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2004

Department of Mechanical and Astronautical Engineering Report (2004)

McNelley, T.R.

Monterey, California: Naval Postgraduate School

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DEPARTMENT OF MECHANICAL AND ASTRONAUTICAL ENGINEERING

T.R. MCNELLEY
CHAIRMAN

MECHANICAL AND ASTRONAUTICAL ENGINEERING

OVERVIEW:

The mission of the Department of Mechanical and Astronautical Engineering is to increase the combat effectiveness of U.S. and Allied armed forces and to enhance the security of the United States through advanced education that focuses on the ability to identify, formulate and solve technical and engineering problems in areas related to mechanical engineering and that spans issues of research, design, development, procurement, operation, maintenance and disposal of components and systems for Naval platforms.

RESEARCH MISSION:

The research mission of the Department of Mechanical and Astronautical Engineering is to increase the combat effectiveness of U.S. and Allied armed forces and to enhance the security of the United States through research in areas related to mechanical engineering and that spans the field from basic phenomena to engineering design, development, operation, maintenance and disposal of components and systems for Naval platforms.

CURRICULA SERVED:

The Mechanical Engineering Department serves the Naval and Mechanical Engineering Curriculum (570) and the Mechanical and Reactors Engineering Curriculum (571). Both curricula are in support of Navy needs for individuals having advanced technical education in mechanical engineering and related fields. The 570 Curriculum provides the educational component for the Engineering Duty Officer program and the research program in the Department is designed to support the requirement for Officers having the ability to identify, formulate and solve technical and engineering problems in areas related to mechanical engineering.

DEGREES GRANTED:

- Master of Science in Mechanical Engineering
- Mechanical Engineer
- Doctor of Philosophy
- Doctor of Engineering

RESEARCH THRUSTS:

There are five different disciplines of research thrusts such as Fluid Dynamics, Heat Transfer and Turbomachinery; Dynamics Systems, Controls and Robotics; Solid Mechanics, Vibrations, and Shock; Materials Science and Engineering; Total Ship Systems Engineering

FACULTY EXPERTISE:

- Fluid Dynamics, Heat Transfer and Turbomachinery:
  Distinguished Professor Turgut Sarpkaya, Professor Matthew Kelleher, Associate Professor Knox Millsaps, Jr., Associate Professor Ashok Gopinath
- Dynamics Systems, Controls and Robotics:
  Professor Anthony Healey, Professor Morris Driels, Associate Professor Fotis Papoulias
- Solid Mechanics, Vibration, and Shock:
  Professor Young Shin, Professor Young Kwon, Associate Professor Joshua Gordis
- Materials Science and Engineering:
  Professor Terry McNelley, Professor Alan Fox, Associate Professor Indranath Dutta
- Total Ship Systems Engineering: Professor Charles Calvano

RESEARCH FACILITIES:

The Mechanical Engineering Laboratories are designed as complements to the educational mission and research interests of the department. In addition to extensive facilities for the support of student and faculty research, a variety of general use equipment is available. This includes equipment and facilities for the investigation of problems in engineering mechanics; a completely equipped materials science laboratory, including advanced scanning electron microscopes, an Auger microprobe, a transmission electron microscope and X-ray diffractometers; an oscillating water tunnel, a unique underwater towing tank and a low turbulence water channel; a vibration analysis laboratory; a fluid power controls laboratory; a robotics and real-time control laboratory; facilities for experimentation with low velocity air flows; equipment for instruction in thermal transport phenomena; a laser doppler velocimeter; nuclear radiation detection equipment and an interactive CAD/CAE computer graphics laboratory. Experimentation is further enhanced by a broad selection of analog and digital data acquisition and processing equipment and instrumentation.

RESEARCH PROGRAM (Research and Academic)-FY2004:

The Naval Postgraduate School's sponsored program exceeded $92 million in FY2004. Sponsored programs include both research and educational activities funded from an external source. A profile of the sponsored program for the Department of Mechanical and Astronautical Engineering is provided below.
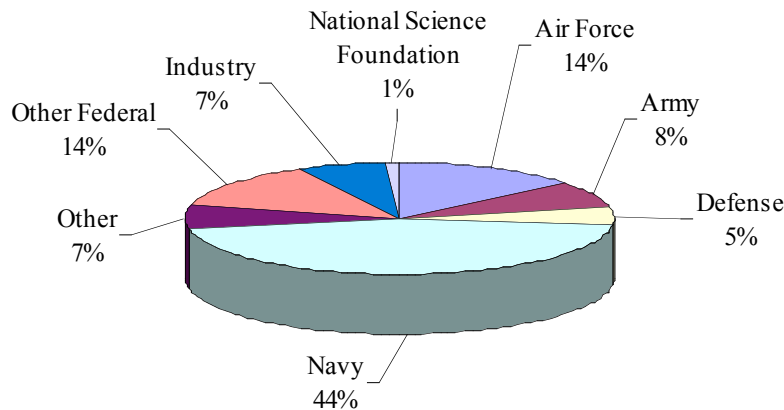
Size of Program: $3,896K

