment compares common solder materials with a new solder alternative, a mixture (alloy) of tin, silver and copper.

MORAN, Angela L., Associate Professor and OSBORNE, M.C., ONR Post-Doctoral Fellow, year-end report to DOE, "USNA Investigation into CMC Damage Assessment Codes."

Abstract is not available for public release.

TUTTLE, Kenneth L., Associate Professor and WU, Chih, Professor, "Intelligent Computer-Based Thermodynamics," Final Report submitted to Office of Naval Research, 2000, 261p.

The teaching of thermodynamics to technical as well as non-technical major midshipmen, as part of the core engineering curricula, has been changing in recent years at U.S. Naval Academy and in other schools in the United States. The movement is away from property table searching and long hand computation. The basic concepts are more important for learning thermodynamics. These changes create pedagogical problems. A subtle and conceptual subject, such as thermodynamics, needs to be presented in greater richness to intellectually capable but less technical sophisticated students. This book is designed with the above trend and pedagogic problem in mind.

Recognizing the power and usefulness of computer databases and software in searching tables and in the solving problems, the authors made CyclePad in order to reduce the time spent doing hand computations. The software also requires the users to learn how to define processes and states. They gain a feel for the significance of concepts and then learn how to solve the problems that are associated.

This class would be significantly different from traditional courses but will emphasize the teaching of the same basic principles. The main difference is that the focus will be more applied and design based. The more holistic approach to teaching thermodynamics, and the use of CyclePad software, is expected to give the students a more complete understanding of the subject matter as well as an early start in the design experience.

Trident Scholar Report

FERRER, Charles P., MIDN 1/C, (USN), "Optimizing the Strength and Stress Corrosion Cracking Resistance of Aluminum Alloys Used for Refurbishing Aging Aircraft," Trident Scholar Report, May 2001.

Aluminum alloy 7075, a common material in the aerospace industry, is susceptible to stress-corrosion cracking (SCC) in the T6, or peak-aged temper. The susceptibility of this temper to SCC is alleviated through the use of the T73, or overaged temper that provides improved SCC resistance, but at a 10-15% strength loss compared to the T6

temper. Experimental test results by Cina and Ranish indicated that retrogress and re-aging (RRA) heat treatments with retrogression performed at 200-280°C for less than 10 minutes reduce the traditional trade-off between T6 strength and T73 SCC resistance. However, the short time heat treatment limited the applicability of RRA to thin sections of material. The primary goal of this effort was to determine if lower retrogression temperatures could be used in the RRA process to extend the applicability of this heat treatment to thick section aircraft components. Tensile, fatigue, fracture toughness, and hardness tests were conducted to characterize the mechanical properties of T6, T73, and various RRA tempers. Alternate immersion and double-cantilever beam tests were conducted to evaluate the SCC resistance of the different tempers. Results verified that the T6 temper exhibits strengths that are ten to fifteen percent higher than the T73 temper, but has crack growth rates that are approximately ten times faster than T73. Furthermore, the T6 temper failed via environmental cracking much more quickly when subjected to 3.5% NaCl in the alternate immersion test. Improvements in properties were demonstrated using RRA heat treatments at lower temperatures and longer times than those previously investigated.

Presentations

CERZA, M., Associate Professor, BOUGHEY, B, Lieutenant (USN), and LINDLER, K.W., Professor, "A Flat Heat Pipe for Use as a Cold Side Heat Sink," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, July 24-28, 2000.

CERZA, M., Associate Professor, "The Effects of Air Infiltration on a Large, Flat Heat Pipe at Horizontal and Vertical Orientations," 34th National Heat Transfer Conference, Pittsburgh, PA, August 20-22, 2000.

CERZA, M., Associate Professor, Adams, J. C., and Ireland, P. T., "WR-21 Spiral Recuperator," Rolls Royce/Oxford UTC Conference on Gas Turbine Technology, Oxford, UK, January, 2001.

CERZA, M., Associate Professor, Ireland, P. T., and Adams, J. C., "The Effect of Perforations on Heat Transfer Enhancement to Extended Surfaces," Rolls Royce/Oxford UTC Conference on Gas Turbine Technology, Oxford, UK, June, 2001.

FLACK, Karen A., Associate Professor, Saylor, J.R., and Smith, G.B.,"Visualization of Evaporative Heat Transfer," 34th American Society of Mechanical Engineers (ASME) National Heat Transfer Conference, Pittsburgh, PA, August 20-22, 2000.

FLACK, Karen.A., Associate Professor, "The Structure of a Wing-Tip Vortex for Two Tip Geometries," 53rd Annual Meeting American Physical Society (APS) Fluid Dynamics Division, Washington, DC 21-23, 2000.

FLACK, Karen A., Associate Professor and SCHULTZ, M.P., Assistant Professor, "Experimental Investigation of Lift Modification on Double Delta Wings using Fillets," American Institute of Aerodynamics and Astronautics (AIAA) Applied Aerodynamics Conference, Anaheim, CA, June 10-13, 2001.

JOYCE, J.A., Professor, "Analysis of the E8.08.02 High Rate Round Robin," 32nd National Symposium on Fatigue and Fracture Mechanics, Conshohocken, PA, June 15, 2000.

JOYCE, J.A., Professor, "Compliance Ratio Method of Estimating Crack Length in Dynamic Fracture Toughness Tests," 32nd National Symposium on Fatigue and Fracture Mechanics, Conshohocken, PA, June 15, 2000.

