Mechanical Engineering Department

Professor Steven M. Miner
Chair

The faculty and midshipmen of the Mechanical Engineering Department have diverse interests in the fields of mechanics, materials and the thermo-fluid sciences. These interests are reflected in the types of research projects undertaken, which include sponsored faculty research, 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 there were a total of 13 faculty members involved in 19 sponsored research projects. Sponsors included government agencies, academic institutions and industry. In addition to the sponsored faculty research there were 12 midshipmen involved in independent research projects with faculty and 1 midshipman involved in a Trident Scholar project. Many of these projects were also funded by outside sponsors. The output for the past year included 56 publications and 26 presentations. Of these midshipmen were involved in 16 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

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

Researchers: Associate Professor Martin R. Cerza,
with Mr. Juan C Adams and Dr. P. T. Ireland (Oxford University)
Sponsor: Oxford University

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

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

Researchers: Assistant Professor Peter J. Joyce
and Mr. Neil Graf (NAWCAD/PAX)
Sponsor: Naval Air Warfare Center, Patuxent River (NAVAIR)

The objective of this research project is to evaluate the state of the art in resin transfer molding (RTM) process technology and examine the influence of controllable process parameters on the thermal and mechanical behavior of composites manufactured from multi-component resin systems. This research involves three thrusts, the first is to evaluate the design and performance of the automated RTM process designed as part of the Advanced Materials Intelligent Processing Center (AMIPC) program at Northwestern University (NWU). The second thrust of this research involves the selection and characterization of materials and processes for multi-component RTM of primary structural composites. The third thrust of this goal is to manufacture aerospace quality composites utilizing the selected resin systems and the NWU system to generate design allowable data for the industrial partners.

Significant progress has been made toward each of these objectives. Tests to date have concluded that while the resin injection equipment designed by NWU has great merit in terms of the concepts being attempted and the potential for improved manufacturing reliability, as yet the system does not perform satisfactorily. For the materials evaluation component of this research two different resin systems have been selected. In order to evaluate the optimum process cycle for each of these material systems, a thermal analysis program to determine the cure kinetics and the basic thermal and mechanical properties of each resin system was performed. The thermal analysis was complemented by a parametric evaluation of the multi-component RTM process which involved the manufacture and testing of composite panels.

Structural Testing of Missile Bodies and Surrogates

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

The design and application of a test apparatus for damage tolerance and is described. The objective of this research program is the experimental validation of computational models under development for damage assessment of missile bodies. USNA involvement focused on full-scale structural integrity testing of both missile bodies and missile surrogates with varying degrees of damage. Cantilever bend testing was chosen for damage tolerance testing because of the relative ease of modeling. The apparatus was designed for full-scale testing of the nine foot long, 30-inch diameter tail section of foreign made missile bodies. The test criteria required that the apparatus generate a maximum internal bending moment in the skin/stringer structure at the root of the cantilever arrangement of $1(10^6)$ in-lbs in pure bending, meaning the loading rig had to specially designed to accommodate large tip displacements both in and out-of the plane of bending. Furthermore, the loading rig was designed for displacement control of the test, rather than load control to avoid sudden catastrophic failure. Each test article was instrumented for displacement at the tip and at the mid-section as well strain along the entire ventral center line and along dorsal center line in the vicinity of the hatch opening. Five tests were performed in all, three on foreign missile bodies, two damaged and one undamaged and two missile surrogates, one damaged and one undamaged. The data and results were turned over to personnel at the Naval Surface Warfare Center for comparison with the results of numerical modeling studies.

Mechanical Characterization of Al/PTFE Reactive Materials

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

The objective of this work is to evaluate the fracture resistance of aluminum/PTFE (polytetrafluoroethylene) composites currently under investigation for use in enhanced warheads (designated RM4). The dramatic reactive nature of aluminum/PTFE composites when subjected to ballistic rate loading has been demonstrated in gas guns and in full scale structural response tests employing foreign made missile bodies and surrogates utilizing a sub-scale launcher. The thrust of this work is to develop a clearer understanding of the mechanical response of these reactive materials to in-flight loads and more importantly to inves-

tigate the mechanisms responsible for fracture initiation. The objectives of this research are twofold (1) to demonstrate the applicability of standardized fracture test techniques to the aluminum/PTFE composite and (2) and to evaluate the fracture resistance of the aluminum/PTFE composite in terms of material variability and optimization. The results will be used to develop a database of fracture toughness properties for these materials for constitutive modeling purposes.

This work was comprised of quasi-static Mode I fracture toughness testing. Our first objective was to explore whether the procedures for fracture toughness testing developed by the metals community were applicable to the aluminum/PTFE composite material. Standard ASTM E1820 fracture toughness specimens were machined from a 14 mm thick sheet of PTFE material. Since the PTFE materials exhibits high ductility and no apparent fracture initiation when loaded quasi-statically at ambient temperature, a series of tests was performed at reduced temperature(s) and high rate(s) to explore just what conditions led to fracture initiation. The fracture toughness was then quantified using the J-integral.

Response of Tapered Composite Structures to Torsional Loading

Researchers: Assistant Professor Peter J. Joyce, Poul Valsgaard (Aalborg University)
and Anthony Vizzini (University of Maryland)
Sponsor: Office of Naval Research (ONR)

The objective of this research was to characterize the behavior of tapered composite structures under torsional loading. Tapered composite beams have been investigated extensively during the last two decades because of their wide application in rotorcraft but also in the burgeoning field of wind energy. Tapered composite beams can be tailored to have varying strength along the length of the beam by using to terminating plies, thereby optimizing strength and removing excess weight. This introduces a complicated problem of intralaminar stresses throughout the structure. While the problem of stress distribution in tapered composite beams under tension loading is well understood in terms of the induced transverse stress and strains, the torsional problem is not. This research aims to use experiments together with numerical analysis to understand the torsional problem. Then using the principle of superposition the two cases of tension and torsion can be summed to describe any combination of tension and torsion.

A series of tension/torsion experiments was performed on model tapered composite beams 254 mm long, 38 mm wide and 4.6 mm thick in the thick end and 2.6 mm thick in the thin end. All of the beam specimens were manufactured from Hexcel IM7/8552 prepreg (an intermediate modulus carbon fiber/toughened epoxy system). All of the specimens consisted of 28 layers in the thick end and 16 layers in the thin end with plies dropped off in two pairs of two to maintain symmetry along the length. Three different layups were tested. Both ends of the specimen were clamped in a set of grips. The load was applied as a moment and a tensional load. In some tests the tensional load was negligible, in others the tension was up to 80% of the failure load in pure tension. In all cases the load, torsion and shear strain was recorded.

Corrosion Effects on Structural Integrity

Researcher: Assistant Professor Michelle G. Koul
Sponsor: Air Force Aging Aircraft Program Office (ASC/AAA)

This effort will help to provide tools to depot persons responsible for selecting environmentally benign corrosion maintenance procedures for aircraft. The evolving maintenance philosophy of “predict and manage” requires additional corrosion maintenance protocols for the depot maintainers. This philosophy is aimed at replacing the “find-and-fix” approach that requires the removal of all corrosion when detected during planned depot maintenance. AFRL and/or their contractors provided corroded specimens for evaluation at USNA. Prior to providing the specimens to USNA, the corrosion damage was evaluated using the NDE technology being developed as a separate part of this program. The primary objectives of the work performed at USNA were: (1) Characterize the types of corrosion damage observed in as a function of alloy, exposure environment and corrosion protection technology, (2) analyze the corrosion damage within the context of the provided sample history, previous corrosion damage evaluations and repairs, and the NDE results and (3) evaluate the incorporation of this data into structural integrity and lifetime predication models. Experimental data and analysis tools have been developed. The research results have been documented in a *Corrosion* journal paper submitted in July 2002.

Topographical Evaluation of Structural Damage

Researcher: Assistant Professor Michelle G. Koul
Sponsor: S&K Technologies, Dayton, OH

As aircraft lifetimes are extended, corrosion of aging aircraft materials has become a driver for re-evaluating current management philosophies due to increased risk and cost, and decreased readiness. The idea is to change to a more selective management scheme where corrosion damage is evaluated prior to repair. In order to implement this new philosophy, careful characterization and quantification of corrosion damage are required. AFRL and/or their contractors have provided corroded specimens for evaluation at USNA. The specimens provided were exposed at various Air Force Bases for 6, 9 and 12 month periods. Laser profilometry was used to evaluate the surface condition of these specimens. Analysis tools have been developed that provide a quantitative measurement of corrosion damage. MATLAB was used for post-processing of the data and visualization. A Java program was developed to quantify the corrosion damage information in the form of a histogram, or a distribution of damage. Most specimens showed minimal corrosion, however specimens exposed at Tyndall AFB showed pitting corrosion with pit depths on the order of 1-mil. The two fractured fatigue specimens provided did not show any differences in damage state via this analysis that could account for differences in fatigue life.

Determination of Clearance Requirements Around Obstructions in Finned Coldplates

Researcher: Professor Steven M. Miner
Sponsor: Naval Research Laboratory (NRL)

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

Multi-Functional Coatings for Military Applications

Researchers: Associate Professor Angela L. Moran
and Dr. Brian Connolly (ONR Post-Doctoral Fellow)
Sponsors: Air Force Multi-University Research Initiative (MURI) Program
and Air Force Office of Sponsored Research (AFOSR)

This effort in support of Multi-University Research Initiative (MURI) project headed by researchers at the University of Virginia seeks to identify the next generation military coating system that will provide a significant evolutionary advancement in performance from the standpoint of mission safety, corrosion protection, and environmental compatibility. The opportunity exists to create a metallic cladding that is easily field applied and has a range of functions to improve corrosion performance, coating adhesion, and provide active corrosion protection (i.e. self-healing). This can be accomplished through implementation of thermal spray technology and the use of nanocrystalline or amorphous matrix metallic glasses such as the Al-transition metal (TM)- rare earth (RE) glasses. A central characteristic of amorphous/ nano-crystalline materials is the ability to supersaturate desired alloying elements to produce a material with superior corrosion performance, as well as high strength, ductility, and wear resistance. Al-based metals have been thermally sprayed in air from wire, ribbon, or powder stock using several thermal spray techniques such as hand-held arc spraying and plasma spraying. Small panels have been produced for materials characterization and corrosion testing. Control claddings have been compared to newer compositions aimed at multi-

functionality. Fatigue life at several stress values have been determined for coated versus uncoated AA2024-T3 in a saltwater environment. Electrochemical inhibition of pitting and other forms of local corrosion, known to reduce fatigue lifetimes, will be distinguished from reductions in purely mechanically-driven fatigue processes by conducting tests in air, in benign solutions and in corrosive solutions. Mechanistic information on factors improving the fatigue resistance of high strength Al alloys will be obtained.