MECHANICAL AND ASTRONAUTICAL ENGINEERING

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MECHANICAL AND ASTRONAUTICAL ENGINEERING

ACQUISITION, TRACKING AND POINTING OF BIFOCAL RELAY MIRROR SPACECRAFT
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Reconnaissance Office

SUMMARY: Developed a bifocal relay mirror test bed, with single axis rotation between the aperatures, to investigate dual line of sight control issues. During Phase I the emphasis was on completion of development of the test bed by procuring flexible simulators, agile laser source, acquisition and targeting sensor, and a track to support laser source and target. During Phase II the test bed was made fully operational. Using analytical simulations and experiments, improved integrated beam control and attitude control techniques will be investigated.

KEYWORDS: Bifocal Relay Mirror, Laser, Beam Control

ACQUISITION, TRACKING AND POINTING OF MILITARY SPACECRAFT
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Reconnaissance Office

SUMMARY: Evaluated state-of-the-art acquisition, tracking, and pointing technologies and developed a road map to develop these technologies to meet the performance requirements of future military spacecraft. The tasks included evaluation of the state of the art, development of a new course on acquisition, tracking, and pointing, and organization of a workshop in summer 2003 at the Naval Postgraduate School.

KEYWORDS: Military Spacecraft, Acquisition, Tracking, Pointing

AUTONOMOUS DOCKING AND ROBOTIC SERVICING PROJECT
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: The Naval Postgraduate School performed analysis, created numerical models, and performed computer simulations of a chaser vehicle with one manipulator, resulting in the design of a control law for the attitude and proximity navigation of a chaser vehicle with respect to a target vehicle. NPS upgraded the satellite servicing testbed in order to perform tests on the proximity navigation maneuver of the chaser with respect to a fixed target using reaction wheel and thrusters in preparation for target capture and docking.

KEYWORDS: Autonomous Docking, Numerical Models, Robotics

DUAL LINE OF SIGHT CONTROL
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Space Missile Command

SUMMARY: Developed a bifocal relay mirror testbed, with single axis of rotation between aperatures, to investigate dual line of sight control issues. Using analytical simulations and experiments on the testbed, improved integrated beam control and attitude control techniques were developed and demonstrated.

KEYWORDS: Bifocal relay mirror, Beam control, Attitude Control

FINE POINTING AND TRACKING CONTROL OF IMAGING SPACECRAFT

Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Reconnaissance Office

SUMMARY: Developed technologies for fine acquisition, tracking, and pointing control of future imaging spacecraft. The emphasis in the program was on fast slewing of flexible imaging spacecraft and finer optical beam jitter, tracking, and pointing control. The work was performed in two phases. Phase I consisted of developing improved techniques and validating them analytically by performing analytical simulations and experimentally by using a flexible spacecraft simulator for fast slewing and precision positioning hexapod and the optical test bed for finer optical beam and jitter control. In Phase II, a three-axis analytical model was developed by including flexibility and control moment gyros control. The improved techniques were validated analytically by simulations and experimentally by using a new attitude control simulator.

KEYWORDS: Imaging Spacecraft, Pointing Control, Tracking Control

A GLOBALLY CONVERGENT ANGULAR RATE ESTIMATOR FOR SPACECRAFT ATTITUDE
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Secretary of the Air Force/Directorate of Budget Management and Execution Financial Management Budget, Special Programs Office-Accounting And Finance Office, Crystal City

SUMMARY: Developed an estimator for the angular velocity of a spacecraft from gyro measurements. The estimator fully exploited the nonlinear kinematics of the problem, and was shown to be globally convergent. Its effectiveness was assessed in terms of computer simulation as well as testing using gyro data from the testbed at the Spacecraft Research and Design Center.

KEYWORDS: Spacecraft, Gyro, SRDC

MULTI-BODY FLEXIBLE DYNAMIC, SYSTEM IDENTIFICATION AND CONTROL
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Secretary of the Air Force/Directorate of Budget Management and Execution Financial Management Budget, Special Programs Office-Accounting And Finance Office, Crystal City

SUMMARY: Evaluated and exploited different techniques in modeling the flexible dynamics, system identification (inertia and modal parameters) and control of a multi-body flexible spacecraft. The flexibility interacts with the control systems and can create instability, vibrations during slew maneuvers, and cause jitter for optical payloads. Both analytical-numerical simulations and experimental testing were conducted.

