DEPARTMENT SUMMARY

The Mechanical Engineering Department's research activities are distributed mainly among five distinct areas of the discipline: the thermal/fluid sciences; solid mechanics, shock and vibration; dynamic systems and controls; materials science; and total ship systems engineering. Most of the efforts are individual investigator programs, although the emphasis on interdisciplinary programs is increasing. Relevance to the needs of the Navy and DoD is a theme in all programs. Results are usually disseminated initially in student theses and NPS Technical Reports. Results are also more widely published in both written and oral presentations at various national and international conferences, as well as in papers in various scientific and engineering journals. The programs associated with each faculty member are described in the following overviews, which are arranged to correspond to the main discipline areas of the Department.

Fluid Dynamics, Heat Transfer and Turbomachinery

TURGUT SARPKAYA, Distinguished Professor

In 1998, Professor Sarpkaya directed four research projects, sponsored by NASA, NSF, and ONR.

THE NASA PROJECT is a *continuing* basic and applied research towards the understanding of the phenomena associated with the motion of trailing of vortices of large aircraft. Its purpose is to alleviate the wake-vortex hazard posed to following aircraft and for decreasing the time-separation between the two landings to increase airport capacity. This research has so far led to the creation of a physics-based turbulence decay model. It is now being verified through the use of field data obtained at major airports.

THE FIRST ONR PROJECT is a *continuing* investigation to perform combined analytical, numerical, physical, and thought experiments to devise a physics-based model for the prediction of flow-induced unsteady forces on bluff bodies immersed in time-dependent flows. The new model, based on a sounder scientific rational, is expected to replace the current models and offer greater universality and higher engineering reliability, particularly in the so-called drag-inertia regime.

THE SECOND ONR PROJECT is a *continuing* investigation of the spray generation from bow-sheets. A series of new experiments have been designed to understand the influence of several competing internal/external influences such as turbulence, gravity, surface tension, liquid-sheet geometry, surface shear, roughness of the contact surfaces, velocity distribution in the sheet, and pressure fluctuations within and outside the sheet to understand, model and predict droplet and spray formation. The technological importance (IR signatures) and intellectual challenges (stability of a two phase flow) presented by this non-trivial flow phenomena demand a scientific understanding of its physics through judiciously conceived physical experiments and numerical analyses which are now underway with both free and wall jets.

THE NSF PROJECT is a *continuing* fundamental research towards the understanding of the characteristics of the conical vortex breakdown discovered by this writer. Trailing vortices, swirling flows in pipes, vortical flows above sweptback wings at large angles-of-attack, flows in closed containers with a rotating lid, and columnar vortices in atmosphere may experience breakdown. Where, how, and under what circumstances does this transformation occur in *viscous* vortical flows constitute the essence of the breakdown problem.

The foregoing four *continuing* sponsored fundamental/applied research projects resulted in numerous journal papers, conference papers, conference presentations, two Ph.D. dissertations and two M.S. theses.

MATTHEW D. KELLEHER, Professor

Professor Kelleher has been continuing studies to model the propagation of fire and smoke in compartments and passageways of surface combatant ships. Detailed computational fluid dynamics models are being used to determine the effects on the missile of fire in the vicinity of and within the missile magazines. It is very important that an understanding of the propagation of fires in the various missile magazines be developed and that some means be developed to apply that understanding to the design of future combatants and to the development of fire fighting procedures. The thermal effects in the Concentric Cannister Launcher due to a fire in an adjacent compartment have been simulated using computational fluid dynamics. A commercial code developed by CFD Research Corporation (CFDRC) has been used to implement the process.

Professor Kelleher has also recently begun work to apply optimization techniques to the design of surface combatants. This study has coupled the MIT Ship Synthesis Model (written in MATHCAD) to the optimization module within MATHCAD. This has provided results for ship designs optimized for a minimum displacement function. This work will continue with efforts to develop optimal designs based on other objectives such as minimum cost.

ASHOK GOPINATH, Assistant Professor

Asistant Professor Gopinath has been conducting research in "Time-Averaged Thermo-Fluid Phenomena induced by Strong Acoustic Fields" as part of an ongoing program on thermoacoustic transport sponsored by two grants from the NASA Microgravity Program. The goal is to obtain a better understanding and quantify the thermoacoustic behavior in strong zero-mean oscillatory flows with potential application to the design of heat exchangers in thermoacoustic engines. Much fundamental insight has been gained into the role of various properties and parameters in the flow using analytical means. With relevance to thermoacoustic engine design, this has helped deduce optimal stack spacing and location that would maximize the performance of such engines.