Evaluation of the Environmentally Assisted Cracking Performance of Candidate Aluminum Alloys for Replacement of AA7075-T6Aaircraft Structures

Researchers: Associate Professor Angela L. Moran, Assistant Professor Michelle G. Koul
and Dr. Brian Connolly (ONR Post-Doctoral Fellow)
Sponsor: Office of Naval Research (ONR)

The objective of this effort is to evaluate the environmentally assisted cracking (EAC) performance of two high strength candidate alloys (AA7249-T76511 and AA7150-T77511) that are being considered for replacement of corrosion-prone AA7075-T6 aircraft extrusions. Previous work has optimized the retrogression and re-aging (RRA) process for AA7249 extrusion with regard to strength and the RRA temper can be evaluated as part of this program. In addition, the crack propagation rate of these materials can be evaluated as a function of the aqueous chloride concentration in order to fully characterize the EAC performance. The focus of this program is the evaluation of EAC propagation rates (da/dt) as a function of applied stress intensity (K_{app}) for pre-cracked specimens. The EAC resistance is evaluated in the short transverse direction with regard to the primary working direction, which commonly represents the lower bound of EAC resistance, as well as the type of orientation obtained in structurally significant locations such as rivet holes. Two test methods are available to USNA for to assessing crack propagation rates. Fatigue pre-cracked double cantilever beam (DCB) specimens are bolt loaded at an initial value of applied stress intensity (K_{app}) and exposed to a NaCl solution, allowing the EAC crack to grow under a constant crack opening displacement and a decreasing K_{app}. The EAC crack propagation resistance is compared by plotting crack propagation rate (da/dt) versus $K_{app.}$ A value for the EAC threshold (K_{EAC}) is obtained from the K_{app} at which crack growth is arrested. The second technique is the rising step load (RSL) test. This test technique measures crack initiation (K_{EAC}) and propagation (da/dt) of immersed fatigue pre-cracked specimens under an increasing, stepwise K_{app}. The effect of crack tip chemistry on EAC propagation rates will be evaluated indirectly by varying the bulk chloride concentration from approximately $3x10^{-4}$ to 3.5 wt.% in a buffered solution. The fracture modes will be evaluated using scanning electron microscopy (SEM) and metallographic sectioning. Quantitative electrochemical evaluation of selected alloys can also be conducted.

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

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

AA7075-T6511 is used for the main structural components on a number of Naval and Air Force aircraft. T6511, or T6, describes the type of temper, which specifically is an artificial aging heat treatment. Although this temper results in high strength, it does not provide good resistance to environmentally assisted cracking (EAC). One heat treatment that can be applied to this alloy to enhance its EAC characteristics without sacrificing strength is called retrogression and re-aging (RRA). RRA consists of a short-time treatment of a T6 temper at an intermediate temperature followed by re-aging with a T6 aging treatment. The resultant aluminum has similar strength characteristics to a T6 temper, but it has improved resistance to EAC. Additionally, the Navy is currently considering the aluminum alloy AA7249 as a replacement for AA7075-T6511 extrusions. Initial testing has shown that the mechanical properties of AA7249-T76511 have met or exceeded the properties of AA7075-T6511 but the corrosion resistance characteristics of the final product form have not been documented. The objective of this effort is to evaluate the environmentally assisted cracking (EAC) performance of AA7249-T76511 as compared to AA7075-T6 utilized in aircraft extrusions. Previous work has optimized the retrogression and re-aging (RRA) process for AA7249 extrusion with regard to strength and the mechanical properties of the optimal RRA tempers will be further evaluated as part of this program.

Ceramic Matrix Composites and High Temperature Materials

Researcher: Associate Professor Angela L. Moran
Sponsor: Department of Energy Knolls Atomic Power Laboratory (KAPL)

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

High Temperature Copper Alloys for the Automotive Industry

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

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

Failures Analysis and Performance Evaluation of Sprinkler Heads

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

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

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

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

This research examined the need for the determination of neutron induced charge deposition in the design of radiation-induced microelectronics utilized in Navy Submarine Launched Ballistic Missile (SLBM) systems. The research to date has examined trends in the commercial and radiation hardened microelectronic industries. Next an investigation has been performed on specific neutron interactions and their effects on microelectronics. An experimental plan was developed to collected response data of Charge Collection Devices (CCDs) to fast neutrons. The first part of this plan was completed in December 2001 when experiments were conducted at White Sands, NM. The next experimental tests are planned for the U.S. Naval Academy in June 2002.

Evaluation of Soft Error Rates in Silicon on Insulator (SOI) Based Microelectronic Devices Design

Researchers: Professor Martin E. Nelson
and Visiting Professor James F. Ziegler (Physics Department)
Sponsor: Naval Research Laboratory (NRL)

A cooperative research investigation has been initiated between the Naval Research Laboratory (NRL) and the U.S. Naval Academy (USNA) to investigate the cause of single event upsets in rad-hardened Silicon-on-Insulator (SOI) microelectronic devices. Experiments are planned at USNA using the 14 MeV neutron generator as well as other Washington D.C. facilities to irradiate various devices in order to gain fundamental understanding of the cause of these failures. It is hoped to identify the major nuclear reaction responsible for the observed SEUs. As these microchips contain boron, the results of previously performed measurements and the recently completed Trident Scholar project with a calibrated neutron detection system by Midshipman 1/C John D. Dirk, USN should be of great use to the project.

Measurement Dose Response to 14 MeV Neutrons of Silicon Oxide Diodes

Researcher: Professor Martin E. Nelson
Sponsor: Korean Atomic Energy Research Institute (KAERI)

Silicon oxide diodes undergo a change in both resistance and threshold voltage due to atomic displacements upon radiation with neutrons with energies greater than 4 MeV. It is the purpose of this project to measure the change in threshold voltage as a function of neutron dose. In this project, devices were radiated with neutron doses that varied from zero to 1000 rads using the Naval Academy's 14 MeV neutron generator. Results were then compared with the diodes response to lower energy neutrons.

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

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

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 promotes 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 at NASA Glenn and continue at the Naval Academy in a single passage turbine cascade installed in a low speed wind tunnel. A series of baseline cases has been completed, including measurements at five different Reynolds numbers and two different free-stream turbulence levels. Surveys of velocity vs distance from the airfoil were acquired at eleven streamwise stations for each case using hot-wire anemometry. Spectral analysis of the turbulence has been completed. Two papers have been written and accepted for conference presentation and journal publication. A new series of experiments has just been completed using boundary layer trips of various heights to control the transition, separation and reattachment. These tests were conducted for all 10 of the conditions from the baseline cases.

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 that implements the use of computer software. Utilizing the thermodynamic based software CyclePad, Intelligent Computer Aided Instruction (ICAI) is incorporated in a basic Engineering Thermodynamics course (EM319) for engineering major students and an advance Energy Conversion Course (EM443) for mechanical engineering students. The use of the CyclePad software enhances lectures and aids students in visualization and design. The contents of undergraduate thermodynamics courses 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 that are difficult to solve or which involve parametric studies are usually not assigned because the long calculation would require an unreasonable time investment by the students. CyclePad allows users to concentrate on the fundamental engineering design principles without being distracted by the tedious computation and wrong input design data. As a consequence, students can do more comprehensive design and cover more material without necessarily devoting more study time to the course.

CyclePad introduces students to the concept of design as an open-ended process involving synthesis, analysis, and choices among design alternatives. It provides a valuable design aid by giving visualization of the schematic combination of a variety of thermodynamic cycles. This visualization allows the students to easily explore the effects that changing design parameters have on the behavior of a cycle. The approach of the CyclePad makes the learning of thermodynamic cycle design more exciting and results in more effective training of future designers. CyclePad has now been in use for design homework and projects, over a period of six semesters at the U.S. Naval Academy. The experience has been a positive one. The future version of the software will incorporate modifications suggested by users.

Independent Research

Computational Fluid Dynamics (CFD) Analysis of the Flow and Forces in a Centrifugal Pump Impeller

Researcher: Professor Steven M. Miner

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

Wavelet Analysis of Boundary Layer Transition Under Turbine Airfoil Conditions

Researcher: Associate Professor Ralph J. Volino

Boundary layer transition is an important phenomenon for the flow over gas turbine airfoils. As the flow moves over the airfoil, it transitions from laminar to turbulent flow. When this occurs, heat transfer rates and skin friction can increase significantly. To accurately predict the flow through a gas turbine engine, which is necessary for improved designs, transition must be predicted accurately. Transition under engine conditions is complicated by several factors, including the high background turbulence level and strong pressure gradients. The problem has been studied extensively, but is still not completely understood. During the Spring 2000 semester, Midshipman 1/C C.M. Pratt, USN made velocity measurements in the boundary layer on a flat plate. These data have now been studied using wavelet analysis. Transitional flow is intermittent, switching

between a laminar-like state and a turbulent-like state at any fixed position in the transition region. Wavelet analysis allows the separate spectral documentation of these laminar and turbulent flows. The streamwise and wall normal velocities were considered, along with the turbulent shear stress. Strong differences between the laminar and turbulent spectra were found. Appropriate scaling parameters for each zone were found, demonstrating considerable self-similarity within each zone, throughout the transition area. A paper has been written and accepted for conference presentation and publication.

Research Course Projects

Seamless Processing of Composite Tubes

Researcher: Midshipman 1/C Andrew Satorius, USN
Adviser: Assistant Professor Peter J. Joyce
Sponsor: Office of Naval Research (ONR)

This project demonstrated a process that combined filament winding of the fiber perform using an expandable mandrel with resin transfer molding (RTM) to manufacture seamless composite tubing. The trouble with conventional liquid composite molding commonly used to manufacture composite tubes is the two-piece mold construction which results in a lengthwise seam in the finished tubes. The expandable mandrel technique incorporates a high coefficient of thermal expansion (CTE) mandrel. The fiber perform is built up on the mandrel by dry filament winding. The pre-form and mandrel are fitted inside an outer mold of seamless drawn on mandrel steel tubing (chosen for its surface finish and the low CTE of the steel.) The pre-from is then infiltrated with resin using vacuum assisted RTM. The mandrel, composite, and mold are then oven cured at elevated temperature and then cooled.

A similar technique has been demonstrated in industry before but with a braided fiber perform, the objective of this project was to evaluate the feasibility of using filament winding instead to make the fiber perform. Four tubes were manufactured using this technique. Each tube was evaluated in terms of resin distribution and fiber volume fraction (using optical microscopy), void content (by visual inspection), and consistency of wall thickness. The expandable mandrel technique worked poorly with the filament wound fiber performs, it is thought that the accumulated winding tension constrained the thermal expansion of the mandrel, explaining the non-uniform fiber/resin distribution through the thickness, the poor void volume, and the inability to get the tubes to release from either the mandrel or the mold.