JOYCE, J.A., Professor, Quantification of Specimen Geometry Effects on the Master Curve and T_o Reference Temperature," 13th European Conference on Fracture, 6-9 September 2000, San Sebastian, Spain.

JOYCE, J.A., Professor, "Progress Report – E8.08.02 High Rate Round Robin," ASTM E8.08.02 Task Group Meeting, ASTM Committee Week, Orlando, FL, November 11-13, 2000.

JOYCE, Peter J., Violette, M. G., and Moon, T. J., "Finite Element Analysis of Undirectional Composite Compression Test Specimens: A Parametric Study," ASTM Symposium on Composite Materials: Testing, Design and Acceptance Criteria, Phoenix, AZ, March 26-27-2001.

JOYCE, Peter J., Assistant Professor, "Composite Materials Research at USNA: A Brief Overview," B/W Chapter, SAMPE, at the U.S. Naval Academy, September, 13, 2000.

JOYCE, Peter J., Assistant Professor, "Constitutive Modeling of Inert HTPB Binder Material," Program Review Meeting, Naval Surface Warfare Center, Indian Head Division, October 20, 2000.

MINER, S.M., Associate Professor and LINK, R.E., Associate Professor, "A Project-Based Introduction to the Finite Element Method," 2000 ASEE Annual Conference & Exposition, June 18-21, 2000, St. Louis, MO

MORAN, Angela, Associate Professor, FERRER, C.P., MIDN 1/C, USN and KOUL, M.G., Assistant Professor, "Study of the Retrogress and Reaging of High Strength Aluminum Alloys," Electrochemical Society, 199th Meeting, Washington, DC, March 2001.

MORAN, Angela, Associate Professor, "Room Temperature Creep of Pb-Sn and Sn-Ag-Cu Eutectic Solders," 16th Annual National Educators Workshop, Gaithersburg, MD, October 2001.

NELSON, Martin E., Professor, Haire, T. W., Cassata, J.R., and Riel,G.K., "Investigation of Photon Spectra and Light Efficiency in a LiF TLD," Health Physics Society, Denver, Colorado, 26 June 2000.

NELSON, Martin E., Professor, Parrella, M. C., Cassata, J. R., and Riel, G. K., "Development of an MCNP Model for the Neutron Response of a Special Area Monitor," Health Physics Society, Denver, Colorado, 26 June 2000.

NELSON, Martin E., Professor, Cassata, J. R., Ruesch, E., Pieski, E., Laird, R., and Kennemur, L., "Development of a Neutron Dose Algorithm for an Albedo Whole Body TLD that Possesses Non-Uniform Filtration over Neutron Sensitive and Non-Sensitive Elements," Health Physics Society, Cleveland, Ohio, 11 June 2001.

PUZINAUSKAS, Paulius V., Assistant Professor, "Optimization of Natural-Gas Combustion in Spark-Ignited Engines Through Manipulation of Intake-Flow Configuration," SAE Fuels and Lubricants Conference, Paris, France, 19-22 June 2000.

PUZINAUSKAS, Paulius V., Assistant Professor, "Analysis of In-Cylinder Heat Transfer in Large-Bore Engines," Pipeline and Compressor Research Council Gas Machinery Conference Colorado Springs, CO, 2-4 October 2000.

TUTTLE, Kenneth L., Associate Professor and WU, Chih, Professor, "Intelligent Computer Assisted Instruction in Thermodynamics at the U. S. Naval Academy," Qualitative Reasoning Workshop, American Association for Artificial Intelligence, San Antonio, TX, 17 May 2001.

VOLINO, Ralph J., Assistant Professor, SCHULTZ, M.P., Assistant Professor and PRATT, C.M, MIDN 1/C, USN, "Conditional Sampling in a Transitional Boundary Layer under High Free-Stream Turbulence," 2000 American Physical Society Division of Fluid Dynamics (APS DFD) Conference, Washington, DC, 20 November 2000.

VOLINO, Ralph J., Assistant Professor and SCHULTZ, M.P., Assistant Professor, "Effects of Concave Curvature on Boundary Layer Transition under High Free-Stream Turbulence," 2000 American Physical Society Division of Fluid Dynamics Conference, Washington, DC, November 19, 2000.

VOLINO, Ralph J., Assistant Professor, SCHULTZ, M.P., Assistant Professor and PRATT, C.M, MIDN 1/C, USN, "Conditional Sampling in a Transitional Boundary Layer Under High Free-Stream Turbulence Conditions," 2001 American Society of Mechanical Engineers International Gas Turbine Conference, New Orleans, Louisiana, June 4, 2001.

VOLINO, Ralph J., Assistant Professor and SCHULTZ, M.P., Assistant Professor, "Effects of Concave Curvature on Boundary Layer Transition Under High Free-Stream Turbulence Conditions," 2001 American Society of Mechanical Engineers International Gas Turbine Conference, New Orleans, Louisiana, 4 June 2001.

VOLINO, Ralph J., Assistant Professor, "Laminar-Turbulent Transition in Low Pressure Turbines," Department of Mechanical Engineering, Villanova University, Villanova, PA, November 10, 2000.

VOLINO, Ralph J., Assistant Professor, "Laminar-Turbulent Transition under Gas Turbine Airfoil Conditions," Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota, April 11, 2001.