Mechanical Engineering Department

Professor Patrick J. Moran
Chair

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

Projects active in this past year involve fracture mechanics, thermal systems design, materials processing and engineering, corrosion, vibrations, flow field studies, and internal combustion engines. In summary, the department was involved in 25 research programs, of which 16 were externally funded, 7 were midshipmen projects earning academic credit, and 2 other were independent projects. Research sponsors included the Office of Naval Research, Naval Surface Warfare Center, Naval Research Laboratory, Nuclear Regulatory Commission, Consumer Product Safety Commission, Ford Motor Company, National Air and Space Administration, Department of Energy, and the Air Force Research Laboratory. The department is grateful for the cooperation and support of these sponsoring agencies and organizations.

Sponsored Research

Mechanical Property Characterization of Impacted Compression Sandwich Panels

RESEARCHERS: Associate Professor Oscar Barton, Jr., Associate Professor Sarah E. Mouring and Assistant Professor Peter J. Joyce

SPONSORS: Office of Naval Research (ONR) and Great Lakes Composite Consortium (GLCC)

The study supported ongoing work in the Fiber Placed Inlet Duct Program. The researchers at the United States Naval Academy will provide technical support for several aspects of mechanical behavior and testing of composite structures. This support is intended to lead to a knowledge base for the utilization of fiber placed sandwich composite structure for advanced aircraft.

Testing for the Fiber Placed Inlet Duct Program will include static compression and damage testing of fiber placed sandwich structure specimens and will address structural integration of this component. Of particular interest is the affect impact damage has on the compressive properties of the panels. Impact damage will be undertaken at Northrop/Grumman. The sandwich panels are made of Quartz/Ep skins [60/-60/0/-60/60] with a F50 core cell. The Naval Academy will participate in the test program and will be tasked with input and evaluation of the results of the mechanical testing. Testing began in the Spring of 2000 and continued into the Summer of 2000.

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

RESEARCHERS: Associate Professor Karen A. Flack and Dr. Michael P. Schultz

SPONSOR: Office of Naval Research (ONR)

The junction of the leading edge extension (LEX) and the delta wing on the F/A-18 E/F aircraft is a region of highly complex vortex flows interactions. The region is important not only to the performance and stability of the aircraft, but may affect cyclical loading of the tail due to vortex buffet. The geometry of the junction is also critical in the overall radar signature of the aircraft. The objective of the present research is to compare the aerodynamic forces on a model with different LEX-wing fillet

configurations. Three fillet types were tested in this junction on a 1:28 scale F/A-18 E/F model in a low speed wind tunnel in the Aeronautics Laboratory at the United States Naval Academy. The fillets were found to have little effect on the aerodynamic forces on the model. This result is contrary to previous research on a flat plate model of a delta wing. Further test are being performed on a flat plat model of the same planform with and without a centerbody to compare to previous research and to investigate the accuracy of using two-dimensional models to model a three-dimensional vortex flows.

Surface Temperature and Subsurface Velocities for Evaporation

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

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

Elastic-Plastic Fracture Mechanics Technology for LWR Alloys

RESEARCHER: Professor James A. Joyce
SPONSOR: U.S. Nuclear Regulatory Commission

This research project involves investigations of fracture behavior of metallic alloys used in commercial nuclear power reactors and their components. The goals of the research are to develop the fracture mechanics technology and methodologies necessary for predicting the behavior of the reactor pressure vessel and reactor components containing flaws and to develop methodology to properly access the effects of radiation embrittlement using small scale surveillance specimens.

Work involves experimental testing, computational analysis, and NRC and ASTM fracture mechanics code and standards development. Most effort during the 1999-2000 time frame is being dedicated to defining methodologies in the ductile-to-brittle transition regime and has involved testing specimens from Charpy scale to full size 1T C(T), standard fracture mechanics specimens. Special short crack specimens have also been investigated because of their special low-constraint properties.

Managing Corrosion in the 21st Century: Strategic Corrosion Reduction Effort

RESEARCHER: Assistant Professor Michelle Gaudett Koul
SPONSORS: Air Force Research Laboratory and University of Virginia

This effort will 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 (PDM). Commercial, off-the-shelf (COTS) corrosion suppression technologies exist, but chemical suppression treatments (known collectively as Corrosion Suppression Compounds (CSC)) have been evaluated only on a limited basis to date. The appropriateness of these COTS technologies for specific, critical aircraft applications needs to be critically evaluated before they are recommended for depot use. In addition, emerging corrosion mitigation technologies that hold promise need to be identified and evaluated at an early stage in their development. In this way, any limitations can be identified and addressed efficiently. As funding permits, this effort will: (1) identify “corrosion hot spots” by specific aircraft where CSC application would be an appropriate PDM maintenance action, (2) map existing CSC technologies

to those areas identified, (3) identify gaps in the current state of the art where research and development efforts are needed to address application areas of interest, (4) test and evaluate the "matches" identified in (2), and (5) plan and execute research and development efforts in the "technology gap" areas identified in (3). A technical information meeting on Feb 28-29 2000 was attended. A meeting with the sponsor was held on May 16, 2000. Literature review is being conducted while awaiting specimens and equipment.

Ductile-Brittle Transition Range Fracture Toughness Characterization of RPV Steels

RESEARCHER: Associate Professor Richard E. Link
SPONSOR: Naval Surface Warfare Center, Fatigue and Fracture Branch, Carderock Division

A new standard test method for characterizing the ductile-brittle transition behavior of ferritic steels is being investigated. The purpose of this investigation is to validate the methodology and the limitations on specimen size, testing procedures and allowable temperatures. Experiments and analysis of shallow and deeply cracked specimens of A533B steel in the ductile-brittle transition region are being performed. Subsize specimens and alternative geometries are also being tested. The results of this investigation will be used to revise and improve the test method.

High Temperature Materials

RESEARCHERS: Associate Professor Angela L. Moran,
Dr. Matthew Osborne (ONR Post-Doctoral Fellow), and Midshipman 1/C Robert T. Neiley, USN
SPONSORS: Department of Energy (DOE) and Office of Naval Research (ONR)

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 will be 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 are being fabricated in-house.

High Temperature Copper Alloys for the Automotive Industry

RESEARCHER: Associate Professor Angela L. Moran
SPONSOR: Ford Research Laboratory

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

Failures Analysis - Special Projects

RESEARCHERS: Associate Professor Angela L. Moran and Ensign Brian Schultz, USN
SPONSOR: Naval Air Warfare Center

Failed components from the Academy Sailing Squadron and from aircraft located at Patuxent River were forwarded for evaluation. Mode and cause of failure were identified using non-destructive testing, optical microscopy, electron microscopy and chemical analysis as well as an evaluation of environmental and operating conditions for these components. Recommendations concerning subsequent prevention of future failures were included in the reports provided to each facility.

Failure Analysis and Performance Evaluation of Sprinkler Heads

RESEARCHER: Associate Professor Angela L. Moran
SPONSOR: Consumer Products Safety Commission

As a result of an CPSC ongoing investigation into the performance of sprinkler heads, USNA 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.

Dynamic Characterization of Urethane Damping

RESEARCHER: Associate Professor Colin P. Ratcliffe
SPONSOR: Naval Surface Warfare Center, Carderock

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

Signal Processing: Automating Window Selection

RESEARCHER: Associate Professor Colin P. Ratcliffe
SPONSOR: Naval Surface Warfare Center, Carderock

This project continued the development of an automatic procedure for determining the optimum exponential window to be applied in a signal processor when measuring transient, decaying signals such as those obtained when vibration testing a structure with impact excitation. Previous automation was reasonably successful, and gave a window that was much improved over previous manual selection methods. The continuation of the project has given a much more stable algorithm that deals well with signal noise and structural nonlinearity.

Damage Detection in Bridges

RESEARCHER: Associate Professor Colin P. Ratcliffe
SPONSOR: Naval Surface Warfare Center, Carderock

There are hundreds of existing small road bridges that are close to the end of their life expectancy. The University of Delaware has designed a 100% composite bridge that was installed near Newark, Delaware. As part of this program, United States Naval Academy has conducted an extensive experimental modal analysis of the deck. The results of the modal analysis were used a) to verify finite element models; and b) to look for damage and other structural irregularities in the bridge. It is the intention that this work will be repeated about once per year, to investigate the change in structural performance of the bridge.