Compressive Strength Measurement of Polymer Matrix Composites Using Combined Shear/End Loading – a Feasibility Demonstration

Researcher: Midshipman 2/C Kevin Yost, USN
Adviser: Assistant Professor Peter J. Joyce
Sponsors: Office of Naval Research (ONR)
and Naval Air Warfare Center (NAVAIR), Patuxent River

This research investigated compression testing of textile composites through combined shear/end loading. Compression testing of advanced composites is difficult and in fact little consensus has been reached in the past three decades in terms of what technique to use. Primary structural applications of textile composites have only just begun to be explored in a market once thoroughly dominated by prepreg composites. On top of that the combined shear/end loading technique for measuring composite compression strength was only recently standardized by ASTM for use with multiaxial laminate composites. There is little to no experience to be found in the literature regarding compression testing of textile composites.

This project sought to explore the feasibility of the combined shear/end loading compression test method as described in ASTM D6641 for use in compression strength measurement of textile composites. For this work several composite panels were fabricated using wet layup from a plain weave (PW) glass fabric with room temperature curing epoxy to examine the feasibility of the combined shear/end loading compression test method. A mold was designed to contain the resin used to wetout the fibers. The effects of vacuum bagging and autoclave pressure on compressive strength were also investigated. Finally a pair of panels was fabricated from a PW carbon fiber fabric and a 350°F curing epoxy resin using wet layup. Specimens from the PW carbon fabric/350°F curing epoxy wet layup panel were tested along with test specimens provided by the Naval Air Warfare Center at Patuxent River manufactured from the same fabric and epoxy but by resin transfer molding.

Metallography of Aluminum Aircraft Wing Skin Material

Researcher: Midshipman 1/C Eric D. Severson, USN
Adviser: Assistant Professor Michelle G. Koul
Sponsor: Air Force Aging Aircraft Program Office (ASC/AAA)

Aircraft structural components made from wrought, high strength aluminum alloys, such as AA7075 and AA7178 are prone to intergranular and exfoliation corrosion in certain tempers. As part of the new Air Force aircraft corrosion management philosophy, the depots must be able to evaluate the exfoliation damage and determine if the current damage state requires repair, or can be delayed until the next inspection. In order to do this, the intergranular growth rates as a function of environment and alloy must be evaluated. AA7178 simulated wing skin samples exposed at numerous bases were examined through cross-sectional metallography. Cross-sectional metallography permitted the determination of the lateral rate of intergranular and exfoliation attack (penetration depth from the edge of the rivet hole) as well as the vertical rate (penetration rate in the through thickness direction). The distribution of attack and relevant statistical parameters (mean, standard deviation, and extreme values) were determined and compared to non-destructive evaluation of the samples obtained previously. A distribution of the lateral and vertical rates of intergranular and exfoliation corrosion as a function of exposure time at each base was obtained. Average rates were then compared to mass loss data as well as to certain environmental parameters for comparison to traditional environmental severity classification methodologies.

Thermal Spray Coatings for Aerospace Applications

Researchers: Midshipman 1/C Rob Kurrle, USN and Midshipman 1/C Rion Martin, USN
Advisers: Associate Professor Angela L. Moran
and Dr. Brian J. Connolly (ONR Post-Doctoral Fellow)
Sponsor: Air Force Office of Sponsored Research (AFOSR)

Aluminum-based metals used on commercial and military aircraft are usually operating in high stress environments and are generally exposed to corrosion. Thermal spraying different types of coatings on these metals can provide significant corrosion protection and a metallic coating of high strength, ductility, and wear resistance. Hand-held arc spraying, plasma spraying and HVOF spraying were evaluated to find which thermal spray method provides the optimal coating. Mechanical properties (bending and bond strength), corrosion fatigue resistance and microstructural variations were determined for each of the different coating methods.

The Environmentally Assisted Cracking of Aluminum Alloys for Aircraft Structures

Researchers: Midshipman 1/C Brendon Bielat, USN
and Midshipman 1/C Andrew Burkhardt, USN
Advisers: Associate Professor Angela L. Moran
and Dr. Brian J. Connolly (ONR Post-Doctoral Fellow)
Sponsor: Office of Naval Research (ONR)

Due to the highly corrosive environment in which Naval aircraft operate, the resistance of the aircraft alloys to crack initiation and propagation is significantly reduced. Environmentally-assisted cracking (EAC) dramatically affects the performance and lifetime of the aircraft. This project evaluated various 7000 series aluminum alloys and thermal treatments in order to identify improved alloys or processing methods to resist EAC. Corrosion testing (double cantilever beam and slow strain rate methods) and materials characterization were conducted on 7050, 7249,and 7040 aluminum alloys.

Spectrometry of Cosmic Ray Induced Neutrons in the Environment that Cause Single Event Upsets

Researcher: Midshipman 1/C Brian T. Murphy, USN
Advisers: Professor Martin E. Nelson
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Sponsor: International Business Machines (IBM) Corporation

Terrestrial cosmic rays, consisting of neutrons and other charged particles, cause soft errors in semiconductor devices such as SRAMs. Recent data indicates that the low energy neutrons, including thermal neutrons, dominate the soft error rate (SER) of memory chips. Additionally, published data indicates that the neutron flux can vary by over an order of magnitude, depending on the local ground environmental and shielding factors, such as building materials. This project examined the history and current state of fast neutron spectrometers in existence. These systems included the Bonner Sphere System, a Time of Flight (TOF) detector with liquid scintillation, the Rossi counter and superheated bubble dosimeters. After analysis, it was determined that both the TOF system and the Rossi counter were viable candidates to measure neutrons with kinetic energy up to 200 MeV.

Temperature Stabilization of a Reference Light Source for Use in a TLD Reader

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Sponsor: Naval Dosimetry Center

Thermoluminiscent dosimeters (TLDs) are used extensively throughout the Navy. However, reference light sources in TLD readers are subject to degrees of variation caused by temperature and/or other factors, which make the light useless for determining the effectiveness of the reader. Specifically, with regard to LED reference lights, the fluctuations in diode resistance over temperature causes for unacceptable instability. This project involved designing circuits based on use of LED and laser light sources that improved the stability of the system with regard to both temperature and wavelength. Equipment was procured and set-up in the Nuclear Laboratory at the U.S. Naval Academy in order to test the designs.

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

Researcher: Midshipman 2/C Crystine M. Good, USN
Adviser: Professor Martin E. Nelson
Sponsor: Defense Threat Reduction Agency

The illegal entry into the United States of special nuclear material (SNM) poses a significant security threat. SNM consists primarily of fissile material such as highly enriched uranium (HEU) or plutonium. The government tracks this material, and has reported that significant quantities are missing from foreign countries. This is an ongoing problem that requires more attention in detecting SNM.

There are two techniques that can be used to detect the presence or absence of SNM. One involves the use of passive radiation detection equipment and looking for spontaneous fission events. The second method uses an external neutron source to produce a given signal for a given quantity of SNM. While significant emphasis has been placed on the first approach, little or no study has been given to the second method. It is the goal of this project to investigate this latter approach.

The feasibility study was conducted by performing simulations using the MCNP radiation transport code. The site modeled was a large seaboard shipping container. A large neutron source was placed on one side of the sea container, while high efficiency neutron detectors were situated on the other side. Primary variables considered in the research included source type, location, and emission energy, number and location of neutron detector, cargo materials, and location and mass of the HEU within the container. The main output of the analysis was to optimize the detector interactions per source neutron emitted.

The Effect of Synthetic Jets on the Efficiency of the Low Pressure Turbine of a Gas Turbine Engine

Researcher: Midshipman 1/C Dirk H. Heron, USN
Adviser: Associate Professor Ralph J. Volino
Sponsor: NASA Glenn Research Center, Turbine Branch

At higher altitudes and lower Reynolds numbers the efficiency of low pressure turbines drops. This is due to boundary layer separation. It may be possible to prevent or control separation using either passive or active devices in the boundary layer. Passive devices stand statically in the flow, acting as a trip and helping to reduce separation. These devices, while improving efficiency at lower Reynolds numbers, may reduce efficiency at higher Reynolds numbers. In the present study, "synthetic" jets were used as an active device, which could be turned on and off at different Reynolds numbers. The synthetic jet is a small oscillating jet that is pulsed in and out of the airfoil surface, into the boundary layer. It has no net mass flow, but it does have a net momentum flux. The synthetic jets were placed along the turbine blade and supplied from an internal cavity in the blade. The cavity was connected to a loudspeaker, which was driven to produce the oscillating jets. The jets disrupted the flow over the blade, creating turbulence. Turbulent flow tended to keep the boundary layer from separating. A preliminary study was completed, showing that synthetic jets are capable of preventing separation, even at very low Reynolds numbers. Measurements included pressure surveys along the airfoil, along with velocity profile measurements near the trailing edge. The jet frequency did not appear to have a large effect, but the amplitude had to be sufficiently high for the jets to be effective.

Simulation and Potential Improvement of Naval Shipboard Power Plants

Researcher: Midshipman 1/C Darren S. Szerdy, USN
Adviser: Professor Chih Wu

The Brayton gas turbine cycle, the Rankine steam turbine and the diesel cycles are accurate models of performance for power generation machinery. Shipboard power generation originates from gas turbines, steam-driven turbines or diesel engines. Through a computer program called CyclePad, these systems are easily simulated with accuracy using realistic data. With the addition of intercoolers, regenerators or other heat exchangers, these systems can be adjusted for maximum efficiency, max power, minimum weight and space or a mix of different characteristics using CyclePad. The objective of this project was to simulate the current shipboard power plants, predict how the addition of mechanical devices would potentially improve shipboard engine performance and make recommendations based on the results. A computer program called CYCLEPAD provides a fast way to model and solve complicated engine problems. This program uses basic thermodynamic equations and working fluid properties to analyze different engine designs.

Trident Scholar Project

Electronic Reliability and the Environmental Thermal Neutron Flux

Researcher: Midshipman 1/C John D. Dirk, USN (Physics major)
Advisers: Professor Martin E. Nelson and Visiting Professor James F. Ziegler (Physics Department)
Sponsors: Office of Naval Research (ONR)
and International Business Machines (IBM) Corporation

Modern microelectronics are characterized by chips with extremely high bit densities, and when boron is used in the manufacturing process, they tend to be highly sensitive to thermal neutrons. When thermal neutrons, which originate from cosmic rays, interact with a nucleus of an atom, electrical charge is produced that can change the logic state of the cell. For example, in a memory cell this interaction could cause a zero to become a one, an occurrence know as a "bit flip". This phenomenon is also known as a single event upset (SEU) and is important problem facing computer manufacturers who employ this material in their microelectronics.

