Mechanical Engineering Department

Professor Steven M. Miner
Chair

The faculty and midshipmen of the Mechanical Engineering Department have diverse interests in the fields of mechanics, materials and the thermo-fluid sciences. These interests are reflected in the types of research projects undertaken, which include sponsored faculty research and midshipmen research course projects, and which run the full spectrum from fundamental to pedagogical research.

This past year there were a total of 14 faculty members involved in 40 sponsored research projects. Sponsors included government agencies, navy labs and industry. In addition to the sponsored faculty research there were 15 midshipmen involved in independent research projects with faculty, four of which were Bowman Scholars. Many of these projects were also funded by outside sponsors. Overall, 24 midshipmen were involved in research with faculty in the department. The output for the past year included 55 publications, 40 of which were refereed journal articles, and 38 presentations. Of these midshipmen or recent graduates were involved in 4 as either co-authors, presenters or both. Faculty in the department also sponsored 2 Post Doctoral researchers.

The scholarly pursuits of the faculty allow them to remain current in their fields. This currency benefits the midshipmen both directly and indirectly. The midshipmen benefit directly because in many cases the midshipmen are involved in doing the research, which broadens and enhances their intellectual experience. Indirectly the midshipmen benefit because the results of the research find their way into the curriculum, which helps to maintain its currency.

Sponsored Research

Ultrasonic Thermometer for High Temperature Materials Testing

Researcher: Associate Professor John A. Burkhardt
Sponsor: Knolls Atomic Power Laboratory

Ultrasonic thermometry offers the potential to measure temperature profiles in high temperature irradiation experiments. Standard thermocouples have reduced reliability in this environment. Ultrasonic thermometers offer the opportunity to measure temperature profiles within or adjacent to a test specimen with higher reliability. Feasibility demonstrations of such devices are reported in the literature but have not been taken to commercial use. Consequently, a project was initiated to research and understand the principles of ultrasonic thermometry for the purpose of designing a thermometer to measure temperature profiles in the range of 1500F to 3000F in an inert radiation environment. Ultimately, a working prototype is to be constructed and demonstrated.

Steady State Thermodynamic Modeling of E6-B Aircraft Cabins Due to Electronic Cabinet Heat Loading

Researchers: Professor Martin R. Cerza and Professor Steven M. Miner
Sponsor: Naval Air Systems Command, Patuxent River

As heat loads on electronics cabinets in aircraft systems increase due to advanced capabilities of radar, surveillance and weapons systems, the temperatures of the cabins are getting hotter and hotter to the point where it is uncomfortable for the crew as they perform their duties. This is especially true when the aircraft is sitting on a runway when it is 120F outside. This project was initiated to develop a steady state thermal model of the cabin temperatures for an E6-B aircraft. The heat sources are the electronics cabinets, solar heating, people, and auxiliary power units. The air conditioner is a reverse Brayton cycle (air cycle) machine. The air cycle plant takes as its source bleed air from an auxiliary power unit (small gas turbine). Initially a steady state model was investigated. Later efforts in the project involved the development of this model into a full transient model to determine cabin and equipment temperatures from transient loads like start-ups, source switching and shut-down.

Capillary Pumped Loop Systems for use in Shipboard Electronic Cooling

Researchers: Professor Martin R. Cerza, Assistant Professor Andrew N. Smith
and Assistant Research Professor ValentinTudor
Sponsor: Department of Energy (DOE)

Electronic cooling is quickly becoming a topic of paramount concern in the Naval Community. As computer chips and circuit boards get smaller while their power generation increases, very high heat fluxes have to be dealt with. Moreover, as power electronics becomes an important parameter in RF devices such as radar control units, IGBT devices in propulsion switchgear, and increasing loads with regards to shipboard HVAC systems, the Navy will have to look at integrating all aspects of the thermal loads brought about by these components.

One potential method of cooling electronic cabinets is the capillary pumped loop system (CPL). The CPL operates on a two-phase liquid-vapor thermodynamic system. Heat dissipated from electronics devices is conducted through the CPL evaporator walls and vaporizes as a working fluid. The vapor is then transported to a condenser where it condenses and releases heat to the ship's cooling water. This transport of heat is order of magnitudes more efficient than the forced air convection produced by fans, and with practically no noise produced.

In this project, the effectiveness of the resulting capillary-assisted thermosyphon (CAT) loop was evaluated by investigating the effects of sub-cooling and orientation [tilt and pitch] on the thermal performance. The sub-cooling effects were studied for a range of heat loads by varying the chill water flowrate between .375 and 3.5 GPM, and varying the chill water temperature between 4 and 37 degrees Celsius. The heat inputs were also varied between 250 and 3200 W. Chill water temperatures were chosen to simulate the conditions of the sea that a warship would experience while operating somewhere between the Artic and the Persian Gulf. Sub-cooling was shown to be dependent upon chill water sink temperature and not strongly dependent upon chill water flowrate. The influence of orientation on the thermal performance of the evaporator plate was also tested by pitching and tilting the plate up to forty-five degrees of inclination and observing the operating temperatures inside the plate. Results showed that the plate operated under all tilt angles, pitch angles, and pressure restrictions imposed. The most significant influence was observed during pitch angle testing due to the geometry of the plate. This research effort is continuing with the design of a prototype electronics cabinet employing two-phase capillary assisted thermosyphon cooling devices.

Small Condensers for Thermosyphon Electronics Cooling Systems

Researchers: Professor Martin R. Cerza, Assistant Professor Andrew N. Smith,
Assistant Research Professor Valentin Tudor,
Midshipman 1/C Michael L. Kendel, USN and Midshipman 2/C William E. Stange, USN
Sponsor: Department of Energy (DOE)

This project involved the design and development of a small shell and tube condenser to mate with the thermosyphon evaporators in the capillary assisted thermosyphon (CAT) electronics cooling cabinet project. The new shell and tube condenser was compared against a simple counter flow cold plate condenser. The optimized variable was the limitation of sub-cooling in the liquid return line to the evaporator plate in the CAT system.

Mean and Turbulent Velocity Profiles for Sandgrain Rough Surfaces

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

Flat plate turbulent boundary layer measurements have been made on surfaces covered with fine and coarse sandpaper. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3000 to 16000, using a two-component, laser Doppler velocimeter (LDV). The results indicate an increase in the boundary layer thickness (δ), the integral length scales, and the skin-friction coefficient (C_f) for the rough surfaces compared to the smooth wall. The roughness functions (ΔU^+) for the sandgrain surfaces agree within their uncertainty with previous results obtained using towing tank tests and similarity law analysis. For sandpaper, it appears that a single roughness length scale ($k = 0.75\ R_t$) is sufficient to characterize the physical surface. The present results indicate that the

mean profiles for both the smooth and rough surfaces collapse well in velocity defect form. The Reynolds stresses also show good collapse outside the roughness sub-layer when normalized with the wall shear stress.

Hybrid Composite Joining and Characterization

Researcher: Assistant Professor Stephen M. Graham
Sponsors: Naval Surface Warfare Center, Carderock Division (NSWC-CD) and Office of Naval Research (ONR)

This research is being conducted in concert with the Marine Composites Branch of the Structures and Composites Department at the Naval Surface Warfare Center, Carderock Division. The objective is to develop an innovative new concept for joining of composite and metal structures that could be used in place of bolting or adhesive bonding, which are either impractical or inefficient for many marine applications. The joint is formed between a glass-reinforced composite and solid metal plate or bar by utilizing metal fibers to make a transition between the two. The glass fibers transition into metal fibers, which are then welded to solid metal. The metal and glass fibers are joined by forming a stepped-lap configuration, co-infusing the joint with resin and then co-curing the two together. There is currently no information in the literature on how to design a joint of this type. Consequently, numerical methods are being developed and used to evaluate stresses in various joint designs, and to optimize the design to obtain the highest joint efficiency. Once joint designs are identified for further evaluation, they are fabricated, instrumented and tested to validate the numerical predictions. The initial phase of this study is focused on design based on numerical prediction of stresses with experimental verification. In the next phase, particular attention will be paid to the initiation and evolution of damage, and how the design of the joint influences the damage process. This project is in the second year. Some preliminary joint concepts have been analyzed, fabricated and tested and predictions are consistent with experimental results.

Investigation into the Relationship between Fracture Behavior and Structural Integrity for Ship and Submarine Metallic Materials

Researcher: Assistant Professor Stephen M. Graham
Sponsors: Naval Surface Warfare Center, Carderock Division (NSWC-CD) and Office of Naval Research (ONR)

This effort provides technical support to engineers and technical staff of the Metals Engineering Branch of NSWC-CD 614 on projects related to structural integrity assessment. Specific projects and the effort covered under this collaboration include:

1. CVNX-1 HSLA-100 Crack Arrestors - Assist in project planning, test development, test execution, data analysis, data interpretation, reporting and presentation of results for a program to characterize the crack arrest performance of HSLA-100 steel as an alternative to HY-80 or HY-100 steels.

2. Fracture Toughness Review Process (FTRP) - Assist in application and interpretation of the FTRP. Review structural or material assessments related to the FTRP. Develop material characterization plans according to Appendix C of the FTRP and provide assistance in the implementation of the plans, and the interpretation of the data. Conduct material screening or flaw assessments per the requirements of the FTRP. Conduct research on alternative criteria for evaluation of the fracture resistance of metallic materials. In particular, prepare criteria for evaluation of low tearing modulus materials with moderate toughness, and for very tough materials with high tearing modulus.

3. Metallic Materials Advanced Development and Certification Program (MMADCP) - Assist in the evaluation of fracture behavior of materials, including titanium alloys, nickel alloys, high-strength steels, and stainless steel alloys, and on the relationship between fracture behavior and structural performance for the various projects covered under MMADCP.

Horizontal Convective Boiling of Refrigerants and Refrigerant Mixtures within a Micro-Fin Tube

Researchers: Commander Leonard J. Hamilton, USN and Dr. Mark Kedzierski (NIST)
Sponsor: National Institute of Standards and Technology (NIST)

Most evaporators and condensers of new unitary refrigeration and air-conditioning equipment are manufactured with micro-fin tubes. The micro-fin tube dominates unitary equipment design because it provides the highest heat transfer with the lowest pressure drop of the commercially available internal enhancements. Together, R134a, R22, and R22 replacements constitute by mass nearly all the refrigerants used in unitary products. Consequently, two phase heat transfer data for the micro-fin tube with R134a, R22, and R22 replacements are essential for the design of evaporators and condensers

for unitary applications. While significant smooth tube data are available in literature, there is a need for micro-fin tube heat transfer data. The goals of this project were to provide empirical micro-fin heat transfer data and to develop a single reliable Nusselt number correlation for all refrigerants tested. All objectives were met and a paper is in the process of being written for conference presentation and journal publication.

HEU Detection by External Neutron Stimulation

Researchers: Professor Mark J. Harper and Professor Martin E. Nelson
Sponsor: Defense Threat Reduction Agency (DTRA)

This investigation evaluated the feasibility requirements in the use of external neutron stimulation in order to detect the presence of 1 kg of highly enriched uranium (HEU) in a large shipping cargo container. After reviewing the neutron and gamma properties of special nuclear material, the existing container inspection process as developed by the container security initiative is described and several current portside inspection technologies were analyzed in order to determine their adequacy for this problem. It was concluded that vulnerabilities exist in each of these technologies and a supplemental technology could increase port security.

A benchmark container, whose dimensions are 20’ x 8’ x 8’, was analyzed with several polyethylene moderated. He neutron detector(s0 on one side and the neutron source on the other side for a wide variety of different energy sources, transmission and backscattered counting options, source distances from the container, prompt and delayed neutrons, and the effect of different cargo materials present with the contained. The study considered solution approaches using both deterministic and Monte Carlo techniques of which the later solution approaches was based on the MCNP4C2 transport code. The study also considered the detector response to the expected neutron background, interference reactions that could produce delayed neutrons, and counting statistics. The project concluded that the neutron stimulation approach would be successful in the presence of different cargo materials expect one if a pulsed 14 MeV source was used and only the delayed neutrons were counted. This could be accomplished by use of a gating technique that turned the neutron detector on when the neutron source was off and visa versa. It was calculated that the system would require a source strength of 10 neutrons/sec and should be cycled on and off 48 times to obtain the maximum signal to noise response for a 5 minute examination time. The one cargo condition that would render this approach ineffective was the case where the cargo had a density of 1 gram/cm or greater and had a hydrogen atom density of 15% or greater.

The study also considered the effect of cargo activation and government regulations for release of activated material. The results showed that cargo hold times due to activation would be less than current practices at the port of Baltimore and thus should have little impact on the flow of commerce. A feasibility study was also performed using the Port of Baltimore as a baseliner. This study estimated that it would cost $2 million to build and operate the facility for one year and less than half this amount for subsequent years. The facility would have more than sufficient capacity to meet the inspection needs at the port.

Fracture Toughness of Nuclear Pressure Vessels

Researcher: Professor James A. Joyce
Sponsor: United States Nuclear Regulatory Commission (NRC)

This work is mostly experimental support for the U.S. Nuclear Regulatory Research work in progress on Pressurized Thermal Shock (Loss of Coolant) Accident Rules. Probabilistic methods are now being applied to those important accident scenarios using software (FAVOR) developed at Oak Ridge National Laboratory. Ductile-to-brittle transition tests on nuclear plate specimens are conducted using a variety of specimen geometries to support the new “Master Curve” characterization of the ductile-to-brittle characterization critical to defining the failure probability the FAVOR code. Continuing work is directed towards an understanding of the constraint differences between C(T), SE(B) and pre-cracked Chary specimens, and how these differences can be modeled and incorporated into U.S. Nuclear Regulatory Commission codes. Major work is also being directed to “Bi-axial Loading” cases in fiscal 2004, especially the development of a small scale cruciform loading specimen and test procedure. Analysis is being conducted at the University of Illinois, and testing is being conducted at the Naval Academy and at the Naval Surface Warfare Center-Carderock Division laboratory.

New work is being initiated in the area of crack arrest, using what has been developed during the past two years on predicting cleavage in the ductile-to-brittle transition regime.

Mechanical Characterization of Al/PTFE Reactive Materials

Researchers: Assistant Professor Peter J. Joyce and Professor James A. Joyce
Sponsor: Office of Naval Research (ONR)

The objective of this research project was to conduct investigations of the mechanical response of Aluminum/Teflon (Al/PTFE) composites for use in enhanced warheads by the U.S. Navy. The addition of a powdered aluminum filler to polytetrafluoroethylene (PTFE) results in a multiphase material which has been shown to react vigorously under dynamic loading motivating the current investigation to better understand the mechanical behavior of Al/PTFE materials.

This work has demonstrated the successful application of fracture toughness testing methodologies mature to the metals community to both PTFE and Al/PTFE composites. Standard ASTM E1820 fracture toughness specimens single-edge bend and compact tension of PTFE and Al/PTFE both pressed and sintered under like conditions were tested. In all cases the fracture toughness was quantified using the *J*-integral. Baseline fracture properties for both the PTFE and Al/PTFE composites were obtained from room temperature quasi-static testing over a range of test temperatures and loading rates.