KEYWORDS: Multi-body Flexible Spacecraft, Modeling

RELAY MIRROR TESTBED
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: Developed a bifocal relay mirror testbed, with single axis of rotation between the aperatures, to investigate dual line of sight control issues. Using analytical simulations and experiments on the testbed, improved integrated beam control and attitude control techniques were developed and demonstrated. The emphasis on this project was on optical payload and beam control for the testbed.

SPACE TECHNOLOGY DEVELOPMENT
Brij N. Agrawal, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: The objective of this project was to extend collaborative research work between the Air Force Research Laboratory (AFRL) and the Spacecraft Research and Design Center (SRDC) at the Naval Postgraduate School in the development of space technologies. There are several research areas of common interest in spacecraft technologies, such as vibration isolation and control, shape control, jitter control, acquisition, tracking and pointing of optical payload spacecraft, and spacecraft system design. The specific areas and tasks are defined and agreed upon each year. The research work done at SRDC will be presented at AFRL annually.

SPACE SITUATIONAL AWARENESS RESEARCH CENTER
Kyle Alfriend, Navy TENCAP Space Chairman
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Office of Scientific Research

SUMMARY: Developed a Joint Space Situational Awareness Research Center with the Air Force Maui Optical Site (AMOS) and performed research vital to this country in space situational awareness (SSA). Educated military officers and government civilians about space situational awareness.

IDENTIFICATION AND CHARACTERIZATION OF CRITICAL ISSUES FOR PULSE DETONATION ENGINES
Christopher M. Brophy, Research Associate Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Office of Naval Research

OBJECTIVES: To determine the performance of a valveless fuel/air pulse detonation engine (PDE) operating at conditions and frequencies representative of a supersonic (M=2.5, h=10 km) cruise missile.

SUMMARY: This effort performed analysis, design, and integration of various engine components critical to PDE operation. A fuel/oxygen initiator was designed and operated at up to 100Hz. Diffraction limits of initiator/receptor geometry were determine through simultaneous shadowgraph and CH* images. The results were used to develop a multi-cycle fuel/air PDE, which was primarily operated on ethylene/air mixtures, but also liquid fuels such as JP-10. The performance of the resulting engine agreed well with predictions and demonstrated the need to replace the fuel/oxygen initiator with a similar fuel/air unit to maximize the resulting fuel-based specific impulse values. The testing also demonstrated the importance of utilizing line-of-site optical fuel measurements to resolve the temporal and spatial fuel loading within the combustor for accurate performance calculations.

PUBLICATIONS:

Brophy, C.M., "Development Efforts on Pulse Detonation Engines and Enabling Technologies," *Continuous and Pulse Detonation Propulsion*, TORUS Press Publishers, ISBN 5-94588-029-9, 2004, (submitted).

Brophy, C.M., Wang, F., and Gundersen, M., "Transient Plasma Ignition of a Hydrocarbon/Air Initiator for Pulse Detonation Engines," *Continuous and Pulse Detonation Propulsion*, TORUS Press Publishers, ISBN 5-94588-029-9, 2004, (submitted).

Brophy, C.M., Sinibaldi, J., Wang, F., Jiang, C., Kuthi, A., and Gundersen, M.A., "Transient Plasma Ignition of Hydrocarbon-Air Mixtures in Pulse Detonation Engines," *American Institute of Aeronautics and Astronautics (AIAA) Aerospace Sciences Meeting*, *Paper No. 2004-0834*, Reno, NV, 2004.

Mattison, D., Brophy, C.M., Sander, S., Ma, L., Hinckley, K., Jeffries, J., and Hanson, R.K., "Pulse Detonation Engine Characterization and Control Using Tunable Diode-Laser Sensors," *Journal of Propulsion and Power*, Vol. 19, No. 4, 2004.

Wang, F., Liu, J.B., Sinibaldi, J., Brophy, C., Kuthi, A., Jiang, C., et al., "Transient Plasma Ignition of Quiescent and Flowing Fuel," *IEEE Transcripts on Plasma Science*, 2004, (accepted).

PRESENTATIONS:

Brophy, C.M., "Development Efforts on Pulse Detonation Engines and Enabling Technologies," International Colloquium on the Detonation for Advanced Propulsion, St. Petersburg, Russia, July 2004.

Brophy, C., "ONR Pulse Detonation Engine Research Efforts," 2004 IHPTET Meeting, Dayton, OH, 2004.

Brophy, C.M., "Pulse Detonation Engine Development and Enabling Technologies," International Colloquium on Application of Detonation for Propulsion, St. Petersburg, Russia, July 2004.

Brophy, C.M., Wang, F., and Gundersen, M., "Transient Plasma Ignition of a Hydrocarbon/Air Initiator for Pulse Detonation Engines," International Colloquium on the Detonation for Advanced Propulsion, St. Petersburg, Russia, July 2004.

THESIS DIRECTED:

Wittmers, N., "Direct-Connect Performance Evaluation of a Valveless Pulse Detonation Engine," Master's Thesis, Naval Postgraduate School, December 2004.