Boundary Layer Separation and Transition Under Low-Pressure Turbine Conditions

RESEARCHERS: Assistant Professor Ralph J.Volino and Dr. L. S. Hultgren, NASA Glenn Research Center
SPONSOR: NASA/ASEE Summer Faculty Fellowship

Boundary layer separation, reattachment, and laminar-turbulent transition are currently under experimental investigation. These phenomena are important in the flow over modern low-pressure turbine airfoils. The flow over the suction side of the airfoil is subject to a favorable pressure gradient near the leading edge, which tends to keep the boundary layer laminar, in spite of the high background turbulence level in the engine. The flow over the trailing section of the suction side is subject to an adverse pressure gradient, which tends to cause boundary layer separation. The adverse pressure gradient also tends to promote transition to turbulent flow. Transition often leads to reattachment of the boundary layer. Boundary layer separation causes a

degradation of performance, particularly if the boundary layer does not reattach. The interaction between separation and transition is complex. Laminar boundary layers are more prone to separation than turbulent boundary layers, and turbulent boundary layers are more likely to reattach than laminar. The transition process is dependent on whether transition is initiated before or after the boundary layer separates. Because the flow is complex, it is difficult to predict. The inability to accurately predict the flow is a limitation to designers. A detailed experimental data base is needed to provide a better understanding of the flow, and a basis for new computational efforts and modeling. Experiments were initiated at the NASA Glenn Research Center under the 1998 NASA/ASEE Summer Faculty Fellowship Program and continued during summer 1999 under the same program. A test wall was placed in a low speed wind tunnel and configured such that the pressure distribution along the wall matched the pressure distribution along the suction side of a modern low-pressure turbine airfoil. Extensive velocity measurements were acquired using hot-wire anemometry. Four different Reynolds numbers and two different free-stream turbulence levels have been considered, for a total of eight different cases. Surveys of velocity vs distance from the test wall were taken at fourteen streamwise stations for each case. The locations of boundary layer separation, transition, and reattachment have been documented. As expected, the length of the separation region is decreased as the Reynolds number and/or the turbulence level is increased. One technical paper has been written, and the data is currently under further analysis. Future funding is uncertain, but plans are being made for continuation work, possible involving separation control experiments.

Intelligent Computer Aided Instruction (ICA)

RESEARCHER: Professor Chih Wu
SPONSOR: Office of Naval Research (ONR)

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

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

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

Independent Research

Failure Analysis of Head Stay

RESEARCHERS: Associate Professor Oscar Barton, Jr. and Professor Thomas W. Butler

The failure analysis of a head-stay taken from the Navy 44's was undertaken to understand if the failure was either environmentally induced, mechanically induced or, induced as a result of poor manufacturing practices. Environmental attack comes in the form of corrosion reducing the surface of the mating parts of the head-stay. Mechanical failure is manifested through fatigue generated by cyclic tension of the head-stay. To investigate each these as a candidate, comparison with an in-situ head-stay played an important role. The investigation consisted of detailed documentation of geometric parameters including thread

details, microscopy of sectioned head-stay components, and hardness testing. Conclusive results indicate that machining the head-stay was the impetus for failure.

The Effect of Ligament Diameter and Shell Core Technology on the Metallurgical Soundness of an ASM A27 Carbon Steel Lattice Block Material Casting

RESEARCHERS: Assistant Professor Michelle Gaudett Koul and Professor Dennis F. Hasson

This research program is a continuation of work conducted at NSWCCD (funded by Steve Fishman, ONR). This work continues the study of a cast ultra light metal concept called lattice block material (LBM). The performance of the LBM structure in a given application depends on a variety of aspects, including (1) the parent material section, (2) the casting quality, (3) optimization of the manufacturing process and (4) the loading condition(s). This research program is aimed towards understanding the effect of a reduced ligament diameter and an improved core-block production technology (shell-core) on the metallurgical soundness of LBM. Tensile and impact toughness testing as well as metallurgical evaluation will be conducted to compare with previously evaluated castings. Specimens were obtained from the manufacturer as a result of discussion generated at the Lattice Block Materials Technology Review meeting, held on 9 May 2000, at which previous results were presented by the authors.

Research Course Projects

Diffuse Ultrasonic Material Testing

RESEARCHER: Midshipman 1/C Erick K. Kammeyer, USN
ADVISER: Assistant Professor John A. Burkhardt

The proposed research is in the field of nondestructive testing of materials using ultrasonic techniques. Internal friction in materials is uniform throughout in a specimen with zero damage. In damaged specimens, the internal friction increases due to dislocations, point defects, and other microstructural characteristics. Rather than use the traditional pulse echo techniques, this work will look to use diffuse ultrasonic fields to determine both the presence and the extent of damage in a specimen. The use of diffuse ultrasonic fields produce more accurate results due to their uniformity throughout the specimen and diminished geometric scatting effects.

Micro-structure Evaluation of Filled-Hole Composites

RESEARCHER: Midshipman 1/C Patrick Bernhard, USN
ADVISERS: Assistant Professor Peter J. Joyce and Associate Professor Oscar Barton, Jr.

The proposed research seeks to characterize the damage to filled-hole fiber steered composite specimens that have been subjected to both compressive and tensile loads. The composite specimens were constructed using a production-level fiber placement machine using IM7/977-3 composite system in the form of 10.7 mil slit tape. The fibers vary in curvature ranging from 20in, 30 in and 40 in radii. Characterization of the micro-damage will be accomplished using Scanning Electron Microscopy - SEM. Other techniques for damage characterization, such as Optical Microscopy, will be explored.

Construction and Testing of Boundary Layer Temperature Probe

RESEARCHER: Midshipman 1/C Jessica Parker, USN
ADVISER: Assistant Professor Ralph J. Volino

A small thermocouple probe will be constructed to measure the temperature within a boundary layer. A heater will also be constructed to fit in a wind tunnel and the thermocouple probe will be tested by measuring the temperature in the boundary layer created over the heater.

Boundary Layer Transition Under Turbine Airfoil Conditions

RESEARCHER: Midshipman 1/C Christopher M. Pratt, USN
ADVISER: Assistant Professor Ralph J. Volino

Flow over a flat turbine blade will be simulated by blowing high speed air from a wind tunnel across a piece of flat plexiglass. A hot wire or laser-doppler velocimeter will be used to measure the local velocities over the entire piece of plexiglass. These velocities will allow the flow characteristics to be determined over the flat plate. The same process will be repeated on a curved piece of plexiglass to determine the effect of curvature on flow over turbine blade.

Publications

BARTON, O., Jr., Associate Professor, "Fundamentals of Composite Structural Mechanicals using I-DEAS," Computers in Education Journal, in press.

In this paper MATLAB is adopted as the programming tool used for the analysis of composite materials mechanics. Since the formulation of the mechanical behavior of composite materials involves extensive use of matrices, MATLAB is ideally suited. Morever, graphical interfaces provide an effective means of use. This article considers several topics presented in an elective course offered at the U.S. Naval Academy in composite mechanics, provides the background of these topics, and presents an overview of the MATLAB code that performs the analysis. Topics discussed included stress and strain distribution, stiffness analysis, and deflection analysis. MATLAB provides a strong platform to undertake the required matrix computation and provides a effective graphical interface, using menu commands, for program execution.

BARTON, O., Jr., Associate Professor, MACKNEY, Michael, Associate Professor, MOURING, Sarah E., Associate Professor, and KARPOUZIAN, Gabriel, Professor, "The Longitudinal and Transverse Properties of Fiber-Steered Composites," ASC 14th Annual Technical Conference, Dayton, OH, September 1999, pp 587-596.

In this paper, results are reported for the mechanical properties of test coupons that have been manufactured using steered fibers. The motivation of the research is to assess the effect of fiber curvature on mechanical properties. The properties under investigation include longitudinal tension and compression response, transverse tension and compression response, and both the longitudinal and transverse compressive strengths. To accomplish this effort, six composite panels were fabricated using a production fiber placement machine. Fiber placement is the technology that uses composite materials in the form of tape to be placed in any desired path thus maximizing the utility of the material. The tape, called tows, and can vary in width from 0.125 in to 0.182 in. Each panel is constructed using an IM7/977-3 composite system in the form of 10.7 mil slit tape which is stacked either in a four or eight-ply unidirectional lay-up. For these tests, the fiber placement occurred along paths with radii varying from 18 in to 45 in. This generated test specimens with 20-in, 30-in and 40-in radii. Specimens tested included a set of baseline coupons with straight fibers for comparison.