The major conclusions to date are that the normalization method is a valuable tool for obtaining fracture toughness measurements for structural polymers, even those that demonstrate considerable visco-elastic response. The normalization method allowed measurement of J_{Ic} and J-R curves over a wide range of test temperatures and loading rates using single specimen procedures. The major results are that while crack extension is difficult at ambient temperature or above, for temperatures slightly below ambient or for elevated loading rates, a rapid degradation of fracture resistance occurs and cracking occurs in a ductile or even brittle manner. Both the neat PTFE material and filled PTFE material tested here transition from crack tip blunting behavior to low toughness J resistance curve behavior as the test rate is increased and/or the test temperature is decreased. The rate effects are significant at servo-hydraulic test rates and are thus important in many structural applications. Similarly, even small temperature changes, dramatically alter the fracture toughness properties of PTFE. Fracture can clearly be a serious problem when this material is used at temperatures slightly above or below ambient no matter what loading rate is applied. Scanning electron microscope observations show that very different micromechanical mechanisms exist under these different loading conditions resulting in the dramatic changes in material toughness observed.

Characterization Testing of Oven Cured K63B12 Pitch Fiber/NB-308 Epoxy Composite

Researchers: Assistant Professor Peter J. Joyce
Sponsor: Northrop Grumman Oceanic Systems, Annapolis, MD

The use of advanced composite materials has increased in the recent years at Northrop Grumman Oceanic Systems (NGOS). As composites applications at NGOS expand, new opportunities for composites have surfaced. Glass-reinforced composite systems manufactured from autoclave cured prepreg or vacuum assisted resin transfer molding are well known and widely used in structural applications. Out-of-autoclave curing techniques are not widely accepted and lesser used but offer significant cost savings potential.

In recent tests having to do with the battery box used on the Advanced Seal Delivery System (ASDS) built by NGOS, a heat transfer problem was suggested as the cause for the premature failure of the ASDS batteries. Several options were considered to get the heat out of the mostly glass-reinforced composite battery tray. One promising solution that NGOS is testing employs a novel oven cured K63B12 Pitch Fiber/NB-308 Epoxy Composite previously only used for such applications as solar arrays and so forth. The battery tray components were to be manufactured from the K63B12 Pitch Fiber/NB-308 Epoxy Composite because of the extraordinary thermal conductivity properties of pitch carbon fiber.

This project sought to provide important mechanical design data relevant to the battery tray design using the K63B12 Pitch Fiber/NB-308 Epoxy Composite. This work involved a complete characterization of the oven cured K63B12 Pitch Fiber/NB-308 Epoxy Composite to include fiber volume fraction measurements, void content measurements, tensile testing of the material both as manufactured (dry) and conditioned in synthetic seawater (wet), compressive testing (wet), in-plane shear testing, and inter-laminar shear strength testing (wet).

Structural Damage and Damage Mapping of Corroded Structures

Researcher: Assistant Professor Michelle G. Koul
Sponsor: SKT Technologies, Dayton, OH

The objective of this project was to refine a topographical analysis software tool developed at the Naval Academy to allow for post processing and visualization of both single and dual laser profilometry data by meeting detailed software requirements. Statistical analysis is part of the software package, allowing the calculation of critical parameters related to structural performance.

Stress Corrosion Crack Growth Rate Evaluation of Aircraft Materials Using a Rising Step Load Method

Researchers: Assistant Professor Michelle G. Koul,
Assistant Research Professor QingJiang Meng and Professor Angela L. Moran
Sponsor: Office of Naval Research (ONR)

Various candidate alloys are being considered for drop-in replacement of corrosion-prone AA7075-T6 parts on aging military aircraft. Therefore, the resistance of the candidate alloys to corrosion damage such as intergranular corrosion, exfoliation and stress corrosion cracking (SCC) is being evaluated. In order to further contribute to this body of knowledge, this project is continuing previous work using an alternate test technique. This test technique will allow the evaluation of a stress corrosion cracking threshold, as well as cracking kinetics. Two aluminum alloys that meet mechanical property requirements and are thought to be superior to AA7075-T6 in terms of corrosion performance are being evaluated, in addition to 4340 steel due to recent concerns regarding aircraft landing gear. A Rising Step Load test method is being implemented to obtain this information, which requires development of a new test protocol.

Diver Heater Using Hydrogen Fuel

Researchers: Professor Keith W. Lindler,
Professor Marshall L. Nuckols (Naval Architecture and Ocean Engineering Department)
and Professor Kenneth A. Knowles (Weapons and Systems Engineering Department)
Sponsor: Naval Surface Warfare Center (NSWC)

The properties and history of hydrogen fuel were reviewed in order to determine its suitability as a fuel source to provide the heating requirements of six divers in 0ºC water for a period of six hours. It was determined that less than one pound of hydrogen combined with oxygen in a catalyst bed could meet the heating needs of the divers. Storing the hydrogen as a metal hydride appears to be the safest method and would lead to the smallest storage volume. It was determined that the electric requirements of the pump used to circulate the heating water through the diver's suit could be provided by several thermoelectric generators which would use the heat released from the hydrogen as an energy source. The waste heat rejected from the thermoelectric generator would provide a large portion of the heating requirements for the divers.

The current research focuses on the testing of various metal hydrides to determine the best candidates to store the hydrogen for this application. Important parameters include the ability to recharge the storage at temperatures above 0ºC, the ability to hold a large amount of hydrogen in a small volume ant the ability to release the hydrogen at 100 psig at temperatures below 100ºC.

Effect of Biaxial Loading on Transition Fracture Toughness

Researcher: Associate Professor Richard E. Link
Sponsor: Naval Surface Warfare Center, Carderock Division (NSWC-CD)

The fracture behavior of a novel, cruciform specimen for investigating the effect of biaxial loading on the ductile-brittle transition was modeled using elastic-plastic finite element analysis. Highly-detailed three dimensional models were analyzed to determine the specimen deformation response, crack driving force and crack tip plasticity development in the specimen as a function of loading. These results were used to develop a suitable instrumentation scheme for experimental tests and to interpret the results of the experiments.

Multi-functional Coatings for Military Applications

Researchers: Professor Angela L. Moran and Assistant Research Professor QingJiang Meng
Sponsor: Air Force Office of Sponsored Programs (AFOSR)

This effort, in support of the AF/MURI project headed by researchers at the University of Virginia, seeks to identify the next generation military coating system that will provide a significant evolutionary advancement in performance from the standpoint of mission safety, corrosion protection, and environmental compatibility. The opportunity exists 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 being accomplished through implementation of thermal spray technology and the use of nano-crystalline or amorphous matrix metallic glasses such as the Al-transition metal (TM)-rare earth (RE) glasses. A central characteristic of amorphous/nano-crystalline materials is the ability to supersaturate desired alloying elements to produce a material with superior corrosion performance, as well as high strength, ductility, and wear resistance. Al-based metals were thermally sprayed in air from powder stock using several thermal spray techniques. Small panels were produced for materials characterization, mechanical testing and corrosion testing. Control claddings were compared to newer compositions aimed at multi-functionality. Fatigue life and corrosion/fatigue life at various stress values were determined for coated versus uncoated AA2024-T3 for a number of chemistry/deposition method combinations. An optimal chemistry for a replacement skin coating was determined and deposition methods are now under development. Small panels were produced for materials characterization, mechanical testing and corrosion testing. Control claddings have been compared to newer compositions aimed at multi-functionality. Fatigue life and corrosion/fatigue life at various stress values were determined for coated versus uncoated AA2024-T3 for a number of chemistry/deposition method combinations.

A Study of Environmentally Assisted Cracking Using the Rising Step Load Technique

Researchers: Professor Angela L. Moran,
Assistant Research Professor Qingjiang Meng and Assistant Professor Michelle G. Koul
Sponsor: Office of Naval Research (ONR)

This effort involves the development of effective methods for applying the rising step load (RSL) technique to the study of EAC, to provide detailed scientific understanding of the environmentally assisted cracking (EAC) in high strength alloys used in fleet applications, and to contribute to a quantitative database of EAC properties to be used as a guideline/justification for part replacement. The threshold K_{IEAC} and crack growth rates at various stress intensities (V-K curve) were measured for Al alloys (T6 and T7 tempers) and 4340 steel. The RSL results in combination with quantitative electrochemical methods were used to better understand the correlation between the EAC initiation and localized corrosion. Conventional methods to evaluate the EAC resistance of aluminum alloys included C-ring constant load or constant displacement testing, and double cantilever beam testing (DCB). Crack growth kinetics, or V-K curves, were measured quantitatively by DCB testing, however, the DCB testing has limitations, such as long test durations to measure $K_{IEAC,}$ inaccuracies in crack length measurement and corrosion product wedging effects. For more EAC resistant alloys, threshold stress intensities and the stage I crack growth region are difficult to evaluate by DCB testing due to very slow crack growth rates. How to study EAC behavior quantitatively and efficiently becomes more pertinent for evaluation and development of EAC resistant high strength Al alloys and steels. The rising step load (RSL) technique is a promising method, which has advantages as compared to the DCB technique and provides ample opportunities to precisely and quantitatively study the EAC behavior within a shorter test duration.

Evaluation of the Environmentally Assisted Cracking Performance of Candidate Aluminum Alloys for Aging Aircraft Refurbishment and Replacement

Researchers: Assistant Professor Michelle G. Koul and Professor Angela L. Moran
Sponsor: Air Force Research Laboratory (AFRL)

AA7075-T6511 is used for the main structural components on a number of Naval and Air Force aircraft. T6511, or T6, describes the type of temper, which specifically is an artificial aging heat treatment. Although this temper results in high strength, it does not provide good resistance to environmentally assisted cracking (EAC). One heat treatment that can be applied to this alloy to enhance its EAC characteristics without sacrificing strength is called retrogression and re-aging (RRA). RRA consists of a short-time treatment of a T6 temper at an intermediate temperature followed by re-aging

with a T6 aging treatment. The resultant aluminum has similar strength characteristics to a T6 temper, but it has improved resistance to EAC. Additionally, the Navy is currently considering the aluminum alloy AA7249 as a replacement for AA7075-T6511 extrusions.

Initial testing has shown that the mechanical properties of AA7249-T76511 have met or exceeded the properties of AA7075-T6511 but the corrosion resistance characteristics of the final product form have not been documented. The objective of this on-going effort is to evaluate the environmentally assisted cracking (EAC) performance of AA7249-T76511 as compared to AA7075-T6 utilized in aircraft extrusions. Previous work has optimized the retrogression and re-aging (RRA) process for AA7249 extrusion with regard to strength and the mechanical properties of the optimal RRA tempers are being further evaluated as part of this program.

Evaluation of Shielding Requirements for the Naval Surface Warfare Center Indianhead Radiography Facility

Researcher: Professor Martin E. Nelson
Sponsor: Naval Surface Warfare Center, Indian Head Division (NSWC-IH)

Dose calculations have been performed on the PL-4 accelerator, which is planned to be installed in building 731 at Indianhead (IH). These calculations were based on the following data sources: (1) information collected during a site visit November 24, 2003, (2) correspondence with people familiar with the design and operation of the PL-4 system, (3) published data on operating parameters of the PL-4 system as well as near identical system previously installed in S. Korea, and (4) published guidelines for design of accelerator facilities, such as NCRP 51 "Radiation Protection Guidelines for 0.1-100 MeV Particle Accelerators."

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

Researcher: Professor Martin E. Nelson and Lieutenant Commander Gene Canfield, USN
Sponsor: Strategic Systems Program (SSP)

This research investigated 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. Experimental data has been collected with both fission neutrons and 14 Mev neutrons on Charge Collection Devices (CCDs) to fast neutrons. The 14 MeV data has been collected using the USNA neutron generator and a data acquisition system developed by Draper labs. Previously the fission data was collected at WSMR. The data has been analyzed and charge distributions have been developed as a function of neutron source, operational conditions, neutron fluence, and shielding materials. More analysis needs to be preformed to understand the experimental results.

14 MEV Neutron Testing of Power Mosfet Optocoupler and Quantum 4M SRAM Technologies

Researcher: Professor Martin E. Nelson
Sponsor: Naval Research Laboratory (NRL)

In the first part of this research the effect of radiation from neutron activation of package materials was studied using a power MOSFET optocoupler as the test device. The optocouplers were exposed to 14 MeV neutrons to a fluence of 1×10^{11} n/cm^2 with the devices switching during the exposure. Electrical characterization was performed following each exposure. A separate set of optocouplers was then irradiated using a Co-60 source. The results combined with gamma ray spectroscopy showed that radiation from neutron activation had a significant effect on the electrical parameters of the optocoupler first.

In the second part of this project, this work investigates the effects of 14 MeV neutron irradiation of BAE's 4MSRAM 0.35um CMOS technology. Two versions of this technology were evaluated. Version one was an in production

0.35um 4MSRAM, referred to as the Quantum, and version two was a 0.25um scaled version of the Quantum, referred to as the Quantum Shrink. Neutron induced soft errors were observed at the bit level in both versions of the technology, and these observed upsets scaled with operational voltage. The scaled technology, the Quantum Shrink, showed an upset sensitivity similar to the Quantum.

Damage Detection in Large Scale Naval Structures

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

Composite materials for large scale Navy structural applications are becoming a reality as seen by their use in applications such as the masts for a LPD-17 class ship, a prototype Joint Modular Lighter System (JMLS) and the advanced composite sail for the Virginia Class Submarine. Inspection methods, capable of providing rapid assessment of the structural integrity of these structures that have planar areas that can be thousands of square feet, are required. Inspection techniques are currently available which can be readily implemented in a laboratory setting, but few exist which can be used for in-service inspections of this magnitude. This research expanded a recently developed broadband vibration-based technique developed at the United States Naval Academy and the Naval Surface Warfare Center - Carderock Division, Structural Irregularity and Damage Evaluation Routine (SIDER) that is applicable for the inspection of large scale Naval composite structures. SIDER has successfully been used to determine the manufactured quality, in-service damage, and changes in damage areas for both sandwich core and monolithic composite structures. Areas of damage that included delamination, debonding of ribs and stringers, bulkhead to hull degradation and localized cracking were successfully identified and correlated with both visual and ultrasonic inspection.

Extending the SIDER Damage Detection Technique to use MEMS in the Inspection of Aircraft

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

Composite materials are gaining increased use in Naval structural applications. These structures can be monolithic with rib stiffeners or they can have a core configuration with material such as balsa, PVC, or urethane foam, with face sheets. These structures have very large planar surface areas, up to several hundred square feet. As such, process monitoring and control are important issues that need to be undertaken to ensure that the part is manufactured properly. In addition, the location of manufacturing defects or service-induced damage and their effect on the mechanical properties of these structures must be monitored and assessed. Embedded or surface mounted sensors can be used to determine these characteristics. The objective of this program is to investigate the utility of using MEMs sensors to determine the structural integrity of composite components. This is being accomplished by modifying the SIDER technique. SIDER technique is an established vibration technique that has been used to locate areas of structural variation both in a laboratory setting and in the service environment. The inspection entails exciting a large number of locations on the composite structure and monitoring the response at a limited number of other locations. The SIDER algorithm then looks at the resultant curvature over a large frequency range, looking for perturbations indicative of structural variability. Currently, SIDER is a relatively rapid procedure when compared to other extant techniques. This effort involves investigating changes to the SIDER technique that will further reduce inspection time. Success with this effort is an enabler toward real time, in-service monitoring of structures. The current SIDER procedure requires excitation at multiple locations, with monitoring at relatively few locations. In this effort the procedure is being reversed such that excitation will be at relatively few locations and the response will be monitored with an extensive array of MEMs sensors. This is an attempt to reduce the interrogation time without compromising the integrity of the SIDER algorithm and its damage detection sensitivity. To determine the utility of the MEMs sensors for this type of inspection, composite components of military fighter aircraft with well characterized damage areas will be interrogated with both the conventional SIDER technique and the modified technique using the MEMs sensors. In addition, both techniques will be used for in-service testing of a large composite structure in order to validate the MEMs work.

