Mechanical Engineering Department

Professor Steven M. Miner
Chair

The faculty and midshipmen of the Mechanical Engineering Department have diverse interests covering the fields of mechanics, materials and the thermo-fluid sciences. These interests are reflected in the research projects conducted by members of the department, which include sponsored faculty research, Trident Scholar projects and Midshipmen Independent Research projects. The focus of these projects runs the full spectrum from fundamental to pedagogical research.

This past year a total of 17 faculty members were involved in 27 research projects, of these 23 were sponsored by outside agencies. Sponsors included Navy laboratories, government agencies and industry. In addition to the sponsored faculty research there were 4 midshipmen involved in independent research projects and 3 midshipmen involved in Trident Scholar projects. Several of these projects were also funded by outside sponsors. In addition, there were two Post Docs in the department. The output for the past year included 55 publications and 25 presentations. Of these midshipmen were involved in 9 as either co-authors, presenters or both.

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 is 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 150 F to 300 F in an inert radiation environment. In addition, a working prototype is to be constructed and demonstrated.

Capillary Pumped Loop Systems for use in Shipboard Electronic Cooling

Researchers: Professor Martin R. Cerza, Assistant Professor Andrew N. Smith
and Assistant Research Professor Valentin Tudor
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 are conducted through the CPL evaporator walls and vaporize 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.

A single loop Capillary Assisted Thermosyphon (CAT) was constructed and steady state performance was evaluated experimentally. Flow rates of chilled water were 0.5 to 2 GPM, heat input ranged from 250 to 1500 W. Sink temperatures evaluated were 7, 22 and 34 C. Results showed that the CAT loop is a viable alternate for the cooling of electronics cabinets. A steady state mathematical model was also developed and compared to the experimental data with very favorable results. In progress is the design of a small electronics prototype cabinet which will house 3 evaporator (CAT) loops for shipboard use.

Thermal Conductivity of SiC Foam

Researcher: Professor Martin R. Cerza
Sponsor: Schaffer Corporation

The objective of this work is to determine the thermal conductivity of Si and SiC foam cylinders. The SiC foam cylinders will be skinned and unskinned.

The approach undertaken in the Mechanical Engineering Department, US Naval Academy was a Fourier approach. The Si and SiC foam cylinders dimensions were approximately 1inch diameter, 1 inch length. The cylinders were mounted interspersed in a column of aluminum one inch diameter cylinders. One foam cylinder was mounted in the column. The aluminum cylinders were drilled from the cylinder surface to the centerline and three thermocouples were mounted to measure the axial temperature in the aluminum along the centerline. A heat flux was generated from a heater located above the topmost aluminum cylinder. The size of the heat input was varied based on the operating temperatures achieved in the Si and SiC foam cylinders as measured by their junction temperatures with the aluminum cylinders. This heat was conducted through the cylindrical column to a chilled water heat sink located at the base of the bottom aluminum cylinder. The range of chill water temperature varied from 4 to 32 degrees C (user set). By inspecting the temperature profile in the instrumented aluminum cylinders, the junction temperatures between the aluminum and foam cylinders can be obtained. The thermal conductivity of the foam specimens will than be calculated taking into account the thermal contact resistance between the aluminum and foam cylinders. Data showed that the thermal conductivity of the SiC and Si foams were 7.5 and 5.5 W/m-K, respectively.

Small Condensers for Thermosyphon Electronics Cooling Systems

Researchers: Professor Martin R. Cerza, Assistant Professor Andrew N. Smith,
Assistant Research Professor Valentin Tudor and Midshipmen 1/C W. Stange, USN
Sponsor: Department of Energy (DOE)

This project involves 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 is being compared against a simple counter flow cold plate condenser. The variable being optimized is the limitation of subcooling in the liquid return line to the evaporator plate in the CAT system.

Steady State Performance of a Capillary Assisted Thermosyphon

Researchers: Professor Martin Cerza and Assistant Research Professor Valentin Tudor
Sponsor: Office of Naval Research (ONR)

The steady state analysis of a single loop capillary assisted thermosyphon (CAT) was examined experimentally and mathematically for cooling a shipboard electronics cabinet (surface ship). Flow rates of chilled

water were 0.5 to 2 GPM, heat input ranged from 250 to 1500 W. Sink temperatures evaluated were 7, 22 and 34 C. Results showed that the CAT loop is a viable alternate for the cooling of electronics cabinets. A steady state mathematical model was also developed and compared to the experimental data with very favorable results.

Effects of Surface Roughness on Near-Surface Turbulence

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

The effect of surface roughness on the overall drag of a surface is investigated. Detailed measurements of near-surface velocity and turbulence parameters are obtained using laser Doppler anemometry in a re-circulating water channel. The near-wall velocity profiles yield local skin-friction values, which can be integrated over the entire surface to determine overall drag on the plate. This drag measurement is compared to results from tow-tank test using plates with the similar surface coatings. Normalized turbulence profiles are compared to those of a smooth surface and mesh, and sand-grain rough surfaces. The goal of the project is a better prediction of drag, using an empirical relationship of a roughness parameter, for any given surface roughness.

Hybrid Composite Joining and Characterization

Researchers: Assistant Professor Stephen M. Graham and Midshipman 1/C Tad Robbins, USN
Sponsor: Naval Surface Warfare Center, Carderock Division (NSWC-CD)

This project is an investigation into novel concepts for joining of composite and metal structures. The objective is to develop integral joining methods that could be used in place of bolting or adhesive bonding. 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. This investigation is being conducted using both numerical and experimental approaches. Novel joint designs have been developed, fabricated, instrumented and tested to evaluate the structural behavior in relation to commonly used joint configurations. Numerical analysis of the joints has been used to assist in design of the joints, and to interpret the test results. Particular attention has been paid to how the design of the joint influences the damage process. During the summer of 2004, Midshipman Robbins interned with the Structures and Composites Department at NSWC-CD as part of his appointment to the Bowman Scholar Program. During the internship, Mr. Robbins fabricated composite panels with joints of various designs. He followed up that internship by testing those joints in a research project in the Fall 2004 semester. He presented the results of his research at the National Conference on Undergraduate Research in Lexington VA in April 2005.

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

Researcher: Assistant Professor Stephen M. Graham
Sponsor: Naval Surface Warfare Center, Carderock Division (NSWC-CD)

The Navy is concerned with the integrity of ship and submarine hull structures subjected to dynamic loading due to wave action or underwater explosion. Ensuring that structures will survive extreme loading conditions requires that the materials they are made of have high resistance to fracture. The materials must have high fracture initiation toughness, which is the resistance to growth of pre-existing cracks, and they must have high crack arrest toughness, which is the ability to arrest a running crack. This program involved two investigations; one on the dynamic fracture initiation toughness of A336 steel and the other on the arrest toughness of HSLA-100 steel. Fracture toughness testing of these two steel alloys was carried out at the Naval Surface Warfare Center – Carderock Division. Test procedures and analysis methods were developed to characterize the fracture toughness of the alloys. The results were presented at the 3rd International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics, 18-20 May 2005.

Quantification of Surface Crack Growth in Titanium Tubing

Researcher: Assistant Professor Stephen M. Graham
Sponsor: Naval Air Warfare Center, Patuxent River

The objective of this project is to assess the structural integrity of high pressure titanium tubing that has suffered surface damage. The project is being conducted jointly by NAWCAD and the U. S. Naval Academy. Fatigue crack growth rate testing is being conducted at Patuxent River while analysis and interpretation of the growth rate data is being pursued at the Naval Academy in Annapolis. Tests were conducted to calibrate the DC Electric Potential Drop Method for measurement of depth of small surface cracks in thin-wall, small-diameter titanium tubing. The calibration was then used to determine crack growth in real time during fatigue cycling, and to calculate the fatigue crack growth rate curves for this titanium alloy.

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 results of this project were empirical micro-fin heat transfer data and the development of a single reliable Nusselt number correlation for all refrigerants tested. A paper has been written for conference presentation and journal publication.

HEU Detection by Active Neutron Interrogation

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

This project continues the investigation evaluating the feasibility of using external neutron stimulation in order to detect the presence of 1 kilogram of highly enriched uranium (HEU) in a large commercial shipboard freight container. Previous studies indicate that, theoretically, this methodology can succeed using currently available technology while having a minimal impact on the flow of commerce. There are, however, safety concerns such as cargo activation or personnel radiation exposure that need to be better understood. Additionally, for the technology to become a useful tool, a facility must be built, which provides both a demonstration of the proof of concept principle and yields data in order to make better evaluations of related issues.

The U.S. Naval Academy has analyzed typical cargo materials and determined their susceptibility for neutron activation, computed expected radiation levels, and detailed the consequences from such doses. This study also provides technical specifications for the design and operation of a prototype neutron interrogation facility, as well as a listing of potential contractors and vendors capable of responding to a request for proposal (RFP) to construct such a facility. A sample RFP was prepared and is included in Appendix A of this report.

Background information about HEU was first presented, outlining its origin and possible location throughout the world. Possible smuggling scenarios and sources of HEU were discussed, and based on these a list of typical cargo items was generated. Experimental studies were conducted to determine, for a wide variety of container materials and types of cargo, the extent of activation and corresponding radiation levels. By predicting the expected radiation level it was possible to address the safety issues related to proximity, expected doses from normal operation, and requisite hold times for cargo to return to releasable status. Allowances for cargo decay (hold times) were found to be less than normal delay times for typical cargo handling, and thus not expected to significantly

impact the flow of commerce. With proper shielding installed, the radiation dose to personnel operating the facility will be far below current regulatory protection standards. One significant finding, previously unreported, suggested that the neutron stimulation of even trace amounts of U^{235}, such as that found in the small percentage of natural uranium, will result in a long-lasting and very distinctive decay radiation signature from the radioisotopes generated by the fissioning of the fissile isotope U^{235}.

Detailed technical specifications have been presented, to aid the Defense Threat Reduction Agency (DTRA) or its authorized contracting representative, in drafting a request for proposal (RFP) for a prototype neutron interrogation facility. Factors addressed in the tech specs include: neutron source and pulsing equipment, radiation detection equipment, shielding, container storage following irradiation, data acquisition/storage and retrieval, operating procedures, test procedures, license and training requirements, budget, timetable, project management, container requirements, and environmental impact statements.

The project also considered radiological health requirements, environmental impact considerations, testing protocols, overall size, shielding requirements, and life cycle cost considerations, including decommissioning and decontamination that need to be considered prior to the construction of an active interrogation facility

Fracture Toughness of Nuclear Pressure Vessels

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

This work is mostly experimental support for U.S. Nuclear Regulatory Commission research work in progress on Pressurized Thermal Shock (Loss of Coolant) Accident Rules. Probabalistic methods are now being applied to these important accident scenarios using software ($FAVOR^{EP}$) 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 in the FAVOR code. Continuing work is directed toward understanding the constraint differences between C(T), SE(B) and pre-cracked Charpy 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 FY05, especially the development of a small scale cruciform loading specimen and test procedure. Cruciform testing has shown that the shift in the ductile-to-brittle transition due to biaxial loading reported by Oak Ridge National Laboratory is not large enough to be a concern in the development of the new $FAVOR^{EP}$ analysis code. Two meeting were held to format the revisions to the FAVOR code and new research on the EURO forging material has been initiated.