Also, during CY-98, an experimental project was carried out to explore the use of a standing wave acoustic field in a high-pressure gas to simulate the hydrodynamic wave loading on an offshore structure. Data gathered for lift and drag forces on a cylinder under such loading conditions corroborate well with existing data in the literature. The technique appears to hold promise for future testing under larger values of the parameter regime, and a patent application for the technique is being prepared.

In addition unsponsored research on the role of intergranular liquid phase on the ability to achieve superplastic-like deformation in covalent ceramic materials is being explored in collaboration with departmental colleague Prof. I. Dutta. The study looks into the fundamental issue of the ability of such liquids to support tensile forces, and the eventual modes of failure.

KNOX T. MILLSAPS, Assistant Professor

A method for determining a Diesel engines cylinder firing pressures, based on instantaneous output shaft speed was developed. A high-fidelity torsional engine model was developed and calibrated for a 3-cylinder, 2-stroke Diesel engine. Experimental measurements of near instantaneous speed fluctuations from this engine were made and good agreement was found between the measurements and the model over a range of speeds and applied torques. A new method for representing the speed fluctuations using integrated deviation from a constant speed shaft phasor was developed. This method is effective in identifying cylinders with low firing pressures. An efficient method for determining the periodic motion of a crankshaft based on dynamic finite elements, which requires less than 1% of the computational resources of a time-marching "shooting" method was developed and verified.

An analytical and experimental research program into enhanced mixing technology for gas turbine exhausts for surface ship, IR signature suppression is being conducted. Methods to increase secondary flow into mixing eductors (ejectors) and hence reduce the mixed-out plume temperature are being investigated. Multiple high aspect ratio slot primary nozzles are being investigated along with enhanced axial vorticity generated by lobed mixing nozzles. A 1-D lumped parameter model was developed and used to obtain preliminary designs for enhanced mixing eductors for signature suppression. These enhanced designs were verified in a 1/5 scale cold flow facility.

Solid Mechanics, Shock and Vibration

YOUNG S. SHIN, Professor

Professor Shin has continued his investigation of “Response of Naval Structures to Underwater Explosion” under the sponsorship of the Naval Sea Systems Command (NAVSEA), and Naval Postgraduate School. Modeling and surface ship shock simulation of DDG-53 has been conducted. This task is a part of team project consisting of NAVSEA, NSWC, Electric Boat, Weidlinger Associates, Gibs & Cox, and NPS. The task includes investigating whether the ship shock modeling and simulation can predict the dynamic transient responses of ship system and subsystem structures accurately. The analysis takes into accounts of the effects of the fluid-ship structure interaction and cavitation effects on a surface ship model(DDG-53) due to a large scale underwater explosion.

Professor Shin has also been conducting an additional research project, “Survivability of Shipboard Personnel Subjected to High Amplitude, Low Frequency Shock Induced By Underwater Explosion.” In an effort to develop a method for estimating crew survivability to a given underwater explosion event, biodynamic simulations of human response to shock induced deck excitation were performed for both male and female subjects using the Articulated Total Body (ATB) program. Subsequently, the results were used to estimate the biodynamic response and injury potentials for human males and females in various positions in a vessel to an underwater explosion event.

YOUNG W. KWON, Associate Professor

The first sponsored research was about the damage and crack study in solid rocket propellant. The Air Force Laboratory and the Naval Postgraduate School as cost sharing supported this work. This was a continuing research project from past years during which a numerical modeling and simulation technique had been developed and evaluated against experimental results. The developed method was called a micro/macro approach. The last year’s effort was to investigate the effects of specimen thickness on the crack tip behavior including onset of crack propagation. A three-dimensional finite element analysis was conducted for the macrolevel analysis. Results showed that damage saturation (i.e. the on set of crack propagation) occurred at the same applied strain level for both thick and thin specimens. For the thick specimens, the damage saturation was uniform more than 90 percent of the thickness. Thus, uniform crack propagation through the thickness was predicted and observed for thick specimens. The short crack had a long delay (about 100 percent larger applied strain) in damage initiation than the long crack, but the damage growth rate in the long crack was about 15 percent greater than the short crack. The slower damage growth in the short crack resulted in the higher maximum stress in the loading direction. At the onset of damage saturation, the longer crack had more damage concentration around the crack tip.