Thermal Analysis of a Naval ElectroMagnetic (EM) Railgun

Researcher: Assistant Professor Andrew N. Smith
Sponsor: Naval Surface Warfare Center, Dahlgren Division (NSWC-DD)

ElectroMagnetic (EM) Railguns are fired by sending electrical current down one conducting rail, through the projectile and then back down the opposite rail. The electrical pulse contains several million amps of current and lasts on the order of a few milliseconds. Due to the very short duration of the pulse, the electromagnetic field does not have sufficient time to diffuse into the conducting rail resulting in an uneven current distribution. This investigation is a computational effort to model the electrical current in the rails and the subsequent resistive heating. Research has shown that an active cooling system is critical to operating an EM Railgun with a sustained rate of fire. Several methods for removing the heat between shots are being modeled. These results are being compared to experimental tests performed at NSWC-Dahlgren.

Development of Heat Load Modules for Electromagnetic Weapons Cooling Systems

Researcher: Assistant Professor Andrew N. Smith
Sponsor: Office of Naval Research (ONR)

This project involves the development of a module that estimates the cooling requirements based on resistive heating in the launcher rails, the distribution cables and the capacitor banks. A similar module, based on using a pulsed alternator and rotating machinery system for energy storage, is also being investigated. Finally, efforts are underway to predict the resistive rail heating using a 2-D transient finite difference code that simultaneously solves for the current distribution and subsequent heat transfer.

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

Researchers: Associate Professor Ralph J. Volino and Assistant Research Professor Douglas Bohl
Sponsor: NASA-Glenn Research Center and Office of Naval Research (ONR)

Boundary layer separation, reattachment, and laminar-turbulent transition are under experimental investigation. These phenomena are important in the flow over modern low-pressure turbine airfoils. The flow on the suction side of the airfoil 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 interaction between separation and transition is complex, and the inability to accurately predict the flow is a limitation to designers. A detailed experimental database is needed to provide a better understanding of the flow, and a basis for new computational efforts and modeling.

Experiments were initiated in 1998 at the NASA Glenn Research Center and continue at the Naval Academy in a single passage turbine cascade installed in a low speed wind tunnel. A series of experiments were completed using boundary layer trips of various heights to control the transition, separation and reattachment. These included measurements at five different Reynolds numbers and two different free-stream turbulence levels. Oscillating jets were used to control the flow in another set of experiments at a single operating condition. The jets proved very effective. One paper has been written and submitted for a conference presentation and a journal publication. Three NASA reports are in preparation based on previously acquired data. The work is ongoing.

Intelligent Computer Aided Instruction (ICAI)

Researcher: Professor Chih Wu
Sponsor: Office of Naval Research (ONR)

The Mechanical Engineering Department at the United States Naval Academy is currently evaluating a new teaching method which 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 were 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 behavior 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 used for seven semesters at the U.S. 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

Manufacturing and Evaluation of Flawed Composites

Researchers: Associate Professor John A. Burkhardt and Assistant Professor Peter J. Joyce

Methods of Non-Destructive Evaluation of composites lack a standard for how certain flaws should appear. Evaluating homogenous materials in better understood because waves propagate in a more predictable manner when the medium is composed of a single material. As composites are used more frequently it is important that it becomes easier to evaluate their flaws. Composites are used as high performance materials because their structures allow them to bear unusually large amounts of force for their weight. If there is a flaw in the internal structure of a composite, it can lose the ability to support the force that it is expected to be able to handle.

Several glass fiber-epoxy resin panels were constructed. Micro-spheres were added to these panels to simulate the flaw porosity, a common flaw in composites. Glass fiber composite, along with resin only panels, were produced with between 0% and 10% micro-spheres by volume. A consistent volume percentage of voids were not attained in all the panels. Several panels had differing amounts of porosity by location.

These panels were tested using immersion ultrasound at the Naval Air Warfare Center-Aircraft Division (NAWC-AD) at Patuxent River, Maryland. It was possible to determine if a panel had more micro-spheres than another panel if both panel were manufactured together. It was not possible to determine the actual amount of porosity in a panel from the ultrasonic scans.

Fully Resolved Simulations of Particle-Turbulence Interaction

Researcher: Assistant Professor Tristan M. Burton

Fully resolved simulations of particle-turbulence interaction are computationally expensive due to the wide range of turbulent scales that must be resolved in space and time. The resolution requirements dictate that the simulations use large computational grids and small computational time steps. A single simulation of a fixed particle in decaying homogeneous isotropic turbulence can be performed on 9 processors of a parallel computer in 10-12 days. However, a large number of these simulations must be performed to obtain converged statistics that allow accurate conclusions about the interaction between the particle and the turbulence.

Thirty-two simulations of a fixed particle in decaying isotropic turbulence were performed previously. The temporal duration for each of these simulations was 10 non-dimensional time units. In order to verify the conclusions reached

about the forces applied to the particle and the effect of the particle on the turbulent kinetic energy and dissipation rate, an additional set of 32 simulations has been performed and the temporal duration of each of the 64 simulations is now 15 non-dimensional time units. The statistical results from the 64 simulation sample are currently being compared to the initial 32 simulation sample to verify that the sample is large enough. The data in the last 5 non-dimensional time units are also being analyzed to determine the magnitude of the turbulence modification at later times.

Determination of Clearance Requirements Around Obstructions in Finned Coldplates

Researcher: Professor Steven M. Miner

This study considers the subsystem level, specifically the transfer of heat from the component case through the coldplate to the coolant. In particular, the effect of bosses, used for mounting components, on the air flow distribution and temperature distribution in the coldplate is evaluated. The top and bottom plates spread the heat generated in the components to reduce the local heat flux. The fins substantially increase the heat transfer area, reducing the temperature rise from the coolant to the top and bottom plates. In this case a uniform distribution of flow across the coldplate can be achieved and there will be no localized hot spots. The presence of a boss has three effects on the coldplate performance. The boss disrupts the flow in its immediate vicinity, reducing the overall heat transfer coefficient. This causes an increase in operating temperature at that location. In addition, the boss will change the flow distribution in the coldplate. Locations both upstream and downstream of the boss may see reduced flow due to the obstruction, which in turn will cause an increase in operating temperature for these areas of the coldplate. The change in flow distribution will also increase the pressure drop through the entire coldplate, increasing the power required to operate the system. An initial evaluation of the flow around an unbounded and wall bounded cylinder was completed. This provides a starting point for the evaluation of clearance requirements for coldplates with fins.

Influence of Leading Edge Tubercles on Lifting Foil Performance

Researchers: Assistant Professor Mark M. Murray
and Assistant Professor David S. Miklosovic (Aerospace Engineering Department)

The reasons for many adaptations animals evolve are not well known. In an aquatic environment, turning performance of animals is constrained by morphology with the hydrodynamic characteristics of the animal's control surfaces being a major factor in determining level of performance. Humpback whales utilize extremely mobile, wing-like flippers with large rounded tubercles along the leading edge for banking and turning. This research effort experimentally explored the performance enhancement of leading edge proturbances or tubercles on a wing that is representative of a humpback whale flipper. Two model geometries were used for comparison: one without leading edge tubercles and one with representative tubercles (which give the leading edge a scalloped appearance). Wind tunnel force measurements were conducted at velocities up to 230 ft/sec and Reynolds of 5.5×10^5 based on mean chord length. The result of adding the tubercles showed significant improvements in the aerodynamic performance of the flipper, delaying the angle of attack at which stall develops by approximately 40%. Maximum lift coefficient and minimum drag coefficient did not change significantly. These results indicate that aerodynamic performance can be enhanced with tubercles present on the leading edge of a fin. A paper has been published in Physics of Fluids outlining the results of this research.

Midshipman Research Course Projects

Fabrication and Testing of Hybrid Composite/Metal Panels

Researcher: Midshipman 1/C Tad Robbins, USN
Adviser: Assistant Professor Stephen M. Graham
Sponsors: Bowman Scholar Program (BSP)
and Naval Surface Warfare Center, Carderock Division (NSWC-CD)

The Naval Surface Warfare Center at Carderock (NSWC-CD), the U.S. Naval Academy (USNA) and the Office of Naval Research are working to develop a hybrid composite/metal joint to support future high performance naval ships,

such as the Littoral Combatant Ship. This hybrid joint is formed by laying up glass fabric on one side and metal fibers on the other, co-infusing the joint with resin and then curing it. During a 3-week internship with the Marine Composites Branch at NSWCCD, the researcher learned about the fabrication and testing of composite, with time spent on the fabrication of panels with several different hybrid joint designs. During the fall semester at USNA, the researcher conducted instrumentation evaluation and testing of various designs of hybrid composite joints.

Manufacturing and Evaluating Flawed Composites

Researcher: Midshipman 1/C Spencer Seufert, USN
Advisers: Assistant Professor Peter J. Joyce and Associate Professor John A. Burkhardt

Methods of non-destructive evaluation of composites lack a standard for how certain flaws should appear. Evaluating homogenous materials in better understood because waves propagate in a more predictable manner when the medium is composed of a single material. As composites are used more frequently it is important that it becomes easier to evaluate their flaws. Composites are used as high performance materials because their structures allow them to bear unusually large amounts of force for their weight. If there is a flaw in the internal structure of a composite, it can lose the ability to support the force that it is expected to be able to handle.

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These panels were tested using immersion ultrasound at the Naval Air Warfare Center Aircraft Division (NAWC-AD) at Patuxent River, Maryland. It was possible to determine if a panel had more micro-spheres than another panel if both panel were manufactured together. It was not possible to determine the actual amount of porosity in a panel from the ultrasonic scans.

Mechanical Tests on Oven Cured K63B12 Pitch Fiber/NB-308 Epoxy Composite

Researcher: Midshipman 2/C Brian Richards, USN
Adviser: Assistant Professor Peter J. Joyce

The purpose of this project was to carry out qualification testing on oven-cured K63B12 Pitch Fiber/Epoxy Composite. This material is under consideration for use in the battery trays used on the Advanced Seal Delivery System built by NGOS. The pitch fiber composite was selected for this application for the exceptional thermal conductivity properties of pitch fiber,to help take the heat out of the battery packs on the ASDS which is thought to have caused premature battery failure in preliminary Sea Trials with the ASDS.

The K63B12 Pitch Fiber/Epoxy Composite in this study was oven-cured to examine low-cost manufacturing alternatives. In this study two batches of material were evaluated. When the material was first delivered to NGOS, there was a problem with the handability of the prepreg, so after only modest initial attempts at manufacturing with the prepreg it was shipped back to Newport Composites for reprocessing.

In this study the tensile properties of a $[\pm 30]_s$ laminate were measured for both the initial lot of prepreg as well as the reprocessed prepreg material. As expected reprocessing on no measurable effect on the stiffness of the laminate since this property is largely fiber dominated. However, reprocessing was demonstrated to increase the tensile strength of the finished laminate by almost 30%, furthermore the standard deviation in the tensile strength of the laminate was reduced by a factor of two by reprocessing.

Mechanical Tests on Oven Cured K63B12 Pitch Fiber/NB-308 Epoxy Composite

Researcher: Midshipman 1/C Jessica McClay, USN
Advisers: Assistant Professor Peter J. Joyce and Assistant Professor Andrew N. Smith

The new Advance Seal Delivery System (ASDS) by Northrop Grumman is a miniature submarine that operates entirely on battery power. These batteries have demonstrated an unacceptable degradation in performance due to the temperature increases during operation. To solve this problem, Northrop Grumman has looked at several solutions for removing the heat from the battery enclosure. One proposed solution was to introduce plates and "hats" constructed of pitch fiber/epoxy composite (K63B12/NB-308) to provide a conduction path to transfer the heat. Pitch fiber/epoxy composites are selected because of their exceptional thermal conductivity and electrical insulating properties as well as their superb mechanical properties.

A simple model for the composite thermal conductivity based on the thermal properties of the constituent materials, the fiber volume fraction of the composite, and the fiber orientation is presented. Experiments to determine the thermal conductivity of the K63B12/NB-308 composite were performed at steady state temperatures to validate the model both for unidirectional material as well as off-axis. Unidirectional samples were first tested to verify the analytical model of thermal conductivity, then a $[\pm 30]_s$ sample and a $[\pm 60]_s$ were tested.

The analytical calculations and the experimental results both demonstrate that the thermal conductivity of the composite is fiber dominated (as expected) and decreases as the fibers are rotated off axis and thermal conductivity is greater with greater fiber volume content. Another conclusion is that given the magnitude of the difference between the thermal conductivity of the fiber and the matrix, the heat transfer potential of the fibers is degraded by the insulating matrix. A documented and repeatable method for predicting and measuring the in-plane thermal conductivity has been implemented for laminate composites.

External Composite Orthopedic Aids in the Treatment of Athletic Forefoot Injuries

Researcher: Midshipman 1/C Eric Frey, USN
Adviser: Assistant Professor Peter J. Joyce

Research was conducted to examine the development of an external orthopedic support constructed from composite materials as an aid for athletes suffering from forefoot injuries. There exist numerous possible forefoot injuries that could be suffered in athletics that would potentially render the athlete unable to compete. The predominate forefoot injury in athletics is the partial or complete tearing of the ligaments of the big toe, commonly referred to as "turf toe." As force is transferred through the foot these ligaments are in a state of high stress which they are unable of carrying adequately when partially torn. Forefoot injuries can take months to heal due to the ease of re-injury and even a minor case of turf toe may remove an athlete from participation. The problem in treating turf toe injury is to provide adequate reinforcement that will provide sufficient stiffness for the stationary isolation of the forefoot joints to prevent further injury and minimize pain. For contact sports there is also concern to provide protection from impact to the injury. Simultaneously, the reinforcement must allow for the semi-natural function of the foot as well as providing good traction on a grass surface and be limited in size and weight so that movement is essentially unrestricted. Current devices to assist with forefoot injuries include reinforced insoles and custom made shoes with aluminum plate inserts to provide stiffness to prevent the bending of the forefoot.

After a turf toe injury to a member of the football team that would have resulted in a career ending injury, a prototype of a composite orthopedic cleat was constructed in an effort to allow him to continue to play. Consultation with the head athletic trainer and team orthopedic surgeon provided guidance to the requirements of the reinforced cleat. The prototype first proved successful in practices and game competition. The composite orthopedic cleat was compared to an orthopedic cleat provided by Nike with aluminum plates, an orthopedic cleat fabricated by the Naval Academy head football athletic trainer out of thermoplastic materials and two out of the box cleats also from Nike, one gently worn, the other in virgin condition. Experimentation was performed to characterize the stiffness of six football cleats using a cantilever bend test model to measure the stiffness to weight ratio. The strength of the protective toe cap was determined through quasi-static load testing to characterize the impact energy absorption ability. Testing was also done to quantify the coefficient of friction on artificial turf and real grass. Comparisons of the cleats were made based on bending stiffness, crush strength, coefficient of friction, and weight. The tested showed that the use of external composite reinforcement of the cleat is the best solution in the treatment of severe forefoot injuries.