A final Trident Scholar report detailed the Naval Academy thermal neutron detection system, which is based on using a bare and borated silicon Helium-3 detector with pulse shape analysis. Calibration of the system was performed with experi-

ments at the Naval Surface Warfare Center (NSWC)-Carderock, at the Armed Forces Radiobiology Research Institute, and at the National Institute of Standards and Technology (NIST). Field measurements were performed around the Washington D.C.-Annapolis area at various locations in buildings with heavy concrete structures and light shielding. Experiments were also performed as a function of depth in water. Meantime to failure of modern microelectronic devices were calculated along with attenuation coefficients for concrete and water. All results were compared with previously published results and showed that the typical thermal neutron flux has a value of 6 neutrons/cm^2 hr with a 2x variation compared to previously published data, which showed a nearly 100 x variation in the thermal neutron flux between 1-100 n/cm^2 hr.

Publications

Journal (Refereed) Manuscripts

CERZA, Martin R., Associate Professor, Adams, J. C., Ireland, P. T. and Oswald, J., "Photographs on the Effect of Perforations on the Heat Transfer due to Laminar Flow over an Extended Surface," *The Journal of Heat Transfer*, Vol.124, n.4, August 2002.

> In the past it has not been resolved as to whether perforated surfaces on a fin enhance heat transfer. In this photographic study, which utilizes liquid crystal thermography, the evidence suggests that there is an increase in the local heat transfer coefficient in the vicinity of the downstream side of the perforations. The perforations appear to partially disrupt the thermal boundary layer and they appear to allow a partial restart of the boundary layer on the backside of the hole. For these series of photographs, a transient heating technique is employed. Helium at approximately 70ºC is allowed to flow through 5 perspex channels separated by 1 mm thick perforated fins. The channel cross sectional areas are 33 mm high by 13.1 mm wide. The channel length is 1 m. The initial temperature of the channels was 24ºC. A one-degree, narrow band, liquid crystal (30ºC color change temperature) was painted over the black painted center channel fin. The time history of the color change of the painted fin was recorded on a standard CCD video camera. The peak intensity-time relationships were obtained from image processing the recorded video and the heat transfer coefficients were evaluated using a transient thin fin heat transfer model. The helium temperature was measured at 5 locations along the channel. As can be seen, there appears to be a local heat transfer enhancement near the backside of the perforations. Comparisons are made to non-perforated fins in the channel Reynolds number range of 750-2500.

FLACK, Karen A., Associate Professor, Saylor, J.R., and Smith, G.B., "Near Surface Turbulence for Evaporative Convection," *Physics of Fluids*, Vol. 13, pp. 3338-3345 (2001).

> The near surface turbulence profiles of water undergoing evaporation was measured using laser Doppler anemometry, demonstrating for the first time the effect of surfactant mono-layers on the turbulence structure near the air/water interface. Measurements were obtained from a water surface that was covered with a surfactant mono-layer and also from a water surface that was nominally free of surfactants. Comparisons were made to previously obtained surface temperature measurements. The presence of a surfactant significantly decreased the near-surface turbulence in both the vertical and horizontal direction.

FLACK, Karen A., Associate Professor, Smith, G.B., SCHULTZ, M.P., Assistant Professor (Naval Architecture and Ocean Engineering Department), and Saylor, J. R., "The Correlation Between Surface Temperature and Subsurface Velocity During Evaporative Convection," *Experiments in Fluids*, Vol. 32, pp. 570-579 (2001).

> The cross-correlation between surface temperature and subsurface velocity is presented for water undergoing evaporative convection. The surface temperature measurements were obtained via quantitative infrared imaging, and the velocity measurements were obtained using a two-component laser Doppler velocimeter (LDV) system. The water surface was covered with a surfactant mono-layer, which did not impede evaporation. The largest

measured correlation coefficient was 0.375. Correlation coefficients obtained after shifting the velocity and temperature time traces with respect to each to each other revealed a peak in the correlation coefficient very close to a zero time shift. The significance of these results and their implications for remote sensing of underwater objects using infrared imaging is discussed.

FLACK, Karen A., Associate Professor and SCHULTZ, M.P., Assistant Professor (Naval Architecture and Ocean Engineering Department), "Experimental Investigation of Lift Modification on Double Delta Wings using Fillets," *American Institute of Aeronautics and Astronautics (AIAA) Journal of Aircraft*, Vol. 39, No. 2, pp. 377-379 (2002).

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

JOYCE, Peter J., Assistant Professor, Violette, M. G. and Moon, T. J., "Finite Element Analysis of Unidirectional Composite Compression Test Specimens: A Parametric Study," *Composite Materials: Testing, Design, and Acceptance Criteria, ASTM STP 1416*, A. Zureick and A. T. Nettles, (Eds.), American Society for Testing and Materials, pp. 30-68 (2002).

This research undertakes a comprehensive parametric study of the ASTM D 6641 Combined Loading Compression (CLC) test fixture from Wyoming Test Fixtures (WTF) using numerical analysis to evaluate various test parameters associated with compression testing of unidirectional test specimens. A two-dimensional finite element analysis of the D 6641 CLC fixture was used to identify loading conditions and tabbing configurations that minimized the peak axial, shear, and through-thickness stress concentrations in the test specimen. Combined shear and end loading appears to offer a good compromise between reducing the tab tip stress concentrations inherent in shear loading, and avoiding premature failure by end brooming associated with end loading. Thin, tapered tabs made of compliant materials were found to have the smallest stress concentrations at the tab tip. Specimens with these tab configurations should yield higher measured compressive strengths since premature failure at the tab tip is less likely to occur. Partial debonding of the tab tip was found to increase the stress concentration compared to the fully-bonded case, but to move its location away from the gage section of the specimen. Tab tip debonding should be avoided for compressive strength testing.

NELSON, Martin E., Professor, SARLESE, J.A., (Trident Scholar, Class of 2000), ZIEGLER, J.F., Visiting Professor (Physics Department), Muhlfeld, H., Peterson, R.J., Campbell, A., Melinger, J.S., Clark, K., and Thompson, A.K., "Cosmic Ray Induced Soft Error Rates of Commercial 16 Mb and 64 Mb DRAMS at Aircraft Altitudes," *Journal of Radiation Effects*, Vol. 19, pp. 100-106 (2002).

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

NELSON, Martin E., Professor, Phillips, G.W., Moscovitch, M., August,R.A., Campbell, A.B., Guardala, N.A., and Price, J. L., "Single Event Upset Neutron Detectors/Dosimeters," *Radiation Protection Dosimetry*, Vol. 101, Nos. 1-4, pp. 129-132 (2002).

Single Event Upset (SEU) Neutron Detectors are devices , which are based on the use of commercial-off-the shelf (COTS) solid-state memory devices. The purpose of these detectors is to provide a very compact, rugged, light weight and low power neutron detector. The basic concept of such a detector is to package one or more commercial low-power high density memory chips, modified for neutron sensitivity, along with a processor and a simple user interface. The paper describes the theory of the basic interactions on which the detector would be designed. Then calculations are given using recent SEU data with current 16 Mb and 64 Mb COTS devices, the system's expected neutron sensitivity. The paper concludes that these devices are practical and could have applications for nuclear waste management or arms control.

OSBORNE, Matthew C., ONR Post-Doctoral Fellow, Antenucci, Anthony, MORAN, Angela, L., Associate Professor, and Lauten, Fred, "A Formation of C/SiC Composites from a Commercially Available Pre-ceramic Polymer," *Ceramic Transactions*, 124, pp. 53-64 (2001).

The physical and mechanical properties of ceramic matrix composites (CMC's) are greatly affected by different fabrication techniques. Density, interphase strength, matrix cracking stress and ultimate strength can be tailored to fit the application by varying the composite's fiber lay-up and the conditions under which the pre-form is filled. Two common ways of producing SiC as the matrix in a CMC are 1) by chemical vapor infiltration (CVI) and 2) by polymer pre-cursor pyrolization. With the interface controlling the failure mode of the CMC, the matrix uniformity and consistency controls the repeatability (statistical distribution) of these failure modes. This study examined the physical property changes of a C/SiC CMC formed by the polymer conversion method.

Converted Ceraset™ MC's with graphite fibers were produced for this study at the Naval Academy. Homogeneity and porosity distribution were examined via optical microscopy. Density measurements were made via immersion in ethyl alcohol. A TGA was used to measure mass loss during heat-up. Results indicate that Ceraset loses 25% of its mass on heating to 2000°F under a N_2 and CH_4 atmosphere. The distribution of densities in the composite plate varied ±10% around the mean density of 1.68 g/cc. The majority of the porosity was open which allows continuing impregnation of the polymer into the composite. Therefore, dense, uniformly porous, composite plates were produced which should have repeatable failure characteristics.

OSBORNE, Matthew C., ONR Post-Doctoral Fellow and MORAN, Angela, L., Associate Professor, "A Stress Pattern Analysis by Thermal Emission of Plain Weave Carbon Fiber-Epoxy Iosipescu Specimens with Three Different Notch Angles," *The Journal of Test and Evaluation*, Vol.29, pp. 453-460 (2001).

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

PUZINAUSKAS, Paul V., Assistant Professor, MATHIS, W.M., (Trident Scholar, Class of 2000), and Dzieciuch, M.A.,"Quantification and Modeling The Effects of Thermal Shock on Combustion Pressure Transducers," *SAE Transactions Journal of Engines*, Vol.110-2, pp. 2139-2151 (2001).

This study's objective was to characterize thermal-shock errors on a specific Kistler pressure transducer and to determine if a thermal-shock correction algorithm using transducer surface temperature could be developed. Atmospheric measurements were made using a thermal-shock rig which intermittently exposed the transducer to a known heat flux while maintaining atmospheric pressure on the transducer diaphragm. Any change in output is attributable to thermal shock. Surface temperature was measured using a separate eroding-type surface thermocouple. The data showed a strong correlation between heat-flux-induced temperature change and thermal shock and were used in a least squares error estimation algorithm to create a model of the thermal shock as a function of transducer surface temperature. The model was calibrated using baseline measurements and tested against measurements made at different heat flux intensities and exposure duration and frequency. The model was able to remove approximately 95% of the error under all tested conditions.

SCHROEDER, James A., (Trident Scholar, Class of 1999), White, Dawn and MORAN, Angela, L., Associate Professor, "Evaluating Electrodes," *Practical Welding Today*, pp. 24-27 (2002).