Crack Arrest Toughness Characterization of Naval Alloys

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

The currently available test procedures are not useful for characterizing the crack arrest toughness of many new grades of steel used in the construction of U.S. Navy surface combatants because of the high toughness of the alloys and the very large specimens that are required by the standard. This program is directed at developing new approaches for characterizing the crack arrest fracture toughness, K_{Ia}, of ferritic materials. New specimen geometries and testing procedures that overcome the limitations of the current technology will be investigated. The concept of a universal crack arrest "master curve" will also be explored to see if it is possible to define the crack arrest toughness transition curve based on a limited number of tests conducted in the lower transition region.

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

Researchers: Assistant Research Professor Qingjiang Meng,
Assistant Professor Michelle G. Koul 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. In order to further contribute to this body of knowledge, this project is continuing using an alternate test technique. This test technique will evaluate stress corrosion cracking (SCC) thresholds, 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 will be evaluated, in addition to 4340 steel due to recent concerns regarding aircraft landing gear. A Rising Step Load test method is implemented to obtain this information, which required development of a new test protocol to obtain crack growth rate information. Initial tests on AA7075-T6, AA7150, AA7040 and 4340 steel have been conducted. Preliminary testing indicates a strong, alloy-specific effect of environment and electrochemical potential on incubation time for cracking at a low initial applied stress intensity. These parameters are being explored to lend insight into the stress corrosion cracking mechanisms involved in both immune and SCC-susceptible alloys.

Diver Heater Using Hydrogen Fuel

Researcher: Professor Keith W. Lindler
Sponsor: Office of Naval Research, (ONR) Code 321OE

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 6 divers in 0 ºC water for a period of 6 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 0 ºC, the ability to hold a large amount of hydrogen in a small volume and the ability to release the hydrogen at 100 psig at temperatures below 100 ºC.

The Development of an Environmentally Compliant, Multi-Functional Coating for Aerospace Application Using Molecular and Nano-Engineering Methods: Multi-functional Coatings for Military Applications

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

The goal of the metallic coatings effort, as part of the integrated multi-functional coating system, is to replace the hot roll-bonded cladding systems currently used on military aircraft with a thermally sprayed or cold sprayed aluminum alloy coating providing the aircraft skin with improved corrosion fatigue lifetime. In Stage I of this program, a 99.0-99.8 % Al coating/AA2024-T3 skin substrate system was used to evaluate the corrosion/fatigue performance as a function of thermal spray coating process (i.e., powder flame spray, atmospheric plasma spray, and HVOF spray) and cold spray process such as Kinetic Metallization (KM). Comparison of the microstructures, mechanical properties, and the fatigue and pre-corroded fatigue properties of samples with the three types of thermal spray coating, as well as samples of bare AA2024-T3 and Alclad AA2024-T3, revealed that HVOF is the most promising thermal spray process for the deposition of aluminum coatings, and, in particular, HVOF coatings greatly increase the fatigue and pre-corroded fatigue lifetimes of the AA2024-T3 substrate. Limited success was achieved with cold spray methods although recent developments in process development (particularly, cold spray nozzle

design) may warrant a future look. In Stage II of this program, Al-Co-Ce alloy coatings with glass-forming compositions developed at the University of Virginia by Scully and Shiflet are being deposited on AA2024-T3 using Pulsed Thermal Spray (PTS) and HVOF spray processes and are being evaluated for microstructure, fatigue and pre-corroded fatigue properties. In addition, the corrosion behavior and anodic protection of amorphous or nano-crystalline AlCoCe coatings will be also evaluated in conjunction with the University of Virginia.

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

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

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, this effort involves the development of effective methods for applying the rising step load (RSL) technique to the study of EAC. The threshold KIEAC and crack growth rates at various stress intensities (V-K curve) are measured for Al alloys (T6 and T7 tempers) and 4340 steel. The RSL results in combination with quantitative electrochemical methods are used to better understand the correlation between the EAC initiation and localized corrosion. Conventional methods to evaluate the EAC resistance of aluminum alloys mainly include C-ring constant load or constant displacement testing, and double cantilever beam testing (DCB). Crack growth kinetics, or V-K curves, can be measured quantitatively by DCB testing. However, the DCB testing has limitations, such as long test durations to measure KIEAC, 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 Shielding Requirements for Naval Surface Warfare Center Indianhead Linatron Facility

Researchers: Professor Martin E. Nelson and Lieutenant Brad Sharpless, USN
Sponsor: Naval Surface Warfare Center, Indianhead (NSWC-IH)

Dose calculations have been performed on the Varian Linatron® 3000 which is planned to be installed in building 1140 at Indianhead (IH). These calculations were based on the following data sources: (1) information collected during a site visit December 21, 2004, (2) correspondence with people familiar with the design and operation of the system, (3) vendor information on the system operating parameters, and (4) published guidelines for design of accelerator facilities, such as NCRP 51 "Radiation Protection Guidelines for 0.1-100 MeV Particle Accelerators". A memo entitled "Report on 35% Calculation Standard for Linatron® 3000 in Building 1140" has been generated and forwarded to NSWC-IH in January, 2005. A complete draft report has been generated entitled "Evaluation of Shielding Design for Varian 3000 Linatron at NSWC Indian Head Division", May, 2005. The report concludes that the current shielding configuration is adequate for system operation to meet the current regulatory dose rate standard to non-radiation workers or operating personnel of 2 mrem/hr.

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

Researchers: Professor Martin E. Nelson and Lieutenant Commander Gene Canfield, USN
Sponsor: Strategic Systems Programs

This research examines 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 a 4 Mb SRAM Technologies

Researcher: Professor Martin E. Nelson
Sponsors: Naval Research Laboratory (NRL) and Office of Naval Research (ONR)

Radiation hardened microelectronic devices are needed for various space applications. This work investigates the effects of 14 MeV neutron irradiation on Honeywell's 4Mb SRAM CMOS technologies. The radiation source is the USNA neutron generator in Rickover Hall. A number of different versions of this technology were evaluated. The results showed that the latest Honeywell design, which contained an additional feedback transistor from the earlier design, was significantly harder (*i.e.,* fewer upsets per neutron fluence per bit) than an earlier version. The collected data will also be compared against high energy proton data collected at Harvard University. Future experiments are next planned with the BAE 4 Mb DRAM in order to make comparisons of different designs between vendors.

MIDN: A Spacecraft Microdosimeter Mission

Researchers: Professor Martin E. Nelson, Professor Vincent L. Pisacane (Aerospace Engineering Department) and Visiting Professor James Ziegler (Electrical Engineering Department)
Sponsor: Naval Air Warfare Center

MIDN (MicroDosimetry Instrument) is payload for use of the MidSTAR-I spacecraft (Midshipmen Space Technology Applications Research). It is a solid state system, which will be designed and constructed to measure microdosimetric spectra to determine radiation quality factors for Space environments. Radiation is a critical threat to the health of astronauts and the success of missions in low-earth orbit and space exploration. MIDN will consist of three separate sensors, one external to the spacecraft, one internal, and one embedded in polyethylene. Design goals are mass < 3 kg, power < 2 W. The MidSTAR-I mission in 2006 will provide an opportunity to evaluate a preliminary version of this system.

HEU Detection by Active Interrogation

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

The Naval Academy, as well as other federal agencies and laboratories, have been investigating the feasibility of detecting 1 kg of Highly Enriched Uranium (HEU) by active interrogation within large cargo carrying commercial shipboard freight containers at a US port of entry. These studies indicate that this technology can succeed using currently available technology, while having a minimal impact on the flow of commerce. However, there are safety concerns such as cargo activation or personnel radiation exposure that need to better understood. Additionally, for the technology to be become a useful tool, a facility must be built, which provides both a demonstration of the proof of concept principle and yields data in order to make better evaluations of other related issues. In order to address the safety concerns related to this technology, this study performs the following evaluations:

1. Perform activation studies on a wide range of commercial products not previously studied with the USNA 14 MeV neutron generator. These tests are being conducted at neutron fluence levels expected to be used by the technology when in field operation. The tests are being designed to produce by product a quantified hold time before their release for transportation;

2. Evaluate the activation data to identify particular isotopes that produce long hold times and apply this data to study radiation effects on potential materials used in constructing a biological shield around the facility when in operation;

3. Evaluate accidental radiation hazards to members of the public such as a stowaway in the container during examination.

Evaluation of the Use of a Portable Electron Accelerator to Deactivate Electronic Devices

Researchers: Professor Martin E. Nelson
and Visiting Professor James F. Ziegler (Electrical Engineering Department)
Sponsor: Office of Naval Research (ONR)

This proposal is for a 20 MeV portable electron beam tool which can generate a beam adequate to deactivate electronic and neutralize bio-weapons at considerable stand-off distances. Past experiments have indicated that the beam will deactivate simple timing devices at distances exceeding 200'. This proposal indicates that evaluation of a portable e-beam for various military applications may be economically accomplished by using reconditioned hospital equipment. The project is being conducted in three phases. During the first phase the following items are being performed:

- Measurements of electronic deactivation using MeV electrons.
  - Assemble electronic parts for testing: various ESAF components, electronic timers, etc.
  - Determine Dose and Energy requirements for deactivation.
  - Establish universality of Deactivation of various types of electronics (CMOS, bipolar, dRAM, CPLDs, etc.)
  - Establish limitations caused by shielding.
- Evaluate vendors of e-beam accelerators
- Evaluate suppliers of used e-beam accelerators
- Design Electronics Reduction / Compaction
- Model radiation leakage for e-beam unit and methods to minimize operator exposure.

Damage Detection in Large Scale Naval Structures

Researcher: 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 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 involves a recently developed broadband vibration-based technique developed at the United States Naval Academy and at 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 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. As a result of ongoing efforts, a U.S. Patent was awarded this year.

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

Researcher: 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 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 was to investigate the utility of using MEMs sensors to determine the structural integrity of composite components. This was accomplished by modifying the SIDER technique. SIDER is a 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. SIDER is a relatively rapid procedure when compared to other extant techniques. This effort investigated changes to the SIDER technique that further reduced inspection time. Success with this effort was an enabler toward real time, in-service monitoring of structures. Previously, SIDER required excitation at multiple locations, with monitoring at relatively few locations. In this effort the procedure was reversed such that excitation was at relatively few locations and the response was monitored with an extensive array of MEMs sensors. This was 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 were interrogated with both the conventional SIDER technique and the modified technique using the MEMs sensors. Results were promising.

Cooling Channel Design and Thermal Testing 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 will include a 2D 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. Different cooling channel shapes, along with the material selection have been identified as critical components of an effective thermal design. Experimental testing will be performed on different cooling channel shapes under steady state and transient conditions.

This project includes thermal testing of a rail section of an EM railgun. The experiments will be performed at the University of Texas during the summer of 2005 on an existing 4MJ launcher. The rail sections include solid ETP Cu and 7075 Aluminum, along with test sections that have cooling channels. The design of experiment and the data analysis is being conducted at the U.S. Naval Academy.