Evaluation of Corrosion Effects on Structural Integrity Using Laser Profilometry

Researcher: Midshipman 1/C Rebecca Gordon, USN
Adviser: Assistant Professor Michelle G. Koul
Sponsor: U.S. Air Force Aging Aircraft Program Office

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. The objective of this project was to use laser profilometry to observe and compare the topographic progression of corrosion damage on the ST face in unstressed AA7075-T6 and AA7075-RRA specimens removed from 3-in thick plate. Correlation of the high cycle fatigue performance of pre-corroded AA7075-T6 samples with quantified corrosion topographies by obtaining S-N curves at R > 0 was undertaken. Comparison of experimental results to structural integrity model predictions to determine the critical parameters that control S-N behavior was performed to validate structural integrity model(s).

Property and Structure Evaluation as a Function of Processing Parameters: Large HY-80 Steel Castings for U.S. Navy Submarines

Researcher: Midshipman 1/C John Holthaus, USN
Advisers: Assistant Professor Michelle G. Koul and Professor Angela L. Moran
Sponsors: Bowman Scholar Program (BSP), Franklin Wharton, SEA 07T, Naval Sea Systems Command (NAVSEA), Gerard (Jeff) Mercier, Code 614, Naval Surface Warfare Center, Carderock Division (NSWC-CD)

The focus of this research was the failure of an SSN764 HY-80 Bridge Access Trunk (BAT) casting. The suspected cause of failure is improper processing techniques. Samples from the failed component were evaluated using tensile, hardness and impact tests as well as optical and electron microscopy to determine microstructure and mechanical properties. Results were compared to required military specifications for the part obtained from NSWCCD and NAVSEA. Additional HY-80 samples will be obtained and representative samples machined. These samples were processed via different heat treatments using specialty furnaces at USNA to evaluate the role of thermal processing in the microstructural development and resulting mechanical properties. Testing similar to that performed on the failed component was performed on the newly processed castings. The goal of the research was to isolate the processing parameters that can result in the microstructure observed in the failed HY-80 BAT, and to clarify the processing windows that will result in HY-80 steel that meets Navy specifications for large submarine castings.

Heat Transfer Analysis of Metal Hydrides Used to Store Hydrogen

Researcher: Midshipman 1/C Justin J. Salvia, USN
Adviser: Professor Keith W. Lindler

Metal hydrides offer a new storage possibility for hydrogen. When metal hydrides are pressurized in a hydrogen rich environment they readily absorb hydrogen atoms. This method of storage offers six times the capacity of hydrogen atoms compared to conventional hydrogen gas pressurized at 200 bar with an equivalent volume. When the metal hydride is heated, it releases the hydrogen in the form of gas. This method of storage offers a safe compact alternative to pressurized hydrogen gas, as an energy source. This energy source could then be further developed to create a heater for underwater divers in harsh ocean environments. In an effort to aid in the development a diver heater, this research project evaluated and recorded the heat transfer rates of different metal hydrides at various conditions so that a suitable metal hydride might be selected for the development of the heater.

New Materials for Aging Aircraft: Multifunctional Coatings and Replacement Component Alloys

Researcher: Midshipman 1/C Jennifer Lipscomb, USN
Advisers: Professor Angela L. Moran and Assistant Research Professor Qingjiang Meng
Sponsor: Air Force Office of Sponsored Research (AFOSR) and Office of Naval Research (ONR)

Aluminum based materials used on commercial and military aircraft operate under high stress and in corrosive environments. Amorphous and nanostructured aluminum alloy coatings are under development to provide enhanced corrosion protection as well as high strength, ductility and fatigue resistance. Thermal spray, detonation bonded, and cold spray methods are under consideration to find which deposition technique provides an optimal coating. Mechanical properties, corrosion fatigue resistance, and microstructural variations were determined for each of the different coating methods. Additionally, aging aircraft experience corrosion related cracking problems that can be detrimental to the structural integrity of affected components made from current aluminum alloys. As the number of aging aircraft increases, the need for more environmentally assisted crack resistant aluminum alloys for component replacement and refurbishment as well as the need for quantitative measurements of the effects of corrosion on component lifetime prediction have become critical. This project involved performing electrochemical tests on candidate replacement alloys to evaluate their basic corrosion properties and assess their potential for use as a replacement of current materials in military aircraft.

The Integration of a Nuclear Acquisition System With Wireless Communications Technology

Researcher: Midshipman 1/C Kevin Behm, USN
Advisers: Professor Martin E. Nelson
and Commander Thaddeus B. Welch, III, USN (Electrical Engineering Department)
Sponsor: Bowman Scholar Program (BSP)

In this project, wireless communication capabilities between two computer platforms were integrated with a portable radiation data collection system. The wireless communication was conducted in two modes: (1) via the USNA Internet system and (2) via a commercial Sprint PCM-CIA card. The neutron detection system collected multi-channel analyzer neutron and gamma data through a commercially available Canberra Genie PC data acquisition system. In addition, the data acquisition system was demonstrated through the use of a batch mode process, in which multiple files were periodically sent from one computer to another. In this project, the wireless communication capabilities of both modes were successfully demonstrated.

Study of the BETA Response Characteristics of the DT-702 Thermoluminscent Dosimeter (TLD)

Researcher: Midshipman 2/C Philip D. Hall, USN
Adviser: Professor Martin E. Nelson
Sponsor: Naval Dosimetry Center (NDC)

Navy personnel encounter ionizing radiation sources on a daily basis, and some of these sources can be beta radiation. In accident scenarios, beta radiation will likely be an important radiological consideration. The DT-702 will shortly become the primary-use TLD in the Navy. However, its response to beta radiation needs to be better understood.

In this project, the response of the DT-702 TLD to beta radiation was studied. Through an internship at the NDC and through a research project during the academic year, the researcher collected data on the DT-702 using calibrated beta radiators that were available at the National Institute of Standards and Technology (NIST). Analysis of the data, which was collected under mixed field and unmixed field conditions, provided the light output of the TLD as measured with a TLD reader. A decision algorithm was formulated to determine whether or not beta radiation was present and to calculate the beta dose in mrem. The collected data was modeled using the Monte Carlo Neutron Photon (MCNP) Transport Code, which was available in the Naval Academy's Nucleonics Laboratory.

Investigation of the Ship Effect in Off-Shore Screening for Nuclear WMD

Researchers: Midshipman 1/C V. D. Scott, USN, and Midshipman 1/C R. J. Mistry, USN
Advisers: Professor Martin E. Nelson
and Visiting Professor James F. Ziegler (Electrical Engineering Department)

Research was conducted into the cause of excessive neutron signatures from naval ships. Data was collected with a 14-element Bonner sphere neutron spectrometer placed onboard the USS Barry and at a Naval Academy off-ship location. The data showed that a significant increase in neutrons in the 1 KeV-2 MeV neutron energy range occurred onboard the ship as compared to the land-based location. The explanation of this response was attributed to spallation neutron reactions as cosmic ray neutrons interacted with the iron in the ship's hull.

Effect of Usage and Temperature with Different Reference Light Sources on TLD Readers

Researcher: Midshipman 1/C Pat Hanks, USN
Adviser: Professor Martin E. Nelson
Sponsor: Naval Dosimetry Center (NDC)

This project evaluated temperature effects on the light output for two reference light sources. These sources could potentially be used for calibration purposes in Thermo Electron thermoluminescent dosimeter (TLD) readers, which are currently in use by the U.S. Navy. The reference light sources consisted of a commercial tritium source and a C-14 source surrounded by a scintillating plastic. Additionally the effect of reader usage was evaluated using data from the Naval Dosimetry Center (NDC). It was determined that the photomultiplier tube (PMT) output with a tritium source is stable to within +/-1.6% over a 30 day period and the PMT output with a C-14 source is stable to within +/-1.2% over a 15 day period.

Investigation into the Feasibility of Highly Enriched Uranium Detection by External Neutron Stimulation

Researchers: Midshipman 1/C Crystine M. Good, USN, Midshipman 1/C Jeffrey Allen, USN
Midshipman 1/C Sean Lock, USN and Ensign Brian Blackburn, USN
Adviser: Professor Martin E. Nelson
Sponsor: Defense Threat Reduction Agency (DTRA)

This project studied the detectability of 1 kg of HEU in a cargo container, whose dimensions are 20' x 20'x 80', by stimulating the HEU with a neutron source located external to the container and counting the above background neutron signature that would be produced due to a fission reaction. The neutron detector used in the project contained nine He^3 tubes moderated with polyethylene that had been designed for nuclear arms control applications. This project examined a wide variety of different energy sources, counting options, and the effect of different cargo materials present within the container. The study considered solution approaches using both deterministic and Monte Carlo techniques of which the latter solution approach was based on the MCNP4C2 transport code.

The major project conclusions are that this approach would be successful in all common environments except one, if a pulsed 14 MeV neutron source with strength of 10^{12} neutrons/sec was used and the delayed neutrons from the fission products are counted when the source is between pulses. The study recommends both a pulse and a count time of 2.9 seconds, 48 cycles, and a total examination time of 300 seconds for each container. The one environmental condition identified that would defeat this technique was the case of when the cargo had both a density of 1 gram/cm^3 or greater and a hydrogen atom content of 15% or greater. To succeed in this environment, the study concluded that the stimulation source strength would have to be increased several orders of magnitude to as high as 10^{15} n/sec, which is beyond current technical capabilities. A dose evaluation of the shielding requirements for a stimulation facility was also performed. For the case of a 14 MeV 10^{12} neutron/sec source, the study recommended a surrounding 7 foot thick concrete shield in order to meet current regulatory standards for facility operational personnel. The study noted that this technique could result in cargo activation that may require a post-irradiation decay time before the container could be released for public transportation to its final destination site. A recommendation is made for future study of this problem.

Determination of the Directional Dependent In-Plane Thermal Conductivity of K63B12 Pitch-Fiber/Epoxy Composites

Researcher: Midshipman 1/c Jessica McClay, USN
Advisers: Assistant Professor Andrew N. Smith and Assistant Professor Peter J. Joyce
Sponsor: Northup Grumman Corporation

Pitch carbon fiber/epoxy composites are being utilized for thermal management in systems where passive means are the only method of heat removal. Due to the exceptional thermal conductivity properties of pitch fibers, these composites are utilized for heat removal while providing electrical isolation between individual components. The mechanical properties of these composites were determined using established micromechanics theory and verified by mechanical testing. Conversely, a method for predicting thermal properties of fiber-reinforced composites is significantly less developed and lacking experimental confirmation. A particular application is thermal management on next generation mini-subs. For this application and study, K63B12/pitch fiber NB 308 expoxy composites were investigated.

An estimate of the thermal conductivity was made using the properties of the constituent materials along with the geometry of the sample. Experimental results of the thermal conductivity of unidirectional composite materials, and laminate materials with multiple fiber orientations, were obtained. A comparison was made between the experimental results and the theoretical predictions. The thermal conductivity was measured with a steady state technique, where a 1D temperature gradient was imposed. The sample was held in a vacuum, and heat was applied at a known rate using a resistance heater. The experimental setup was calibrated using materials with known thermal properties.

This research showed the directional dependence of the in-plane thermal conductivity of K63B12 pitch fiber/NB 308 epoxy composite. A documented and repeatable method for predicting and measuring the in-plane thermal conductivity has been implemented for laminate composites.

Publications

Journal (Refereed) Manuscripts

FLACK, Karen A., Associate Professor, and SCHULTZ, M. P., Assistant Professor (Naval Architecture and Ocean Engineering Department), "Outer Layer Similarity in Fully Rough Turbulent Boundary Layers," *Experiments in Fluids*, accepted for publication.

Turbulent boundary layer measurements were made on a flat plate covered with uniform spheres and the same surface with the addition of a finer scale grit roughness. The measurements were carried out in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3000 to 15000, using a two-component, laser Doppler velocimeter (LDV). The results show that the mean profiles for all the surfaces collapse well in velocity defect form. Using the maximum peak to trough height (R_t) as the roughness length scale (k), the roughness functions (ΔU^+) for both surfaces collapse, indicating that roughness texture has no effect on ΔU^+. The Reynolds stresses for the two rough surfaces also show good agreement throughout the entire boundary layer and collapse with smooth wall results outside of the roughness sublayer. Turbulence statistics up to fourth moment show excellent agreement for the two rough surfaces. Quadrant analysis and the velocity triple products show changes in the rough wall boundary layers that are confined to $y < 8k_s$, where k_s is the equivalent sand roughness height. The present results provide support for Townsend's wall similarity hypothesis for uniform three-dimensional roughness, however, departures from wall similarity may be observed for rough surfaces where $5k_s$ is large compared to the thickness of the inner layer.

FLACK, Karen A., Associate Professor, and SCHULTZ, M. P., Assistant Professor, (Naval Architecture and Ocean Engineering Department), "Turbulent Boundary Layers over Surfaces Smoothed by Sanding," *American Society of Mechanical Engineers (ASME) Journal of Fluids Engineering*, Vol. 125, pp. 863-870, 2003.

Flat plate turbulent boundary layer measurements have been made on painted surfaces, smoothed by sanding.

The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number ($Re_{\square}$) range of 3000 to 16000, using a two-component, laser Doppler velocimeter (LDV). The mean velocity and Reynolds stress profiles are compared with those for smooth and sandgrain, rough walls. The results indicate an increase in the boundary layer thickness (□) and the integral length scales for the unsanded, painted surface compared to a smooth wall. More significant increases in these parameters, as well as the skin-friction coefficient (C_f) were observed for the sandgrain surfaces. The sanded surfaces behave similarly to the smooth wall for these boundary layer parameters. The roughness functions (□U^+) for the sanded surfaces measured in this study agree within their uncertainty with previous results obtained using towing tank tests and similarity law analysis. The present results indicate that the mean profiles for all of the surfaces collapse well in velocity defect form. The Reynolds stresses also show good collapse in the overlap and outer regions of the boundary layer when normalized with the wall shear stress. Roughness parameter measurements are compared to results from tow-tank test using plates with the similar surface coatings.

JOYCE, James A., Professor, "Fracture Toughness Evaluation of Polytetrafluoroethylene," *Polymer Engineering and Science*, Vol. 43, n.10, pp. 1702-1714, October 2003.

The objective of this preliminary work was to explore the fracture resistance of polytetrafluoroethylene (PTFE) (Dupont Tradename Teflon) as part of materials characterization work related to the development of "reactive" material projectiles. Little mechanical property data is available on this material since it is commonly used only as a coating material with the dominant properties being its low friction coefficient and high application temperature. Additional end products of the "7C" derivative, however, includes sheet, gaskets, bearing pads, piston rings and diaphragms. In this work, standard ASTM E1820 fracture toughness specimens were machined from a 14 mm thick sheet of this material obtained from NSWC Dahlgren Laboratory and these specimens were tested at three test temperatures and four test rates to determine if fracture would occur in this material, and if so, how the fracture toughness depends on the test temperature and specimen loading rate. Standard axial tensile specimens were also tested at quasi-static and elevated loading rates at temperatures from ambient to –73°C. The major results are that while crack extension is difficult at ambient (20°C) temperature, for temperatures slightly below ambient, a rapid degradation of fracture resistance occurs. This reduction in fracture resistance is enhanced by rapid loading, and the material loses approximately 75% of its toughness (fracture energy absorption ability) at –18°C if the crack opening loading rate of the C(T) specimen approaches 0.25 m/s. Further reductions in temperature or increases in the loading rate appear to result in a reduced rate of degradation of fracture toughness.

JOYCE, Peter J., Assistant Professor and JOYCE, James A., Professor, "Evaluation of the Fracture Toughness Properties of Polytetrafluoroethylene," *International Journal of Fracture*, Vol. 127, n.4, pp. 361-385, June 2004.