KEYWORDS: Valveless Fuel/Air Pulse Detonation Engine, PDE, Supersonic, Cruise Missile.

LIQUID ROCKET ENGINE PLUME SIGNATURES
Christopher M. Brophy, Research Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

OBJECTIVES: To determine the soot production characteristics for various hydrocarbon fuels and the associated optical properties, including index of refraction, Sauter Mean Diameter, and size distribution for a well-mixed liquid rocket engine operating on the various hydrocarbon/oxygen mixtures.

SUMMARY: This research involved the determination of the soot production curve over an O/F range of 0.3 to 1.5 for various hydrocarbon fuels with gaseous oxygen and for well-mixed conditions. The resulting soot mass fraction curves and the associated optical properties were determined through the use of Mie theory and multiple wavelength transmission measurements. Maximum soot levels approached 25% by mass, but quantitative maximum values were resolved due to excessive attenuation at the associated O/F conditions. Multiple transmission paths across the plume have since greatly improved the approach and are now being used on film-cooled liquid rocket engine configurations.

PUBLICATION:

Brophy, C. and Hartsfield, C., "Sooting Characteristics of Toluene/Oxygen Mixtures for Signature Analysis," *Exhaust Plume Technical Subcommittee Meeting*, San Diego, CA, November 2004.

PRESENTATION:

Brophy, C. and Hartsfield, C., "Sooting Characteristics of Toluene/Oxygen Mixtures for Signature Analysis," Exhaust Plume Technical Subcommittee Meeting, San Diego, CA, November 2004.

THESIS DIRECTED:

Carter, M., "Tunable Diode Lasers for Plume Characterization," Master's Thesis, Naval Postgraduate School, December 2004.

KEYWORDS: Plume Signatures, Soot, Hydrocarbon Fuel, Optical Properties, Liquid Rocket Engine, Hydrocarbon/Oxygen Mixtures.

LIQUID ROCKET ENGINE SIGNATURE STUDIES
Christopher M. Brophy, Research Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: Characterized the spatial distribution and mass concentration of soot in a liquid rocket engine exhaust plume for both well-mixed and film-cooled geometries. Multi-wavelength transmission measurements, planar imaging, and tomography were applied to specified motor geometries and conditions.

KEYWORDS: Plume Signatures, Soot, Hydrocarbon Fuel, Optical Properties, Liquid Rocket Engine, Multi-Wavelength Transmission Measurement, Planar Imaging, Tomography, Motor Geometries

PULSE DETONATION ENGINE STUDIES
Christopher M. Brophy, Research Associate Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: General Electric Aircraft Engines

OBJECTIVES: To determine the ability to initiate an ethylene/air detonation through the use of four fuel/air supersonic jets discharging onto a central axis.

SUMMARY: This effort is proprietary and the results cannot be discussed.

THESIS DIRECTED:

DeLarosa, G., "Supersonic Jet Initiation of Ethylene/Air Mixtures," Master's Thesis, Naval Postgraduate School, December 2004.

KEYWORDS: Pulse Detonation, Ethylene, Supersonic, Jet

PULSE DETONATION TECHNOLOGY DEVELOPMENT
Christopher M. Brophy, Research Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: General Electric Aircraft Engines

CONTINUED INVESTIGATION OF THE EFFECTS OF DETONATION MERGING ON UNDERWATER BLAST

Ronald E. Brown, Research Professor
Department of Physics
Ashok Gopinath, Associate Professor
Department of Mechanical and Astronautical Engineering
Donald v. Z. Wadsworth, Senior Lecturer
Space Systems Academic Group and Department of Electrical and Computer Engineering
Sponsor: Office of Naval Research

OBJECTIVES: This continuing effort is directed towards exploring and quantifying means for applying the detonation merging mechanism for enhancing explosive blast.

SUMMARY: Detonation rates predicted by a finite difference code were found to be in excellent agreement with those reported from a spherical explosive implosion experiment. In addition, the supra-pressure conditions, above the Chapman-Jouguet state, leading to these increases in detonation rates were established. These results provide confidence in the code and equations of state models employed to accurately predict detonation rates resulting from detonation convergence. Additional simulations of underwater blast experiments performed by the Naval Surface Warfare Center (NSWC) and SRI were also completed for purposes of forming bases of comparison for the evaluation of novel design schemes derived for increasing the directionality and intensity of underwater explosive detonation. Two explosive devices were recommended for government testing.

TECHNICAL REPORT:

Brown, R., "Investigation of the Effects of Detonation Merging on Underwater Blast," Naval Postgraduate School Annual Report, RBHB3-AR-01reb, Office of Naval Research Contract N0001405WR 20144, July 2004. (Limited Distribution.)