The second project was also a continuing effort from the previous year. It was about development of a robust, higher-order shell element with pressure variation through the shell thickness. It was funded by the Naval Surface Warfare Center. During the project period, a shell element including both transverse shear and normal deformations was developed and the Gurson constitutive model for void growth with plastic deformation was also implemented into the shell element for transient analysis using the central time integration scheme. An algorithm for stable time solutions for the void model was developed and hourglass model control was implemented caused by under-integration. Various examples were analyzed to check the accuracy and the efficiency of the element.

The last project was a biomechanical study of the human injury exposed impact loading. A computer simulation model was developed and validated using some experimental data. Three kinds of studies were conducted. The first one investigated the head and neck injury of a solider with a helmet impacted by a bullet at different angle. The second study evaluated the effectiveness of countermine boots against AP mine explosion. Finally, the last study investigated possible injury of a solider in a HUMVEE vehicle when the vehicle drove on a land mine. The biomechanical responses of the human were predicted under each different impact condition and they were assessed using available injury criteria. The study showed that there was a great chance of injury of the human body, which varied depending on the loading conditions.

JOSHUA GORDIS, Associate Professor

Associate Professor Joshua H. Gordis of the Department of Mechanical Engineering is conducting research in several areas in structural dynamics, vibration, and acoustics. In structural synthesis, a family of analytic methods have been developed which allow the direct calculation of modified dynamic response of structural dynamic system computer models which have been arbitrarily modified and/or combined with other models. These methods are distinguished by their ability to treat modifications of arbitrary size, distribution and damping, and that the methods provide a highly efficient and exact solution in all cases, where the synthesis is independent of model size. The time domain synthesis formulation is recently been extended to address local nonlinearities in large linear systems. The formulation provides an order of magnitude reduction in the time required to solve large, locally nonlinear structural dynamics problems. The nonlinear synthesis theory is being applied to the optimal design of seismic isolation.
Research is also being performed in structural system identification, where deficiencies in math models are identified through the use of measured dynamic response data. Recent results here include the identification of an non-standard set of eigenvalues which provide a additional, independent data with which to tackle the underdetermined system identification problem. The system identification methods are being applied in the area of structural damage detection, which seeks to uncover structural damage in components using measured dynamic response data.

Research and development continues in the structural dynamic analysis of the Boeing-Sikorsky RAH-66 Comanche helicopter. Working with two additional faculty members, identification of random airloads on the Comanche empennage was performed using a combination of flight test data and finite element modeling.

Dynamic Systems, Controls and Robotics

ANTHONY H. HEALEY, Professor

Professor Healey was active in furthering the technology of Autonomous Underwater Vehicles and land based robot systems for minefield and unexploded ordnance clearance. In particular, the ***Center for Autonomous Underwater Vehicle Research***, directed by Professor Healey, has facilities that include the AUV laboratory in Building 230. In late 1997, a major advance was made towards performing the first experimental operation in open water outside the Monterey Harbor in the Monterey Bay. This work continued during 1998 with major software developments being performed including the purchase and networked integration of a Pentium based processor running the QNX operating system in the Phoenix vehicle. The AUV has been equipped with a 900 MHz. Radio modem for communications between shore and vehicle when surfaced. The vehicle has a new propulsion system using two 1/4 horsepower DC brushless motors and larger propellers giving an expected forward speed of 3-4 knots when submerged. Reconnaissance operations in the Monterey Bay have been conducted with the use of imaging sonar and a newly purchased acoustic doppler velocimeter (ADV) to combine with a bottom locked acoustic doppler navigator for ground speed sensing and dead-reckoning navigation. Contributions have been made to the compensation of magnetic compass bias errors using extended kalman filtering.

International visitors to the Center included Professor Antonio Pascoal, and his doctoral student Carlos Silvestri from the University of Lisbon in Portugal. Professor Pascoal spent his sabbatical year in the Center. Three French students spent their 6-month advanced training in the Center and studied the use of the Lon-Works operating system for system data acquisition and distributed control networking. Working with Professor Pascoal, significant work has been accomplished in optimum design of controls configured vehicle design, and research has shown that compensation and even cancellation of wave motions induced by wave action could be feasible, if proper measurement of wave velocities becomes practical.