Resistance welding has many challenges. Aluminum has a higher electrical and thermal conductivity than steel. The specific heat – heat required to change the temperature of a unit weight of material by one degree – and heat of fusion are high. Additionally, aluminum forms easily with copper. Because most spot welding electrodes are copper-based, this is a problem. In fact, aluminum is occasionally deposited on the electrodes as a result of the electrode force, even when no current is applied. This can lead to rapid electrode degradation which eventually shortens electrode life.

VOLINO, Ralph J., Associate Professor, Smith, G. B., Handler, R.A., and Leighton, R.I., "The Thermal Signature of a Vortex Pair Impacting a Free Surface," *Journal of Fluid Mechanics*, Volume 444, pp. 49-78 (2001).

The action of a rising vortex pair on the thermal boundary layer at an air-water interface is studied both experimentally and numerically. The objective is to relate variations in the surface temperature field to the hydrodynamics of the vortex pair below. The existence of a thermal boundary layer on the water side of an air-water interface is well known; it is this boundary layer which is disrupted by the action of the vortex system. Experimentally, the vortices were generated via the motion of a pair of submerged flaps. The flow was quantified through simultaneous measurement of both the subsurface velocity field, via digital particle image velocimetry (DPIV) and the surface temperature field, via an infrared ((IR) sensitive imager. The results of the physical experiments show a clearly defined disruption of the ambient thermal boundary layer which is well correlated with the vorticity field below. Numerical experiments were carried out in a parameter space similar to that of the physical experiments. Included in the numerical experiments was a simple surfactant model which enabled the exploration of the complex role surface elasticity played in the vortex-free surface interaction. The results of this combined experimental and numerical investigation suggest that surface straining rate is an important parameter in correlating the subsurface flow with the surface temperature field. A model based on surface straining rate is presented to explain the interaction.

VOLINO, Ralph J., Associate Professor, "Separated Flow Transition Under Low-Pressure Turbine Airfoil Conditions: Part 2 – Turbulence Spectra," American Society of Mechanical Engineers (*ASME) Journal of Turbomachinery*, Vol. 124, pp. 656-664 (2002).

Spectral analysis was used to investigate boundary layer separation, transition and reattachment under low-pressure turbine airfoil conditions. Cases with Reynolds numbers ranging from 25,000 to 300,000 (based on suction surface length and exit velocity) have been considered at low (0.5%) and high (9% inlet) free-stream turbulence levels. Spectra of the fluctuating streamwise velocity and the turbulent shear stress are presented. The spectra for the low free-stream turbulence cases are characterized by sharp peaks. The high free-stream turbulence case spectra exhibit more broadband peaks, but these peaks are centered at the same frequencies observed in the corre-

sponding low turbulence cases. The frequencies of the peaks suggest that a Tollmien-Schlichting instability mechanism drives transition, even in the high turbulence cases. The turbulent shear stress spectra proved particularly valuable for detection of the early growth of the instability. The predictable nature of the instability may prove useful for future flow control work.

WU, Chih, Professor, (co-author), "Exergy Analysis for a Braysson Cycle," *Exergy, an International Journal*, v.1, n.1, pp. 52-57 (2001).

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

WU, Chih, Professor, (co-author), "Optimization of the Rate of Exergy Output of a Multi-stage Endo-reversible Combined Refrigeration System," *Exergy, an International Journal*, v.1, n.2, pp. 100-106 (2001).

A general endo-reversible refrigeration cycle model which includes the irreversibility of heat transfer across finite temperature difference and the heat leak loss between the external heat reservoirs is used to analtyze the rate of exergy output of a multi-stage combined refrigeration system. The relations between the rates of exergy output and refrigeration and between the rates of exergy output and coefficient of performance are derived.

WU, Chih, Professor, (co-author), "Thermodynamic Analysis of Energy Intensive Systems Based on Exergy-topological Models," *Exergy, an International Journal*, v.1, n.3, pp. 173-179 (2001).

Improving the efficiency of energy intensive systems is a major challenge. The primary conventional techniques for tackling such problems are thermodynamic analysis and optimization. This paper describes an innovative general approach called the structural exergy analysis method for thermodynamic analysis of systems with arbitrary structures. The innovative method is based on the construction and analysis of a particular exergy-topological model. An example of its application to a gas turbine installation is provided.

WU, Chih, Professor, (co-author), "Effect of Heat Transfer Law on the Finite Time Exergoeconomic Performance of a Carnot Heat Pump," *Exergy, an International Journal*, v.1, n.4, pp. 295-302 (2001).

The operation of a Carnot refrigerator is viewed as a production process with exergy as its output. The economic optimization of the endoreversible refrigerator is carried out in this paper.

WU, Chih, Professor, (co-author), "Exergy Efficiency Calculations of Energy Intensive Systems," *Exergy, an International Journal*, v.2, n.2, pp. 78-86 (2002).

An innovative method for the exergy efficiency calculation of a complex energy intensive system with arbitrary structures is described in this paper. The method is based on a general equation to calculate the total system exergy efficiency, and on an exergy flow graph. This approach allows a user to obtain not only the exergy efficiency of the total system, but also to show the relationship between the exergy efficiency of an individual element and that of the whole system.

WU, Chih, Professor, (co-author), "The Equivalent Combined Cycle of a Chemical Potential Transformer Affected by the Irreversibility of Finite-rate Mass Transfer," *Exergy, an International Journal*, v.2, n.2, pp.119-124 (2002).

It is shown that a chemical potential transformer operating among three reservoirs at different chemical potentials is analogous to a heat transformer operating among three heat reservoirs. When the influence of the irreversibility of finite-rate mass transfer between the working fluid and the reservoirs is taken into account, a chemical potential

transformer may be conceived as a combined system having a chemical pump driven by a chemical engine. The fundamental optimal relations of the chemical engine and pump operating between two reservoirs are used to derive the fundamental optimal relation of the chemical potential transformer. Consequently, it is proved that such a combined cycle system is equivalent to the chemical potential transformer operating among three reservoirs at different chemical potentials. Moreover, the main optimal performances of the chemical potential transformer are discussed. The results obtained here may reveal some inherent connections between the chemical potential transformer and the chemical engine and provide some theoretical bases for the development of chemical potential transformers.

WU, Chih, Professor, (co-author), "Accoustically Controlled Heat Transfer of Ferromagnetic Fluid," *International Journal of Heat and Mass Transfer,* v.44, pp. 4427-4432 (2001).

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

WU, Chih, Professor, (co-author), "The Specific Heats of Gases in an Arbitrary Process," *International Journal of Mechanical Engineering Education,* v.29, n.3, pp. 227-232 (2001).

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

WU, Chih, Professor, (co-author), "Heating Load Versus COP Characteristics for Irreversible Air Heat Pumps," *International Journal of Power and Energy Systems,* v.21, n.2, pp. 105-111 (2001).

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

WU, Chih, Professor, (co-author), "Collector Performance Prediction of a Solar Ground Source Heat Pump," *International Journal of Power and Energy Systems,* v.21, n.3, pp. 136-141 (2001).

The heat output of a solar collector, which is used for solar ground source heat pump, is predicted in this paper. Valuable numerical results are obtained.

WU, Chih, Professor, "Environmental Impact and Design of an OTEC Plant," *International Journal of Global Energy Issues,* v.15, n.3/4, pp.186-194 (2001).

This paper presents a critical examination of the environmental impact and design Optimization of a potential OTEC power plant on the island of Diego Garcia in the Indian Ocean. Specific power of a finite time thermodynamic heat engine is chosen to be the objective function in the design of the OTEC. An ICAI computer software is used in the analysis process. Through manipulation of the boiler pressure and condenser pressure, the specific power of the OTEC plant is optimized.

WU, Chih, Professor (co-author), "Power Density Optimization for an Irreversible Regenerated Closed Brayton Cycle," *Physica Scripta*, v.64, pp. 184-191 (2001).

Analytical formulae about the relations between power density and pressure ratio are derived with heat resistance losses in the hot- and cold-side heat exchangers and the regenerator, the irreversible compression and expansion losses in the compressor and turbine, and the pressure drop loss in the piping of a regenerated closed Brayton cycle.

WU, Chih, Professor, (co-author), "Optimal Performance of a Generalized Irreversible Carnot Heat Pump with a Generalized Heat Transfer Law," *Physica Scripta*, v.64, pp. 584-587 (2001).

The sole irreversibility considered in an endo-reversible Carnot heat pump is the loss of heat resistance between the heat pump and its surrounding heat reservoirs. This paper presents a generalized irreversible Carnot heat pump model by taking into account several additional internal irreversibilities of the heat pump such as heat leakage, friction, turbulence and other undesirable irreversibility factors. This is done by means of a constant parameter and a constant coefficient, together with the loss of heat resistance. The relation between optimal heating load and COP is derived.

WU, Chih, Professor, (co-author), "Optimum Allocation of Heat Exchanger Inventory of Irreversible Air Refrigeration Cycles," *Physica Scripta*, v.65, pp. 410-415 (2002).

The finite time thermodynamics is applied to analyze the performance of irreversible air refrigeration cycles in this paper. The influences of various parameters on the characteristics of the cycle are derived. The results obtained may provide guidance for the design of practical air refrigeration plants.

WU, Chih, Professor, (co-author), "Cooling Load Density Analysis and Optimization of an Endo-reversible Air Refrigerator," *Open Systems and Information Dynamics*, v.8, n.2, pp. 147-155 (2001).

The performance analysis and optimization of an endo-reversible air refrigerator is carried out by taking the cooling load density as the optimization objective in this paper. The results obtained are different from those with the Cooling load objective. Numerical examples show the effects of pressure ratio and allocation of heat exchanger inventory on the cooling load density of the refrigerator.

WU, Chih, Professor, (co-author), "Power Density Optimization for an Irreversible Closed Brayton Cycle," *Open Systems and Information Dynamics*, v.8, n.3, pp. 241-260 (2001).

The power density of an irreversible closed Brayton cycle is taken as objective for performance optimization. The analytical formulas about the relationship between power density and pressure ratio are derived. The maximum power density optimization is performed by searching the optimum heat conductance distribution corresponding to the optimum power density of the hot- and cold-side heat exchangers.

WU, Chih, Professor, (co-author), "Optimal Zone on the Performance of a Generalized Irreversible Magnetic Stirling Refrigerator," *Open Systems and Information Dynamics*, v.8, n.3, pp. 291-301 (2001).

Finite time thermodynamic performance of a generalized irreversible magnetic Stirling cryocooler coupled to constant-temperature heat reservoirs has been analyzed in this paper. The relationship between the optimal cooling load and the COP of the magnetic Stirling cryocooler is derived. The optimization zone on the performance of the cryocooler is obtained.