A Study of the Effects of Applying Directional Coatings to Grooved Surfaces on Radiation Exchange within Enclosures

Researcher: Assistant Professor Dwight E. Smith
Sponsor: Naval Academy Research Council (NARC)

The combination of directional coatings applied to grooved surfaces within the nozzle of an aircraft engine might be able to reduce the infrared signature of a jet engine. It is proposed that an effort be made to determine if knowledge of a coating's bi-directional reflectivity as measured on a smooth, flat surface can be used to predict the directional behavior of a grooved surface that has been covered by that same directional coating. To accomplish this, the bi-directional reflectivity of a directional coating is being measured on a smooth, flat surface using the SOC-200 reflectometer at the Naval Surface Warfare Center, Carderock Division. This bi-directional reflectometer is also being used to determine the reflectance behavior of a grooved surface before and after the directional coating has been applied to its surface. In this on-going project, once the BDRF's of these surfaces have been obtained, a model of the grooved surface will be created in a commercial drafting package, such as AutoCad, and then imported into a Monte Carlo ray-trace (MCRT) environment. This model will be used in a pre-existing MCRT code to simulate the mapping of the grooved surface with the directional coating by the SOC-200 at Carderock. A comparison will be made between the BDRF produced by the simulation and the experimental BDRF measured by the SOC-200 to determine the effectiveness of predicting the directional behavior of a collection of ordered planes formed into a single grooved surface.

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

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

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 continued 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. Both two and three dimensional trips were studied. These experiments 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.

Surface Roughness Effects on Frictional Drag and Turbulent Boundary Layer Structure

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

In turbulence research, a great deal of attention has been given to the "canonical" smooth wall, zero pressure gradient boundary layer. Smooth wall boundary layer studies far outnumber rough wall studies. While the smooth wall studies have provided a basis of understanding turbulent wall flows, in most engineering applications, surface roughness is present (*i.e.,* ship hulls, atmospheric boundary layers, turbomachinery). It is, therefore, of interest to gain a better physical understanding of these flows. The goal of the proposed research is to do this by documenting fully-developed turbulent boundary layers on a range of rough surfaces. From this, the similarity of both the mean velocity and turbulence structure on rough and smooth walls can be critically evaluated. Detailed

measurements of the roughness topography will allow roughness scaling parameters for the prediction of skin-friction drag at full scale to be developed. Practical payoffs of this research to the U.S. Navy would include: Provide data for more refined turbulence models to be developed for prediction of ship resistance; Develop and evaluate roughness correlations for skin-friction drag based on measurements of roughness topography; Allow more sound economic decisions regarding hull cleaning and drydocking to be made.

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 softwares CyclePad and CycleTalk, Intelligent Computer Aided Instruction (ICAI) is incorporated in a second Engineering Thermodynamics course (EM485D) for general engineering major students and an advance Energy Conversion Course (EM443) for mechanical engineering students. The use of the CyclePad and CycleTalk softwares enhance 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 and CycleTalk allow 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 and CycleTalk introduce 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 and CycleTalk make the learning of thermodynamic cycle design more exciting and results in more effective training of future designers.

CyclePad has been used for eight semesters at the Naval Academy for design homework and project. The experience has been a positive one. Future versions of the software will incorporate user-suggested modifications.

Independent Research

Fully Resolved Simulations of Particle-Turbulence Interaction

Researcher: Assistant Professor Tristan M. Burton

The interaction between a fixed particle and decaying homogeneous isotropic turbulence is studied numerically using an overset grid that provides resolution of all scales of fluid motion. A description of the numerical technique and validation of the solution procedure are presented. An ensemble of 64 simulations with the particle in different regions of the flow is computed. The particle diameter in the simulations is approximately twice the size of the unladen Kolmogorov length scale and the maximum value of the particle Reynolds numbers due to the turbulent fluctuations is close to 20. Ensemble averages of quantities from the numerical solution are used to investigate the turbulence modification and the fluid forces on the particle. Volume-averaged profiles of the turbulent kinetic energy and dissipation rate from the overset grid simulations reveal that the displacement of fluid by the particle and the formation of the boundary layer at the particle surface lead to turbulence modification in a local region. Time histories of the force applied to the particle from each overset grid simulation are compared to those predicted by a particle equation of motion. The particle equation of motion is shown to under-predict the root mean square (RMS) force applied to the particle by the turbulence. RMS errors between the forces from the overset grid simulation and those predicted by the particle equation of motion are shown to be between 15% and 30% of the RMS force on the particle. The steady viscous drag force is shown to be the dominant term in the particle equation of motion while the history integral term is negligible.

Investigation of Point-Force Turbulence Modification

Researcher: Assistant Professor Tristan M. Burton

A particle equation of motion and the point-force approximation are commonly used in simulations of particle-laden, turbulent flow to model the two-way momentum coupling between the phases. The assumption required to justify the use of these techniques is that the particle diameter is much smaller than the Kolmogorov length scale of the flow. However, in most applications this assumption is violated as the particle diameter is the same order as the Kolmogorov scale. In this work, the ability of the point-force approximation to reproduce turbulence modification is studied for a case where the particle diameter is twice the Kolmogorov length scale. The results from a set of 64 fully resolved, overset grid calculations of the interaction between a fixed particle and decaying homogeneous isotropic turbulence are compared to those from unresolved calculations with an added forcing term to mimic the presence of the particle. The forcing term for the unresolved simulations is determined from the integration of the stresses at the particle surface during the corresponding overset grid calculation. The overset grid simulations show a significant enhancement of the average turbulent dissipation rate in volumes surrounding the particle. The point-force simulations also show enhancement of the turbulent dissipation rate but the magnitude of the enhancement is significantly under-predicted. Analysis of the discrete turbulent kinetic energy equation reveals that the forcing term in the momentum equations also introduces dissipation of turbulent kinetic energy. Therefore, the combined effect of fluid dissipation and point-force dissipation in the point-force simulations is now being compared to the fluid dissipation in the fully resolved, overset grid simulations. Direct numerical simulations of a fixed particle in a steady or unsteady uniform stream are also being compared to point-force simulations to assess the accuracy of point-force momentum coupling in cases where the particle is smaller than the Kolmogorov length scale.

Resolution Criteria for Finite-Difference Simulation of Turbulent Flows

Researcher: Assistant Professor Tristan M. Burton

Spectral methods are the highest-fidelity tool for simulation of turbulent flows, though extension to complex geometries remains a formidable task. Overset grid and immersed boundary techniques are often suitable for flow in complex geometries. However, the choice of these methods precludes the use of spectral methods for spatial representation of flow variables and the governing equations must be treated with finite-difference or finite-volume techniques. While the small-scale resolution requirements for spectral simulation of turbulent flows are reasonably established, analogous requirements for direct numerical simulation using finite-difference or finite-volume methods are less well-established and are the main interest of this work. As a first step in establishing a small-scale resolution requirement for finite-difference or finite-volume calculations of turbulent flow, simulations of decaying homogeneous isotropic turbulence were conducted. Local values and global averages of the turbulent kinetic energy and dissipation rate from spectral calculations were compared to corresponding quantities from a second-order-accurate, finite-volume calculation started from the same developed turbulent initial condition. Agreement between the spectral and finite difference simulation results was excellent indicating that the resolution requirement used for spectral simulation can also be applied to the finite-volume simulation of decaying homogeneous isotropic turbulence. In the future a similar comparison between spectral and finite-volume simulation of statistically stationary turbulence will be performed.

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. This study is a basic investigation of the physics associated with the leading edge tubercles found on the flukes of humpback whales. The study is currently broken into three parts. 1) Wind tunnel testing to obtain lift and drag comparisons between a baseline and modified fin model. 2) Computational fluid dynamics modeling of the fins. 3) Fin testing in the water flow channel. 4) Flow visualization of the fins using the USNA flow channel and new PIV system. Current status of part 1 is that initial testing has been completed in the USNA CCWT comparing the lift and drag characteristics of a foil with and without leading edge tubercles at sweep angles of 0 degree, 15 degree and 30 degree. The initial results for 0 degree

sweep case have been presented at three separate conferences and a journal article printed. The initial results for the 15 degree and 30 degree swept cases have been presented at a conference. The in depth results for all sweep angles are to be submitted to an AIAA journal and presented at a conference this summer. Further wind tunnel investigation must wait until the USNA CCWT is functioning. Current status of part 2 is that the baseline and modified fin models have been successfully built in the solid modeling program Solid Edge and imported into CF design computational fluid dynamics software. Computational analysis is currently being run for several of the experimental cases that were run in the CCWT. Current status of part 3 is that several tests have been run on modified models that were milled from aluminum. The thrust of the experiment is to analyze the cavitation and trans-cavitation effectiveness of several fin models.

Midshipman Research Course Projects

Study of the BETA Response Characteristics of the DT-702 Thermoluminscent Dosimeter

Researcher: Midshipman 1/C Philip Hall, USN
Adviser: Professor Martin E. Nelson
Sponsors: Bowman Scholar Program and Naval Dosimetry Center (NDC)

In this project the response of the DT-702 TLD to beta radiation has been investigated. Navy personnel encounter ionizing radiation sources on a daily basis, some of which 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 for the above reasons. Through an internship at the NDC, data was collected on the DT-702 using calibrated beta radiators, which use Kr-85 and Sr-90/Y-90 sources. Through analysis of the data, three independent chip response ratios were obtained. The experimental conditions were also modeled using the Monte Carlo Neutron Photon (MCNP) Transport Code, of which version 5 is available in the Naval Academy's Nucleonics Laboratory. This analysis also produced values for the same corresponding chip response ratios as experimentally determined. Good agreement was obtained between these two approaches. The results were then applied to the NDC beta decision algorithm. This analysis showed that beta radiation should be considered present when the response ratio of chip 3 to chip 2 is 7.4 or greater.

Stall Mechanism Analysis of Humpback Whale Fin Model

Researcher: Midshipman 1/C Benjamin Stein, USN
Adviser: Assistant Professor Mark M. Murray

The goal of this project was to experimentally determine the relative importance of the two theorized mechanisms of delaying stall on a wing with a tubercle leading edge. The more popularly held belief is that vortices created by the tubercles cause a mixing in the boundary layer and the additional fluid energy delays separation of flow from occurring. A second theory is that the vortices created by the tubercles act as an artificial stall gate that does not allow the stall to progress from the wing tip inward.

Experiments were performed in one of the educational wind tunnels in the aero laboratory. The first sets of experiments focused on full span airfoil models (removing wing tip effects) that will compare the lift and drag produced by full span NACA 0020 model with and without leading edge tubercles. This set of experiments will help determine the relative importance of the vortices in delaying stall by adding energy to the boundary layer and preventing separation to occur.

A Computational Fluid Dynamics Analysis of Variable Submarine Sails

Researcher: Midshipman 1/C Andrew P. Thompson, USN
Adviser: Assistant Professor Tristan M. Burton

The Office of Naval Intelligence previously obtained pictures of two foreign submarines. The primary difference between the two was the presence of a step in the sail of one of the submarines. Previously, the hydromechanics laboratory at USNA built models replicating the different submarine sails and attached the sails to an identical body shape. A control sail was also built which replicated an American submarine without a step. Testing was conducted in the hydromechanics laboratory and data was collected for two of the three sail configurations. In this work a computational fluid dynamics analysis of the flow around a submarine sail was attempted in order to determine the effect of the step in the submarine sail. The CFD-ACE software package was used to generate a computational grid and run a Reynolds-Averaged Navier-Stokes simulation at conditions similar to those used in the experimental tests.