A major new program was begun in late 1998 with ONR funding to participate in the AUVFEST 98 demonstration in the Gulf of Mexico in November 1998. We mobilized the Phoenix vehicle and its support equipment for deployment off the R/V Gyre. This successful ocean experiment verified that 3 hour duration runs could be made, and most importantly, that ocean direction wave spectra and short term current data could be obtained from a moving AUV. The program is supported by NICOP funds to join with Professor Pascoal in Lisbon in a joint vent survey mission which will involve multi-vehicle coordination control.

Continued work to develop software for the Navy's 21 UUV Tactical Size Vehicle that will automatically detect control subsystem faults and make appropriate control reconfiguration actions was undertaken. This program also focuses on fault tolerant control architectures and in particular studying the vehicle motion control in very shallow waters with wave conditions. Robust observer designs are being studied for error generation in the detection of actuator and sensor faults. It has been shown that fin faults can be reliably detected by roll system observers and likelihood function processing.

During this year, the final steps in the studies of BUGS were made to simulate the cooperative behavior between a high resolution, fast, detection robot, and a fleet of low resolution robots in UXO clearance operations. This work has led to the development of a new ONR funded program to study modeling and simulation tools for evaluating multi-robot cooperation in reconnaissance of VSW minefields.

MORRIS DRIELS, Professor

Professor Driels' research focused on the following research areas:

TARGET ACQUISITION MODEL EVALUATION**:** The Handbook is intended to support the Target Acquisition Models Library under development by Australia, Britain, Canada and America (ABCA). The library will research, collate and document target acquisition models available to modelers so that the selection of a specific model for a particular combat simulation is enhanced. This work completes release 1.1 of the Handbook, summarizing and documents seven of the most widely used models.

TARGET ACQUISITION MODULE UPDATE: A stand-alone module was developed in FY97 and validated against data and other sources. In FY98, this program was interfaced with the JAWS database, and included in JAWS version 2.0, due for release in 1999. In transitioning from an analyst's model to a user model, the inputs were made more operationally relevant, and data imported directly from the weaponeering part of the program. This research program is on-going, and will be extended into FY99. The planned work will be to complete the integration of the current TA module into JAWS, and extend it to cover FLIR sensors.

A/S and S/S TARGET ACQUISITION METHODOLOGIES: This program uses target imagery, and a DTED terrain data base to define local natural features in the vicinity of a specific target which will be attacked by aircraft. Cultural features are then raised up from the terrain to provide detailed masking contours, based on the approach angle and altitude of the attacking aircraft. The user then types in data regarding the weapon to be used and the program generates release conditions for the attack. In addition, a perspective view allows pilots to visualize the target area at a user-specified range.

IMPLEMENTATION OF THE DELPHI TARGET ACQUISITION MODEL: Previous work in FY97 laid the theoretical basis for the foveal component of a visual performance model based on proprietary work in the UK. This phase of the work completed the development of the model and allowed it to be compared to the US Acquire model. In addition, work was done on the peripheral channel, allowing the development of a search component.

REVIEW OF DELIVERY ACCURACY METHODOLOGY: The standard methodologies used to determine statistical descriptions of weapon accuracy was applied to a new class of GPS/INS guided weapon. Using field data, the accuracy was described in a manner allowing it to be included into the Joint Air to surface Weaponeering System JAWS. In doing so several issues regarding the methodology were highlighted, and improvements made. This work will be continued into FY99.

SCALABLE SEARCH METRICS: This was a collaborative project with UC Berkeley, where Professor Stark's team had a proposed way to define spatial locations within a field of regard. This allows eye movements to be specified in terms of these locations, rather than segmenting the image into regions of fixed size. This allows the scanpath to be defined independently of the segmentation sizes, and leads to a way of describing search that is applicable to mere general imagery.