THESES DIRECTED:

Biesterveld, A., "Novel Techniques for Enhancing Blast Intensity and Directionality," Master's Thesis, Naval Postgraduate School, June 2004.

Moore, T., "Constructive Explosive Blast and Shock Focusing," Master's Thesis, Naval Postgraduate School, March 2004.

DOD KEY TECHNOLOGY AREAS: Littoral ASW, Shallow Water ASW Technology

KEYWORDS: Computational Fluid Dynamics, CFD, Finite Difference, Explosives, Detonation, Underwater Blast

FIRST PRINCIPLES PREDICTION OF X-RAY IMPULSE

Ronald E. Brown, Research Professor
Department of Physics
Ashok Gopinath, Associate Professor
Department of Mechanical and Astronautical Engineering
Donald v. Z. Wadsworth, Senior Lecturer
Space Systems Academic Group and Department of Electrical and Computer Engineering
Sponsor: Navy Strategic Systems Programs Office

OBJECTIVES: To develop a first-principles physics model for predicting the impulse induced on selected surfaces by an X-ray burst in space. To validate the theoretical model by comparing predictions with available underground test data and other experimental data.

SUMMARY: This multi-year research project supports the Trident Stockpile-to-Target Stewardship program. The 2003 calendar year research provided confidence in the hydrocode model since the AUTODYN hydrocode compared favorably with the SNL CTH hydrocode in predicting the effects of an x-ray burst on the RV aeroshell (LT Sylvester's Master's Thesis). As a result of a March 1, 2004 meeting with the SSP chief scientist, it was concluded that further work should be based on the CTH hydrocode (vice AUTODYN) to take advantage of related SSP funded-research at SNL utilizing CTH. In particular the continuing effort at NPS should address improving the physics model, including the EOS and effects of viscosity. Due to late receipt (June, 2004) of the two-year funding for this task and the PI's academic schedule, further research efforts had to be postponed until CY 2005.

THESIS DIRECTED:

Sylvester, C.A., "Cold X-Ray Radiation Absorption and Material Response: Numerical Model to Predict Blow-Off and Impulsive Loading in Re-Entry Vehicles," Master's Thesis, Naval Postgraduate School, March 2004.

DoD KEY TECHNOLOGY AREA: Nuclear Weapons

KEYWORDS: X-ray, Lasers, Weapons Effects

A FUNDAMENTAL STUDY OF COMPRESSIBLE DYNAMIC STALL AND ITS CONTROL OVER A VARIABLE DROOP LEADING EDGE AIRFOIL
Muguru Chandrasekhara, Research Professor
Department of Mechanical and Astronautical Engineering
Navy – National Aeronautics and Space Administration (NASA) Joint Institute of Aerospace Sciences
Sponsor: U.S. Army Research Office

OBJECTIVES: To investigate basic vorticity dynamics issues of compressible dynamic stall control using a Variable Droop Leading Edge (VDLE) airfoil.

SUMMARY: This continuing effort was initiated in September 2002. The goal of the project is to identify the fundamental fluid mechanics issues associated with dynamically drooping the airfoil leading edge as a means to control dynamic stall. In particular, the study is being focused on the flow vorticity distributions to establish the reasons for the notable success achieved in controlling compressible dynamic stall using the VDLE airfoil. Since a large amount of vorticity is produced, a fact supported by the noted increases in lift, it is of interest to see how the vorticity gets redistributed to levels that do not produce a vortex. The results in hand validate the hypothesis that vorticity management holds the key for effective flow control. During the calendar year, National Aeronautics and Space Administration (NASA) Ames Research Center (ARC) decided to reclaim the compressible dynamic stall facility laboratory space. However, prior to this event, a large body of data had been collected and presently, detailed analysis of this is ongoing. The goal is to establish the flow physics for different flow conditions, when different mechanisms induce dynamic stall.

PUBLICATION:

Chandrasekhara, M.S., Martin, P.B., and Tung, C., "Compressible Dynamic Stall Control Using a Variable Droop Leading Edge Airfoil," *Journal of Aircraft (AIAA Paper 2003-0048)*, Vol. 41, No. 4, pp. 862-969, July-August 2004.

CONFERENCE PUBLICATIONS:

Chandrasekhara, M.S., "A Review of Compressible Dynamic Stall Principles and Methods," *Proceedings of the 10th Asian Congress of Fluid Mechanics*, Sri Lanka, 17-21 May 2004.

Chandrasekhara, M.S., Tung, C., and Martin, P.B., "Aerodynamic Flow Control Using a Variable Droop Leading Edge Airfoil," *Specialists Meeting (RSM) on Enhancement of Military Flight Vehicle Performance by Management of Interacting Boundary Layer Transition and Separation (Paper No. 2, RTO/AVT-111),* Prague, Czech Republic, 4-7 October 2004.