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, Naval Sea Systems Command and Office of Naval Research (ONR)

The properties in metals are not only a function of the composition. Processing techniques can significantly alter how a metal performs and can ultimately determine whether a material will fail. It is imperative that metals be processed correctly so that components do not fail before their expected lifetime. This Bowman Scholar project involved the investigation of the processing parameters of HY-80 steel castings. Preliminary studies indicate that the HY-80 Bridge Access Trunk casting failed while in service due to improper processing. In this effort, samples taken from the failed casting were evaluated. Heat treating furnaces and quenching apparatus at USNA were utilized to austenitize sections of casting and then subject each to different quench and temper conditions. During Fall semester, macro- and microhardness measurements and optical microscopy were used to evaluate how certain intercritical heat treatments affect the metallurgical condition of the high strength steel to simulate possible processing errors in the original casting. During Spring semester, the heat treatment conditions were correlated to impact properties and compared to military specification requirements. The window(s) of favorable processing parameters defined by heat treatment temperature were clarified based on the requirements set by the U.S. Navy for large HY-80 castings.

Evaluation of a Composite and Metal Hybrid Co-Cured Joint

Researcher: Midshipman 1/C Tad Robbins, USN
Adviser: Assistant Professor Stephen M. Graham
Sponsor: Bowman Scholar Program

This Bowman Scholar project involved the investigation of a novel hybrid composite joint in which a glass-reinforced composite material transitions into metal without the use of mechanical fasteners or adhesives. The joint is fabricated by resin infusion and co-curing, meaning that the metal fibers overlapping the composite glass fibers are injected with resin simultaneously and then harden to form the joint. The joint is the point of focus, as previous research has shown that the joint is much weaker than the two materials being joined. The goals of this project include: fabricate various joints, conduct tests to observe joint behavior, quantitatively describe behavior of different joints, and optimize the joint to provide maximum strength. Several joints have been analyzed including symmetric and asymmetric stepped lap joints of different step lengths. Analysis has shown that the strength of the hybrid joint is directly related to the step length and joint configuration. There are numerous Naval applications for this material. Currently, the only means of joining a composite material to a metallic material is by means of either a bolt or an adhesive. Both methods of joining have inherent negative effects. However, this technology would eliminate these problems, thus providing a much stronger transition. Any design that may require a reduction in weight without a reduction in strength could benefit from this technology. One area of interest for this technology is for the future Littoral Combat Ship (LCS). The LCS is designed to operate in the littoral regions and operate at

speeds in excess of fifty knots. Therefore, the design must incorporate a shallow draft and a lighter displacement. Alternatives to conventional materials must be used. A hull made of this hybrid material would not only save on weight but would also allow for weapons systems and other systems to be easily joined to the hull. Another possible application would be a hybrid shaft. A metal shaft with the center span being of a composite material would greatly reduce the weight of the shaft. This also would make shaft production easier since a large metal shaft would no longer need to be forged.

Low-Velocity Boundary Layer Temperature Probe

Researcher: Midshipman 1/C Gabrielle Scarlata, USN
Adviser: Associate Professor Ralph J. Volino

A precise low-velocity boundary layer temperature probe was constructed using butt welded Chromel and Constantan thermocouple wire of .076mm (.003 in) diameter. The probe was used to measure temperature profiles within the logarithmic portion of a 9.9 mm thick boundary layer along a flat plate under a constant air velocity. These profiles were used to compare dimensionless temperature (T^+) versus position (Y^+) distributions above the plate within the boundary layer to expected distributions for turbulent boundary layers. Probe and wire geometry were considered in calculating the difference between the thermocouple temperature readings and the true air temperature at the thermoelectric pair junction. These calculations showed the error was less then 3% of the overall temperature difference in a typical boundary layer.

Combined Effects of Pulsed Film Cooling and Upstream Wakes on Gas Turbine Airfoil Heat Transfer

Researcher: Midshipman 2/C Kristofer M. Womack, USN
Advisers: Associate Professor Ralph J. Volino and
Associate Professor Michael P. Schultz (Naval Architecture and Ocean Engineering Department)

This project is follow-on to current research involving pulsed film cooling with a steady mainstream flow. For the current study, a large test plate was constructed with a row of holes through which film cooling air could be pulsed. A wind tunnel provides a wall jet at a controlled velocity across the test plate. The plate is heated in order to determine the heat transfer coefficient between the mainstream air and the test plate. The current study is examining the film cooling effectiveness and the heat transfer coefficient as a function of the blowing rate of pulsed jets and the frequency of pulsing. The proposed project will add a wake generator between the nozzle and the test plate and study the resulting flow field, film cooling effectiveness, and heat transfer coefficient. Temperature measurements will be made with thermocouples mounted in the test plate and an infrared (IR) camera. Flow field measurements will be taken with cold-wire and hot-wire probes and a particle image velocimeter (PIV). The primary objective of this project is to study the effects of pulse timing on the passing of a wake over the test plate. As the experiment progresses, the goal is to look for ways to increase film cooling effectiveness and lower heat transfer to reduce the chances of turbine blade failure. Furthermore, the project is designed to look at the feasibility of applying considered flows to an actual gas turbine. Finally, the project will create experimental data that may be used by Computational Fluid Dynamics researchers as a spring board to further innovative research.

Trident Scholar Projects

Effects of Pulsing on Film Cooling of Gas Turbine Airfoils

Researcher: Midshipman 1/C Sarah M. Coulthard, USN
Advisers: Associate Professor Ralph J. Volino and Professor Karen A. Flack
Sponsor: Office of Naval Research (ONR)

The objective of this project was to determine the effects of pulsed film cooling on turbine blades. High combustor temperatures, resulting in elevated turbine inlet temperatures, produce high engine efficiency. At current operating temperatures, the turbine inlet temperature is above the melting point of the turbine blades. Thus cooling the blades in the first stages after the combustor is essential. Current methods for film cooling utilize a continuous stream of bleed air from the compressor. This air is routed into a cavity inside each blade and bled out of holes onto the blade surface, creating a film of cool air. Pulsed film cooling may reduce the amount of bleed air used, thus increasing the efficiency of the engine by allowing more air to flow through the combustor, while providing equivalent protection for the blades.

In this study, a section of a turbine blade was modeled using a plate with a row of five film cooling holes. Coolant air was pulsed via solenoid valves from a plenum, while a wind tunnel provided a mainstream flow. Temperature and velocity fields were measured over the blade surface with varying blowing rates of the coolant and frequencies of pulsing. The film cooling effectiveness, a measure of how well the coolant protects the blade surface, was calculated based on the measured temperatures. The results were compared to baseline cases with continuous blowing and no blowing. Results showed that pulsed film cooling has the potential to provide an equivalent or greater film cooling effectiveness. The case of pulsed jets with a jet velocity equal to the mainstream velocity, pulsing frequency of 20 Hertz, and 50% duty cycle showed an increased film cooling effectiveness compared to the continuous blowing case. At this velocity, the momentum of the continuous jet caused the flow to lift off the test wall, while the pulsed jet flow remained closer to the surface. The same effect was not observed for higher and lower jet velocities.

This study suggests that pulsed film cooling has the potential to adequately protect gas turbine blades, ultimately allowing for an increased efficiency in a gas turbine engine.

Investigation of Elliptical Cooling Channels for a Naval Electromagnetic Railgun

Researcher: Midshipman 1/C Elizabeth Kealey, USN
Advisers: Assistant Professor Andrew N. Smith and Assistant Professor Peter J. Joyce
Sponsors: Office of Naval Research (ONR) and Naval Surface Warfare Center, Dahlgren Division (NSWC-DD)

The future Naval Electromagnetic Railgun will use a mega-ampere electrical current to generate an electromagnetic force capable of accelerating a projectile to hypersonic velocities. The applied current raises the bulk temperature of the rails by over 100 degrees Celsius, necessitating an active cooling system for the rails. The electromagnetic force on the projectile and the rails creates a complicated stress state that varies as the projectile passes along the rail, first with uniaxial then with biaxial compression.

In this study, a system of cooling channels for fluid flow down the length of the rails was investigated. Channels with elliptical cross sections were examined. Elliptical shapes were considered due to the high surface area available for convection, relatively low impact on the stress distribution, and low stress concentration effect. By treating an elliptical channel as a variable area fin and varying the size and aspect ratio of the ellipse and the distance between channels, the heat transfer capability of a channel array was maximized based on given flow conditions and applied heat flux. The optimal channel design was further constrained by the applied compressive stresses. It was found that ellipses of different aspect ratios are optimal for the uniaxial and biaxial stress states, and the optimal channel design was limited by the competing effects of these two structural constraints.

To test the thermal aspect of the design, a representative set of channels was machined into one-third scale copper rails, using wire electrical discharge machining. Tests were performed using a steady state heat flux to determine the overall heat transfer coefficient and via transient conditions to determine the system thermal

relaxation time. To verify the structural aspect of the design, small cross sections of the rail were subjected to a uniaxial compressive loading test to compare the experimental stress concentration factors with the theoretical correlations used in the literature. The results of both the thermal and structural testing were found to be in reasonable agreement with the predicted results.

Publications

Journal (Refereed) Manuscripts

FLACK, Karen A., Professor and SCHULTZ, Michael P., Associate Professor, "Outer Layer Similarity in Fully Rough Turbulent Boundary Layers, *Experiments in Fluids*, Vol. 38, pp. 328-340, 2004.

> 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. Professor, SCHULTZ, Michael P., Associate Professor and SHAPIRO, Thomas A. (Trident Scholar 2004), "Experimental Support for Townsend's Reynolds Number Similarity Hypothesis on Rough Walls," *Physics of Fluids*, Vol. 17, 2005.

> The Reynolds number similarity hypothesis of Townsend states that the turbulence beyond a few roughness heights from the wall is independent of the surface condition. The underlying assumption is that the boundary layer thickness (δ) is large compared to the roughness height (k). This hypothesis was tested experimentally on two types of three-dimensional, rough surfaces. Boundary layer measurements were made on flat plates covered with sandgrain and woven mesh roughness in a closed return water tunnel at a momentum thickness Reynolds number (Re_θ) of ~14000. The boundary layers on the rough walls were in the fully rough flow regime ($k_s^+ \geq 100$) with the ratio of the boundary layer thickness to the equivalent sand roughness height, δ / k_s, greater than 40. The results show that the mean velocity profiles for rough and smooth walls collapse well in velocity defect form in the overlap and outer regions of the boundary layer. The Reynolds stresses for the two rough surfaces agree well throughout most of the boundary layer and collapse with smooth wall results outside of $3k_s$. Higher moment turbulence statistics and quadrant analysis also indicate the differences in the rough wall boundary layers are confined to $y < 5k_s$. The present results provide support for Townsend's Reynolds number similarity hypothesis for uniform three-dimensional roughness in flows where $\delta / k_s \geq 40$.