FOTIS A. PAPOULIAS, Associate Professor

Prof. Papoulias conducted research on maneuvering and control of submersible vehicles in varying operational specifications and environmental conditions. The objective of this work, which was funded in 1997, is the development of a control strategy, which allows for on-the-fly reconfiguration of integrated guidance and control strategies of an underwater vehicle in shallow and littoral waters. In 1998, work performed was in the areas of accurate assessment of dive plane reversal bifurcation envelopes in the presence of biased external excitation. Further studies were conducted in order to assess the importance of nonlinearities in coupled sway, yaw, and roll stability of motion.

Additional work that was initiated in FY 97 demonstrated the feasibility of using Matlab based code to model the quasistatic response of a ship under conditions of progressive flooding. Two main limitations of this work are the applicability to rectangular compartments and the lack of an intuitive human interface in order to study “what-if” scenarios and counter-flooding actions. Current and future work in this area concentrates on overcoming these limitations as follows: First, a Matlab interface is under development to process the output of existing ship hydrostatic calculations programs. Second, a graphical user interface (GUI) will be constructed in order to allow the user to manipulate the data and interact with the results in an intuitive way. This GUI will be written using primitive Matlab and/or Visual Basic functions. The results will be tested against results produced by using the software package “Simsmart” which is more powerful but less commonly available.

Ship Systems

CHARLES N. CALVANO, Associate Professor

Professor Calvano’s work with the Institute for Defense Analyses (IDA) culminated in 1998 with the presentation of the paper Operationally Oriented Vulnerability Requirements (OOVRs) in Ship Design, presented at the annual meeting of the American Society of Naval Engineers (ASNE) in March 1998 and published in the January 1998 edition of the Society’s Journal. The Navy partially adopted the principles espoused in this work, in the first draft of the SC-21 Operational Requirements Document (ORD) which includes them in some ship performance areas. Adoption of this approach is expected to increase the likelihood that ships will be able to “fight hurt” after receiving expected levels of damage.

Surface ship survivability work, under OPNAV N86D sponsorship, continues, building on the start made in 1997. Fourteen faculty members working in research areas relatable to surface ship survivability were identified and expressed an interest in becoming part of a Surface Ship Survivability Resource Center AT NPS. As part of his work with N86D, in promoting surface ship survivability, Professor Calvano was requested to participate in the preparation of a Surface Ship Survivability Handbook for the fleet. This work will commence in FY 99, and will incorporate the work of individuals at the Naval Surface Warfare Center and, perhaps, others.

A new, and highly interesting, research effort was undertaken in 1998. This was the exploration of methods for applying numerical optimization to existing ship synthesis tools and resulted in the work described under the sponsorship of NAVSEA 03D. Further development of these ideas in 1999, to include optimization based on characteristics other than displacement is expected to occur.

Exploration of the nature of, and design tools for, such ship survivability-related concerns as progressive flooding and ship damaged stability is continuing. The first design tool using SIMSMART software to evaluate progressive flooding was brought to near completion in 1998. The future will see this work extended to generalized ship geometries, beyond the mathematically determinate hull form used for the initial development.

DEPARTMENT SUMMARY

Materials Science

TERRY R. MCNELLEY, Professor

Professor McNelley's current research efforts are concentrated in the areas of mechanical behavior of particle-reinforced aluminum (PRA) metal matrix composites, and deformation processing and recrystallization in aluminum alloys. During 1998 work continued work on processing, deformation behavior and fracture toughness enhancement of particle-reinforced aluminum (PRA) metal matrix composites. Over a period of time this work has been sponsored by the Army Research Office, the Army Research Laboratory, the Air Force Wright Aeronautical Laboratories, and was initiated under of CRADA agreement with Duralcan-USA, a composites manufacturer located near Detroit, MI. The role of particle cracking during tensile extension of an aluminum–alumina PRA has been evaluated by measurement of the axial and diametral strains of deformed and unloaded tensile samples. These measurements have shown that the material experiences dilatation during tensile extension, and that this effect is accompanied by particle cracking. Analysis has shown that the observed dilatation can be modeled in terms of the fraction of cracked particles and the separation of the resulting particle fragments. The cracking process occurs throughout straining of this material and is not confined to a brief strain interval near the point of fracture. This work suggests that there is a critical condition involving the state of the matrix, the interfacial strength and the extent of particle cracking that leads to the nucleation of a macroscopic crack and unstable fracture. The evolution of microstructure and mechanical properties, and especially the strength – fracture toughness relationship has been examined in aluminum – silicon carbide PRA material. By control particulate distribution, matrix grain and subgrain structure, and matrix precipitate state the strength – fracture toughness combination can be optimized. Following an appropriate combination of processing and novel heat treatments the composite may possess better stiffness and strength as well as fracture toughness when compared to a similar unreinforced matrix alloy.