PRESENTATIONS:

Chandrasekhara, M.S., "A Review of Compressible Dynamic Stall Principles and Methods," 10th Asian Congress of Fluid Mechanics, Sri Lanka, 17-21 May 2004.

Chandrasekhara, M.S., Tung, C., and Martin, P.B., "Aerodynamic Flow Control Using a Variable Droop Leading Edge Airfoil," Specialists Meeting (RSM) on Enhancement of Military Flight Vehicle Performance by Management of Interacting Boundary Layer Transition and Separation*,* Prague, Czech Republic, 4-7 October 2004.

KEYWORDS: Basic Vorticity Dynamics, Compressible Dynamic Stall, Variable Droop Leading Edge, VDLE, Airfoil

STUDY OF A VARIABLE DROOP LEADING EDGE (VDLE) AIRFOIL WITH A GURNEY FLAP IN THE COMPRESSIBLE DYNAMIC STALL FACILITY
Muguru Chandrasekhara, Research Professor
Department of Mechanical and Astronautical Engineering
Navy - National Aeronautics and Space Administration Joint Institute of Aerospace Sciences
Sponsor: National Aeronautics and Space Administration - Ames Research Center/U.S. Army

OBJECTIVES: To enhance the performance of a Variable Droop Leading Edge (VDLE) airfoil by attaching a simple Gurney flap.

SUMMARY: This project draws from the success of the above described Army Research Office (ARO) project. The effort concluded in June 2004. In the previous year, the ARO and Air Force Doctrine Document (AFDD) projects had indicated a spectacular result that the dynamic stall phenomenon could be fully controlled using the VDLE airfoil. However, the cost of this success was a small loss of lift, but in addition to the avoidance of dynamic stall consequences, both the drag and adverse pitching moment were dramatically improved also. The Army is requiring high lift performance out of its rotorcraft in the field and so it was imperative that even this small price was not paid. Hence, a small Gurney flap was attached to the airfoil section and tested. Even though a passive device, the Gurney flap was successful in more than recovering the "lost lift" described above, with almost insignificant increases in drag and moment coefficients.

PUBLICATION:

Chandrasekhara, M.S., Martin, P.B., and Tung, C., "Compressible Dynamic Stall Performance of a Variable Droop Leading Edge Airfoil with a Gurney Flap," AIAA Paper No. 2004-0041, *American Institute of Aeronautics and Astronautics (AIAA) Journal of Aircraft*, Reno, NV, January 2004, (submitted).

CONFERENCE PUBLICATION:

Chandrasekhara, M.S., Martin, P.B., and Tung, C., "Compressible Dynamic Stall Performance of a Variable Droop Leading Edge Airfoil with a Gurney Flap," *AIAA Paper No. 2004-0041*, Reno, NV, January 2004.

KEYWORDS: Gurney Flap, Basic Vorticity Dynamics, Compressible Dynamic Stall, Variable Droop Leading Edge, VDLE, ARO, AFDD

SUPPORT OF FLORIDA STATE UNIVERSITY/FLORIDA A&M UNIVERSITY EXPERIMENTAL STUDIES OF COMPRESSIBLE DYNAMIC STALL
Muguru Chandrasekhara, Research Professor
Department of Mechanical and Astronautical Engineering
Navy - National Aeronautics and Space Administration Joint Institute of Aerospace Sciences
Sponsor: Florida A&M University

OBJECTIVES: To investigate compressible dynamic stall control using supersonic micro-jets.

SUMMARY: These studies were successfully completed and the project concluded in March 2004. The aim was to demonstrate the proof of concept of compressible dynamic stall control using microjets. The necessary experimental data was collected in CY' 2003. In the tests, two unsteady pressure transducers were mounted on the airfoil upper surface at 2.5% and 7.5% chord lengths from the leading edge and the local time dependent pressures were measured as the airfoil executed sinusoidal pitching oscillations. Results for cases with and without blowing were compared at two Mach numbers and one reduced frequency, at different blowing pressures. The results confirmed successful control. However, preliminary calculations of the blowing mass flow requirements indicated that a larger than anticipated mass flow may have to be drained from the available system resources to make it a practical and reliable tool.