Polytetrafluoroethylene (PTFE) (Dupont trade name Teflon) is a common polymer with many structural applications including sheet, gaskets, bearing pads, piston rings and diaphragms. The interest here developed because this polymer is being considered as the major component of a newly proposed "reactive" material with a possible application as a projectile to replace common inertial projectiles made of tungsten. Little mechanical property data is available on this material since it is commonly used only as a coating material with the dominant properties being its low friction coefficient and high application temperature. Previous work (Joyce, 2003a) on commercially available sheet material has demonstrated the applicability of the normalization method of ASTM E1820, the elastic-plastic fracture toughness standard to develop fracture toughness properties of this material over a range of test temperatures and loading rates. Additional work on an aluminum loaded derivative of the basic PTFE polymer (Joyce, 2003b) has also recently been completed. In this work, standard ASTM E1820 fracture toughness specimens were machined from these pucks and these specimens were tested at four test temperatures and at a range of test rates to determine the J_{Ic} and J resistance curve characteristics of the PTFE material. The major results are that while crack extension is difficult at ambient (20°C) temperature or above, for temperatures slightly below ambient or for elevated loading rates, a rapid degradation of fracture resistance occurs and cracking occurs in a ductile or even brittle manner.

JOYCE, James A., Professor and JOYCE, Peter J., Assistant Professor, "Toughness Characterization of a Metal Filled PolyTetraFluoroEthylene Using the J Integral," *Engineering Fracture Mechanics*, Vol. 71, n, 16-17, pp. 2513-2531, November 2004.

PolyTetraFluoroEthylene (PTFE) is a semi-crystalline polymer that demonstrates a range of fracture properties when tested at various temperatures and loading rates. Addition of a powdered aluminum filler, to obtain enhanced mechanical properties, results in a multiphase material that contains crystalline, amorphous and filler phases. In this work fracture toughness is measured for the aluminum filled PTFE material over a range of test temperatures and loading rates using a version of the ASTM E1820 normalization method and the non-linear elastic J integral. The normalization method works exceptionally well for this material to define both the initiation fracture toughness and the J integral resistance curves over a wide range of test conditions. When this material is loaded at modest rates, at or above ambient temperature it demonstrates a high toughness behavior, but if the test rate is elevated to 25 mm/s or above the fracture toughness rapidly falls. On the other hand, if elevated temperatures or slow loading rates are used, time-dependent crack growth is observed, and the fracture toughness in this instance is also very low. Scanning electron microscope observations show that very different micromechanical mechanisms exist under these different loading conditions resulting in the dramatic changes in material toughness observed.

KOUL, Michelle G., Assistant Professor, "Topographical Analysis of Pitting Corrosion in AA7075-T6 using Laser Profilometry," *Corrosion,* 59(7), p. 564, 2003.

Laser profilometry (LP) is explored as a means for mapping g and quantifying the corrosion damage of AA7075-T6 specimens exposed to cyclic prohesion spray for various times. Analysis tools were developed and employed to provide quantitative measurements of the distribution of damage site shape, area and volume and depth. Evaluation of these parameters with exposure time was examined. The measured maximum damage site depths of 22-55 mm agree well with values obtained using other techniques. Modeling the damage sites as elliptical surface flaws yielded maximum DK values for the individual fatigue specimens (2-5 MPa√m) that are equal to or higher than typical fatigue crack growth thresholds available in the literature. The maximum (or average) DK values calculated from the corrosion damage distributions correlate well with measured fatigue life.

LINK, Richard E., Associate Professor, JOYCE, James A., Professor, and Gaies, J., "Evaluation of the Effect of Biaxial Loading on the T_0 Reference Temperature Using a Cruciform Specimen Geometry," *Fatigue and Fracture Mechanics: 34th Volume, ASTM STP 1461*, S. R. Daniewicz, J. C. Newman and K.-H. Schwalbe, (Eds), ASTM International, West Conshohocken, PA, 2004.

A series of 12 cruciform geometry fracture toughness specimens have recently been tested using A533B base plate obtained from the decommissioned Shoreham plant pressure vessel. Specimens were tested at –100°C, placing them in the lower ductile to brittle transition of this ferritic structural steel. The overall objective of this work is to compare the results of these biaxial cruciform tests to the results of standard and shallow crack fracture toughness tests to assess the effect of biaxial loading on the measured master curve and the T_o reference temperature as defined by ASTM E1921. Previous work done at Oak Ridge National Laboratory (ORNL) appeared to demonstrate an increase in the T_o reference temperature due to the presence of the biaxial stress field established in the cruciform test geometry. Because of the cost of the ORNL tests, only a few specimens could be run and full statistical support of the "biaxial effect" could not be demonstrated. A second goal is to demonstrate that smaller size specimens, and hence lower cost tests, can be used to evaluate the magnitude of the biaxial effect in nuclear reactor pressure vessel materials. This report presents a brief overview of the test procedure, presents the test results, and compares the results to the database available on standard and shallow crack fracture toughness results available for the Shoreham plate material.

MINER, Steven M., Professor, "CFD Analysis of the First Stage Rotor and Stator in a Two Stage Mixed Flow Pump," *International Journal of Rotating Machinery,* accepted for publication.

A commercial CFD code was used to compute the flow field within the first stage rotor and stator of a two stage mixed flow pump. The code solved the 3-D Reynolds Averaged Navier Stokes equations in rotating and stationary cylindrical coordinate systems for the rotor and stator, respectively. Turbulence effects were modeled using a standard $k-\varepsilon$ turbulence model. Stage design parameters were, rotational speed 890 rpm, flow coefficient

$\phi = 0.116$, head coefficient $\psi = 0.094$, and specific speed 2.01 (5475 US). Results from the study included velocities, and static and total pressures for both the rotor and stator. Comparison was made to measured data for the rotor. The comparisons in the paper were for circumferentially averaged results and included axial and tangential velocities, static pressure, and total pressure profiles. Results of this study showed that the computational results closely match the shapes and magnitudes of the measured profiles, indicating that CFD can be used to accurately predict performance.

MORAN, Angela L., Professor, FERRER, Charles P., (Trident Scholar, Class of 2001), KOUL, Michelle G., Assistant Professor, and CONNOLLY, Brian J., Assistant Research Professor, "Improvements in Strength and Stress Corrosion Cracking Properties in Aluminum Alloy 7075 Via Low Temperature Retrogression and Re-Aging Heat Treatments," *Corrosion*, 59 (6), pp. 520-528, June 2003.

The susceptibility of aluminum alloy 7075 (AA7075) to intergranular stress-corrosion cracking (SCC) in the peak strength T6 temper is alleviated through the use of the T73, or overaged temper, which provides improved SCC resistance with a 10-15% strength loss compared to the T6 temper. Cina and Ranish indicated that retrogression and re-aging (RRA) heat treatments reduce the trade-off between T6 strength and T73 SCC resistance. The short time heat treatment they used, however, limited the applicability of RRA to thin sections of material. The primary goals of this research effort were to (1) 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 and (2) to quantify any observed improvements. Alternate immersion (AI) and double-cantilever beam (DCB) tests were conducted in a 0.6 M NaCl solution to evaluate the SCC resistance of various tempers. Improvements in properties were demonstrated using RRA heat treatments at lower temperatures and longer times than those previously investigated. In general, the various RRA tempers below 200°C produced strengths similar to that of T6 with improved SCC properties. The RRA temper with retrogression at 160°C for 660 minutes produced the greatest improvement in SCC resistance, with only a 4% reduction in strength below T6.

MURRAY, Mark M., Assistant Professor, MIKLOSOVIC, David S., Assistant Professor (Aerospace Engineering Department), Howle, L.E., and Fish, F.E., "Leading-edge Tubercles Delay Stall on Humpback Whale (Megaptera novaengliae) Flippers," *Physics of Fluids*, Vol. 16 (5), pp. L39-L43, May 2004.

The humpback whale (Megaptera novaeangliae) is exceptional among the baleen whales in its ability to undertake acrobatic underwater maneuvers to catch prey. In order to execute these banking and turning manoeuvres, humpback whales utilize extremely mobile flippers. The humpback whale flipper is unique because of the presence of large protuberances or tubercles located on the leading edge which gives this surface a scalloped appearance. We show, through wind tunnel measurements, that the addition of lading edge tubercles to ¼ scale models of an idealized humpback whale flipper delays the stall angle by approximately 40%, while increasing lift and decreasing drag.

NELSON, Martin E., Professor, DIRK John D., (Trident Scholar, Class of 2002), Thompson, A., Zabel, T., and ZIEGLER, James F., Visiting Professor (Electrical Engineering Department), "Terrestrial Thermal Neutrons," *Institute of Electrical and Electronics Engineers* (*IEEE) Transactions of Nuclear Science*, Vol. 50 (6), pp. 2060-2064, December 2003.

The first NIST-traceable measurements of environmental thermal neutrons have been completed. The average sea level flux of thermal neutrons is 4/cm^2-hr. This flux changes less than 2x over wide varieties of terrain, in all weather conditions and over the solar year. The neutron flux is normalized to 39N-76.5W. This flux scales with geomagnetic Lat/Long and with altitude in a manner similar to the flux of incident energetic cosmic rays. The shielded flux has been measured under 3100 g/cm2, with a residual flux of 0.1x the sea level value. Preliminary shielding studies inside buildings and under water shows significant variability in the thermal neutron mean attenuation coefficient.

NELSON, Martin E., Professor, McMarr, P., Hughes, H. and DELIKAT, Kelly, "MeV Neutron and Co-60 Gamma Testing of a Power MOSFET Optocoupler," *Institute of Electrical and Electronics Engineers* (*IEEE) Transactions of Nuclear Science*, Vol. 50 (6), pp. 2030-2037, December 2003.

The effect of radiation from neutron activation of package materials was studied using a power MOSFET optocoupler as the test device. The optocouplers were exposed to 14 MeV neutrons to a fluence of 1 x 10^{11} n/cm^2 , with the device switching during the exposure. A separate set of optocouplers was then irradiated with a Co^{60} source. These results combined with gamma ray spectroscopy showed that the radiation from the neutron activation had a significant effect on the electrical parameters of the optocoupler.

NELSON, Martin E., Professor, McClellan, Y., August, A., Gosz, J., Gann, S., Parmenter, R., and HARPER, Mark J., Professor, "Plant and Environmental Interactions," *Journal of Environmental Quality*, Vol. 32, pp. 1759-1763, September-October 2003.

The effect of radiation from neutron activation of package materials was studied using a power MOSFET optocoupler as the test device. The optocouplers were exposed to 14 MeV neutrons to a fluence of 1 x 10^{11} n/cm^2, with the device switching during the exposure. A separate set of optocouplers was then irradiated with a Co^{60} source. These results combined with gamma ray spectroscopy showed that the radiation from the neutron activation had a significant effect on the electrical parameters of the optocoupler.

RATCLIFFE, Colin P., Associate Professor, Crane, Roger M., and Gillespie, John W., Jr., "Damage Detection in Large Composite Structures Using A Broadband Vibration Method," *Insight*, Vol. 46 (1), pp. 10-16, 2003.

This paper presents a broadband vibration-based Structural Irregularity and Damage Evaluation Routine (SIDER) that uses features in complex curvature operating shapes to locate damage and other areas with structural stiffness variations. SIDER was developed for the inspection of large-scale composite structures not amenable to more conventional inspection methods. This paper extends the procedure such that it can be used on general, multi-dimensional engineering structures. Experimental results from a composite road bridge and a composite ship hull show that even when an a priori model of the structure is not available, structural variability and some manufacturing defects can be located. Damage caused over time can be detected by comparing results of an inspection with the results obtained from the structure before it is put into service. Underwater explosion testing of the ship hull deliberately caused damage, which was located using this method. The results are reported here.

RATCLIFFE, Colin P., Associate Professor, Yoon, M. K., Heider, D., Gillespie, J. W., Jr., "Local Damage Detection Using The Two-Dimensional Gapped Smoothing Method," accepted for publication.

This paper presents a procedure for locating variability in structural stiffness. For some types of structure, this variability is directly related to manufacturing defects and/or in-service damage. Unlike many published damage detection methods, the procedure presented here does not require a baseline data set or theoretical model for comparison. The procedure is a two-dimensional generalization of a previously published one-dimensional gapped smoothing method, whereby local features in frequency dependent vibration curvature shapes are extracted using a localized curve fit. A variability index is generated for each test point on the structure. Increased variability is due either to structural stiffness features, or damage. A statistical treatment of the variability indices enables discrimination of areas with significant variability. The procedure can either analyze mode shape data, or frequency dependent operating displacement shape data.

The procedure is demonstrated with a finite element model of a plate, and experiments on composite plates with deliberately induced multiple delaminations. Finally, the method is demonstrated on data taken from a large composite structure; a hull component from a ground armored vehicle. In all cases the procedure successfully located the damaged regions.

RATCLIFFE, Colin P., Associate Professor, BAGARIA William, (Aerospace Engineering Department), GARCIA, Sonia M. F., (Mathematics Department) and FAHEY, Richard P., (Aerospace Engineering Department), "Rapid Binary Gage Function to Extract a Pulsed Signal Buried in Noise," *EURASIP Journal on Applied Signal Processing*, accepted for publication.

The type of signal studied in this paper is a periodic pulse, with the pulse length short compared to the period, and the signal is buried in noise. If standard techniques such as the Fast Fourier Transform are used to study the signal, the data records need to be very long. Additionally, there would be a very large number of calculations. The Rapid Binary Gage Function was developed to quickly determine the period of the signal, and the start time of the pulse in the data. Once these two parameters are determined, the pulsed signal can be recovered using a standard data folding and adding technique.

SMITH, Andrew N., Assistant Professor and Calame, J., "Impact of Thin Film Thermophysical Properties on Thermal Management of Wide Bandgap Solid-State Transistors," *International Journal of Thermophysics*, Vol. 25 (2), pp. 409-422, March 2004.

Wide bandgap semiconductor solid-state transistors continue to have a wide array of applications that include power supplies, communications, electronic warfare, and multifunctional RF systems. Two viable wide bandgap semiconductor materials currently under investigation are silicon carbide (SiC) and gallium nitride (GaN). One interesting aspect of these devices is their ability to operate at elevated temperatures on the order of 500 ºC. At higher temperatures the heat capacity of semiconductors is constant, while the phonon mean free path is inversely proportional to the lattice temperature. This causes a significant reduction in the thermal conductivity over the operating temperature range. The submicron-scale conducting channels and junctions of wide bandgap devices can create highly localized heat fluxes on the order of several hundred kilowatts per square centimeter. Since these heat fluxes lead to localized hot spots within the electrically critical regions of the transistors, they can have a strong impact on device gain, power capability, and reliability. Quantifying the thermophysical properties of the underlying thin film materials is of critical importance for the accurate prediction of these localized temperature extremes.

VOLINO, Ralph J., Associate Professor, "Passive Flow Control on Low-Pressure Turbine Airfoils," *American Society of Mechanical Engineers (ASME) Journal of Turbomachinery,* Vol. 125, pp. 754-764, October 2003.