WU, Chih, Professor, (co-author), "Power Density Analysis for a Regenerated Closed Brayton Cycle," *Open Systems and Information Dynamics*, v.8, n.3, pp. 377-391 (2001).

The power density is the objective in this paper for performance analysis of an irreversible regenerated and closed Brayton cycle coupled to constant temperature heat reservoirs from the view point of finite time thermodynamics. The analytical formula about the relationships between power density and pressure ratio are derived. The results obtained are compared with those obtained by using the maximum power criterion.

WU, Chih, Professor, (co-author), "Optimal Configuration and Performance of Heat Engines with Heat Leak and Finite Heat Capacity," *Open Systems and Information Dynamics*, v.9, n.2, pp. 85-96 (2002).

The optimal configuration of a class of two-heat-reservoir heat engine cycle in which the maximum work output can be obtained under a given cycle time is determined with the consideration of heat leak, finite heat capacity high temperature source and infinite heat capacity low temperature sink. The relations between the optimal power output and the efficiency of three configurations are derived, and it is shown that the heat leak most affects the power versus efficiency characteristics of the heat engine cycles.

WU, Chih, Professor, (co-author), "The Maximum COP of a Two-stage Combined Heat Pump System Affected by Multi-irreversibilities," *International Journal of Ambient Energy*, v.22, n.3, pp. 163-168 (2001).

A general cycle model which includes the multi-irreversibilities often existing in real heat pump systems is established and used to analyse the influence of the irreversibility of finite rate heat transfer across finite temperature differences, the heat leak between the external heat reservoirs, and the internal dissipation of the working fluid on the performance of a two-stage combined heat pump system. The COP is taken as an objective function for optimization. The maximum COP with non-zero specific heating load is determined.

WU, Chih, Professor, (co-author), "Ecological Optimization of an Irreversible Stirling Heat Engine," *International Journal of Ambient Energy*, v.22, n.4, pp. 211-220 (2001).

A general cycle model of an irreversible Stirling heat engine using an ideal Van der Waals gas as the working fluid is established. Three irreversibilities are included in the analysis. The ecological function is taken as an objective function for optimization. The performance characteristics of the Stirling heat engine at maximum ecological function are revealed.

WU, Chih, Professor, (co-author), "Ground Heat Exchanger Temperature Distribution Analysis and its Experimental Verification," *Applied Thermal Engineering*, v.22, n.2, pp. 183-189 (2002).

The underground two dimensional symmetry temperature field of a vertical double spiral coil ground heat exchanger designed by the authors for a ground source heat pump system was simulated using the volume control method. A heat transfer model of underground coil is made, and the underground temperature distribution of the coil was solved numerically. Experimental temperature data are measured. The analytical results are compared thoroughly with the experimental data.

WU, Chih, Professor, (co-author), "Performance Comparison of an Endo-reversible Closed Variable-temperature Heat Reservoir Brayton Cycle Under Maximum Power Density and Maximum Power Conditions," *Energy Conversion and Management*, v.43, n.1, pp. 33-43 (2002).

The analytical formula among the relations of power density, pressure ratio, heat resistance losses in the hot and cold side heat exchangers are derived. A power plant design with maximum power density leads to a higher efficiency and smaller size.

WU, Chih, Professor, (co-author), "Maximum Work Output of an Electric Battery and its Load Matching," *Energy Conversion and Management*, v.43, n.2, pp. 241-247 (2002).

A simple battery model is used to investigate the basic question of how to maximize the work output of an electric battery. The discharge time is determined reasonably and the load resistance is matched optimally. The results obtained in this paper can be used to explain quantitatively the examples given by Gyftopoulos.

WU, Chih, Professor, (co-author), "Performance Characteristics of a Magnetic Stirling Cooler," *International Journal of Energy Research*, v.26, n.3, pp. 217-228 (2002).

The quantum mechanics model of a magnetic Stirling cooler is established. The optimal relation between the cooling load and the COP is obtained. The maximum cooling load and the corresponding COP as well as the maximum COP and the corresponding cooling load are derived. The optimization criteria for a magnetic Stirling cooler are determined.

WU, Chih, Professor, (co-author), "Traveling Wave Solution of Heat Transfer for Small Samples Moving in the Sub-cooled Liquid Nitrogen," *International Journal of Engineering Science*, v.40, n.6, pp. 673-691 (2002).

The temperature field of a traveling wave in a system is analyzed. The system consists of a rapidly moving small specimen tube and subcooled liquid nitrogen. The temporal and spatial temperature distribution of the subsonic wave is investigated. The relationship between a dimensionless cooling rate and thermal Mach number is derived.

WU, Chih, Professor, (co-author), "Intelligent Computer Aided Design, Analysis, Optimization, and Improvement of Thermodynamic Systems," *Computer Applications in Engineering Education*, v.9, n.4, pp. 220-227 (2002).

An intelligent computer aided instruction software to aid teaching, design, and optimization of thermodynamic systems is presented. The concept of articulate virtual laboratory, the role of design, the ICAI software, and the use of AVL at the U.S. Naval Academy are described.

Conference Proceedings

CERZA, Martin R., Associate Professor, HERRON, R. C., (Trident Scholar, Class of 2001) and HARPER, Mark J., Professor, "The Effect of Sink Temperature on a Capillary Pumped Loop Employing a Flat Evaporator and Shell and Tube Condenser," *2001 International Mechanical Engineering Congress and Exposition*, Symposium Session 12DI - Heat Pipes and Capillary Pumped Loops for Electronic Cooling, 11-16 November 2001. (CD-ROM)

An experimental facility for conducting research on capillary pumped loop (CPL) systems was developed. In order to simulate shipboard cooling water encountered at various locations of the ocean, the heat sink temperature of the facility could be varied. A flat plate, CPL evaporator was designed and tested under various heat sink temperatures. The sink temperature ranged from 274.3 to 305.2 K and the heat input varied from 250 to 800 W which corresponds to heat fluxes up to 1.8 W/cm^2. The CPL flat plate evaporator performed very well under this range of heat input and sink temperatures. The main result obtained showed that a large degree of subcooling developed between the evaporator vapor outlet line and liquid return line. This condensate depression increased with increasing heat input.

CONNOLLY, Brian, J., ONR Post-Doctoral Fellow, McCaw, Robert, Pugh, James, Scandell, Ken and MORAN, Angela, L., Associate Professor, "Thermal Sprayed Aluminum Alloy Cladding for Aircraft Skin Replacements," *Proceedings of the Tri-Services Corrosion Conference*, San Antonio, TX, January 2002. (CD-ROM)

Although universally used, commercially available roll bonded aluminum claddings have limited corrosion fatigue performance in military applications. The goal of this effort, which is part of an Air Force Multi-University Research Initiative (MURI) Program to develop next generation multi-functional coating systems, is to replace these current claddings with a thermally sprayed aluminum or aluminum alloy coating. Specifically the new thermal sprayed cladding would be used to increase the corrosion fatigue lifetime of the aircraft skin. Thermally sprayed amorphous/nano-crystalline materials are desirable due to their ability to supersaturate desired alloying elements to produce superior corrosion performance as well as high strength, ductility, and wear resistance. The application of the thermal spray can be tailored to place the metal substrate in compression for improved fatigue resistance. Aluminum based metals will be thermally sprayed in air from powder stock on AA2024 thin sheet using several techniques including flame-arc, plasma, and HVOF spraying. In the first stage of this program the effect of compressive stresses introduced by thermal sprayed layers on fatigue life in ambient lab air will be investigated. Bending fatigue specimens of AA7075-T6, AA2024-T3 will be used as a control for comparison to AA2024-T3 specimens coated with thermally sprayed 99.0-99.8 wt% pure aluminum, and to conventional AA7075-Alclad, and AA2024-Alclad systems. Future stages of this project will investigate the effects of thermal sprayed coatings on corrosion fatigue lifetime as well as incorporating the use of exotic aluminum alloy systems (e.g., cerium additions) aimed at developing a multi-functional thermal sprayed coating system. This paper will discuss the advantages and disadvantages of the different thermal spray methods for producing advanced coatings as well as progress to date with the program.

FERRER, Charles F., (Trident Scholar, Class of 2001), KOUL, Michelle G., Assistant Professor, CONNOLLY, Brian J., ONR Post-Doctoral Fellow, and MORAN, Angela L., Associate Professor, "Utilization of Low Temperature Retrogression and Re-Aging (RRA) Heat Treatments to Improve Strength/SCC Properties for Thick Section Components of Aluminum Alloy 7075 for Aging Aircraft Refurbishment," *NACE 2002 Conference*, Paper No. 02159, Denver, CO, April 2002.

Aluminum alloy 7075, a common material in the aerospace industry, is susceptible to intergranular stress-corrosion cracking (SCC) in the T6, or peak-aged temper. The susceptibility of this temper to SCC is alleviated through the use of the T73, or overaged temper that provides SCC resistance, but at a 10-15% strength loss compared to the T6 temper. Experimental test results by Cina and Ranish indicated that retrogress and re-aging (RRA) heat treatments with retrogression performed at 200-280°C for less than 10 minutes reduce the traditional trade-off between T6 strength and T73 SCC resistance. However, the short time heat treatment limited the applicability of RRA to thin sections of material. The primary goal of this effort was to determine if lower retrogression temperatures could be used in the RRA process to extend the applicability of this heat treatment to thick section aircraft components. Tensile, fatigue, fracture toughness, and hardness tests were conducted to characterize the mechanical properties of T6, T73, and various RRA tempers. Alternate immersion (AI) and double-cantilever beam (DCB) tests were conducted to evaluate the SCC resistance of the different tempers. Improvements in properties were demonstrated using RRA heat treatments at lower temperatures and longer times than those previously investigated. In general, the various RRA tempers below 200°C produced strengths similar to that of T6 with lower crack growth rates.