GRAHAM, Stephen M., Assistant Professor, "Evaluation of Welds Exhibiting Large Scatter in Charpy Toughness Using the Reference Temperature", *ASTM Journal of Testing and Evaluation,* Vol. 23, No. 1, January 2005.

> Conformance tests 7018M weld wire revealed that some lots exhibited excessive scatter in Charpy toughness. A test program was conducted to determine if fracture behavior of the welds was significantly influenced by the occasional low Charpy values. Charpy and tensile data was collected on welds made

from lots of 7018M wire that failed conformance testing. Fracture toughness tests were also conducted to characterize the fracture performance in the transition temperature region. A baseline for acceptable fracture behavior was established based on fracture toughness and Charpy data from 70-series weld wires that are typically used in the same, or similar, applications. The reference temperature of the 7018M weld was determined to be –72.1°C (–97.7°F), which was well below the baseline of –45°C (-49 °F). Therefore, the 7018M weld was shown to have equal or better fracture toughness than the baseline at any temperature. Consequently, the large scatter in Charpy toughness was not indicative of poor fracture performance.

GRAHAM, Stephen M., Assistant Professor and Crane, Roger M., "Stress Analysis of Asymmetric Co-Cured Stepped-Lap Joints", *Journal of ASTM International*, accepted for publication.

Manufacturing of large adhesively-bonded structural joints in the marine composites industry requires careful design and manufacturing to ensure durability of the joint. 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 influences the load transfer and the corresponding stresses developed in the joint. In this study, finite element analysis was used to investigate the stresses developed in a co-cured stepped-lap joint made from adherends with unequal stiffness. Two different approaches were used to model asymmetric joints with uniform step lengths; a homogeneous approach that modeled each adherend as transversely isotropic, and a constituent-level approach that modeled the resin and idealized fibers individually. It was found that the co-cured stepped lap joint behaves very much like a series of adhesively bonded lap joints. The shear stress distribution for step length to ply thickness ratios greater than about 10 exhibits a parabolic shape with peaks at the ends and lower values in the center, which is very similar to the stress distribution in adhesively bonded stepped lap joints. It was observed that the peak and minimum stresses approach a steady value with increasing step length, implying that there may be a limiting strength for an asymmetric co-cured stepped lap joint.

JOYCE, James, A., Professor, "Evaluation of the Effect of Crack Tip Constraint on Fatigue Crack Growth Rate in Inconel 718", *Journal of ASTM International*, Vol. 2, No. 1, January 2005.

The objective of this work has been to characterize the fatigue crack growth rate of Inconel 718 in the elastic and elastic-plastic regimes. The major new contribution here is to develop fatigue crack growth rate data on this alloy using shallow crack specimens subjected to cyclic loadings that involve material plasticity exceeding what is allowed by the standard Linear Elastic Fracture Mechanics (LEFM) procedures of ASTM E647.

Compact (C(T)) and three point bend (SE(B)) specimen geometries were used in this investigation. The SE(B) specimens were used to obtain shallow crack data using crack to depth ratios (a/W) as small as 0.08 in standard bend specimens with W = 50.8 mm. Compliance methods were used to estimate the crack length during the cyclic testing. The C(T) specimens were used to investigate the effect of fully reversed loading, i.e. R = -1.0. These specimens were tested only in deep crack configurations with a/W > 0.3. Both C(T) and SE(B) specimens were used to obtain high cycle fatigue crack growth data and to obtain at least some component of the low cycle fatigue crack growth rate data. The cyclic elastic stress intensity range was used to characterize the crack growth driving "force" in the high cycle regime as defined in ASTM E647. A cyclic J integral range, as originally utilized by Dowling and Begley, was used in the elastic-plastic regime.

High cycle and low cycle fatigue crack growth data was successfully obtained from tests on shallow crack SE(B) specimens. High cycle fatigue crack growth was not affected by specimen geometry or by crack length ratio, even for a/W ratios as low as 0.08. The R ratio did not affect the crack growth rate for the two cases tested here, namely R = 0.1 and R = -1.0. The low cycle fatigue crack growth rate was similar, but not identical to what one would get by extrapolating the high cycle fatigue crack growth rate, as proposed by Dowling and Begley. Under conditions of increasing J range, the crack growth rate under elastic-plastic

conditions was accelerated, while under decreasing J range conditions the crack growth rate was decelerated in comparison to the extrapolated high cycle fatigue crack growth rate measurements. More rapidly increasing J range conditions resulted in greater crack growth rate acceleration. In the elastic-plastic fatigue regime, shallow crack specimens demonstrated slower crack growth rates than deep crack specimens.

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, Issues 16-17, pp. 2513-2531.

Polytetrafluoroethylene (PTFE) is a semi-crystalline polymer that demonstrates a range of fracture properties when tested at various temperatures and loading rates. The addition of a powdered aluminum filler to obtain enhanced mechanical properties resulted in multiphase material containing 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.

JOYCE, Peter, J., Assistant Professor and JOYCE, James, A., Professor, "Evaluation of the Fracture Toughness Properties of Polytetrafluoroethylene", *International Journal of Fracture*, Vol. 127, No. 4, June 2004, pp. 361-385.

Polytetrafluoroethylene (PTFE) (Dupont Tradename 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 ($20^{o}C$) 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.

MORAN, Angela L., Professor, Connolly, Brian J., MENG, Qingjiang, Assistant Research Professor, and McCaw, Robert L., "Mechanical and Precorroded Fatigue Properties of Coated Aluminum Aircraft Skin System as a Function of Various Thermal Spray Processes", Corrosion *Engineering, Science & Technology*, pp 137-142, Vol. 39, Issue 2, June 2004.

Aluminum coatings deposited on AA2024-T3 by the flame arc, atmospheric plasma and high velocity oxyfuel (HVOF) processes were evaluated using quantitative metallography, microhardness, adhesion, three point bend and conventional fatigue tests as well as fatigue tests on precorroded samples. Comparison of the microstructures, mechanical properties, and the fatigue and precorroded fatigue properties of samples

with the three types of thermal spray coating, as well as samples of bare AA2024-T3 and Alclad AA2024-T3, revealed that HVOF is the most promising thermal spray process for the deposition of aluminum coatings, and, in particular, HVOF coatings greatly increase the fatigue and precorroded fatigue lifetimes of the AA2024-T3 substrate.

MORAN, Angela L., Professor, Connolly, Brian J., and KOUL, Michelle G., Assistant Professor, "A Comparison Study of Stress Corrosion Crack Growth Rates For Aa7xxx Alloys As A Function of Bulk Aqueous Chloride Concentrations", *Corrosion*, July 2005.

Alternative aluminum alloys are under consideration for drop-in replacement and refurbishment of corrosion and stress corrosion cracking prone AA7075-T6 components on aging military aircraft. An assessment of new materials for refurbishment and replacement of older generation, aging components is necessary for a viable life extension program. A quantitative database of stress corrosion cracking (SCC) properties of old generation materials compared to currently available materials is needed as a guideline/justification for part replacement. This effort evaluates AA7150-T7751 and AA7040-T7651, both which meet mechanical property requirements and are thought to be superior to AA7075-T6 in terms of corrosion performance. Specifically, stress corrosion crack growth rates for these plate alloys were documented and found to be similar in various bulk aqueous chloride environments and to represent a significant improvement over measured rates for AA7075-T651.

RATCLIFFE, Colin P., Professor, Yoon, Myung Keun, Heider, Dirk, Gillespie, Jr., John W., and Crane, Roger M., "Local Damage Detection using the Two-dimensional Gapped Smoothing Method", *Journal of Sound and Vibration*, V279, pp. 119-139, January 2005.

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., Professor, BAGARIA, William J., Professor (ret), GARCIA, Sonia M. F., Professor (Mathematics Department) and FAHEY, Richard P., Visiting Professor, (Aerospace Engineering Department), "Rapid Binary Gage Function to Extract a Pulsed Signal Buried in Noise," *EURASIP Journal on Applied Signal Processing*, pp. 1985-1992, Vol. 2004, N13, October 2004.

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, Stevens, R.J., Lichtenberger, A.W. and Norris, P.M., "Thermal Boundary Resistance of Thin Metal Films and Thermally Conductive Dielectric Materials", *Journal of Heat Transfer*, Vol. 127, pp. 315-322, March 2005

Measurement of the thermal boundary conductance (TBC) by use of a non-destructive optical technique, transient thermoreflectance (TTR), is presented. A simple thermal model for the TTR is presented with a discussion of its applicability and sensitivity. A specially prepared sample series of Cr, Al, Au, and Pt on four different substrates (Si, sapphire, GaN, and AlN) were tested at room temperature and the TTR signal fitted to the thermal model. The resulting TBC values vary by more than a factor of three ($0.71 \times 10^8 - 2.3 \times 10^8$ W/m^2 K). It is shown that the Diffuse Mismatch Model (DMM) tended to over-predict the TBC of interfaces with materials having similar phonon spectra, while under-predicting TBC for interfaces with dissimilar phonon spectra. The DMM only accounts for diffuse elastic scattering. Other scattering mechanisms are discussed which may explain the failure of the DMM at room temperature.

SMITH, Andrew N., Assistant Professor, Ellis, R.L., Bernardes, J.S. and Zielinski, A.E., "Thermal Management and Resistive Heating of a Large-Scale Naval Electromagnetic Launcher", *IEEE Transactions on Magnetics*, Vol. 41, pp. 182-187, January 2005.

This paper presents a model that can be implemented to quickly estimate the resistive heating and the resulting transient temperature response. Quantifying the energy deposited in the rails and implementing an effective thermal management system will be key elements of an effective design for a large-scale electromagnetic launcher. The total current was divided between the inside, upper/lower and outside surface based on the results of a current distribution calculation. The diffusion of the magnetic field into each surface was modeled in order to determine the current distribution and the resistive heating. Cooling between shots was taken into account by solving the one dimensional transient heat diffusion equation within each surface. Repeating these calculations for a number of discrete segments down the length of the rail enabled the prediction of the total resistive rail heating and the temperature profile along the length of the rail. Experimental tests were conducted that verify the presence of localized heating in the corners of a U-shape conductor made of 7075 Aluminum. Taking into account the localized resistive heating near the surface of the conductor will become increasingly important with large-scale guns.

SMITH, Andrew N., Assistant Professor, Ellis, R.L., Poynor, J.C. and McGlasson, B.T., "Influence of Bore and Rail Geometry on an Electromagnetic Naval Railgun System", *IEEE Transactions on Magnetics*, Vol. 41, pp. 235-240, January 2005.

A large scale railgun is being considered by the U.S. Navy as a future long range (>200 nm) naval weapon system. The notional concept includes a 15 kg projectile with a 2.5 km/sec muzzle velocity. The choice of bore and rail geometry for such a weapon can influence key aspects of the total system design. This study explored a range of bore and rail geometries and looked at their effect on key railgun system parameters such as parasitic mass, inductance gradient, linear current density, required pulse forming network (PFN) size, and barrel weight. Preliminary solid modeling and structural analysis of the integrated launch package was performed in order to quantify parasitic mass. Inductance gradient calculations were based on a current density distribution analysis. A PFN/Launcher numerical simulation model was then used to determine linear current density and PFN size. Finally, barrel weight was estimated by structural analysis based on calculated rail repulsive forces. Trends and sensitivities of the different parameters to changes in the bore and rail geometries are presented and conclusions and recommendations are given.