Two-dimensional rectangular bars have been used in an experimental study to control boundary layer transition and reattachment under low-pressure turbine conditions. Cases with Reynolds numbers (Re) ranging from 25,000 to 300,000 (based on suction surface length and exit velocity) have been considered at low (0.5%) and high (8.5% inlet) free-stream turbulence levels. Three different bars were considered, with heights ranging from 0.2% to 0.7% of suction surface length. Mean and fluctuating velocity and intermittency profiles are presented and compared to results of baseline cases from a previous study. Bar performance depends on the bar height and the location of the bar trailing edge. Bars located near the suction surface velocity maximum are most effective. Large bars trip the boundary layer to turbulent and prevent separation, but create unnecessarily high losses. Somewhat smaller bars had no immediate detectable effect on the boundary layer, but introduced small disturbances which caused transition and reattachment to move upstream from their locations in the corresponding baseline case. The smaller bars were effective under both high and low free-stream turbulence conditions, indicating that the high free-stream turbulence transition is not simply a bypass transition induced by the free-stream. Losses appear to be minimized when a small separation bubble is present, so long as reattachment begins far enough upstream for the boundary layer to recover from the separation. Correlations for determining optimal bar height are presented. The bars appear to provide a simple and effective means of passive flow control. Bars which are large enough to induce reattachment at low Re, however, cause higher losses at the highest Re. Some compromise would, therefore, be needed when choosing a bar height for best overall performance.

VOLINO, Ralph J., Associate Professor, "Separation Control on Low-Pressure Turbine Airfoils Using Synthetic Vortex Generator Jets," *American Society of Mechanical Engineers (ASME) Journal of Turbomachinery*, Vol. 125, pp. 765-777, October 2003.

Oscillating vortex generator jets have been used to control boundary layer separation from the suction side of a low-pressure turbine airfoil. A low Reynolds number (*Re*=25,000) case with low freestream turbulence has been

investigated with detailed measurements including profiles of mean and fluctuating velocity and turbulent shear stress. Ensemble averaged profiles are computed for times within the jet pulsing cycle, and integral parameters and local skin friction coefficients are computed from these profiles. The jets are injected into the mainflow at a compound angle through a spanwise row of holes in the suction surface. Preliminary tests showed that the jets were effective over a wide range of frequencies and amplitudes. Detailed tests were conducted with a maximum blowing ration of 4.7 and a dimensionless oscillation frequency of 0.65. The outward pulse from the jets in each oscillation cycle causes a disturbance to move down the airfoil surface. The leading and trailing edge celerities for the disturbance match those expected for a turbulent spot. The disturbance is followed by a calmed region. Following the calmed region, the boundary layer does separate, but the separation bubble remains very thin. Results are compared to an uncontrolled baseline case in which the boundary layer separated and did not reattach, and a case controlled passively with a rectangular bar on the suction surface. The comparison indicates that losses will be substantially lower with the jets than in the baseline or passively controlled cases.

WU, Chih, Professor (co-author), "Optimization on the Performance Characteristics of a Magnetic Ericsson Refrigeration Cycle Affected by Multi-irreversibilities," *American Society of Mechanical Engineers (ASME) Journal of Energy Resources Technology*, Vol. 125(4), pp. 318-324, 2003.

A general magnetic Ericsson refrigeration cycle is proposed and optimized. The fundamental optimal relationship between the cooling rate and the COP of the cycle is derived.

WU, Chih, Professor (co-author), "Ecological Optimization for Generalized Irreversible Carnot Engines," *Applied Energy*, Vol. 77(3), pp. 327-338, 2004.

The optimal ecological performance of a Newton's law generalized irreversible Carnot engine with losses due to heat resistance, heat leak, and internal irreversibility is derived by taking an economical optimization criterion as the objective. This consists of maximizing a function representing the best compromise between the power and entropy production rate of the heat engine.

WU, Chih, Professor (co-author), "Optimum Allocation of Heat Exchanger Area for Refrigeration and Air Conditioning Plants," *Applied Energy*, Vol. 77(3), pp. 339-354, 2004.

The analytical expression for the optimal allocation of heat exchanger area for the endo-reversible and irreversible Carnot cycles with constant and variable-temperature reservoirs are derived. The optimal values for real vapor compression cycles are obtained by numerical analysis.

WU, Chih, Professor (co-author), "Closed Iinter-Cooled Regenerator Brayton Cycle with Constant Temperature Heat Reservoirs," *Applied Energy*, Vol. 77(4), pp. 429-446, 2004.

The performance of an irreversible closed inter-cooled regenerator Brayton cycle coupled to constant temperature heat reservoirs is analyzed. Analytical formulae for dimensionless power and efficiency are derived.

WU, Chih, Professor, (co-author), "Performance Analysis and Optimization of a Supercharged Miller Cycle Otto Engine," *Applied Thermal Engineering*, Vol. 23(5), pp. 511-521, 2003.

This paper deals with the analysis of a supercharged Otto engine adopted for Miller cycle operation. The Miller cycle shows no efficiency advantage and suffers a penalty in power output in the normally aspirated version. Sensitivity analysis of cycle efficiency versus early close of intake valve and that of the cycle network versus early close of intake valve are performed. Optimization on the cycle efficiency is obtained.

WU, Chih, Professor (co-author), "Optimization for a Steam Turbine State Efficiency Using a Genetic Algorithm," *Applied Thermal Engineering*, Vol. 23(18), pp. 2307-2316, 2003.

Based on a genetic optimization theory, a design method for the flow path of an axial flow steam turbine stage is presented. In this paper, the maximum efficiency of the stage is taken as the objective function, and a series of functions are taken as constraints, and the optimal geometric and aerodynamic parameters are solved using the genetic optimization process.

WU, Chih, Professor, (co-author), "Power, Density and Efficiency Optimization for a Closed-Cycle Helium Turbine Nuclear Power Plant," *Energy Conversion and Management*, Vol. 44 (15), pp. 2393-2401, 2003.

The performance of a closed helium nuclear power plant for submarine propulsion is optimize in this paper. The Power output, power density and efficiency relationships are derived. The maximum power output, power density and efficiency of the cycle are obtained by optimum arrangement of the heat conductance distribution among the heat exchangers and recuperator for a fix total heat exchanger inventory.

WU, Chih, Professor, (co-author), "Performance Analysis for an Irreversible Closed Variable Temperature Heat Reservoir Intercooled Regenerated Brayton Cycle," *Energy Conversion and Management*, Vol. 44(17), pp. 2713-2732, 2003.

Analytical formula for dimensionless power and efficiency, as functions of several parameters such as total pressure ratio, intercooling pressure ratio, component effectiveness, compressor and turbine efficiencies, and the thermal capacity ratio of the working fluid and the heat reservoirs, pressure recovery coefficients, heat reservoir inlet temperature ratio, and cooling fluid inlet pressure ratio, are derived. The effects of these parameters on the power and efficiency of the cycle are investigated.

WU, Chih, Professor (co-author), "Optimal Allocation of Heat Transfer Surface Area for Cooling Load and COP Optimization of a Thermoelectric Refrigerator, *Energy Conversion and Management*, Vol. 44(20), pp. 3197-3206, 2003.

The performance of a multi-element thermoelectric refrigerator is analyzed. For the fixed total heat transfer surface area of two heat exchangers, the ratio of heat transfer surface area is optimized for maximizing the cooling load and COP of the refrigerator.

WU, Chih, Professor (co-author), "Phase Space Analysis on the Thermo-Acoustic Heat Engine System," *Energy Conversion and Management*, Vol. 45(10), pp. 2197-2205, 2003.

The phase space method is used in studying a thermo-acoustic heat engine in this paper. The maximum Lyapunov exponent is used to quantify the phase space that is reconstructed from the pressure signal of a thermo-acoustic heat engine. For quantifying the system change, the maximum Lyapunov exponents of the reconstructed pressure space trails are calculated.

WU, Chih, Professor (co-author), "Optimization of a Thermo-Acoustic Engine with a Complex Heat Transfer Exponent," *Entropy*, Vol. 5, pp. 1-9, 2003.

Heat Transfer between a thermo-acoustic engine and its surrounding heat reservoirs can be out of phase with oscillating working gas temperature. This paper presents a generalized heat transfer model using a complex heat transfer exponent. Both the real part and the imaginary part of the heat transfer exponent change the power versus efficiency relationship quantitatively. It is found that the power output decreases and efficiency increases along with increasing of the imaginary part when the real part of the heat transfer exponent is fixed. The optimization zone on the performance of the thermo-acoustic engine is then found.

WU, Chih, Professor, (co-author), "The Universal Power and Efficiency Characteristics for Irreversible Reciprocating Heat Engine Cycles," *European Journal of Physics*, Vol.24 (4), pp. 359-366, 2003.

The performance of irreversible reciprocating heat engine cycles including Diesel, Otto, Atkinson and Brayton cycles with heat transfer loss and friction-like term loss is analyzed. The universal relationships between the power output and the compression ratio, between the thermal efficiency and the compression ratio, and the optimal relationship between the power output and the thermal efficiency of the cycles are derived. Analysis and optimization of the model were carried out to investigate the effect of the cycle processes on the performance of the cycle using numerical examples.

WU, Chih, Professor, (co-author), "The Influence of Heat Transfer Laws on the Performance Characteristics of a Magnetic Stirling Refrigeration Cycle," *International Journal of Ambient Energy,* Vol. 24 (2), pp. 75-82, 2003.

The influence of irreversibilities of the heat transfer between working substance and external heat reservoirs and regenerative loss in the regenerative processes on the performance of a magnetic Stirling refrigeration cycle is investigated. Based on an expression of the magnetization intensity of a ferromagnetic material and a class of heat transfer laws, the optimum relations between the cooling rate and the COP, and between the power input and the COP are derived.

WU, Chih, Professor (co-author), "Power Density Analysis and Optimization for an Irreversible Closed Variable-Temperature Heat Reservoir Simple Brayton Cycle," *International Journal of Ambient Energy*, Vol. 24(3), pp. 133-148, 2003.

Analysis of an irreversible closed variable temperature heat reservoir simple Brayton cycle is performed. The power density is taken as the objective for the cycle optimization. The influence of several design parameters including temperature ratio of the heat reservoirs, heat exchanger inventory between the working fluid and the heat reservoirs, the efficiency of the compressor, and the efficiency of the turbine re studies.

WU, Chih, Professor (co-author), "Performance of a Four-Heat-Reservoir Absorption Refrigerator with Heat Resistance and Heat Leak," *International Journal of Ambient Energy*, Vol. 24(3), pp. 157-168, 2003.

The optimal relation between the COP and the cooling load, the maximum COP and the corresponding cooling load, as well as the maximum cooling load and the corresponding COP of a four-heat-reservoir absorption refrigerator with heat resistance and heat leak are derived. The optimal distribution relation of the heat transfer surface is also obtained. The effects of the cycle parameters on the COP and the cooling load are analyzed.

WU, Chih, Professor, "Influence of Temperature Gradients on Acoustic Characteristic Parameters of Stacks in a Thermo-Acoustic Engine," *International Journal of Engineering Science*, Vol. 41 (12), pp.1337-1349, 2003.

The expressions of the important acoustic characteristic relationships of stack in a thermo-acoustic engine are derived. Calculation results show that the imposed temperature gradients have an influence on the acoustic characteristic parameters of the stack.

WU, Chih, Professor (co-author), "Performance Analysis of a Mirror Gas Turbine with Split Shaft Engine," *International Journal of Engineering Science and Technology*, Vol. 3 (1), pp 17-26, 2003.

A conceptual combination of Brayton and inverted Brayton cycles with a heat sink and inter-cooling is proposed as a mirror cycle in this paper. Analysis of the mirror gas turbine with split shaft engine is performed.

WU, Chih, Professor, "Performance of a Regenerative MHD Power Plant," *International Journal of Power and Energy Systems*, Vol. 24(20), pp. 98-103, 2004.

A theoretical model for investigating the performance of a regenerative magnetohydrodynamic (MHD) power plant is presented. Using continuity, momentum, and energy equations of the flowing gas in the MHD generator,

the effect of constant velocity and constant Mach number cases as operating conditions of the MHD generator on the power plant performance are investigated.

WU, Chih, Professor (co-author), "Theoretical Optimization of a Regenerated Air Refrigerator," *Journal of Physics D: Applied Physics*, Vol. 36 (18), pp. 2304-2311, 2003.

The performance analysis and optimization of a regenerated air refrigerator are carried out by taking the cooling load density as the optimization objective function. The analytical relationships between cooling load density and pressure ratio, as well as between COP and pressure ratio are derived. The optimal performance characteristics of the cycle are obtained.

WU, Chih, Professor (co-author), "Intelligent Computer Aided Design Optimization of Heat Pumps," *Structural and Multi-disciplinary Optimization*, Vol. 24 (6), pp 457-463, 2003.

This paper describes the use of an Intelligent computer aided software in design and possible refinements of vapor heat pump technology. Several different arrangements of heat pump cycles are demonstrated.

Conference Proceedings

CERZA, Martin R., Professor, Adams, J. C., Ireland, P. T., and Oswald, J., "A Detailed Experimental Investigation of a Perforated Heat Transfer Surface Applied to Gas Turbine Recuperators," *Proceedings of the American Society of Mechanical Engineers (ASME) Turbo Expo 2003 – Power for Land, Sea and Air,* Atlanta, GA, 16-19 June 2003, ASME Paper GT2003-38740.

An effort is made to explain and improve the understanding of the mechanisms behind the thermo-hydraulic performance of perforated extended surfaces used in compact heat exchangers in the laminar flow regime (Re_D = 400-2500). A transient liquid crystal technique, which uses Helium as operating fluid, together with digital image photographic processing have been used to provide measurements of local heat transfer coefficients for this geometry. This work has found that through the use of perforated surfaces there exists a local heat transfer enhancement benefit. It has also been found that although perforations cause a partial restart of the thermal boundary layer, a significant overall surface heat transfer enhancement may not be achieved over plain surfaces. It was also found that the distance between the fin's leading edge and the point of last significant enhancement resulting from a perforation, linearly depends on Reynolds number. Local heat transfer coefficient measurements were validated by single blow experimentation of similar geometries. The transient single blow technique used the curve-matching method to compare predicted and experimental temperatures.

CERZA, Martin R., Professor, LARSEN, Eric H. (Trident Scholar, Class of 2003), SMITH, Andrew N., Assistant Professor, and Conroy, C.T., "The Effect of Ship Tilt and Pitch on a Capillary Assisted Thermosyphon (CAT) for Shipboard Electronics Cooling," *Proceedings of the International Mechanical Engineering Congress and Exhibition (IMECE)*, Washington, DC, 11-14 November 2003. (CD-ROM)

As microprocessors shrink in size and increase in power dissipation levels, the current need for advanced electronics cooling techniques is paramount. Power dissipation levels are rapidly exceeding the capabilities of forced air convection cooling. This paper reports an investigation of using a capillary assisted thermosyphon (CAT) for the shipboard cooling of electronics components. The capillary assisted thermosyphon differs from the capillary pumped loop or loop heat pipe system in that the basic cooling loop is based on a thermosyphon. The capillary assist comes from the fact that there is a wicking structure in the flat evaporator plate. The wicking structure is there to spread the working fluid across the vertical flat plate evaporator to the areas under the heat sources. This differs from a capillary pumped loop in that the capillary pumping action of the wick structure does not produce the sole pumping head from the liquid return to the vapor outlet side of the evaporator. In fact, the liquid return and vapor outlet are almost at the same pressure. The forced circulation in the thermosyphon is caused by a gravity head between the condenser cold plate and the flat plate evaporator.