FERRER, Charles F., (Trident Scholar, Class of 2001), KOUL, Michelle G., Assistant Professor, CONNOLLY, Brian J., ONR Post-Doctoral Fellow, and MORAN, Angela L., Associate Professor, "Low Temperature Retrogression and Re-Aging Heat Treatments for Thick Section Components of Aluminum Alloy 7075 for Aging Aircraft Refurbishment," *Proceedings from the Tri-Service Corrosion Conference*, San Antonio, TX, January 2002. (CD-ROM)

Aluminum alloy 7075, commonly used on military aerospace platforms, is susceptible to intergranular stress-corrosion cracking (SCC) in the peak strength T6 temper. The susceptibility of this temper to SCC is alleviated through the use of the T73, or overaged temper, that provides improved SCC resistance, but with a 10-15% strength loss compared to the T6 temper. Experimental test results by Cina and Ranish indicated that retrogress and re-aging (RRA) heat treatments reduce the trade-off between T6 strength and T73 SCC resistance. However,

the short time heat treatment used limited the applicability of RRA to thin sections of material. The primary goals of this research effort were to determine if lower retrogression temperatures could be used in the RRA process to extend the applicability of this heat treatment to thick section aircraft components and to quantify any observed improvements. Alternate immersion (AI) and double-cantilever beam (DCB) tests were conducted in a 0.6 M NaCl solution to evaluate the SCC resistance of various tempers. Improvements in properties were demonstrated using RRA heat treatments at lower temperatures and longer times than those previously investigated. In general, the various RRA tempers below 200°C produced strengths similar to that of T6 with improved SCC properties. The RRA temper with retrogression at 160°C for 660 minutes produced the greatest improvement, with only a 4% reduction in strength below T6. As an added benefit, heat transfer analysis indicated the RRA tempers with lower retrogression temperatures and longer retrogression times are more viable for use in industry for thick section components.

JOYCE, Peter J., Assistant Professor, Boswell, R. F. and Graf, N. A, "Thermal Characterization and Process Modification of an RTM Epoxy Resin," *Proceedings of the 33rd International SAMPE Technical Conference – Advancing Affordable Materials Technology,* Society for Advanced Materials Processing and Engineering, Covina, CA, 2001, pp. 1148-1157.

The objective of this research is to demonstrate to a high level of confidence the viability of an agile resin transfer molding (RTM) manufacturing process, also known as intelligent processing. One objective of the program was to evaluate novel resin systems for use in RTM processes. This focus of this paper is the thermal characterization of the selected SI- ZG-5A epoxy resin, formulated by A.T.A.R.D. Laboratories. This analysis consists of a comprehensive program of resin characterization and cure modeling. Modulated Differential Scanning Calorimetry (MDSC), rheology measurements and thermogravimetric analysis (TGA) were used to determine the cure kinetics, glass transitions, processing temperature and volatility during cure. A baseline glass transition (T_g), enthalpy of cure, and gel point during cure were developed using the manufacturer's recommended cure cycle. Once this analysis was complete, variations of the cure cycle were performed in order to determine if the cure cycle could be modified. Cure kinetics were also determined using the variable heating rate method. Finally, a study investigating the effect of mix ratio variations was begun, and preliminary results and cure models developed. In conclusion, the SI-ZG-5A resin system has been found to be a robust RTM resin by being forgiving of process variations.

JOYCE, Peter J., Assistant Professor, and Graf, N. A., "Evaluation of Automated RTM Processes and Materials for Naval Aircraft," *Proceedings of the 33rd International SAMPE Technical Conference – Advancing Affordable Materials Technology,* Society for Advanced Materials Processing and Engineering, Covina, CA, 2001, pp. 1133-1147.

The objective of this work is to demonstrate the viability of resin transfer molding (RTM) for naval aviation applications. The first goal was to evaluate the design and performance of the automated RTM equipment designed by Northwestern University (NWU) as part of the Advanced Materials Intelligent Processing Center (AMIPC) program. The second goal of this research was the selection and characterization of materials and processes for RTM of primary structural composites using multi-component resin systems. The third goal was to manufacture aerospace quality composites utilizing the selected resin systems and the NWU equipment to demonstrate feasibility for naval aircraft structural applications. The resin injection equipment was designed with the aim of providing increased control and repeatability of material metering, mixing, and delivery. Equipment trials have demonstrated these concepts and identified potential areas for improvement. This equipment was used to fabricate a series of test panels using a commercial two-part epoxy resin to study various process parameters such as injection flow rates and pressures, cure cycle modifications, mold styles, and fiber reinforcements. The automated injection equipment, along with the selected material systems, has demonstrated feasibility for naval aircraft applications by processing flexibility and excellent mechanical performance.

JOYCE, Peter J., Assistant Professor, BARTON, Oscar, Jr., Associate Professor and MOURING, Sarah E., Associate Professor (Naval Architecture and Ocean Engineering Department), "Evaluation of the Effect of Impact Damage on the Mechanical Response of Composite Sandwich Structures," *Proceedings of the 16th Annual Technical Conference of the American Society for Composites (ASC)*, CRC Press LLC, Boca Raton, FL, 2001. (CD-ROM)

This research seeks to evaluate the effect of impact damage on the mechanical response of composite sandwich structures. The sandwich panels in this investigation are under consideration for aerodynamic structural applications. A total of twenty-four panels, with varying levels of impact damage, were tested including four control panels containing no impact damage. The remaining twenty specimens were grouped according to the size of the impactor, which consisted of a 0.5 inch and 1.0 inch diameter impactor and impact energy. The impact energy levels consisted of 6 ft-lbs, 20 ft-lbs, and 35 ft-lbs, representing relatively low, moderate, and high impact energy levels. Properties investigated included both the compressive strength and elastic stiffness. Results are presented for the compressive strength. Each panel was manufactured using fiber placement technology and consisted of AQII/977-3 Astroquartz/Ep upper and lower face sheets and HRP/F50-5.5 Flexcore core. General results were correlated both with impactor size and energy level, and indicated a reduction of compressive strength with an increase in impact energy and impactor size.

JOYCE, Peter J., Assistant Professor, Boswell, R. F. and Graf, N. A., "Processability and Thermal Characterization of ATARD Epoxy RTM Resin," *Proceedings of the 16th Annual Technical Conference of the American Society for Composites (ASC)*, CRC Press LLC, Boca Raton, FL, 2001. (CD-ROM)

The Materials and Structures Divisions at the Naval Air Systems Command have teamed together along with industry to demonstrate to a high level of confidence the viability of an agile resin transfer molding (RTM) manufacturing process, also known as intelligent processing. Utilizing fabrication, analysis, modeling and testing efforts, this program will provide an assessment of the Northwestern University's advanced injector system. This paper's objective is to thermally characterize the selected SI- ZG-5A epoxy resin, formulated by A.T.A.R.D. Laboratories. This analysis consists of a comprehensive program of resin characterization and cure modeling. Modulated Differential Scanning Calorimetry (MDSC), rheology measurements and thermogravimetric analysis (TGA) were used to determine the cure kinetics, glass transitions, processing temperature and volatiles during cure. The manufacturer's recommended cure cycle was followed in order to establish a reference glass transition (Tg), enthalpy of cure and gel point during cure. Once this analysis was complete, variations of the cure cycle were performed in order to determine if the cure cycle could be modified. Cure kinetics were also determined using the variable heating rate method. In conclusion, the SI-ZG-5A resin system has been found to be a robust RTM resin by being forgiving of process variations. However, the effect of these variations on final mechanical properties is still being determined.

MINER, Steven M., Professor, and TYLER, Trevor N., Lieutenant, (USN), "A Project Based Introduction to Mechanical Engineering," *Proceedings of the 2001 American Society for Engineering Education (ASEE) Annual Conference*, Albuquerque, NM, June 2001. (CD-ROM)

The Mechanical Engineering Department at the Naval Academy has developed and instituted a new introductory course that all mechanical engineering majors are required to take. The goals of the course are to introduce the midshipmen to the major areas of study in mechanical engineering, to enhance the visualization skills of the midshipmen, and to introduce the midshipmen to the design process. For all three goals hands-on projects are used as the vehicle to introduce the midshipmen to mechanical engineering. The desire is to enhance their understanding and enthusiasm for the major, and to give them a basis for appreciating the sequence of engineering science courses. This paper describes the format and content of the course, and provides a brief description of the projects used to address each goal. In addition, results from the first two offerings of the course are discussed.

MINER, Steven M., Professor, "Computational and Experimental Investigation of the Velocities, Pressures, and Forces in a Single Volute Centrifugal Pump," *Proceedings of the ISROMAC9 Conference,* Honolulu, HI, February 2002. (CD-ROM)

Static pressure and laser velocimeter measurements recorded around the impeller periphery and along the casing wall of a single volute centrifugal pump are compared to results computed using potential flow. The time-averaged forces on the impeller are determined by integrating the pressure and momentum profiles around the impeller. These integrations are done for both the measured and computed results. Comparisons between the measured and computed results are presented for the velocities, pressures, and forces at design flow and 80% of design flow. Comparisons are also made to results previously reported in the literature.

OSBORNE, Matthew C., ONR-Post-Doctoral Fellow, HURLEY, Monica, Midshipman 1/C (USN), and MORAN, Angela L., Associate Professor, "Room Temperature Creep of Pb-Sn and Sn-Ag-Cu Eutectic Solders," *Proceedings of the 16th National Educators Workshop,* October 2001, pp. 75-86.

When a metal or an alloy is under a constant load or stress, it may undergo a progressive plastic deformation over a period of time. This time-dependent strain is called creep. Creep occurs at different rates, the rate being dependent on the stress level, material properties, and the application temperature. If a constant stress level is applied to a material, an increase in temperature can increase the creep rate. This characteristic is termed as a thermally activated process. Creep rate is also affected by the microstructure of the material, its prior processing and mechanical history, and its composition. When considering long term applications such as steam plants, nuclear power plants or gas turbine engines, it can be seen that creep rate is an extremely important property of a material to understand, for it can be regulated and controlled by the materials processing, environment, and application.

Books

WU, Chih, Professor, (co-author), "Thermodynamics, A Computer-based Approach," Kendall/Hunt Publishing Co., ISBN 0-7872-8902-7 (2001).

The book is a full-immersion intelligent computer aided thermodynamics. Included are basic concepts, finding properties, First law and Second law analysis for control mass and control volume systems, and thermodynamic cycle analysis. The book is the first computer software manuscript of its kind in thermodynamics.

Technical Reports

HURLEY, Monica, Midshipman 1/C (USN) and OSBORNE, M.C., ONR Post-Doctoral Fellow, U.S. Naval Academy Report # EW-01-01, "Materials Evaluation of SnAg Alternatives to PbSn Solders," June 2001.

When a metal or an alloy is under a constant load or stress, it may undergo a progressive plastic deformation over a period of time. This time-dependent strain is called creep. Creep occurs at different rates, the rate being dependent on the stress level, material properties, and the application temperature. If a constant stress level is applied to a material, an increase in temperature can increase the creep rate. This characteristic is termed as a thermally activated process. Creep rate is also affected by the microstructure of the material, its prior processing and mechanical history, and its composition. When considering long term applications such as steam plants, nuclear power plants or gas turbine engines, it can be seen that creep rate is an extremely important property of a material to understand, for it can be regulated and controlled by the materials processing, environment, and application.

KOUL, Michelle G., Assistant Professor, U.S. Naval Academy Report # EW-01-02, "Topographical Analysis of Corrosion in Al7075 Using Laser Profilometry – Part I," May 2002.