KEYWORDS: FMU, FAMU,   Dynamic Stall, Supersonic, Micro-jet

MISCELLANEOUS AIR TO SURFACE TASKS
Morris Driels, Professor
Department of Mechanical and Astronautical Engineering
Sponsors: Joint Technical Coordinating Group–Eglin Air Force Base

OBJECTIVES: To improve delivery accuracy methodology and to develop a real time delivery accuracy capability

SUMMARY: This continuing task completed a major milestone in 2003 by delivering the prototype Joint Delivery Accuracy Program (JDAP) to the sponsors. This product will now be integrated by the contractor into JAWS version 2.3 due for release in July 2003.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Bombing Accuracy, Weaponeering

GOALI: CREEP AND MICROSTRUCTURAL COARSENING OF LEAD FREE SOLDERS IN MICRO-ELECTRONIC PACKAGING APPLICATIONS
Indranath Dutta, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Science Foundation

INTERFACIAL CREEP IN MULTI-COMPONENT MATERIALS SYSTEMS
Indranath Dutta, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Science Foundation

MECHANICAL AND ASTRONAUTICAL ENGINEERING

SUMMARY: A comprehensive investigation of diffusionally accommodated interfacial sliding (interfacial creep) in multi-component materials systems, with a view to obtaining a fundamental understanding of the operative mechanism and its dependence on interfacial structure. The objectives were to develop experimental and analytical approaches to study interfacial creep in both bulk and thin film materials systems; to develop mechanistic insight into interfacial sliding by correlating the sliding kinetics with the interfacial morphology, structure and chemistry; to generate sliding kinetics data for selected interfaces of practical importance; and to evaluate the impact of sliding on the performance of two engineering systems of importance (fibrous composites and film-substrate systems).

KEYWORDS: Interfacial Creep, Fibrous Composites, Film Substrate

MINIATURIZED IMPRESSION CREEP TEST FOR BALL-GRID ARRAY (BGA) AND FLIP CHIP (FC) SOLDER JOINTS
Indranath Dutta, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Semiconductor Research Corporation (SRC)

THERMO-MECHANICAL BEHAVIOR OF ADAPTIVE LEAD-FREE SOLDERS FOR ELECTRONIC PACKAGING APPLICATIONS
Indranath Dutta, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: U.S. Army Research Office

SUMMARY: Developed adaptive Pb-free solders which can respond intelligently to externally applied loads so as to minimize the inelastic strain induced in the solder during thermo-mechanical cycling. The 95.5sn3.8ag0.7cu solder, reinforced with a small volume fraction of shape-memory alloy (SMA) whiskers, was fabricated and tested under creep and thermo-mechanical cycling conditions, with the goal of obtaining a mechanistic understanding of the contribution of SMA to the inelastic strain.

KEYWORDS: Interfacial Creep, Solder, Lead-Free, BGA, FC

THERMOPHOTOVOLTAIC (TPV) POWER SYSTEMS
Ashok Gopinath, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsors: Naval Sea Systems Command, Office of Naval Research International Field Office

OBJECTIVES: To build and measure the performance of a moderate sized Thermophotovoltaic (TPV) device and model the energy transfer rates to carry out a design study of the parameters that influence its performance.

SUMMARY: TPV technology is of great interest to naval reactors as a potential solution for direct energy conversion for submarine propulsion in the future. The device works by transfer of thermal energy by radiation from a high temperature emitter to a semiconductor collector placed in close proximity in which it is converted to electrical energy.

The primary work on this project was carried out in two parts. The major part was during the first half of CY-04 while the Principal Investigator was on sabbatical leave at the Fraunhofer Institute of Solar Energy Systems (ISE) in Freiburg, Germany. There he was involved in the successful development and construction of a full scale TPV system. The principal challenge was to design and successfully integrate the complex mix of the advanced technological sub-systems that make up the whole system. The Principal Investigator was the primary organizer and editor of the Sixth International Conference in TPV Technologies, which was held in Freiburg in June 2004.

An experimental phase of the project was also started at the Naval Postgraduate School to demonstrate high heat flux removal techniques, such as spray cooling, that are required for the back-end cooling of high

power-density MTPV devices. Low cost commercially available industrial nozzle and spray components were used to study the role of water mass flux and droplet size on the removal of heat fluxes as large as 100 W/cm^2.

CONFERENCE PUBLICATIONS:

Aicher, T., Kastner, P., Gopinath, A., Gombert, A., Bett, A.W., Schlegl, T., et al., "Development of a Novel TPV Power Generator," *Proceedings of TPV6 - Sixth International Conference on the Thermophotovolatic Generation of Electricity*, AIP Conference, Vol. 738, pp. 71-78, Freiburg, Germany, 14-16 June 2004.

Gopinath, A., Aschaber, J., Hebling, C., and Luther, J., "Modeling of Radiative Energy Transfer and Conversion in a TPV Power System," *Proceedings of TPV6 – Sixth International Conference on the Thermophotovolatic Generation of Electricity*, AIP Conference, Vol. 738, pp. 162-168, Freiburg, Germany, 14-16 June 2004.

THESES DIRECTED:

Fillius J.B., "An Experimental Study of Steady State High Heat Flux Removal Using Spray Cooling," Master's Thesis, Naval Postgraduate School, December 2004.

Presby, A.L., "Thermophotovoltaic Energy Conversion in Space Nuclear Power Systems," Master's Thesis, Naval Postgraduate School, December 2004.