An experimental facility for conducting research on a capillary assisted thermosyphon was developed. In order to simulate the shipboard cooling water encountered at various locations of the ocean, the heat sink temperature of the facility was varied. A vertical flat plate, CAT evaporator was designed and tested with a thermal sink temperature of 21 C. The condenser cold plate cooling water flowrate was set at 1 GPM. The heat input was held constant at 1500W for the independent tilt and pitch cases. For the extreme tilt and pitch combined case, the heat input varied from 400 to 2000 W. The flat evaporator plate was tilted from side to side over a range +/- 45 degrees from vertical and the plate was pitched fore and aft over a range of +/- 45 degrees. This tilt and pitch orientation was to simulate that orientation which a ship might undergo in various sea states. In addition an extreme case which consisted of a 45 degree tilt and a 45 degree pitch was tested and compared to the normal vertical geometry. Results indicate that the CAT loop was very robust and handled all geometric orientations with minimal degradation in operating temperature performance.

FLACK, Karen A., Associate Professor, and SCHULTZ, Michael P., Assistant Professor, (Naval Architecture and Ocean Engineering Department), "Mean and Turbulent Velocity Profiles for Sand-Grain Rough Surfaces," *Proceedings of the 3rd International Symposium on Turbulence and Shear Flow Phenomena*, Sendai, Japan, 25-27, pp. 129-134, June 2003.

Flat plate turbulent boundary layer measurements have been made on surfaces covered with fine and coarse sandpaper. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3000 to 16000, using a two-component, laser Doppler velocimeter (LDV). The results indicate an increase in the boundary layer thickness (δ), the integral length scales, and the skin-friction coefficient (C_f) for the rough surfaces compared to the smooth wall. The roughness functions (ΔU^+) for the sandgrain surfaces agree within their uncertainty with previous results obtained using towing tank tests and similarity law analysis. For sandpaper, it appears that a single roughness length scale ($k = 0.75\ R_t$) is sufficient to characterize the physical surface. The present results indicate that the mean profiles for both the smooth and rough surfaces collapse well in velocity defect form. The Reynolds stresses also show good collapse outside the roughness sublayer when normalized with the wall shear stress.

GRAHAM, Stephen M., Assistant Professor, "Stress Analysis of a Co-Cured Innovative Hybrid Composite Joint for Marine Composites," *Society for the Advancement of Material and Process Engineering* (*SAMPE) 2004 Conference Proceedings*, Long Beach, CA, 16-20 May 2004. (CD-ROM)

The use of adhesively bonded joints is problematic in the marine composites industry where the aqueous environment degrades the properties of adhesives. When the adherends to be joined are both fiber-reinforced laminates, an alternative to adhesive bonding is to co-cure the joint. This process eliminates the adhesive layer and the two interfaces between the adhesive and the adherends. The continuous matrix surrounding the fibers on either side of the joint significantly changes the stresses developed in the joint. Early analytical approaches for stress analysis of adhesively bonded joints are not directly applicable to the co-cured stepped scarf joint. In this study, finite element analysis was used to investigate the stresses developed in a co-cured stepped scarf joint made from adherends with unequal stiffness. Two different approaches were used to model the adherends; a homogeneous approach that modeled each adherend as transversely isotropic, and a constituent-level approach that modeled the resin and fibers individually. The homogeneous model showed that it is important to model the resin gaps between the ends of the fibers where the plies end. Two different joint configurations were then compared to investigate the effects of asymmetry and arrangement of plies on the stress distribution.

JOYCE, James A., Professor and JOYCE, Peter J., Assistant Professor, "The Fracture Toughness of Polytetrafluoroethylene," *Proceedings of The 15th European Conference of Fracture- Advanced Fracture Mechanics for Life and Safety Assessments*, Stockholm, Sweden, 11-13 August 2004. (CD-ROM)

Polytetrafluoroethylene (PTFE) is an important structural polymer that in the "7C" derivative is used for gaskets, bearing pads, piston rings and diaphragms. Addition of 10 to 40 weight % aluminum 5μm spheres can increase stiffness and strength while the effect on toughness can be either positive or negative, depending on the loading rate and test temperature, as this polymer is very viscoelastic.

In this study compact tension (C(T)) specimens of pure PTFE and two aluminum filled mixtures have been tested at temperatures from 33°C to –10°C at crack mouth opening displacement rates from 2.5 x10^{-6} mm/s to 350 mm/s.

Previous methods used to obtain fracture toughness for polymers have involved multi-specimen methods, but these were not feasible for this study because the material availability was limited and many different test conditions were to be investigated. The normalization method originally proposed by Landes and co-workers and subsequently included in Annex A15 of ASTM E1820-99a (Standard Test Method for Measurement of Fracture Toughness), has been adapted for use with this polymeric material to obtain J_{Ic} and J resistance curves directly from the measured load versus crack mouth opening displacement records. Work of Bernal and associates has shown that a load separation criterion is valid for polymeric materials using the methods of Sharobeam and Landes. This work and work by Che and others has also demonstrated the equivalence of normalization function methods and multi-specimen methods at test conditions where both methods can be used. J-resistance curve results show the fracture toughness varies widely over the narrow range of test temperatures investigated here, while the mixture effects, orientation effects, and rate effects are much less dramatic. A brittle run/arrest phenomena similar to brittle "pop-ins" often observed in metals or weldments is observed at higher loading rates in all mixtures, while a thermal creep type crack growth appears important for the mixture including 25% aluminium.

RATCLIFFE, Colin P., Associate Professor, and Crane, Roger M., "The Nondestructive Inspection of a ½ Scale Corvette Hull Test Section and a Royal Navy Archer Class Fast Patrol Craft Using the Structural Irregularity and Damage Evaluation Routine (SIDER)," *Advanced Marine Materials: Technology & Applications, Royal Institute of Naval Architects*, London, pp. 135-150, 9-10 October 2003.

The Naval Surface Warfare Center, Carderock Division has been investigating composite materials for ship hull applications. Four ½ scale corvette hull sections were manufactured and their UNDEX performance evaluated. A new nondestructive evaluation technique, which uses vibrational excitation, was utilized to inspect the hull prior to shock and after shock testing. This new technique developed at NSWCCD and the United States Naval Academy, Structural Irregularity and Damage Evaluation Routine (SIDER), was successfully used to determine the manufactured quality, and changes in the structure caused by UNDEX testing. The SIDER procedure looks at an entire structure and identifies locations where there is variability in structural stiffness. These areas are either due to the variability of the structure itself, or are caused by damage. Areas of damage that resulted in delaminations, debonding of ribs and stringers, bulkhead to hull degradation and localized cracking were successfully identified and correlated with both visual and ultrasonic inspection. The SIDER technique was able to inspect the entire hull section in about 6 hours. This paper discusses the SIDER technique and the results of the SIDER testing on this large scale composite structural component.

RATCLIFFE, Colin P., Associate Professor, and Crane, Roger, "Rapid Non-Destructive Testing of Large Naval Structures using the SIDER Technique," *Society for the Advancement of Material and Process Engineering* (*SAMPE) 2004 Conference Proceedings*, Long Beach, CA, 16-20 May 2004. (CD-ROM)

Composites materials for large scale Navy structural applications are becoming a reality as seen by their use in applications such as the masts for LPD-17 class ship, a prototype Joint Modular Lighter System (JMLS) and the advanced composite sail for the Virginia Class Submarine. Inspection methods capable of providing rapid assessment of the structural integrity of these structures that have planar areas that can be thousands of square feet are required. Inspection techniques are currently available which can be readily implemented in a laboratory setting, but few exist which can be used for in-service inspections of this magnitude. This paper presents inspection results for several large scale Naval composite structures using a recently developed broadband vibration-based technique developed at the United States Naval Academy and the Naval Surface Warfare Center Carderock Division, Structural Irregularity and Damage Evaluation Routine (SIDER). SIDER was successfully used to determine the as manufactured quality, in-service damage, and changes in damage areas for both sandwich core and monolithic composite structures. Areas of damage that included delamination, debonding of ribs and stringers, bulkhead to hull degradation and localized cracking were successfully identified and correlated with both visual and ultrasonic inspection. This paper discusses the SIDER technique and the results of the SIDER testing on large scale composite structural components.

RATCLIFFE, Colin P., Associate Professor, Yoo, Myung Keun, Krauthauser, Carl, Heider, Dirk, Gillespie, John W., Jr., and Crane, Roger, "Damage Detection in Large-Scale Composite Structures via Vibration R=Technique using MEMS Accelerometers," *Society for the Advancement of Material and Process Engineering* (*SAMPE) 2004 Conference Proceedings*, Long Beach, CA, 16-20 May 2004. (CD-ROM)

The present paper presents vibration based damage detection techniques for large-scale composite structures. Damage results in local stiffness changes, which affects dynamic characteristics of the structure. The 'Two Dimensional Gapped Smoothing Method' (2DGSM) is used to calculate the structural irregularity index over the structure that identifies the size and location of defects. The 2DGSM uses Operating Curvature Shapes (OCS) derived from experimental Frequency Response Function (FRF) data. Required input for this technique is the vertical acceleration at a pre-specified grid pattern covering the structure. Traditionally, the structure is excited at each grid point with an instrumented hammer and the response is measured using a few accelerometers. This approach can be quite time consuming. Alternatively, a large number of accelerometers can be used with only small number of excitations reducing the time for inspection. In the present study, both approaches have been evaluated. Affordable MEMS accelerometers have been used and compared with the traditional approach on four different case studies: 1) composite beam with embedded interlaminar delaminations; 2) 3.7 inch thick sandwich panel with delamination between the balsa core and face sheets; 3) 8 x 4 x 4 foot section of a topside ship structure containing manufacturing defects; and 4) 32 x 26 ft x 31 inch deep all-composite bridge fabricated by joining two sandwich core sections. For the lab-scale panels the study validates the vibration results with ultrasonic C-scans and in case of the corner specimen by visual inspection. Defects are successfully detected in the first 3 structures and the adhesive joint line between the two decks was also found in the composite bridge. In all cases, the multiple MEMS accelerometers approach provided equivalent accuracy and sensitivity.

VOLINO, Ralph J., Associate Professor, "Passive Flow Control on Low-Pressure Turbine Airfoils," *Proceedings of the 2004 American Society of Mechanical Engineers (ASME) International Gas Turbine Conference*, Atlanta, GA, June 2003, ASME Paper GT2003-38728.

Two-dimensional rectangular bars have been used in an experimental study to control boundary layer transition and reattachment under low-pressure turbine conditions. Cases with Reynolds numbers (Re) ranging from 25,000 to 300,000 (based on suction surface length and exit velocity) have been considered at low (0.5%) and high (8.5% inlet) free-stream turbulence levels. Three different bars were considered, with heights ranging from 0.2% to 0.7% of suction surface length. Mean and fluctuating velocity and intermittency profiles are presented and compared to results of baseline cases from a previous study. Bar performance depends on the bar height and the location of the bar trailing edge. Bars located near the suction surface velocity maximum are most effective. Large bars trip the boundary layer to turbulent and prevent separation, but create unnecessarily high losses. Somewhat smaller bars had no immediate detectable effect on the boundary layer, but introduced small disturbances which caused transition and reattachment to move upstream from their locations in the corresponding baseline case. The smaller bars were effective under both high and low free-stream turbulence conditions, indicating that the high free-stream turbulence transition is not simply a bypass transition induced by the free-stream. Losses appear to be minimized when a small separation bubble is present, so long as reattachment begins far enough upstream for the boundary layer to recover from the separation. Correlations for determining optimal bar height are presented. The bars appear to provide a simple and effective means of passive flow control. Bars which are large enough to induce reattachment at low Re, however, cause higher losses at the highest Re. Some compromise would, therefore, be needed when choosing a bar height for best overall performance.

VOLINO, Ralph J., Associate Professor, "Separation Control on Low-Pressure Turbine Airfoils Using Synthetic Vortex Generator Jets," *Proceedings of the 2003 American Society of Mechanical Engineers (ASME) International Gas Turbine Conference*, Atlanta, GA, June 2003, ASME Paper GT2003-38729.

Oscillating vortex generator jets have been used to control boundary layer separation from the suction side of a low-pressure turbine airfoil. A low Reynolds number (Re=25,000) case with low freestream turbulence has been investigated with detailed measurements including profiles of mean and fluctuating velocity and turbulent shear stress. Ensemble averaged profiles are computed for times within the jet pulsing cycle, and integral parameters and local skin friction coefficients are computed from these profiles. The jets are injected into the mainflow at a compound angle through a spanwise row of holes in the suction surface. Preliminary tests showed that the jets

were effective over a wide range of frequencies and amplitudes. Detailed tests were conducted with a maximum blowing ration of 4.7 and a dimensionless oscillation frequency of 0.65. The outward pulse from the jets in each oscillation cycle causes a disturbance to move down the airfoil surface. The leading and trailing edge celerities for the disturbance match those expected for a turbulent spot. The disturbance is followed by a calmed region. Following the calmed region, the boundary layer does separate, but the separation bubble remains very thin. Results are compared to an uncontrolled baseline case in which the boundary layer separated and did not reattach, and a case controlled passively with a rectangular bar on the suction surface. The comparison indicates that losses will be substantially lower with the jets than in the baseline or passively controlled cases.

VOLINO, Ralph J., Associate Professor, and Murawski, Christopher, "Separated Flow Transition in a Low-Pressure Turbine Cascade – Mean Flow and Turbulence Spectra," *Proceedings of the 2003 American Society Mechanical Engineering (ASME) International Gas Turbine Conference*, Atlanta, GA, June 2003, ASME Paper GT2003-38727.

Boundary layer separation, transition and reattachment have been studied experimentally in a low-pressure turbine cascade. Cases with Reynolds numbers (Re) ranging from 50,000 to 200,000 (based on suction surface length and exit velocity) have been considered under low free-stream turbulence conditions. Mean and fluctuating velocity profiles and turbulence spectra are presented for streamwise locations along the suction side of one airfoil and in the wake downstream of the airfoils. Hot film gages on the suction side surface of the airfoil are used to measure the fluctuation level and the spectra of the fluctuations on the surface. Higher Re moves transition upstream. Transition is initiated in the shear layer over the separation bubble and leads to boundary layer reattachment. Peak frequencies in the boundary layer spectra match those found in similar cases in the literature, indicating that the important frequencies may be predictable. Spectra in the wake downstream of the airfoils were similar to the spectra in the boundary layer near the trailing edge of the airfoil. Comparisons to the literature indicate that small but measurable differences in the spectra of the low free-stream turbulence can have a significant effect on boundary layer reattachment.

VOLINO, Ralph J., Associate Professor, Huang, P.G., Suzen, Y.B., Corke, T.C., Thomas, F.O., Huange, J., Lake, J.P., and King, P.I., "A Comprehensive CFD Study of Transitional Flows in Low-Pressure Turbines Under a Wide Range of Operating Conditions," *Proceedings of the 33rd American Institute of Aeronautics and Astronautics (AIAA) Fluid Dynamics Conference*, Orlando, FL, June 2003, AIAA Paper 2003-3591.