VOLINO, Ralph J., Associate Professor, "An Investigation of the Scales in Transitional Boundary Layers under High Free-stream Turbulence Conditions", *Experiment in Fluids*, Vol. 38, pp. 516-533, March 2005.

The scales in a transitional boundary layer subject to high (initially 8%) free-stream turbulence and strong acceleration (K as high as 9×10^{-6}) have been investigated using wavelet spectral analysis and conditional sampling of experimental data. The boundary layer shows considerable evolution through transition, with a general shift from the lower frequencies induced by the free-stream unsteadiness to higher frequencies associated with near wall generated turbulence. Within the non-turbulent zone of the intermittent flow, there is considerable self-similarity in the spectra from the beginning of transition to the end, with the dominant frequencies in the boundary layer remaining constant at about the dominant frequency of the free-stream. The frequencies of the energy containing scales in the turbulent zone change with streamwise location and are significantly higher than in the non-turbulent zone. When normalized on the local viscous length scale and velocity, however, the turbulent zone spectra also show good self-similarity throughout transition. Turbulence dissipation occurs almost exclusively in the turbulent zone. The velocity fluctuations associated with dissipation are isotropic, and their normalized spectra at upstream and downstream stations are nearly identical. The distinct differences between the turbulent and non-turbulent zones suggest the potential utility of intermittency based transition models in which these zones are treated separately. The self-similarity noted in both energy containing and dissipation scales in both zones suggests possibilities for simplifying the modeling for each zone.

VOLINO, Ralph J., Associate Professor and BOHL, Douglas G., Assistant Research Professor, "Experiments with Three Dimensional Passive Flow Control Devices on Low Pressure Turbine Airfoils," *ASME Journal of Turbomachinery*, accepted for publication.

The effectiveness of three dimensional passive devices for flow control on low pressure turbine airfoils was investigated experimentally. A row of small cylinders was placed at the pressure minimum on the suction side of a typical airfoil. Cases with Reynolds numbers ranging from 25,000 to 300,000 (based on suction surface length and exit velocity) were considered under low freestream turbulence conditions. Streamwise pressure profiles and velocity profiles near the trailing edge were documented. Without flow control a separation bubble was present, and at the lower Reynolds numbers the bubble did not close. Cylinders with two different heights and a wide range of spanwise spacings were considered. Reattachment moved upstream as the cylinder height was increased or the spacing was decreased. If the spanwise spacing was sufficiently small, the flow at the trailing edge was essentially uniform across the span. The cylinder size and spacing could be optimized to minimize losses at a given Reynolds number, but cylinders optimized for low Reynolds number conditions caused increased losses at high Reynolds numbers. The effectiveness of two-dimensional bars had been studied previously under the same flow conditions. The cylinders were not as effective for maintaining low losses over a range of Reynolds numbers as the bars.

WU, Chih, Professor, "Closed Inter-cooled Regenerator Brayton Cycle with Constant Temperature Heat Reservoirs", *Applied Energy*, pp. 429-446, 77(4), 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, "Performance of a Regenerative MHD Power Plant", *International Journal of Power and Energy Systems*, pp. 98-103, 24(2), 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), "Phase Space Analysis on Thermo-acoustic Heat Engine System", *Energy Conversion and Management*, pp. 2197-2205, 45(10), 2004.

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 the 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), "Optimal Configuration and Performance for a Generalized Carnot Cycle Assuming the Heat Transfer Law $Q \propto (\Delta T)^m$", *Applied Energy*, pp. 305-313, 78(3), 2004.

The finite-time-thermodynamic performance of a generalized Carnot cycle, in which the heat transfer between the working fluid and the heat reservoirs obeys a generalized heat transfer law is studied. The optimal configuration and fundamental optimal relation between power output and efficiency of the cycle are derived.

WU, Chih, Professor, (co-author), "Cooling Load Density Optimization for a Regenerated Air Refrigerator", *Applied Energy*, pp. 315-328, 78(3), 2004.

A performance analysis and optimization of a regenerated air refrigerator cycle with variable temperature heat reservoirs is carried out by taking the cooling load density as the optimization objective using finite-time-thermodynamics.

Wu, Chih, Professor, "An Absorption Heat Transformer and its Optimal Performance", *Applied Energy*, pp. 329-346, 78(3), 2004.

On the basis of an endoreversible absorption heat transformer cycle, a generalized irreversible four-heat-reservoir heat transformer cycle model has been established by taking account of the heat resistances, heat leaks and irreversibilities due to the internal dissipation of the working substance. The heat transfer between the four-heat-reservoir and the working substance is assumed to obey the linear Newtonian heat transfer law, and the overall heat transfer surface area of the four heat exchangers is assumed to be constant. The fundamental optimal relations between the COP and the heating load, the maximum COP and the corresponding heating load, the maximum heating load and the corresponding COP, as well as the optimal temperatures of the working substance and the optimal heat transfer surface area of the four heat exchangers are derived.

WU, Chih, Professor, (co-author), "Performance of an Endoreversible Closed Intercooled Regenerated Brayton Cycle", *International Journal of Ambient Energy*, pp. 199-211, 25(4), 2004.

The performance of an endoreversible closed intercooled regenerated Brayton cycle coupled with constant-temperature heat reservoirs is investigated. The analytical formulae of dimensionless power and efficiency are derived. The intercooling pressure ratio is optimized for dimensionless power and efficiency.

WU, Chih, Professor, (co-author), "Optimum Performance of an Irreversible Dual Cycle", *Applied Energy*, pp. 3-14, 79(1), 2004.

The finite-time-thermodynamic performance of an air standard Dual cycle with heat transfer and friction-like term losses is analyzed and optimized in this paper.

WU, Chih, Professor, "Maximum Profit Performance for Engines", *Applied Energy*, pp. 15-25, 79(1), 15-25, 2004.

The operation of a Newton's law system generalized Carnot engine with heat resistance, heat leakage and internal dissipation is viewed as a production process with exergy as its output. The finite-time exergoeconomic performance optimization of the engine is investigated by taking the profit maximization criterion as the objective.

WU, Chih, Professor, (co-author), "Optimal Cooling Load and COP Relationship of a Four-heat-reservoir Endoreversible Absorption Refrigeration Cycle", *Entropy*, pp. 316-326, 6(3), 2004.

On the basis of a four-heat-reservoir endoreversible absorption refrigeration cycle model, another linear heat transfer law is adopted, the fundamental optimal relation between the COP and the cooling load, as well as the maximum cooling load and the corresponding COP of the cycle coupled to constant-temperature heat reservoirs are derived by using finite-time thermodynamics.

WU, Chih, Professor, (co-author), "Power Optimization of Open Cycle Regenerator Gas Turbine Power Plants", *Applied Energy*, pp. 199-218, 79(2), 2004.

A performance analysis and optimization of a open cycle regenerator gas turbine power plant is performed in this paper. The analytical formulae about the relation between power output and cycle overall pressure-ratio are derived taking into account the eight pressure drop losses in the intake, compression, regeneration, combustion, expansion, and discharge process and flow process in the piping, the heat transfer loss to the ambient environment, the irreversible compression and expansion losses in the compressor and the turbine, and the irreversible combustion loss in the combustion chamber.

WU, Chih, Professor, (co-author), "Optimum Performance of an Endoreversible Four-Heat-Reservoir Absorption Heat Transfer", *Open System and Information Dynamics*, pp 147-159, Vol. 11 (2), 2004.

Optimum performance of an endoreversible four-heat-reservoir absorption heat transformer is investigated. The fundamental optimal relation between the COP and the specific heating load, as well as the maximum specific heating load and the corresponding COP of the cycle, and the optimal heat transfer surface areas of the four heat exchangers are derived.

WU, Chih, Professor, "Power and Efficiency Analysis of an Endoreversible Closed Intercooled Regenerated Brayton Cycle", *International Journal of Exergy*, pp. 475-494, 1(4), 2004.

The performance of an endoreversible closed intercooled regenerated Brayton cycle coupled with variable-temperature heat reservoirs is investigated. The analytical formulae of dimensionless power and efficiency are derived. The intercooling pressure ratio is optimized for maximum power and maximum efficiency.

WU, Chih, Professor, (co-author), "Ecological Optimization for Generalized Irreversible Carnot Refrigerators", *Journal of Physics D: Applied Physics*, pp. 113-118, Vol. 38, 2005.

The optimal ecological performance of a Newton's law generalized irreversible Carnot refrigerator with the losses of heat resistance, heat leakage and internal irreversibility is derived by taking an ecological optimization criterion as the objective, which consists of maximizing a function representing the best compromise between the exergy output rate and energy loss rate of the refrigerator.

WU, Chih, Professor, (co-author), "Important Optimum Criteria on the Performance Parameters of an Irreversible Brayton Heat Engine", *International Journal of Ambient Energy*, pp. 37-44, Vol. 26, 2005.

> Internal irreversibilities due to non-isentropic processes in the compressor and turbine, and external irreversibilities due to finite temperature differences between the external heat reservoirs and a Brayton heat engine are considered in the paper. The power output is maximized with respect to the working fluid temperatures and the pressure ratio of the two isobaric processes.

WU, Chih, Professor, "Compromise Optimization between Heating Load and Entropy Production Rate for Endoreversible Absorption Heat Pumps", *International Journal of Ambient Energy*, Vol. 26, pp. 106-112, 2005.

> The optimal relation between the ecological criterion and the COP, and maximum ecological criterion and the corresponding COP, heating load and entropy production rate are derived. The results reflect that the ecological criterion is a factor which can have long-term significance for optimal design of absorption heat pumps.

Conference Proceedings

CERZA, Martin, R., Professor, "Navy Future Technologies for Next Generation Naval Systems", 3rd Workshop on Thermal Packaging of High Flux Military and Commercial Electronics, University of Maryland, College Park, MD, 18 October 2004.

> In the past, thermal management onboard naval vessels amounted to the cooling of power plant components, air conditioning and chilled water systems. Electronic systems were cooled essentially by the air conditioning systems as well and there was no real need to think about thermal management from a naval architecture point of view. With the current technological explosion in the processing power of electronics systems, high thermal dissipation rates are starting to outpace the cooling capabilities of air cooled systems. Heat loads in the commercial sector have been increasing at a rate of 30 percent every two years and are expected to increase 100 fold over the next five years. That electronic heat dissipation rate coupled with thermal energy generated in such areas as solid state refrigeration and HVAC devices, RF devices, electric drive, electric weapons systems, electromagnetic launch devices, thermoelectric systems and the desire to shift the naval platform to an all electric ship means that shipboard thermal management must be resolved from a naval architecture perspective. The ship's hull for instance must not only be designed for speed, to support the ship's functions and to provide a stable platform, it must also be designed to help deal with the large thermal loads of an all electric ship (AES) such as a load that may be upwards of 700 to 1000 percent of the thermal load of present day warships. Not only must we improve thermal management on a systems level, but areas like waste heat utilization and increased thermal performance of non-electronic systems must also be investigated.
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> What makes a shipboard system unique from its space or aircraft counterparts is that earth's largest heat sink, the ocean, is readily available and currently under-utilized as a thermal sink. Thermal systems which can utilize this 'infinite' heat sink have an inherent advantage over systems which do not. The Navy through its Office of Naval Research (ONR) has recognized this thermal management and integrated power systems point of view and has started to rethink the way the Navy should deal with increased energy consumption and it's resulting thermal dissipation loads. Since naval platforms are generally built to last 25-50 years, unlike the 6 to 18 month life of an advanced computer, any plan on thermal management has to span a near term (5 years or less), midterm (5 to 15 years), and far term (beyond 15-25 years) in the development of future systems. Near term projects are generally projects that can be implemented in a short time with minor changes to existing equipment in order to keep up with certain technological advances, while far term projects usually require major changes in the ship's naval architecture hence they require much lead time and are designated as projects for the future Navy.