FLACK, K. A., Associate Professor, AUNAPU, N. V. MIDN 1/C, and VOLINO, Ralph J., Assistant Professor, "Surface Flow Visualization of a Scaled-up Turbine Blade Passage," Accepted. "Measuring Techniques for Turbomachinery," a topical issue of Measurement, Science, and Technology.

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

FLACK, K. A., Associate Professor, AUNAPU, N. V., MIDN 1/C, VOLINO, R. J., Assistant Professor, and Stoddard, R. M., "Secondary Flow Measurements in a Turbine Passage with Endwall Flow Modification," Proceedings of ASME TURBO EXPO 2000, May 8-11, 2000, Munich, Germany.

A flow modification technique is introduced in an attempt to allow increased turbine blade inlet temperatures. A large-scale two half-blade cascade simulator is used to model the secondary flow between two adjacent turbine blades. Two techniques are employed to modify the endwall secondary flow, specifically the path of the passage vortex. These techniques include a centerline fence on the endwall surface and a row of centerline jets on the endwall surface. Both techniques were successful in diverting the path of the passage vortex, however the jets increased the aerodynamic losses in the passage.

FLACK, K.A., Associate Professor, Saylor, J. R., and Smith, G. B., "The Effect of a Surfactant Monolayer on the Temperature Field of a Water Surface Undergoing Evaporation," Accepted, *International Journal of Heat and Mass Transfer*, November, 1999.

The surface temperature of a body of water undergoing evaporation was measured using infrared imaging techniques, demonstrating for the first time the effect of surfactant monolayers on the spatial structure of this field. Measurements were obtained from a water surface which was covered with a surfactant monolayer and also from a water surface which was nominally free of surfactants. The heat flux for these two cases was also varied by a factor of approximately 10. The presence of a surfactants increased the characteristic length scale of the temperature field for both heat flux conditions.

FLACK, K. A., Associate Professor, Saylor, J. R., and Smith, G. B., "Infrared Imaging of Free Surface Turbulence, Damped by a Spreading Film of Immiscible Liquid," Accepted, *Physics of Fluids*, October, 1999.

The effect of a spreading surfactant film on the surface turbulence at and air/water interface is investigated by means of infrared thermal imaging. The turbulence is significantly damped by the spreading film, leaving a less active turbulent region within the film.

JOYCE, James A., Professor, "Development of the T_o Reference Temperature from Pre-cracked Charpy Specimens," PVP Vol. 393, ASME Pressure Vessel and Piping/Section XI Symposiums, August 1999.

The master curve approach specified within the new ASTM E1921 Test Standard is a significant advance in defining an indexing temperature, T the median fracture toughness, and associated failure probability bounds for ferritic steels in the ductile-to-brittle transition regime. An objective in developing this standard test procedure has been that it should, if possible, allow the use of prec-cracked Charpy-size specimens to measure T and the associated fracture performance. However, the technical basis document (Merkle et al., 1998) which supports much of the E1921 criteria presents no evidence to justify using the smallest allowable number of Charpy-size specimens to estimate the reference temperature.

Further, during the development of the standard, there was no independent experimental verification that the specified deformation criterion would result in acceptably accurate T values. Computational and analytical support of the deformation criterion for precracked Charpy specimens is also dramatically lacking. Recent computational work by Ruggieri et al 91998) supports a deformation criterion that is almost twice as stringent as the E1921 standard. There is also no historical precedent within existing fracture toughness testing standards to support the E1921 relaxation of the deformation criterion.

This work evaluates this criteria experimentally for several materials using experimental data sets which contain sufficient numbers of both precracked Charpy and 1T (or larger) fracture toughness measurements. The data demonstrates that the Charpy-size specimens accuratley predict T for certain materials, while in other materials, the Charpy results tend to be non-conservative, even when the data fall within the allowable E1921 deformation criterion. This effect may be a function of the degree of crack tip constraint loss, which strongly depends on the material flow properties. An attempt is made to correct for the constraint loss in the Charpy-size specimen and remove any bias in the measured T using a simple constant stressed volume cleavage failure criteria (Nevalainen and Dodds, 1995). While this method does decrease the difference between T values measured using Charpy and conventional 1T specimens, detailed cleavage initiation models which can be independently calibrated will be required to rigorously account for possible constraint loss in Charpy and smaller specimens.

JOYCE, J. A., Professor, Gao, X., Dodds, Jr., R. H., Tregoning, R. L., and LINK, R. E., Assistant Professor, "A Weibull Stress Model to Predict Cleavage Fracture in Plates Containing Surface Cracks," Fatigue Fract Engrg Material Structure, 22, pp. 481-493.

This study applies recent advances in probabilistic modelling of cleavage fracture to predict the measure fracture behaviour of surface crack plates fabricated from an A515-70 pressure vessel steel. Modifications of theFFrations using only small scale yielding toughness data. Here, the Weibull stress model is calibrated using toughness data from deep-notch C(T) and shallow-notch SE(B) specimens, and is then applied to predict the measured response of surface crack plates loaded in different combinations of tension and bending. The model predictions accurately capture the measured distributions of fracture toughness values.

JOYCE, James A., Professor, Tregoning, Robert L., and Zhang , X. Jie, "Application of Master Curve Technology to Biaxial and Shallow Crack Fracture Data for A533B Steels," Effects of Radiation on Materials: 19th International Symposium, ASTM STP 1366, M. L. Hamilton, A. S. Kumar, S. T. Rosinski and M. L. Grossbeck, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.

The Master Curve approach has recently been proposed by Wallin [1] to define the expected toughness of ferritic steels in the ductile-to-brittle transition. This method has been standardized in ASTM E1921-98 using deeply cracked fracture toughness specimens tested quasistatically in the lower transition regime. However, the commercial nuclear power industry will often use this method to infer structural performance where the critical crack of interest is shallow, rather than deep, and the loading is biaxial rather than uniaxial. Research has been funded by the U.S. Nuclear Regulatory Commission (NRC) and conducted at the Oak Ridge National Laboratory (ORNL), the U.S. Naval Academy (USNA), and the Naval Surface Warfare Center (NSWC) to address potential shortcomings of the present ASTM Standard Master Curve method for such applications.

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

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

Recent ASTM Subcommittee E08.08 on Elastic-Plastic Fracture Technology activities have concentrated on the development of a common fracture test standard that allows the evaluation of elastic and elastic-plastic fracture toughness properties from tests on a single specimen. Many technical changes have been made to allow this process to go forward, but one area in which progress has not been made is in clarifying the various specimen size requirements that were part of the earlier standards. Instead, the size requirements in the new toughness testing standard E1820 have been extracted from the earlier standards, like ASTM E399 and ASTM E813 and extended to the new standard without change in spite of their clear inconsistency.

A review of the development of the E399 size criteria [1] seems to make it clear that the E399 size criterion was meant by its originators to represent only a requirement that allowed the 0.95 secant offset method to adequately evaluate a consistent measure of crack initiation. The later J-integral-based size criteria of E813, E1152, E1737, E1820 and the recent To Reference Temperature standard E1921 are based on finite element analysis [2], which ensures that a minimal deviation from small scale yielding (SSY) occurs. This is intended to generate consistent crack up constraint as the specimen size decreases or the crack length increases.

In this work, specimens from three materials: a 6061-T651 aluminum, a 6A1-4V titanium alloy, and a 4340 steel alloy, were tested to investigate what the proper size criteria should be for a combined fracture mechanics test standard. Larger specimens from each material were tested to obtain Kb values meeting the stringent size criteria of ASTM E399. Smaller

specimens of each material were tested that intentionally failed the E399 size criteria, but satisfied the less stringent criteria of ASTM E813 and E1820. The unloading compliance method has been used in the testing of the smaller specimens so that an estimate of the true crack initiation point on the specimen load displacement record can be measured.