As aircraft lifetimes are extended, corrosion of aging aircraft materials has become a driver for re-evaluating current management philosophies due to increased risk and cost, and decreased readiness. The idea is to change to a more selective management scheme where corrosion damage is evaluated prior to repair. In order to implement this new philosophy, careful characterization and quantification of corrosion damage are required. The Air Force Research Laboratories (AFRL) and/or their contractors have provided corroded specimens for evaluation at the Naval Academy. The specimens provided were exposed at various Air Force Bases for 6, 9 and 12 month periods. Laser profilometry was used to evaluate the surface condition of these specimens. Analysis tools have been developed that provide a quantitative measurement of corrosion damage. MATLAB® is used for post-processing of the data and visualization. A Java program was developed to quantify the corrosion damage information in the form of a histogram, or a distribution of damage. Most specimens showed minimal corrosion, however specimens exposed at Tyndall Air Force Base showed pitting corrosion with pit depths on the order of 1-mil. The two fractured fatigue specimens provided did not show any differences in damage state via this analysis that could account for differences in fatigue life.

KOUL, Michelle G., Assistant Professor, U.S. Naval Academy Report # EW-02-02, "Topographical Analysis of Corrosion in Al7075 Using Laser Profilometry - Part II," May 2002.

As aircraft lifetimes are extended, corrosion of aging aircraft materials has become a driver for re-evaluating current management philosophies due to increased risk and cost, and decreased readiness. Interdisciplinary research programs are in place within which the groundwork is being laid to change the philosophy for maintenance of aging military aircraft. In particular, optimization of the Air Force aircraft maintenance program has focused on changing the corrosion management philosophy from the current "find-and-fix" technique to an "anticipate-and-manage" process. The idea is to change to a more selective management scheme where corrosion damage is evaluated prior to repair. In order to implement this new philosophy, careful characterization and quantification of corrosion damage are required. The Air Force Research Laboratories (AFRL) and/or their contractors have provided corroded specimens for evaluation at the Naval Academy. The specimens provided were exposed at various Air Force Bases for 6-month periods. Laser profilometry was used to evaluate the surface condition of these specimens and provide a qualitative measurement of corrosion damage. It is anticipated that this type of data will eventually be incorporated into structural integrity and lifetime predication models.

OSBORNE, Matthew C., ONR Post-Doctoral Fellow and MORAN, Angela, L., Associate Professor, year-end report to the Department of Energy (DOE), "USNA Investigation into CMC Damage Assessment Code," October 2001.

Candidate materials were fabricated into larger complex components and evaluated in an effort to extend the existing property database for high temperature ceramics. Analytical models were evaluated and developed to relate laboratory property measurements to component size and geometry. Extensive mechanical testing was completed to augment the analysis. The material system to test the validity of the various computer models/simulations is SiC/SiC with a carbon interface. Models were evaluated on the basis of a full range of thermal and mechanical data.

Presentations

CERZA, Martin, R., Associate Professor, Adams, J.C., Ireland, P.T. and Oswald, J., "Detailed Investigation of a Perforated Heat Transfer Surface Applied to Gas Turbine Recuperators," Symposium on Heat Exchanger Enhancement HEXAG, Oxford University, 24 October 2001.

CERZA, Martin, R., Associate Professor, Adams, J.C., and Ireland, P.T., "The Effect of Perforations on the Heat Transfer from an Extended Surface," 2001 International Mechanical Engineering Congress and Exposition, Session on Heat Transfer Photography, New York, NY, 11-16 November 2001.

CERZA, Martin, R., Associate Professor, HERRON, R.C., (Trident Scholar, Class of 2001) and HARPER, M. J., Professor, "The Effect of Sink Temperature on a Capillary Pumped Loop Employing a Flat Evaporator and Shell and Tube Condenser," 2001 International Mechanical Engineering Congress and Exposition, Session 12DI - Heat Pipes and Capillary Pumped Loops for Electronic Cooling, New York, NY, 11-16 November 2001.

CERZA, Martin, R., Associate Professor and LARSEN, E.H., Midshipman 2/C (USN), "Electronics Cooling Using Capillary Pumped Loops," U.S. Naval Academy Workshop on Electronics Cooling, Annapolis, MD, February 2002.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, and McCaw, Robert, Pugh, James, Scandell, Ken and MORAN, Angela, L., Associate Professor, "Thermal Sprayed Aluminum Alloy Cladding for Aircraft Skin Replacements," San Antonio, Tri-Services Corrosion Conference, San Antonio, TX, January 2002.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, and MORAN, Angela, L., Associate Professor, "Multi-Functional Cladding: Effects on Alloy Substrate," Air Force Multi-University Research Initiative (MURI) Program Meeting on Multi-Functional, Nano-Engineered Coatings, Charlottesville, VA, October 2001.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, FERRER, Charles P., (Trident Scholar, Class of 2001), KOUL, Michelle G., Assistant Professor, and MORAN, Angela, L., Associate Professor, "Low Temperature Retrogression and Re-Aging Treatments for Thick Section Components of Aluminum Alloy 7075 for Aging Aircraft Refurbishment," 2002 Tri-Service Corrosion Conference, San Antonio, TX, January 2002.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, and J.R. Scully, "The Transition from Localized Corrosion to SCC in an Al-Li-Cu-Ag Alloy," CORROSION/2002, Technical Symposium: Environmentally Assisted Cracking, NACE International, Denver, CO, April 2002.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, FERRER, Charles P., (Trident Scholar, Class of 2001), KOUL, Michelle G., Assistant Professor, and MORAN, Angela, L., Associate Professor, "Utilization of Low Temperature Retrogression and Re-Aging (RRA) Heat Treatments to Improve Strength/SCC Properties for Thick Section Components of Aluminum Alloy 7075 for Aging Aircraft Refurbishment," CORROSION/2002, Technical Symposium: Military Corrosion, NACE International, Denver, CO, April 2002.

CONNOLLY, Brian J., ONR Post-Doctoral Fellow, KOUL, Michelle G., Assistant Professor, and MORAN, Angela, L., Associate Professor "Evaluation of Environmentally Assisted Crack Propagation Rates of Candidate Aluminum Alloys for Replacement of AA7075-T6 Aircraft Structures," Gordon Research Conference, New Hampshire, July 2002.

FLACK, Karen A., Associate Professor, "Near Surface Turbulence for Evaporative Convection at an Air/Water Interface," research seminar presented at the VPI&SU Mechanical Engineering Department, 22 October 2001, at the Naval Research Laboratory, Remote Sensing Division, 7 November 2001, and at the Rice University Mechanical Engineering Department, 20 February 2002.

JOYCE, Peter J., Assistant Professor, BARTON, Oscar, Jr., Associate Professor and MOURING, Sarah E., Associate Professor (Naval Architecture and Ocean Engineering Department), "Evaluation of the Effect of Impact Damage on the

Mechanical Response of Composite Sandwich Structures," 16th Annual Technical Conference of the American Society for Composites, Blacksburg, VA, 9-12 September 2001.

JOYCE, Peter J., Assistant Professor, Boswell, Robert F., and Graf, Neil A., "Processability and Thermal Characterization of ATARD Epoxy RTM Resin," 16th Annual Technical Conference of the American Society for Composites, Blacksburg, VA, 9-12 September 2001.

JOYCE, Peter J., Assistant Professor, "Residual Strength Determination for Composite Sandwich Panels Subjected to Low Velocity Impact," SAMPE Student Chapter at University of Delaware, Center for Composite Materials, 2 October 2001. (Invited seminar)

JOYCE, Peter, J., Assistant Professor and Graf, Neil A., "Evaluation of Automated Resin Transfer Molding Processes and Materials for Naval Aircraft Components," 33rd International SAMPE Technical Conference, Seattle, WA, 5-9 November 2001.

JOYCE, Peter J., Assistant Professor, Boswell, Robert F., and Graf, Neil A., "Thermal Characterization and Process Modification of an RTM Epoxy Resin," 33rd International SAMPE Technical Conference, Seattle, WA, 5-9 November 2001.

KOUL, Michelle G., Assistant Professor, Cooper, Kevin, and Williams, Jackie, "Analyses of Exfoliation/IGA Coupons and Accelerated Laboratory Testing," Corrosion Effects on Structural Integrity Technical Information Exchange sponsored by the Air Force Aging Aircraft Program Office, Dayton, OH, April 2002.

MINER, Steven M., Associate Professor, "A Project Based Introduction to Mechanical Engineering," 2001 American Society for Engineering Education (ASEE) Annual Conference, Albuquerque, NM, June 2001.

MINER, Steven M., Professor, "Computational and Experimental Investigation of the Velocities, Pressures, and Forces in a Single Volute Centrifugal Pump," ISROMAC9 Conference, Honolulu, HI, February 2002.

OSBORNE, Matthew C., ONR Post-Doctoral Fellow, HURLEY, Monica, Midshipman 1/C (USN), and MORAN, Angela L., Associate Professor, "Room Temperature Creep of Pb-Sn and Sn-Ag-Cu Eutectic Solders," 16th Annual National Educators Workshop, Washington, D.C., October 2001.

NELSON, Martin E., Professor, MESSNER, G., Midshipman 1/C (USN), JENKINS, R. Brian, Associate Professor (Electrical Engineering Department), and Cassata J.R., "Development of a Temperature Sensitive Light Source for TLD," Health Physics Society, Tampa Florida, June, 2002.

VOLINO, Ralph J., Associate Professor, "Wavelet Analysis of Bypass Transition," 54th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, San Diego, CA, 19 November 2001.

VOLINO, Ralph J., Associate Professor, "Separated Flow Transition Under Low-Pressure Turbine Airfoil Conditions: Part 1 – Mean Flow and Turbulence Statistics," 2002 American Society of Mechanical Engineers (ASME) International Gas Turbine Conference, Amsterdam, The Netherlands, 3 June 2002.

VOLINO, Ralph J., Associate Professor, "Separated Flow Transition Under Low-Pressure Turbine Airfoil Conditions: Part 2 – Turbulence Spectra," 2002 American Society of Mechanical Engineers (ASME) International Gas Turbine Conference, Amsterdam, The Netherlands, 3 June 2002.

VOLINO, Ralph J., Associate Professor, "An Investigation of the Scales in Transitional Boundary Layers Under High Free-Stream Turbulence Conditions," 2002 American Society of Mechanical Engineers (ASME) International Gas Turbine Conference, Amsterdam, The Netherlands, 4 June 2002.

WU, Chih, Professor, "Exergy Efficiency Calculations of Energy Intensive Systems by Graphs," ECOS'01, Istanbul, Turkey, 4-6 July 2001.