FLACK, K.A., Professor, SCHULTZ, Michael P., Associate Professor and SHAPIRO, Thomas A. (Trident Scholar 2004), "Turbulent Structure over Two Types of Uniform Roughness," *Proceedings of the 10th European Turbulence Conference*, Trondheim, Norway, 29 June – 2 July 2004.

> Current engineering models treat roughness as a small perturbation to the smooth wall boundary layer. Understanding the extent of this perturbation for a variety or roughness types would improve predictive capabilities. In this investigation, the flow over two three-dimensional, rough surfaces (mesh and sandpaper) are presented. The mean velocity and Reynolds stress profiles over these surfaces are compared to smooth walls. An increase in the physical growth of the boundary layer as well as an increase in C_f was measured for the rough surfaces. The two rough surfaces produced similar roughness functions, even for roughness heights that differed by a factor of 2. The profiles of the normalized Reynolds stresses for both the smooth and rough surfaces show agreement within experimental uncertainty in the overlap and outer regions of the boundary layer.

GRAHAM, Stephen M., Assistant Professor, and Crane, Roger M., "Tensile Strength of a Co-Cured Innovative Hybrid Joint for Marine Composites", *Proceedings of the SAMPE 2005 Conference*, 2-5 May 2005.

> The use of adhesively bonded joints is problematic in the marine composites industry where the aqueous environment degrades the properties of adhesives. When the two adherends 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. Another problem facing the industry is the joining of fiber-reinforced composite structure with metal structure. The innovative joint design that is the subject of this study transitions from glass fibers to steel fibers using a co-cured stepped-lap joint. The steel fibers can then be joined with solid metal, although that is not addressed in this study. Numerical methods were used to estimate the stresses in various asymmetric stepped-lap joints loaded in tension in an effort to optimize the joint configuration. The initial analysis focused on joints with uniform steps of various lengths. It was found that the peak stresses reach a steady value as the step length increases, thereby implying a limiting tensile strength. Further analysis looked at joints with variable step lengths in an effort to achieve more uniform load sharing between steps.

GRAHAM, Stephen M., Assistant Professor, ROBBINS, Tad, Midshipman 1/C, USN, and Crane, Roger M., "Influence of Joint Geometry on Tensile Strength of a Co-Cured Symmetric Stepped-Lap Joint", *Proceedings of the SAMPE 2005 Conference*, 2-5 May 2005.

> In the design of high-performance composites for the marine industry there are situations where it may be necessary to join fiber-reinforced panels that have different fiber stiffnesses. One method of joining the panels is to create a co-cured stepped-lap joint. This joint eliminates the use of adhesive, and all of the problems associated with degradation of adhesives in marine environments. The stress distribution in the joint is determined by the configuration of the joint and the stiffnesses of the fibers on either side of the joint. In this study numerical methods were used to estimate stresses in various symmetric stepped-lap joints loaded in tension in an effort to optimize the joint configuration. The joints studied had a glass-reinforced adherend on one side and a steel fiber reinforced adherend on the other, where the modulus of the steel fibers was almost three times the modulus of the E-glass fibers. In a symmetric joint the load transfer through the joint is influenced by the lengths of the steps and which adherend has extended center plies. Joints were optimized based on resin stresses and uniformity of load transfer throughout the joint. Joints were then fabricated and tested to confirm the numerical predictions

JOYCE, Peter J., Assistant Professor, MCCLAY, Jessica, N., Ensign, USN, and SMITH, Andrew, N., Assistant Professor, "Determination of the Directional Dependence of the In-Plane Thermal Conductivity of K63B12 Pitch-Fiber/ Epoxy Composite", *Proceedings of the 2004 IMECE*, Anaheim, CA, 13-19 November 2004.

Measurements of the in-plane thermal conductivity and the directional dependence of Mitsubishi K63B12 pitch-fiber/Epoxy composite from Newport Composites are reported. This composite is being explored for use in the Advanced Seal Delivery System for effective thermal management. The thermal conductivity was measured using a steady state technique. The experimental results were then compared to a model of the thermal conductivity based on the direction of the fibers. These estimates are based on the properties of the constituent materials and volume of fibers in the sample. Therefore the density and the fiber volume fraction were experimentally measured. The thermal conductivity is clearly greatest in the direction of the fibers and decreases as the fibers are rotated off axis. In the case of pitch fiber composite materials, the contribution of the fibers to the thermal conductivity dominates. The experimental data clearly followed the correct trends; however, the measured values were 25% to 35% lower than predicted.

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.

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 et al., has also demonstrated the equivalence of normalization function methods and multi-specimen methods at test conditions where both methods can be used.

The 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.

KOUL, Michelle G., Assistant Professor, MENG, Qingjiang, Assistant Research Professor, and MORAN, Angela L., Professor, "A Comparison Study of Environmentally Assisted Crack Growth Behavior for AA7XXX Alloys", *Proceedings from the 6th International Corrosion Workshop*, Solomons, MD, August 2004.

Alternative aluminum alloys are under consideration for drop-in replacement and refurbishment of corrosion and environmentally assisted cracking prone AA7075-T6 components on aging military aircraft. A quantitative database of environmentally assisted cracking (EAC) properties of old generation materials compared to currently available materials is needed as a guideline/justification for part replacement. This effort evaluates the EAC behavior of AA7150-T7751 and AA7040-T7651, both which meet mechanical property requirements and are thought to be superior to AA7075-T6 in terms of corrosion performance. Results indicate that the new alloys afford a decrease in environmentally assisted crack growth kinetics

with increased strength over AA7075-T651. Incubation times for EAC crack initiation were observed for the new generation alloys and were a function of bulk alloy chemistry. A brief discussion of the use of the rising step load (RSL) test technique to study the crack growth behavior of aluminum alloys is included.

LINDLER, Keith W., Professor, "Compact Hydrogen Fuel Storage for a Diver Heater", *Proceedings of the Underwater Intervention Conference*, New Orleans, LA, 14-16 February 2005.

The necessity for active diver heating during long duration, cold water, swimmer delivery vehicle (SDV) operations is well established. Alternative approaches to supply this active heating requirement have covered a wide range of technologies, including thermoelectric heaters, magnesium combustion, propane/catalytic heating, and direct electrical resistive heating. While all of these methods have been shown to be capable of producing sufficient quantities of heat, each has its own inherent restrictions and interface issues when applied to an SDV operation.

A simple hydrogen catalytic combustion heater was tested as a breath heater for deep diving applications. The high heat production demonstrated during this testing suggested that this approach could also be used as a diver heater to potentially minimize package size and power requirements and yet meet all the diver heating requirements for long duration Spec War missions. Preliminary analysis has shown that less than 0.4 kg of hydrogen could supply the 2 kW of heat needed to sustain up to 6 divers in 0C water for up to 6 hours. This paper presents the results of experiments conducted with various metal hydrides used to provide a compact means of storing and delivering the hydrogen required for the heater.

LINK, Richard E., Associate Professor and CARR, Matthew A., CDR, USN, "Application of Standards in Capstone Design", *Proceedings of the Fall 2004 ASEE Middle Atlantic Section Conference*, Session 1234, 22-23 October 2004.

Lack of proper exposure to and practice with engineering codes & standards handicaps new engineers and forces employers to expend additional time and financial resources to remediate this lack of knowledge. While some on-the-job training in the specific engineering disciplines of the employer is to be expected, students should not graduate with a total ignorance of the role of codes & standards in the engineering profession. Design methodology and factors of safety incorporated in textbook presentations and homework problems often fail to make the connection to professional codes & standards as the source. Typical design texts and engineering handbooks give scant coverage to codes & standards. Most junior faculty members, who earned their degrees in the traditional academic sequence, lack sufficient experience in engineering design or industrial operations where codes & standards are required and enforced by regulators, inspectors, and liability insurers. The facts that there are numerous code issuing and regulatory organizations and that their codes & standards are constantly under revision make thorough education in this area a daunting task. A balanced approach to addressing these issues involves developing faculty expertise and guiding the students to appropriate professional codes & standards. This paper addresses both of these issues and discusses: (1) ideas for faculty to improve their own knowledge of codes & standards; and, (2) ideas for engaging engineering students with codes & standards during the conduct of their capstone design project.

ROBBINS, Tad, Midshipman 1/C, USN, and GRAHAM, Stephen M., Assistant Professor, "Tensile Strength Evaluation of an Innovative Hybrid Composite/Metal Joint", *Proceedings of the National Conference on Undergraduate Research*, Lexington, VA, 21-23 April 2005.

The United States Navy is currently in the process of designing a ship that will be able to engage and function in littoral regions. Due to the restrictions inherent in functioning in the littoral region, it is imperative that the ship be lightweight and agile. This presents a significant material selection challenge. Weight and signature issues related to all-metallic hulls may limit its ability to meet the performance objectives. Composite materials can alleviate some of these limitations, but have limitations of their own. Consequently, there is a need for the development of new materials that combine the beneficial attributes of

each in order to meet the specifications. This is the impetus for the development of a hybrid glass/metal composite panel. This hybrid panel, with its unique metal and composite construction, will combine the valuable strength to weight ratio of a composite with the ability to weld to adjacent metallic structure, providing flexibility to the ship designer. The objective of this study is to optimize the construction of the panel to maximize the strength. Specific attention will be focused on the stepped lap joint, where the composite meets the metal. Hybrid panels are designed, fabricated and tested under tensile loading to find the optimal joint characteristics that provide the highest achievable strength.

SMITH, Andrew N., Assistant Professor, and VOLINO, Ralph J., Associate Professor, "Versatile Heat Transfer Lab for Conducting Bench-Top Experiments", *Proceedings of the 2005 American Society of Engineering Education Annual Conference and Exposition*, Portland, OR, 12-16 June 2005.

This paper describes heat transfer benches that were developed at the U.S. Naval Academy, and several basic experiments that have been implemented to date. Each bench contains the necessary equipment for a variety of experiments. Using the heat transfer bench, and working in groups of four or five, students perform hands-on heat transfer and thermo-fluids experiments. These experiments include measuring the thermal conductivity of different materials; measuring an overall heat transfer coefficient; testing the performance of heat sinks; monitoring transient heat conduction; measuring convection heat transfer coefficients and measuring the effectiveness of different sized heat exchangers. The students are required to perform uncertainty analyses, and recommend methods for reducing uncertainty. The flexibility of the heat transfer bench also allows the students to design and conduct their own experiments. Involving the students in the design of the experiment places the responsibility for the outcome on them, and challenges their basic understanding of the subject. A description of each experiment is presented along with some anecdotal student evaluations.