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

GAUDETT, Michelle A., Assistant Professor and Scully, John R., "Part II. Metallurgical Factors Governing the H-Assisted Intergranular Cracking of Peak Aged Ti-3Al-8V-6Cr-4Mo-4Zr (Beta-C)," Metallurgical and Materials Transactions A, 31A, (January 2000), 81-92.

A previous study [Part I] showed that the peak aged condition of Beta-C Ti (STA, $s_{.2\%y}$=1260 MPa) possesses an enhanced hydrogen (H) embrittlement susceptibility compared to the solution treated condition (ST, $s_{.2\%y}$=865 MPa), as measured by reductions in the fracture initiation stress with pre-dissolved H content and the introduction of an intergranular (IG) fracture mode. It was also shown that yield strength elevation and, subsequently, enhancement in the local hydrostatic stresses within the notch root is *not* the controlling factor in the H-assisted IG fracture initiation of the STA condition. Previous work [Part I[1]] implicates a microstructural feature or condition associated with the 500°C aging treatment. In this study, it is shown that localized internal hydride precipitation at the grain boundaries or alpha beta interfaces was not detected by a variety of experimental methods over the range of internal H contents for which IG fracture initiation was observed. It was also shown that grain boundary alpha colonies or films are not responsible for the IG fracture initiation in the STA condition. A measured increase in hydrogen embrittlement susceptibility as a function of aging time at 500°C is consistent with the segregation or depletion of a critical species at the grain boundary. However, grain boundary segregation/depletion could not be detected with Auger electron spectroscopy of specimens fracture in vaccuo. Compression tests used to characterize and compare the alloys' slip behavior showed that plastic deformation is concentrated at or near the grain boundaries in the STA condition. Therefore, a possible intergranular fracture initiation mechanism that includes the effects of hydrogen and localized deformation is discussed.

KOUL, Michelle G., Assistant Professor and Scully, John R.,"Hydrogen Desorption Mechanisms in Metastable Beta Ti-3Al-8V-6Cr-4Mo-4Zr," Proceedings from the 197th Annual Electrochemical Society Meeting, Symposium on Oxide Films, (May 15-18, 2000) Toronto, Canada.

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

LINK, Rick E., Associate Professor, JOYCE, James A., Professor, Tregoning, Robert L., Gao, Xiaosheng, and Dodds, Robert H., "Cleavage Fracture in Surface Cracked Plates: Experiments and Numerical Predictions, Fatigue Fract, Engrg. Material Structure, 22, pp. 481-497.

This study applies recent advances in probabilistic modelling of cleavage fracture to predict the measure fracture behaviour of surface crack plates fabricated from an A515-70 pressure vessel steel. Modifications of the conventional, two-parameter Weibull stress model introduce a non-zero, threshold parameter. The introduction of this parameter brings numerical predictions of scatter in toughness data into better agreement with experimental measurements, and calibration of this new parameter requires no additional experimental data. The Weibull modulus (m) and scaling parameter are calibrated using a new strategy based on the toughness transferability model, which eliminates the non-

uniqueness that arises in calibrations using only small scale yielding toughness data. Here, the Weibull stress model is calibrated using toughness data from deep-notch C(T) and shallow-notch SE(B) specimens, and is then applied to predict the measured response of surface crack plates loaded in different combinations of tension and bending. The model predictions accurately capture the measured distributions of fracture toughness values.

MORAN, Angela L., Associate Professor, Carsten, J., and Cover, G., "Undergraduate Laboratory - Wear Properties of Materials," Journal of Materials Education, v. 20, (3&4), 1999; pp. 1-4.

There are numerous methods of wear testing, many of which are expensive and time consuming. These techniques generally have four parameters - contact velocity, contact area, contact pressure, and entry angle which can be varied to compare materials and lubricants in a theoretical setting or to simulate an actual mechanical situation.

The purpose of this experiment was to develop a low cost demonstrator that can be used to introduce engineering students to the concepts of wear and tribology. A device was found that can create abrasive or adhesive wear depending on materials. The unmodified device is simple and inexpensive as provided, but results were difficult to quantify. Modifications were made to the basic equipment to control experimental variables and make the experiment quantitative. Also, a process was developed for testing which improves repeatability and precision.

The design goals of the device were to build a system that was easily transported (to the classroom) and fairly inexpensive with defined test parameters. The intent was to develop a process that could be used by a classroom instructor to demonstrate the factors of time, temperature, load, lubricant, and material on wear. To do this, it was necessary to first find test parameters that were convenient for a classroom time frame and a method for quantifying the results of the equipment.

MORAN, Angela L., Associate Professor and Schulz, B. A., "Failure Analysis of an F/A-18 E/F Super Hornet Retainer Ring," Engineering Failure Analysis, Vol. 8 (2001) pp. 167-172.

The goal of this course is to develop within the engineering student the ability to distinguish between cause and mode of failure. Given a failed material component, the student should be able to identify possible modes of failure and outline experimental tasks and inspection methods required to select the correct mode. He or she should collect all necessary facts and information to recreate the environmental factors, operator errors, design flaws, processing effects or maintenance mistakes that may have contributed to the failure of the component. Upon completion of the course, the student must present his or her engineering analysis in clear and technically correct terms, understand a broad range of investigation techniques used by engineers to characterize materials failures and make competent decisions on material selection, based on designed operating and environmental conditions.

MORAN, Angela L., Associate Professor, SCHROEDER, J. A., MIDN 1/C, and White, D. R., "Improvements in Copper Welding Electrodes via Powder Metallurgy Processing," Proceeding of the 2000 International Conference on Powder Metallurgy, June 2000. pp. 12-29.

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

MORAN, Angela L., Associate Professor, OSBORNE, M. C., Postdoctoral Fellow, Antenucci, A., and Lauten, F., "Formation of C/SiC Composites from a Commercially Available Pre-Ceramic Polymer," Proceedings of the 102nd Annual American Ceramic Society Conference, May 2000, pp. 53-64.

The physical and mechanical properties of ceramic matrix composites (CMC's) are greatly affected by different fabrication techniques. Density, interphase strength, matrix cracking stress and ultimate strength can be tailored to fit the application by varying the composite's fiber lay-up and the conditions under which the pre-form is filled. Two common ways of producing SiC as the matrix in a CMC are 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* CMC's with graphite fibers were produced for this study at the USNA. Homogeneity and porosity distribution were examined via optical microscopy. Density measurements were made via immersion in ethyl alcohol. A TGA was used to measure mass loss during heat-up. Results indicate that Ceraset loses 25% of its mass on heating to 2000°F under a N2 and CH4 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.

RATCLIFFE, Colin, Associate Professor, and Crane, Roger, "Automatic Procedure for Optimizing the Analyzer Window Setting for Transient Vibration Data Capture," American Society of Mechanical Engineers, Noise Control and Acoustics Division, NCA-V26, pp. 313-318, 1999.

When conducting experimental vibration tests on composite structures, one of the most important settings in the spectrum analyzer is the window function. This setting effects the performance of the Fourier analyzer, and can change the observed energy dissipation of the structure. For impact excitation techniques the window used for transient response signals is typically an exponential function. Traditionally, the window setting is chosen by what "looks right." Too little windowing introduces errors during the Fourier transforms; too much degrades the signal. This paper presents an automatic procedure for optimizing the exponential window function when measuring transient, decaying signals. Initially, the natural attenuation of a signal is automatically determined, and this attenuation is then used to determine the optimum window parameters. The theory is developed for a single-degree-of-freedom system and demonstrated for theoretical and experimental multi-modal structures with poor signal-to-noise ratios. In all cases it is shown that the computationally inexpensive optimization procedure is highly satisfactory. There is also a side benefit in that almost identical numerical procedures can be used to automate the logarithmic decrement technique of estimating structural damping.

RATCLIFFE, Colin, Associate Professor, Gillespie, Jr., John W, Heider, Dirk, Eckel II, Douglas A., and Crane, Roger M., "Experimental Investigation into the Use of Vibration Data for the Long Term Monitoring of an All Composite Bridge," SPIE 5th International Society of Optical Engineering, Nondestructive Evaluation of Highways, Utilities and Pipelines IV Symposium," Newport Beach, 7 - 9 March 2000, pp. 64 - 75.