A program of research into processing, recrystallization and superplasticity of aluminum alloys also continued. Particular attention has been given to materials such as Supral 2004, Al-10Mg-0.1Zr and Al-5Ca-5Zn, which all transform by continuous recrystallzation reactions under appropriate post-processing annealing or annealing/straining conditions. The grain boundary geometry of these materials becomes established in a cellular dislocation structure produced during deformation processing. Most of the higher angle grain boundaries (misorientation > 30_) are interfaces between symmetric variants of the main texture components, while lower misorientation boundaries (misorientation _ 30_) are the result of random dislocation interaction within the texture variants. Bimodal misorientation distributions that persist through prolonged annealing treatments are frequently seen in such materials. The distribution of the high-angle boundaries can be modeled if a distribution of orientations around the main texture components is assumed. The superplastic response appears to be sensitive to the population of boundaries of misorientation in the range of 5_ - 20_. The role of particle size and size distribution in discontinuous recrystallzation reactions has been investigated. Because the critical size for particle-stimulated nucleation (PSN) of recrystallzation is relatively large and also strain dependent it is necessary to incorporate the particle size distribution into models for grain refinement via PSN. Accordingly, overaging treatments should be designed to increase the density of particles of size exceeding some critical value. This may suggest increased rather than decreased overaging temperatures as a means of increasing the density of nucleation sites in order to refine grain size.

ALAN G. FOX, Professor

During 1998 the members of Professor Fox's research team in the Center of Materials Science and Engineering were Professor E.S.K. Menon, Dr Martin Saunders (NRC Research Associate), Dr Nagarajan Rajagopalan (NRC Research Associate), Mr R. Y. Hashimoto (Materials Engineer) and Graduate Students, Lts J.D. Walters, R.D. Manning, T. Halladay and D.J. Chisholm.

In 1998 these group members have been pursuing various projects. Work has been continuing in collaboration with the Carderock Division of the Naval Surface Warfare Center and the Naval Research Laboratory on studies of the mechanical properties of Navy high strength steels and their weldments so that new weld consumables and parent steels for Naval applications can be developed. As in 1997, projects were undertaken in collaboration with the Naval Air Warfare Center, Pax River, MD. These concerned the microstructural characterisation of new high temperature intermetallic alloys (including TiAl and NiAl) using new methods in x-ray and electron diffraction. Also during 1998 an ongoing project on the topic of underwater wet welding was continued in collaboration with the Underwater Ship Husbandry Division of the Office of the Director of Ocean Engineering/Supervisor of Salvage and Diving, Naval Sea Systems Command. Finally, a new project on the microstructural characterization of glass-ceramic composites was started in collaboration with Systran Corp. and the Wright-Patterson Air Force Base.

In 1998, the Fox group presented and published eight conference papers and two journal articles were published with two others accepted for publication.

INDRANATH DUTTA, Associate Professor

Professor Dutta's current research efforts are concentrated in the areas of Mechanical Behavior and Electronics Packaging Materials Science. In the area of Mechanical Behavior, there are two programs. One is on creep and thermal cycling behavior of fiber reinforced metal-matrix composites at elevated temperatures, which is currently supported by the National Science Foundation. During 1998, constitutive laws for interfacial deformation were identified, and the effect of such interfacial sliding on the overall creep response of a model composite was evaluated by experimental and analytical means. The second program is on the improvement of fracture toughness of discontinuously reinforced aluminum (DRA) composites to via innovative processing routes, and was supported in 1998 by the Wright Patterson Air Force Base. During 1998, in an extension of previous work, it was demonstrated that both fracture and strength properties of DRA can be improved relative to unreinforced aluminum if the process and microstructural conditions are precise understood and controlled. In the area of Electronics Packaging, Professor Dutta is continuing his work on adhesion between metallizations and substrates for hybrid micro-electronics packaging applications. Also, Professor Dutta is initiating a new research program on Liquid Phase Sintering of Ceramics (LPSF) in collaboration with Prof. A. Gopinath.