SMITH, Andrew N., Assistant Professor, MCCLAY, J. N., Midshipman 1/C, USN, and JOYCE, Peter J. Assistant Professor, "Determination of the Directional Dependence of the In-Plane Thermal Conductivity of K63B12 Pitch-Fiber / Epoxy Composite", *Proceedings of the 2004 IMECE*, Anaheim, CA., 13-19 November 2004.

Measurements of the in-plane thermal conductivity and the directional dependence of Mitsubishi K63B12 pitch-fiber/Epoxy composite from Newport Composites are reported. This composite is being explored for use in the Advanced Seal Delivery System for effective thermal management. The thermal conductivity was measured using a steady state technique. The experimental results were then compared to a model of the thermal conductivity based on the direction of the fibers. These estimates are based on the properties of the constituent materials and volume of fibers in the sample. Therefore the density and the fiber volume fraction were experimentally measured. The thermal conductivity is clearly greatest in the direction of the fibers and decreases as the fibers are rotated off axis. In the case of pitch fiber composite materials, the contribution of the fibers to the thermal conductivity dominates. The experimental data clearly followed the correct trends; however, the measured values were 25% to 35% lower than predicted.

SMITH, Andrew, N., Assistant Professor, KEALEY, Elizabeth R., Midshipman 1/C, USN (Trident Scholar 2005), JOYCE, Peter J. Assistant Professor, and CERZA, Martin R, Professor, "Elliptical Cooling Channel Design for a Naval Electromagnetic Railgun", *Proceedings of the 2004 ASNE High Power Weapons Systems Conference*, Annapolis, MD, 7-9 December 2004.

Elliptical cross sections are examined for the design of cooling channels subjected to compressive loading conditions. The principal application of this study is the U.S. Navy's proposed 64 MJ Electro-Magnetic (EM) railgun. An electromagnetic railgun is fired using a mega-ampere electrical current applied to two parallel conducting rails. This current induces both a significant heat load and a high compressive stress on the conducting rails. The current pulse deposits approximately 15 MJ of energy per shot that must be removed between shots. Maintaining a sustained rate of fire for the proposed electromagnetic railgun requires an active cooling system. The heat transfer capability of elliptical channels is maximized based on the applied heat flux and given flow conditions, by treating the channel as a variable area fin and varying

the major and minor axis of the elliptical cross- these channels. The optimal channel shape is further constrained by the compressive forces acting on the rails, and that the stress induced on the rails of the EM railgun varies with time.

Technical Reports

GRAHAM, Stephen M., Assistant Professor and Stiles, Daniel J., "Evaluation of Cylindrical Air Flask from USS Albuquerque (SSN 706)", NSWCCD-61-TR-2003/23, June 2004.

An investigation was conducted to characterize and assess indications on the inner surface of a main ballast tank (MBT) air flask removed from USS Albuquerque (SSN 706). Metallographic examination discovered that the indications were laps form the rotary forging process used to manufacture the flask. There was no evidence of extension of the lap defects by fatigue or any other mode of crack growth, indicating that there was not growth in approximately 20 years of service. Fracture and mechanical property testing was conducted on the received section of air flask. Testing included tensile tests, Charpy V-Notch, quasi-static fracture toughness, and dynamic fracture toughness tests. The results of these tests show that the steel used for air flask manufacture met property requirements for compressed air flasks specified by Navy and ASTM. Fracture toughness testing showed that the material used for flask fabrication was relatively tough and that defects of this nature should be monitored, but are not a cause for immediate removal from service.

Presentations at Professional Meetings and Conferences

BURTON, Tristan M., Assistant Professor, "Investigation of Point Force Turbulence Modification", IUTAM Symposium on Computational Approaches to Disperse Multiphase Flow, Argonne, IL, 5 October 2004.

BURTON, Tristan M., Assistant Professor, and Squires, Kyle D., "Resolution Criteria for Finite-Difference Simulation of Turbulent Flows", 57th Annual Meeting of the APS Division of Fluid Dynamics, Seattle, WA, 21 November 2004.

CERZA, Martin, R., Professor, "Navy Future Technologies for Next Generation Naval Systems", 3rd Workshop on Thermal Packaging of High Flux Military and Commercial Electronics, University of Maryland, College Park, MD, 18 October 2004.

FLACK, Karen A., Professor, SCHULTZ, Michael P., Associate Professor and SHAPIRO, Thomas A., (Trident Scholar 2004), "Turbulent Structure over Two Types of Uniform Roughness", 10th European Turbulence Conference, Trondheim, Norway, 29 June – 2 July 2004.

FLACK, Karen A., Professor and SCHULTZ, Michael P., Associate Professor, "Extent of Roughness Sub-Layer in Turbulent Boundary Layers", 56th Annual Meeting American Physical Society Fluid Dynamics Division, Seattle, WA, 21-23 November 2004.

GRAHAM, Stephen M., Assistant Professor, "Hybrid Composite Joints For Composite-to-Metal Joining", ShipTech 2005 Conference, 28 February – 2 March 2005.

GRAHAM, Stephen M., Assistant Professor, "Tensile Strength of a Co-Cured Innovative Hybrid Joint for Marine Composites," SAMPE 2005 Conference, 2-5 May 2005.

GRAHAM, Stephen M., Assistant Professor, "Influence of Joint Geometry on Tensile Strength of a Co-Cured Symmetric Stepped-Lap Joint", SAMPE 2005 Conference, 2-5 May 2005.

GRAHAM, Stephen M., Assistant Professor, **"**Application of the Reference Temperature to the Evaluation of Cleavage Fracture in HSLA-100 Steel**",** International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics, RENO, NV, 18-20 May 2005.

GRAHAM, Stephen M., Assistant Professor, "Application of the Normalization Method to Dynamic Fracture Toughness Testing of Alloy 718", International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics, 18-20 RENO, NV, May 2005.

JOYCE, James A., Professor and JOYCE, Peter J., Assistant Professor, "An Investigation of Specimen Geometry effects on the Fracture Behavior of A Metal Filled Polymer", International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics (35th ASTM National Symposium on Fatigue and Fracture), Reno, NV., 18-20 May 2005.

JOYCE, Peter J., Assistant Professor, KEALEY, Elizabeth R., Midshipman 1/C, USN, (Trident Scholar 2005), CERZA, Martin, R., Professor, and SMITH, Andrew, N., Assistant Professor, "Elliptical Cooling Channel Design for a Naval Electromagnetic Railgun", 2004 American Society of Naval Engineers (ASNE) High Power Weapons Systems Conference, Annapolis, MD, 7-9 December 2004.

JOYCE, Peter, J.., Assistant Professor, MCCLAY, Jessica, N., Ensign, USN, and SMITH, Andrew, N., Assistant Professor, "Determination of the Directional Dependent In-Plane Thermal Conductivity of K63B12 Pitch-Fiber/Epoxy Composite", 2004 International Mechanical Engineering Congress and Exposition (IMECE), Anaheim, CA, 13-19 November 2004.

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.

KOUL, Michelle G., Assistant Professor, MENG, Qingjiang, Assistant Research Professor, and MORAN, Angela L., Professor, "A Comparison Study of Environmentally Assisted Crack Growth Behavior for AA7XXX Alloys", 6th International Corrosion Workshop, NAVMAR Sciences Corporation, Solomons, MD, August 2004.

LINK, Richard E., Associate Professor and CARR, Matthew A., CDR, USN, "Application of Standards in Capstone Design", Fall 2004 ASEE Middle Atlantic Section Conference, Washington, D.C., 22-23 October 2004.

LINK, Richard E., Associate Professor, "Review of Crack Arrest Testing and Analysis Procedures", Naval Surface Warfare Center, Carderock Division, Code 60, Carderock, MD, September 2004.

LINK, Richard E., Associate Professor, "Crack Arrest Evaluation of HSLA-100 Steel", Naval Surface Warfare Center, Carderock Division, Code 60, Carderock, MD, 10 March 2005.

LINK, Richard E., Associate Professor, "Analysis of Dynamic Fracture and Crack Arrest of an HSLA Steel in an SE(T) Specimen", 5th International ASTM/ESIS Symposium on Fatigue and Fracture, Reno, NV, 18-20 May 2005.

MORAN, Angela L., Professor, KOUL, Michelle G., Assistant Professor, and MENG, Qingjiang, Assistant Research Professor "A Comparison Study of Environmentally Assisted Crack Growth Behavior for AA7XXX Alloys", 6th International Corrosion Workshop, NAVMAR Sciences Corporation, Solomons, MD, August 2004.

MURRAY, Mark M., Assistant Professor, MIKLOSOVIC, David S., Assistant Professor, Fish, Frank and Howle, Laurens, "Effect of Leading Edge Tubercles on Swept Humpback Whale Flipper", 57th Annual Meeting of the APS Division of Fluid Dynamics, Seattle, WA, 21-23 November 2004.

NELSON, Martin E., Professor, PISACANE, Vincent L., Professor, DiCello, J.F., Rosenfeld, A.B., and ZIEGLER, James F, Visiting Professor., "MIDN: A Spacecraft Microdosimetry Mission", 2004 Solid State Dosimetry Conference, New Haven, CT, June 2004.

NELSON, Martin E., Professor, ZIEGLER, James F., Visiting Professor, Fiegel, H. F., Good, C. M., Blackburn, B. N., St. John, J. S., Locke, S. J., and Allen, J.D., "Investigation into the Feasibility of High Enriched Uranium Detection by External Neutron Stimulation", AIW Workshop, Idaho Falls, ID, June 2004

NELSON, Martin, E., Professor, McMarr, P.J., Liu, T.J., Hughes, H., Nelson, D., and Delikat, D.J., "Asymetric SEU in SOI SRAMS", 42nd Annual Nuclear and Space Radiation Conference, Seattle, WA, 11-15 July 2005.

SMITH, Andrew N., Assistant Professor, "Thermal Management of a Naval Electromagnetic Railgun", 3rd Annual Workshop on Thermal Management of High Flux Commercial and Military Electronics, University of Maryland, College Park, MD, 18 October 2004.

SMITH, Andrew N., Assistant Professor, "Versatile Heat Transfer Lab for Conducting Bench-Top Experiments", 2005 American Society of Engineering Education Annual Conference and Exposition, Portland, OR, 14 June 2005.

VOLINO, Ralph J., Associate Professor, and BOHL, Douglas G., 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, Vienna, Austria, 15 June 2004.

VOLINO, Ralph J., Associate Professor, and BOHL, Douglas G., Assistant Research Professor, "Three-Dimensional Flow Structure Resulting from Oscillating Vortex Generator Jets", 57th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Seattle, WA, 22 November 2004.

VOLINO, Ralph J., Associate Professor, and BOHL, Douglas G., Assistant Research Professor, "Experiments with Three Dimensional Passive Flow Control Devices on Low Pressure Turbine Airfoils", 2005 ASME International Gas Turbine Conference, Reno, NV, 8 June 2004.