This paper presents the results of an ongoing investigation into using broadband vibration data to monitor the structural integrity and health of an all-composite bridge. Bridge 1-351 on Business Route 896 in Glasgow, Delaware, was replaced with one of the first state-owned all-composite bridges in the nation in the fall of 1998. The bridge consists of two E-Glass/vinyl ester sandwich core sections (13-ft x 32 ft) joined by a longitudinal joint in the traffic direction. Each sandwich core section consists of a 28-inch deep core and 0.4-0.6-inch thick facesheets.

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

A novel algorithm using the vibration data is being developed that enables local perturbations sensitive to the state of the material (e.g. manufacturing defects, material degradation or service damage) to be detected and spatially located in the bridge. This technique has been successfully validated for locating damage in 1-D beam structures and is being extended to the 3-D sandwich structure. Experimental results generated by this algorithm are discussed and applications for quality assurance/quality control and health monitoring of large composite bridge structures will be discussed.

RATCLIFFE, Colin, Associate Professor, "A Frequency and Curvature Based Experimental Method for Locating Damage in Structures," Journal of Vibrations and Acoustics, JVA Vol. 122, N3, July 2000, pp. 324-329.

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

VOLINO, Ralph J., Assistant Professor, AUNAPU, N. V., MIDN 1/C, FLACK, K. A., Associate Professor, and Stoddard. R. M., "Measurements in a Gas Turbine Cascade Passage with Endwall Flow Modification," ASME Paper 2000-GT-0212, presented at the 2000 ASME International Gas Turbine Conference, Munich, Germany, May 2000. Also to appear in the ASME Journal of Turbomachinery.

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

VOLINO, Ralph J., Assistant Professor and L.S. Hultgren, "Measurements in Separated and Transitional Boundary Layers under Low-Pressure Turbine Airfoil Conditions," ASME Paper 2000-GT-0260, presented at the 2000 ASME International Gas Turbine Conference, Munich, Germany, May 2000. Also to appear in the ASME Journal of Turbomachinery.

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

boundary layers. Transition moves upstream, resulting in shorter separation regions. At Re above 200,000, transition begins before separation. Mean velocity, turbulence and intermittency profiles are presented.

VOLINO, Ralph J., Assistant Professor and Simon, T. W., "Spectral Measurements in Transitional Boundary Layers on a Concave Wall under High and Low Free-Stream Turbulence Conditions," accepted for the ASME Journal of Turbomachinery.

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

WU, Chih, Professor, "Performance analysis for endoreversible closed regenerated Brayton heat Pump cycles," *Energy Conversion and Management*, v.40, n.4, pp. 393-406, 1999.

Finite-time thermodynamic performance of isentropic closed regenerated Brayton heat pump cycles coupled to constant and variable temperature heat reservoirs has been analyzed in this paper. The relations between heating load and pressure ratio and between COP and the heat resistance losses in the heat exchangers between the working fluid and the high, and low temperature heat reservoirs and the regenerator. A numerical example is also given.

WU, Chih, Professor, "Effect of heat transfer law on the performance of a generalized irreversible Carnot engine," *Journal of Physics D: Applied Physics*, V.32, pp. 99-105, 1999.

In a classical endoreversible Carnot engine model, irreversibility in the form of heat resistance between the reversible Carnot cycle and its heat reservoirs is taken into account. This paper presents a generalized reversible Carnot engine model that incorporates several internal irreversibilities such as heat leak, friction, turbulence, etc. These added irreversibilities are characterized by a constant parameter and a constant coefficient. The relation between optimal power output and efficiency is derived based on a generalized heat transfer law. The effect of heat leakage, internal irreversibilities and heat transfer law on the optimal performance of the generalized irreversible heat engine is investigated.

WU, Chih, Professor, "Optimum performance of an irreversible Stirling crycooler," *International Journal of Ambient Energy*, v20, n1, pp. 39-44, 1999.

An irreversible simplified model for a Stirling crycooler is presented in this paper. This model takes into account the finite rate heat transfer, finite time evolution of the cycle's regenerative process and the friction irreversibility. The maximum cooling load and the corresponding coefficient of performance at the maximum cooling load are derived. The effects of the regenerative time, finite rate heat transfer and friction on the optimal COP at the maximum cooling load are found. Numerical example demonstrates the relation between the cooling load and the COP.

WU, Chih, Professor, "Performance analysis for a real closed regenerated Brayton cycle via methods of finite time thermodynamics," *International Journal of Ambient Energy*, v20, n2, pp. 95-104, 1999.

Performance analysis of a real power cycle has been performed using finite time thermodynamics. The analytical formula about the relations between power output and pressure ratio, and between efficiency and pressure ratio of a real closed regenerated Brayton cycle coupled to variable temperature hear reservoirs are derived.

WU, Chih, Professor, "Intelligent computer aided optimization of power and energy systems," *Proceedings of the Institution of Mechanical Engineers, Part A, Journal of Power and Energy*, v213, nA1, pp. 1-6, 1999.

CyclePad, an intelligent computer aided instruction (ICAI) software package is described. It can be used for design, analysis and improvement of power and energy systems. Performance and sensitivity analysis of a Brayton cycle are discussed in order to illustrate its capabilities.

WU, Chih, Professor, "Transient flow analysis on the regenerator tube of a magnetic heat pump," *International Journal of Power and Energy Systems*, v19, n1, pp. 38-47, 1999.

This paper presents a numerical study of the transient flow phenomena in the regenerator tube of a magnetic heat pump. The problem is solved using the Navier-Stokes equations with a body force term in the momentum equation. The results show that a 40 K temperature span can be reached in 10 minutes of charge time through the use of a 7-T magnetic field. Using the second approach, temperature stratification in the regenerator fluid column was clearly indicated through temperature contours. The regenerator efficiency and energy delivery rates when heating load and cooling load are applied are also calculated.

WU, Chih, Professor, "Performance characteristic of an endoreversible Stirling refrigerator," *International Journal of Power and Energy Systems*, v19, n1, pp. 79-82, 1999.

An endoreversible Stirling refrigerator is modeled in this paper. The performance characteristic relationships among working fluid temperatures, COP (coefficient of performance) and cooling load of the endoreversible refrigerator is derived in this paper. These equations provide a base for practicing engineers to design a new refrigerator.

WU, Chih, Professor, "Finite time thermodynamic performance of a Dual cycle," *International Journal of Energy Research*, v23, n9, pp. 765-772, 1999.

Finite-time thermodynamic analysis of an air-standard internal combustion Dual cycle is performed in this paper. The relation between the net work output and efficiency of the cycle is derived. The maximum net work output and the corresponding efficiency limit of the cycle with heat transfer considerations are found. Detailed numerical examples are given. The results obtained herein provide a guidance to the performance evaluation and improvement for practical internal combustion engines.

WU, Chih, Professor, "Effect of heat resistance on the performance of closed gas turbine regenerative cycles," *International Journal of Power and Energy Systems*, v19, n2, pp. 141-145, 1999.

The effect of heat resistance on the performance of a closed gas turbine regenerative cycle is examined. The analysis focuses on the heat resistances associated with the hot and cold side heat exchangers as well as with the regenerator of the cycle. The relations among power output, thermal efficiency and compressor pressure ratio are derived by considering the irreversibilities of heat resistance losses in the three heat exchangers and non-isentropic power losses in compressor and turbine. The results indicate that the power output of the cycle is strongly dependent on the effectiveness of the three heat exchangers. It is concluded that there exist some optimal temperature matching among the working fluid of the cycle and the working fluid of the surrounding heat reservoirs for maximum power production.

WU, Chih, Professor, "Intelligent computer aided design, analysis, optimization and improvement of thermodynamic systems", pp437-444, *Thermodynamic Optimization of Complex Energy Systems* (Book editors: A. Bejan and E. Mamut), Kluwer Academic Publishers, Netherland, 1999.

An artificial intelligence technique based software for computer aided design, analysis, optimization and improvement of thermodynamic systems is described. This paper describes the implementation of the software into the engineering curriculum at the U.S. Naval Academy. It is concluded that intelligent computer aided instruction teaching and design is not only in the future of education, but will also be an effective design tool for engineering students.