A transport equation for the intermittency factor is employed to predict the transitional flows in low pressure turbines. The intermittent behavior of the transitional flows is taken into account and incorporated into computations by modifying the eddy viscosity, μ_t, with the intermittency factor, γ. Turbulent quantities are predicted by using Menter's two-equation turbulence model (SST). The intermittency factor is obtained from a transport equation model which can produce both the experimentally observed streamwise variation of intermittency and a realistic profile in the cross stream direction. The model had been previously validated against low pressure turbine experiments with success. In this paper, the model is applied to predictions of three sets of recent low-pressure turbine experiments on PAK-B blade to further validate its predicting capabilities under various flow conditions. Comparisons of computational results with experimental data are provided. Overall, good agreement between the experimental data and computational results is obtained. The new model has been shown to have the capability of accurately predicting transitional flows under a wide range of low pressure turbine conditions.

VOLINO, Ralph J., Associate Professor, and BOHL, Douglas, Assistant Research Professor, "Separated Flow Transition Mechanism and Prediction with High and Low Freestream Turbulence under Low Pressure Turbine Conditions," *Proceedings of the 2004 American Society of Mechanical Engineering (ASME) International Gas Turbine Conference*, Vienna, Austria, June 2004, ASME Paper GT2004-53360.

Boundary layer separation, transition and reattachment have been studied experimentally in a low-pressure turbine cascade. Cases with Reynolds numbers (*Re*) ranging from 50,000 to 200,000 (based on suction surface length and exit velocity) have been considered under low free-stream turbulence conditions. Mean and fluctuating velocity profiles and turbulence spectra are presented for streamwise locations along the suction side of one airfoil and in the wake downstream of the airfoils. Hot film gages on the suction side surface of the airfoil are used to measure the fluctuation level and the spectra of the fluctuations on the surface. Higher *Re* moves transition upstream.

Transition is initiated in the shear layer over the separation bubble and leads to boundary layer reattachment. Peak frequencies in the boundary layer spectra match those found in similar cases in the literature, indicating that the important frequencies may be predictable. Spectra in the wake downstream of the airfoils were similar to the spectra in the boundary layer near the trailing edge of the airfoil. Comparisons to the literature indicate that small but measurable differences in the spectra of the low free-stream turbulence can have a significant effect on boundary layer reattachment.

Technical Reports

GRAHAM, Stephen M., Assistant Professor, Mercier, G.P., L'Heureux, B. P. and Waskey, J.P., "Fracture Toughness Characterization of HSLA-100 Steels for Carrier Crack Arrestor Applications," NSWCCD-TR-2003/11, August 2003.

HSLA-100 steel is being considered as a replacement for HY-100 in aircraft carrier crack arrestor applications. The various compositions of HSLA-100 were evaluated and compared to 1.25 in. thick HY-100. Tests were conducted to measure tensile properties, Charpy impact energy, dynamic tear energy, fracture toughness and the reference temperature. The two alloys compared favorably on all tests except the fracture toughness tests at –40°F. HSLA-100 in the T-L orientation exhibited fracture by cleavage after ductile crack growth, whereas the HY-100 remained ductile. This result was unexpected since it is commonly believed that fracture behavior can be correlated with impact tests and the reference temperature. At –20° fracture remained ductile in the HSLA-100. Consequently, it is recommended that HSLA-100 in the T-L orientation only be used where the minimum service temperature is above –20°F.

GRAHAM, Stephen M., Assistant Professor, "Task 5 Report: Dynamic Fracture Toughness Characterization of NS110 Weld Metal," NSWCCD-61-TR-2004/01 + CR, February 2004.

The work presented here was one task in the larger US-Japan Advanced Steel Technology (AST) program, which was a cooperative research project to evaluate the use of under-matched welding in naval hull structures. Under-matched welding technology shows promise for reduced cost construction and improvements in performance of high strength steel structures. The objective of this task was to characterize the fracture behavior of under-matched welds made from high strength steels through small specimen testing. This report covers specifically the quasi-static and dynamic fracture toughness testing of NS110 baseplate and weld at temperatures ranging from 32°F (0°C) to 72°F(22°C), and loading rates from quasi-static to impact at 136 in./sec (3.5 m/s). Fracture toughness tests of the NS110 base metal at quasi-static loading rates showed that it has excellent fracture toughness and tearing resistance. However, tests of the weld metal showed that the fracture toughness and tearing resistance are considerably less than that of the base metal, especially for cracks oriented in the T-S direction. Crack growth in the weld metal tended to go unstable, especially for T-S oriented cracks, and the probability of unstable fracture appeared to increase as the applied J increased. This observation led to the concept of an instability band for T-S oriented cracks. Cracks in the T-L orientation were much less likely to go unstable. Welds, by their very nature, are a composite of various microstructures. The fracture behavior will depend on the microstructure at the crack tip. Since the precise crack tip location is not known for typical structures, a stochastic approach must be adopted that addresses structural integrity in terms of probability of failure. The weld metal exhibited an interesting combination of micro-void coalescence (MVC) and quasi-cleavage (QC) fracture modes. The relative amount of QC increased with increases in loading rate, however, the fracture surface was still dominated by MVC for the temperatures and loading rates studied.

Presentations at Professional Meetings and Conferences

CERZA, Martin R., Professor, Adams, J.C., Ireland, P. T., and Oswald, J., "A Detailed Experimental Investigation of a Perforated Heat Transfer Surface Applied to Gas Turbine Recuperators," American Society of Mechanical Engineers (ASME) Turbo Expo 2003 - Power for Land, Sea and Air, Atlanta, GA, 16-19 June 2003.

CERZA, Martin R., Professor, "Navy Future Technologies for Next Generation Naval Systems," 2nd Workshop on Thermal Packaging of High Flux Military and Commercial Electronics, University of Maryland, College Park, MD, 27 October 2003.

CERZA, Martin R., Professor, SMITH, Andrew N., Assistant Professor, LARSEN, Eric H. (Trident Scholar, Class of 2003), and Conroy, C.T., "The Effect of Ship Tilt and Pitch on a Capillary Assisted Thermosyphon (CAT) for Shipboard Electronics Cooling," International Mechanical Engineering Congress and Exhibition (IMECE), Washington, D.C., 11-14 November 2003.

CERZA, Martin R., Professor, Adams, J.C., Ireland, P. T., and Oswald, J., "Thermal Hydraulic Performance of Perforated Surfaces for Use in Compact Heat Exchanger," 8th UK National Heat Transfer Conference, Oxford, UK, 9-10 September 2003.

CERZA, Martin R., Professor, SMITH, Andrew N., Assistant Professor, LARSEN, Eric H. (Trident Scholar, Class of 2003), and Conroy, C.T., "Investigation of a Capillary Assisted Thermosyphon (CAT) for Shipboard Electronics Cooling," Joint National Heat Transfer – Fluids Engineering Conference, Charlotte, NC, July 2004.

FLACK, Karen A., Associate Professor, and SCHULTZ, Michael P., Assistant Professor (Naval Architecture and Ocean Engineering), "Mean and Turbulent Velocity Profiles for Sandgrain Rough Surfaces," 3rd Symposium on Turbulent Shear Flows Phenomena, Sendai, Japan, 24-27 2003.

FLACK, Karen A., Associate Professor, and SCHULTZ, Michael P., Assistant Professor (Naval Architecture and Ocean Engineering), "Extent of Roughness Sub-Layer in Turbulent Boundary Layers," 55th Annual Meeting American Physical Society Fluid Dynamics Division, Meadowlands, NJ, 22-25 November 2003.

GRAHAM, Stephen M., Assistant Professor, "Stress Analysis of a Co-cured Innovative Hybrid Joint for Marine Composites," Society for the Advancement of Material and Process Engineering (SAMPE) 2004 Annual Conference, Long Beach, CA, 19 May 2004.

JOYCE, James A., Professor, "A Proposed Common Pre-cracking Procedure for ASTM Standards E1820 and E1921," ASTM Committee Week, E08.08.02 Task Group Meeting, Tampa, FL, November 2003.

JOYCE, James A., Professor, "Evaluation of the Effect of Crack Tip Constraint on Fatigue Crack Growth Rate in Inconel 718," ASTM 34th National Symposium on Fatigue and Fracture, Tampa, FL, 20 November 2003.

JOYCE, James A., Professor, "Evaluation of the Effect of Biaxial Loading on the T_o Reference Temperature Using a Cruciform Specimen Geometry," ASTM 34th National Symposium on Fatigue and Fracture, Tampa, FL, 20 November 2003.

JOYCE, James A., Professor and JOYCE, Peter J., Assistant Professor, "The Fracture Toughness of Polytetrafluoroethylene," 15th European Conference of Fracture- Advanced Fracture Mechanics for Life and Safety Assessments, Stockholm, Sweden, 11-13 August 2004.

JOYCE, Peter J., Assistant Professor, "Two Experiments to Teach Modulus of Elasticity and Modulus of Rigidity," American Society of Electrical Engineers (ASEE) 2004 Annual Conference & Exposition, Salt Lake City, UT, 20-23 June 2004.

JOYCE, Peter J., Assistant Professor, "Mechanical Behavior of Composites: Effects of Fiber Type and Content," National Educator's Workshop: Update 2003, Standard Experiments in Engineering, Materials Science and Technology, Hampton, VA, 19-22 October 2003.

LINK, Richard E., Associate Professor, "Applications of Fatigue Crack Growth Rate Testing," Naval Surface Warfare Center, Carderock Division, Code 60, Carderock, MD, 28-29 July 2003.

LINK, Richard E., Associate Professor, "Fracture Toughness Testing in the Ductile-Brittle Transition Region," Naval Surface Warfare Center, Carderock Division, Code 60, Carderock, MD, 14 August 2003.

LINK, Richard E., Associate Professor, JOYCE, James A., Professor, and Gaies, Jennifer, "Evaluation of the Effect of Biaxial Loading on the T_o Reference Temperature Using a Cruciform Specimen Geometry," 2nd ASTM/ESIS International

Conference on Fatigue and Fracture, Tampa, FL, 19 November 2003.

MURRAY, Mark M., Assistant Professor, MIKLOSOVIC, David S. (Aerospace Engineering Department), Fish, F.E. and Howle, L.E., "Stall Delay by Leading Edge Tubercles on Humpback Whale Flipper," 56th Annual Meeting of the APS Division of Fluid Dynamics, East Rutherford, NJ, 23-25 November 2003.

MURRAY, Mark M., Assistant Professor, Fish, F.E., MIKLOSOVIC, David S. (Aerospace Engineering Department), and Howle, L.E., "Hydrodynamic Function of Leading Edge Tubercles of the Humpback Whale Flipper," Biennial Conference on the Biology of Marine Mammals, Greensboro, NC, December 2003.

MURRAY, Mark M., Assistant Professor, Fish, F.E., MIKLOSOVIC, David S. (Aerospace Engineering Department), and Howle, L.E., "Delayed Stall Due to Leading Edge Tubercles of the Humpback Whale Flipper," Annual Meeting of the Society for Integrative and Comparative Biology, New Orleans, LA, January 2004.

NELSON, Martin E., Professor, DIRK, John D., (Trident Scholar, Class of 2002), Thompson, A., Zabel, T., ZIEGLER, James F., Visiting Professor (Electrical Engineering Department), "Terrestrial Thermal Neutrons," 2003 NESREC Conference, Monterey, CA, July 2003.

NELSON, Martin E., Professor, McMarr, P., M., Hughes, H., and DELIKAT, Kelly, '14 MeV Neutron and Co-60 Gamma Testing of a Power MOSFET Optocoupler," 2003 NESREC Conference, Monterey, CA, July 2003.

NELSON, Martin, Professor, DORMO, Jeffrey (Trident Scholar, Class of 2003), St. John, T., and JENKINS, R. Brian, Associate Professor (Electrical Engineering Department), "Comparison of Light Sources for Use in a Commercial TLD Reader," 48th Annual meeting of Health Physics Society, San Diego, CA, July 2003.

NELSON, Martin E., Professor, Hughes, H.L., McMarr, P. J., Lawrence, R. K., Liu, S. T., and Thompson, A .K., "Feasibility of Neutron detection Using a Boron-10 Loaded Silicon-on-Insulator Substrate for Unattended Applications," 2004 GOMAC Conference, Monterey, CA, March 2004.

NELSON, Martin E., Professor, Liu, S. T., Hughes, H. L., Jenkins, W.C., Lawrence, R.K., and Thompson, A.K, "Thermal Neutron Single Event Effects in SOI CMOS 4M SRAMS," 2004 HEART Conference, Monterey, CA, March 2004.

NELSON, Martin E., Professor, Lawrence, R., Jenkins, W. C., and Haddad, N., "14 MeV Neutron Testing of BAE Quantum and Quantum Shrink 4M SRAM Technologies," 22nd Annual HEART Conference, Monterey, CA, March 2004.

NELSON, Martin E., Professor, Liu, S.T, Liu, H.Y., Hughes, H.L., Jenkins, W.C., Lawrence, R.K., and Thompson, A.K., "Neutron-Insensitive SOI CMOS 4M SRAM," 2004 SEE Symposium, Los Angles, CA, April 2004.

NELSON, Martin E., Professor, PISACANE, V.L., Professor (Aerospace Engineering Department), DiCello, J.F., Rosenfeld, A.B., and ZIEGLER, James F., Visiting Professor (Electrical Engineering Department), "A Spacecraft Microdosimetry Mission," 2004 Solid State Dosimetry Conference, New Haven CT, June 2004.

SMITH, Andrew N., Assistant Professor, "Impact of Thin Film Thermophysical Properties on Thermal Management of Wide Bandgap Solid-State Transistors," 15th Symposium on Thermophysical Properties, Boulder, CO, 22-27 June 2003.

SMITH, Andrew N., Assistant Professor, "Thermal Management and Resistive Heating of a Large-Scale Naval Electromagnetic Launcher," 12th Electromagnetic Launch Symposium, Snowbird, UT, 25-28 May 2004.

VOLINO, Ralph J., Associate Professor, "Passive Flow Control on Low-Pressure Turbine Airfoils," 2003 ASME International Gas Turbine Conference, Atlanta, GA, 19 June 2003.

VOLINO, Ralph J., Associate Professor, "Separation Control on Low-Pressure Turbine Airfoils using Synthetic Vortex Generator Jets," 2003 ASME International Gas Turbine Conference, Atlanta, GA, 19 June 2003.

VOLINO, Ralph J., Associate Professor, "Separated Flow Transition I a Low-Pressure Turbine Cascade - Mean Flow and Turbulence Spectra," 2003 ASME International Gas Turbine Conference, Atlanta, GA, 19 June 2003.

VOLINO, Ralph J., Associate Professor, Huang, P.G., Suzen, Y. B., Corke, T. C., Thomas, F. O., Huange, J., Lake, J. P., and King, P. I., "A Comprehensive CFD Study of Transitional Flows in Low-Pressure Turbines Under a Wide Range of Operating Conditions," 33rd American Institute of Aeronautics and Astronautics (AIAA) Fluid Dynamics Conference, Orlando, FL, 26 June 2003.

VOLINO, Ralph J., Associate Professor, "Passive and Active Flow Control on Low-Pressure Turbine Airfoils," Minnowbrook IV Workshop on Transition and Unsteady Aspects of Turbomachinery Flows, Blue Mountain Lake, NY, 18 August 2003.

VOLINO, Ralph J., Associate Professor, "Separated Flow Transition Mechanism with Passive Flow Control under Low Pressure Turbine Conditions," 56th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, East Rutherford, NJ, 23 November 2003.

VOLINO, Ralph J., Associate Professor and BOHL, Douglas, Assistant Research Professor, "Separation Flow Transition Mechanism and Prediction with High and Low Freestream Turbulence under Low Pressure Turbine Conditions," 2004 ASME International Gas Turbine Conference, Austria, 15 June 2004.