WU, Chih, Professor, "Maximum profit performance of a three-heat-reservoir heat pump", *international Journal of Energy Research*, v23, n9, pp. 773-777, 1999.

The operation of a three-heat-reservoir heat pump is viewed as a production process with energy as its output. The relations between the optimal profit and COP (coefficient of performance), and the COP bound at the maximum profit of the heat pump are derived based on a general heat transfer law. The results provide a theoretical basis for developing and utilizing a variety of heat pumps. The focus of this paper is to search the compromised optimization between economics (profit) and the utilization factor (COP) for finite time endoreversible thermodynamic cycles.

WU, Chih, Professor, "Steady flow combined power plant performance with heat leak", *International Journal of Power and Energy Systems*, v19, n2, pp. 103-106, 1999.

The influence of a bypass leak on the optimal performance of a combined power plant is examined in this paper. This is done by adding a heat leak term into an endoreversible combined cycle. The relation between optimal power output and efficiency, the maximum power and the corresponding efficiency, and the maximum efficiency and the corresponding power for a steady state irreversible combined power plant are found to be deeply affected by the rate of the heat leak. This model allows a very reasonable prediction of the performance of an actual combined power plant.

WU, Chih, Professor, "A generalized model of a combined refrigeration cycle and its performance", *International Journal of Thermal Sciences*, v38, n8, pp. 712-718, 1999.

The building of a steady flow combined refrigeration cycle model with heat resistances, heat leakage and internal irreversibility is described in this paper. The optimal performance of the model is studied. The relation between optimal cooling load and coefficient of performance, as well as the maximum coefficient of performance and the corresponding cooling load are derived.

WU, Chih, Professor, "Performance analysis of a closed regenerated Brayton heat pump with internal irreversibilities", *International Journal of Energy Research*, v23, n2, pp. 1039-1050, 1999.

This paper analyzes the performance of a real heat pump via methods of entropy generation minimization or finite time thermodynamics. The analytical relations between heating load and pressure ratio, and between coefficient of performance and pressure ratio of a real closed regenerated Brayton heat pump coupled to constant- and variable-temperature heat reservoirs are derived. In the analysis, the irreversibilities include heat transfer irreversible losses in the hot- and cold-side heat exchangers and the regenerator, the non-isentropic expansion and compression losses in the compressor and expander, and the pressure drop loss in the pipe and system.

WU, Chih, Professor, "Effect of heat transfer law on the performance of a generalized irreversible Carnot heat pump," *Journal of the Institute of Energy*, v72, n2, pp. 95-104, 1999.

The sole irreversibility considered in an endoreversible 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, turblence 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.

WU, Chih, Professor, "Performance of combined cycle chemical engines," *Journal of Non-equilibrium Thermodynamics*, v24, n3, pp. 280-290, 1999.

The performance of an isothermal combined cycle chemical engine with mass leaks is analyzed in this paper. The relation between optimal power output and efficiency, the maximum power output and the corresponding efficiency, as well as the maximum efficiency and the corresponding power output are derived.

WU, Chih, Professor, "Effect of heat transfer law on the performance of a generalized irreversible Carnot engine," *Journal of Physics D: Applied Physics*, v32, n12, pp. 1346-1349, 1999.

In a classical endoreversible Carnot engine model, irreversibility in the form of heat resistance between the reversible Carnot cycle and its heat reservoirs is taken into account. This paper presents a generalized irreversible Carnot engine model that incorporates several internal irreversibilities, such as heat leak, friction, turbulence, etc. These added irreversibilities are characterized by a constant parameter and a constant coefficient. The relation between optimal power output and efficiency is derived based on a general heat transfer law. The effect of heat leakage, internal irreversibilitity and heat transfer law on the optimal performance of a generalized irreversible Carnot engine is investigated.

WU, Chih, Professor, "Intelligent computer aided optimization of reheating in Rankine cycles," *International Journal of Ambient Energy*, v20, n4, pp. 171-176, 1999.

An intelligent computer aided optimization of the application of reheating to reversible and non-reversible Rankine vapour cycles is performed. Cycle efficiency is adopted as the objective function in the optimization process.

WU, Chih, Professor, "Universal power optimized work potential for reciprocating endoreversible Carnot heat engine cycles," *International Journal of Power and Energy Systems*, v19, n3, pp. 207-211, 1999.

Finite time thermodynamic analysis for reciprocating endoreversible Carnot heat engine results in an optimal efficiency at maximum power output based on a minimized cycle time is obtained. The study presented makes use of the ideal gas model, though the results are shown to be universal for a Carnot cycle using vapours and real gases.

WU, Chih, Professor, "Performance of real regenerated air heat pumps," *International Journal of Power and Energy Systems*, v19, n3, pp. 231-238, 1999.

This paper analyzes the Performance of real regenerated air heat pumps via methods of Finite time thermodynamics. The analytic relations between heating load and pressure ratio, and between coefficient of performance and pressure ratio of real regenerated air Brayton heat pumps coupled to constant- and variable-temperature reservoirs are derived. Detailed examples are given to demonstrate the influence of various irreversibility factors on the cycle performance characteristics.

WU, Chih, Professor, "Progress in finite-time thermodynamics," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 1-35, 1999.

The historical background, research development, and the state-of-the-art of finite time thermodynamics theory and applications are reviewed from the point of view of both physics and engineering.

WU, Chih, Professor, "Generalized power optimization of regenerative reprociating Stirling-like heat engines with various heat transfer mode combinations and finite non-interactive thermal reservoirs," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 49-64, 1999.

An analytical compact approach has been developed which enables the semi-decoupling of the solutions for the upper and lower operating temperatures which give internally reversible Stirling and Stirling-like heat engines the highest potential. This highly innovative approach not only enables the analysis of the effect of various combinations of single and mixed heat transfer modes on the power optimization of these cycles, but also enables the study of trade-off between optimization with respect to work and optimization with respect to the rate of work.

WU, Chih, Professor, "Heating rate limit and cooling rate limit of a reversed reciprocating Stirling cycle," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 85-96, 1999.

An optimal heating rate and cooling rate analysis is conducted on a reversed reciprocating Stirling cycle with ideal regeneration. The maximum heating rate and cooling rate obtained for the cycle based on the upper and lower temperature bounds by employing several novel irreversible Thermodynamic concepts.

WU, Chih, Professor, "Combined law power optimization of closed Joule-Brayton heat engines with finite non-interactive thermal reservoirs," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 105-120, 1999.

Significant improved analytical expressions for optimum power and the operating temperatures which yield optimum power for the closed Joule-Brayton heat engines have been obtained through the concurrent employment of first and second laws of Thermodynamics. The resulting expressions are applicable for configurations with finite non-interactive thermal reservoirs where the outlet reservoir temperature values are maintained at fixed values.

WU, Chih, Professor, "Finite-time thermodynamic Analysis of a MHD power plant," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 227-235, 1999.

Finite-time thermodynamic Analysis has been applied to an MHD power plant. General expressions for power and efficiency of the power plant have been derived when MHD generator is operating at constant velocity and constant Mach number conditions. It is shown that when electrical efficiency of the MHD generator is 100%, both cases are identical and the efficiency at maximum power is identical to Curzon and Ahlborn efficiency.

WU, Chih, Professor, "A generalized model of a combined heat pump cycle and its performance," *Recent Advances in Finite-time Thermodynamics, (Book Editors: C.Wu, L. Chen and J. Chen), Nova Science Publishers, NY*, pp. 489-502, 1999.

A steady flow combined heat pump cycle model with heat resistance, heat leakage and internal irreversibility is built in this paper. The optimal performance of the model is studied. The relation between optimal heating load and coefficient of performance, as well as the maximum coefficient of performance and the corresponding heating load are derived.

WU, Chih, Professor, "Teaching Rankine cycle by using an intelligent computer aided instruction software," *The International Journal of Mechanical Engineering Education*, V27, n4, pp. 337-346, 1999.

This paper describes the use of an ICAI (intelligent computer aided instruction) software in teaching thermodynamics at the U.S. Naval Academy. Historical evolution and several different arranged Rankine cycles can be demonstrated quickly in classroom. Objectives for improvements, constraints, and consequently design, which can not be easily accomplished from the conventional teaching, are emphasized. ICAI evokes the intellectual curiosity of students and increases their interest and design ability in thermodynamics.

WU, Chih, Professor, "Finite time thermodynamic optimization or entropy generation minimization of energy systems", *Journal of Non-equilibrium Thermodynamics*, v24, pp. 327-359, 1999.

The historical background, research development, and the state-of-the-art of finite time thermodynamic theory and applications are reviewed from the point of view of both physics and engineering. It is pointed out that the generalized thermodynamic optimization theory is the development direction of finite time thermodynamics in the future.

WU, Chih, Professor, "A generalized model of a real combined power plant and its performance", *International Journal of Energy, Environment and Economics*, v9, n1, pp. 35-49, 1999.

The finite-time thermodynamic analysis has been applied to real combined power plant. General expressions for power and efficiency of the power plant have been derived.

WU, Chih, Professor, "Intelligent computer aided simulation, design and improvement of heat pump," *Simulation*, v74, n, pp. 18-27, 2000.

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

WU, Chih, Professor, "A combined law power optimized open Joule-Brayton heat engine cycle with a fixed-finite thermal reservoir", *International Journal of Power and Energy Systems*, v20, n1, pp. 1-6, 2000.

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

WU, Chih, Professor, "Intelligent computer aided simulation of a thermodynamic cycle," *International Journal of Modelling and Simulation*, v74, n1, pp. 18-27, 2000.

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

WU, Chih, Professor, "Cooling and heating rate limits of a reversed reciprocating Ericsson cycle at steady state", *Proceedings of the Institute of Mechanical Engineers, Part A, Journal of Power and Energy*, v214, nA1, pp. 75-85, 2000.

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

WU, Chih, Professor, "Finite-time exergoeconomic performance bound for a quantum Stirling engine," *International Journal of Engineering Science*, v38, n2, pp. 239-247, 2000.

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

Technical Reports

FLACK, K.A., Associate Professor and GRANGER, R.A., Professor, "The Structure of a Wing-tip Vortex,"Report # EW-07-99.

The effect of wing tip configuration on trailing vortex breakdown and vortex migration downstream of a rectangular wing was investigated. Two wing tip configurations were tested for a NACA 0015 rectangular axisymmetric wing: a nominal flat tip and a streamlined rounded tip. Planar velocity measurements were obtained with a particle image velocimetry system at five axial locations up to two chordlengths downstream of the trailing edge of the wing tip. Results indicate that the two wing tip configurations produce similar levels of peak vorticity without significant vortex breakdown by two chordlengths. The only significant difference between the two wing tip configurations was a reduced migration in the spanwise direction for the vortex from the rounded tip. The vortices from both wing tips migrated a similar distance in the spanwise normal direction.

KOUL Michelle G., Assistant Professor, "A Metallurgical and Impact Toughness Evaluation of Two Large HY-80 Submarine Castings", NSWCCD-TR-61-2000/06, Naval Surface Warfare Center, Carderock Division, West Bethesda, MD, April 2000.

This report describes work that has been performed to determine the severity and extent of processing problems associated with the production of the HY80 Bridge Access Trunk (BAT) casting on the SSN764 that cracked while in service. Only a small wedge sample removed from the cracked area in the port side of the casting was initially available for analysis. Metallographic results indicated a non-optimal HY80 microstructure, likely due to improper heat treatment. Due to the limited availability of the BAT for additional sample removal, a separate Cusped casting was destructively examined. The Cusped casting had been heat treated in the same furnace lot as the casting that cracked in service. A high hardness area was detected in the Cusped casting and measured impact toughness values were below specification values, with brittle cleavage as the primary fracture mode at 30°F. Metallographic analysis indicated the presence of ferrite and under tempered martensite. Based on these observations, the most likely scenario that resulted in this structure is a local overheating during the tempering process to a temperature within the intercritical region (approximately 1325-1475°F). Based on these results, a more extensive survey of the BAT casting was conducted upon the availability of the SSN764. Five additional high hardness specimens, sufficient in size for impact toughness testing, were obtained from the BAT casting at various locations. The results indicated that three out of five of these specimens (all removed from the port side of the casting, remote from the crack) possessed below specification impact toughness, a brittle cleavage fracture mode at temperatures below transition and a ferrite + under tempered martensite structure. This microstructure is indicative of heat treatment within the intercritical region. Based on the microhardness and microstructures observed, it can be concluded that the material associated with the crack in the BAT casting possessed below specification impact toughness due to temperature excursions into the intercritical region during heat treatment.

MORAN, Angela L., Associate Professor and Schulz, B., "Failure Analysis of an F/A-18 E/F Super Hornet Retainer Spring," EW-003-99 Report, July 1999.

Boeing's lead structural engineer on the F/A-18 E/F program at Patuxent River Naval Air Station supplied a failed LAU-127A/A AIM-9 Fin Retainer Spring for failure analysis. The spring is responsible for holding the missiles fins in place while the missile is in the prone position attached to the plane's wing. The analysis was conducted to find the mode and cause of failure. The Super Hornet is a significantly modified and upgraded version of the Navy's current F/A-18 C/D fighter/attack plane. The purpose of the Super Hornet is to modernize the Navy's air-to-air fighting capabilities as well as its air-to-ground. It is designed to lead the way into the next millennium until the Joint Strike Fighter (JSF) takes control of the skies after the year 2010. In order for the Super Hornet to successfully complete its mission, it must be operational ready at all times. This means being able to trust each and every component that combine to form a war-fighting machine. One of these vital components is the Fin Retainer Spring which is responsible.

MORAN, Angela L., Associate Professor, OSBORNE, M. C. and Neiley, C. R., "Microscopy and Property Evaluation of Ceramic Matrix Composites," EW-08-99 Report, December 1999.

The purpose of this work was to develop a means of evaluating the structural nature of ceramic composite materials in order to relate them to mechanical properties as well as the mechanisms of failure identified during mechanical testing. The particular analyses that were performed included assessment of area percentage of voids at various microscopic magnifications, as well as measurement of crack spacing. The resulting evaluation, used in conjunction with current research into the mechanical properties of composite materials provides a means of evaluating the performance of the composites. This allows modification of fabrication methods to enhance material properties and performance. Two specific composites were investigated. The first, a Hi-Nicalon/CVI SiC composite, was fabricated via the method of chemical vapor infiltration at Allied Corporation. Chemical vapor infiltration (CVI) involves infiltrating composite tooling containing fibers with gaseous methyltrichloralsilane (MTS) and a carrier gas, allowing the MTS to diffuse within the fiber lay-up. This process is carried out at temperatures nearing 1000 C. The resulting SiC that forms is crystalline, but tends to contain many stacking faults. In many cases it is believed that the composite becomes sealed off during infiltration, preventing complete penetration to the internal sections of the material and creating a partially dense piece. The second material being investigated was a C/Ceraset composite, manufactured in the Materials Labs at the Naval Academy via polymer pre-cursor conversion (PPC). This method involves impregnating a mold containing carbon cloth with a pre-ceramic polymer. USNA is currently using the pre-ceramic polymer Ceraset. The polymer composite is then heated in a furnace, to temperatures in excess of 1000 C, under methane to form a material that is

predominantly Si and C in it. Crystallization occurs when the plate is processed under argon to a temperature greater than 1500 C. These steps are repeated until the desired density is achieved. The one disadvantage to this method is that the polymer shrinks as it is processed which results in a large amount of internal cracking.

MORAN, Angela L., Associate Professor, SAXTON, P., MIDN 1/C, and Rutledge S., "Emissivity Measurement Comparison," Ceramics Bulletin, October 1999.

Emissivity measurements generated by two different methods were compared for selected candidate materials. The emission from a material is a direct result of the energy released by the oscillations or transitions of the electrons in that material. The oscillations of the electrons are dependent on the internal energy of the material, which in turn is dependent on its temperature. Radiation emerging from a finite volume of matter is the integrated effect of the local emission throughout the volume. In most solids though, radiation emitted from interior molecules is rapidly absorbed by adjoining molecules. Therefore, radiation that actually escapes the surface of the body originates from the molecules that are within approximately 1 μm from the exposed surface. Due to this effect, radiative emission is viewed as a surface phenomenon for solids. Initial testing occurred at the NASA Lewis Research Center in Cleveland, Ohio as part of a U.S. Naval Academy program to screen thermophotovoltaic (TPV) radiator materials. A Perkin Elmer spectrophotometer was used to measure total hemispherical reflectance at room temperature in air, after which the data was corrected to represent total hemispherical emittance as a function of temperature. Comparative testing was performed to directly measure the normal emissivity (with wavelengths between 2.0 and 2.6 microns) of the same samples in vacuum at elevated temperatures (900-1100 degrees C).

RATCLIFFE, Colin, Associate Professor and Crane, Roger, "Modal Testing of a Composite Bridge Deck," NSWCCD-65-TR-1999/26, December 1999, p. 31.

Composite materials are gaining increased use as a structural material for Navy applications such as ship decks and causeways. With structures of this size, methodologies for ensuring the structural integrity become very important. This report presents the results of an ongoing investigation into using broadband vibration data to monitor the structural integrity and health of an all-composite bridge representative of the deck sections which have been manufactured for both ther ship decks and causeways. Demonstrating the structural health monitoring of the bridge in its service environment would illustrate the utility of this technique for Navy structures. Vibration data were obtained from a mesh of 1050 test points covering the upper and lower face sheets of the bridge. From the modal information and the visualization of the data, several aspects of the structural behavior of the bridge are reported. The vibration data were obtained to develop a vibration-based non-destructive evaluation method for long-term inspection of composite deck bridges. This report covers the data collection phase of the projects, and the results of a preliminary modal analysis.

Presentations

FLACK, K.A., Associate Professor, Saylor, J.R., and Smith, G.B., "Surface Temperature and Subsurface Velocity Near a Free Surface," 52nd Annual Meeting American Physical Society Fluid Dynamics Division, New Orleans, LA, 21-23, 1998.

FLACK, Karen A., Associate Professor, AUNAPU, N.V., Midn 1/C, and VOLINO, R.J., Assistant Professor, "Improved Turbine Blade Cooling using Endwall Flow Modifications," ASME Winter Annual Meeting, Nashville, TN, November 15-17, 1999, Presented by Aunapu.

FLACK, Karen A., Associate Professor, AUNAPU, N.V., Midn 1/C, VOLINO, R.J., Assistant Professor, and Stoddard, R.M. "Secondary Flow Measurements in a Turbine Passage with Endwall Flow Modification," ASME TURBO EXPO 2000, May 8-11, 2000, Munich Germany, Presented by Volino.

HASSON, Dennis A., Professor, Yu, M. et.al., "High Strain Rate Testing of Aluminum Foams," International Conference: Metal Foams and Porous Metal Structures, Bremen, Germany, June 1999.

HASSON, Dennis A., Professor, Sastry, S. M. L., et.al., "Grain Refinement of Titanium Aluminides by Equal Channel Angular Extrusion," Ultrafine Grained Materials Symposium, 2000 TMS Annual Meeting, Nashville, TN, March 2000.

JOYCE, James A., Professor, "Development of the T_o Reference Temperature from Precracked Charpy Specimens," ASME Pressure Vessel and Piping Conference, Boston, MA, 2-4 Aug 1999.

JOYCE, James A., Professor, "Application of Master Curve Technology to Biaxial And Shallow Crack Fracture Data for A533B Steels," Effects of Radiation, 19th Int. Symp., ASTM, Seattle, WA, 17-21 June 1999.

JOYCE, James A., Professor, "Evaluation of Fracture Toughness in the Ductile-to-Brittle Transition," Mech Engr Dept Seminar, USNA, 8 December 1999.

JOYCE, James A., Professor, "Progress Report - High Rate Round Robin," ASTM Task Group E08.08.02, ASTM Committee Week, Kansas City, MO, 15 Nov 1999.

JOYCE, James A., Professor, "Initial Report of Results from the High Rate Round Robin," ASTM Task Group E08.08.02, ASTM Committee Week, West Conshohocken, PA, June 13, 2000.

JOYCE, James A., Professor, "Estimating Crack Length in Dynamic Fracture Toughness Tests with the Compliance Ratio Method," 32 National Symposium on Fatigue and Fracture Mechanics, ASTM, West Conshohocken, PA, June 15, 2000.

KOUL, Michelle G., Assistant Professor, and D. F. Hasson, Professor, "Metallurgical Evaluation of Two Ferrous Lattice Block Material (LBM) Castings," SBIR PHASE II REVIEW: Development of Lattice Block Material as an Ultra-Light Metasllic Fabrication Technology Technique, Naval Warfare Center, Carderock Division, West Bethesda, MD, 9 May 2000.

KOUL, Michelle G., Assistant Professor, and Scully, John R., "Hydrogen Desorption Mechanisms in Metastable Beta Ti-3SA1-8V-6Cr-4Mo-4Zr," 197th Meeting of the Electrochemical Society, Toronto, Canada, 15 May 2000.

LINK, Rick E., Associate Professor, "Round-robin on Shallow Crack Fracture Toughness Test Procedure," ASTM Spring Committee Week, 13 JUN 00, Philadelphia, PA.

LINK, Rick E., Associate Professor, Gao, X. G., Dodds, R. H., Tregoning, R. L. and Joyce, J. E., "Cleavage Fracture in Surface Cracked Plates: Experiments and Numerical Predictions," presented at 1999 ASME Pressure Vessel and Piping Conference, August 1999.

MORAN, Angela L., Associate Professor, and OSBORNE M., Postdoctoral Fellow, "Mechanical Properties and Microstructure of Hi-Nicalon Si/C Ceramic Matrix Composites," Department Seminar, September 1999.

MORAN, Angela L., Associate Professor, OSBORNE, M. C., Postdoctoral Fellow, Antenucci, A., and Lauten, F., "Formation of C/SiC Composites from a Commercially Available Pre-ceramic Polymer,"102nd Annual American Ceramic Society Conference, May 2000.

MORAN, Angela L., Associate Professor, SCHROEDER, J. A., MIDN 1/C, and White, D. R., "Improvements in Copper Welding Electrodes Via Powder Metallurgy Processing", 2000 International Conference on Powder Metallurgy & Particulate Materials, June 2000.

OSBORNE, Matthew C., Postdoctoral Fellow, Antenucci, A., Lauten, F. S. and MORAN, A. L., Associate Professor, "Formation of C/SiC Composites From a Commercially Available Pre-Ceramic Polymer, J. P. Singh, ed., 102nd Annual AcerS Conference, St. Louis, MO, (American Ceramic Society, 2000).

PALMER, Sheila C., Assistant Professor, "A New Approach to Thermodynamics," 1999 ASEE Annual Conference, June 1999.

PALMER, Sheila C., Assistant Professor, "Research Activity," presented to the Mechanical Engineering Faculty, USNA, 22 MAR 2000.

VOLINO, Ralph J., Assistant Professor, AUNAPU, N. V., MIDN 1/C, FLACK, K. A., Associate Professor, and Stoddard, R. M., "Measurements in a Gas Turbine Cascade Passage with Endwall Flow Modification," ASME Paper 2000-GT-0212, presented at the 2000 ASME International Gas Turbine Conference, Munich, Germany, May 2000.

WU, Chih, Professor, Heat output prediction of solar collector for a solar-ground source heat pump, pp.107-109, Proceedings of the Third IASTED International Conference on Power and Energy Systems, Las Vegas, Nevada, 8-10 November 1999.

WU, Chih, Professor, Method of thermodynamic analysis and optimization of energy intensive systems on exergy flow graphs, pp. 489-491, Proceedings of the Third IASTED International Conference on Power and Energy Systems, Las Vegas, Nevada, 8-10 November 1999.

WU, Chih, Professor, Finite time thermodynamic performance for a class of irreversible refrigerators, pp. 241-245, Proceedings of the Third IASTED International Conference on Power and Energy Systems, Las Vegas, Nevada, 8-10 November 1999.

WU, Chih, Professor, Heating load versus COP characteristics for irreversible air-heat pumps, pp. 246-251, Proceedings of the Third IASTED International Conference on Power and Energy Systems, Las Vegas, Nevada, 8-10 November 1999.