DoD KEY TECHNOLOGY AREA: Propulsion and Power (Nuclear)

KEYWORDS: Thermophotovolatic, TPV, Micro-TPV, Emitter, Collector, Receiver, Radiation, Quantum Efficiency, Fill Factor, Dark Current, Power Density

TURBINE CONVECTIVE COOLING CONCEPTS EVALUATION
Ashok Gopinath, Associate Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsors: Naval Air Systems Command, Naval Air Warfare Center, Naval Postgraduate School

OBJECTIVES: To establish computational analysis tools and develop a prototype of a new Micro-Electro-Mechanical Systems (MEMS)-based micro-heat exchanger turbine cooling concept.

SUMMARY: This project is ongoing from FY-2001. The micro- heat exchanger is based on the concept of the use of pin fins in the narrow gap of a shroud enclosed turbine blade to obtain a large volumetric density of heat transfer area. As of CY-2004 a multi-physics based computational tool has been developed for the analysis of the proposed heat exchanger design to a satisfactory degree of fidelity. A scaled-up macro-rig has also been built and scaled-up Hx models have been used to successfully test the numerical models and gather empirical data. The primary thrust in CY-04 was to use MEMS-based techniques to construct the actual micro-Hx on wafers and etc them out and finally test them using a specially constructed micro-wind tunnel. Experiments were carried out using a high-pressure air bottle for the source of flow and the test section was carefully instrumented with strip heaters to provide the power input and thermocouples to measure inlet and outlet air temperatures. Pressure taps at the inlet and outlet were also used to measure pressure drop to rate Hx performance. Preliminary data was gathered which provided much needed evidence of corroboration of the numerical modeling and the scaled up experimental effort. The project supported the thesis work of two Master's students.

PRESENTATION:

Rose, G.D., Rousssakies, J.C., Sinibaldi, J.O., and Gopinath, A., "Numerical and Experimental Study of Pin-Fin Array Heat Exchangers," *CANEUS 04*, Monterey CA, 1-5 November 2004.

MECHANICAL AND ASTRONAUTICAL ENGINEERING

THESES DIRECTED:

Rose, G.D., "Design and Fabrication of a Short Pin-Fin Micro Heat Exchanger," Master's Thesis, Naval Postgraduate School, September 2004.

Roussakies, J.C., "Empirical Study of the Performance of a Micro Pin Fin Heat Exchanger," Master's Thesis, Naval Postgraduate School, September 2004.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Pin-Fin Array, Compact Heat Exchanger, Micro Heat Exchanger, Turbine Blade Cooling

DEVELOPMENT OF AN ACTIVE MOTION COMPENSATION SYSTEM FOR ROLL-ON ROLL-OFF (RORO) OPERATIONS IN ELEVATED SEA STATES
Joshua H. Gordis, Associate Professor
Fotis A. Papoulias, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Surface Warfare Center - Carderock Division

OBJECTIVES: The current stern ramp designs on many Navy ships (Cape T, Cape H, LMSR, etc.) used in roll-on roll-off operations has been determined to be structurally inadequate in sea state three and above. The prior year's research involved the technical evaluation of two concepts for motion compensation systems to be placed between the foot of the ramp and the RRDF (barge) on which the ramp rests. The two concepts were proposed to Naval Surface Warfare Center (NSWC)/Carderock by two independent vendors, and Naval Postgraduate School (NPS) (Gordis/Papoulias) was funded by NSWC/Carderock to critically evaluate these concepts for effectiveness in reducing ramp stresses. The work performed last year conclusively demonstrated the ineffectiveness of both vendor concepts, and the thorough analysis of the problem, revealed what would be needed from a motion compensation system in order to effectively reduce the ramp stresses in elevated sea states, while carrying a vehicle.

SUMMARY: The critical issues made plain by the prior research are two-fold. The elevated sea state induces large relative end-to-end twists on the ramp and, a vehicle that does not travel down the centerline of the ramp induces large stresses in the ramp. The research performed led to the development of a hybrid compensator system which addresses both of these issues: 1) ramp end-to-end twist due to barge roll motion, and 2) off-centerline vehicle loading. The pivoting support placed under the foot of the ramp (as proposed in similar forms by two commercial vendors, and evaluated by NPS) was augmented by active support arms which are mounted on the RRDF (barge) and which extend out and under the ramp, on each side. The research performed in 2004 developed this hybrid compensation system, and addressed the scheduling of the force required in each arm, as well as determined the optimal location of each support point on the underside of the ramp. Numerous simulations demonstrated that this system reduces peak stress in the ramp to levels well below allowable.

TECHNICAL REPORTS:

Brock, G.N., Gordis, J.H., and Papoulias, F.A., "Dynamics and Control of the Roll-On/Roll-Off Stern Ramp Support System," 18 March 2004.

Christensen, J.A., Echols, R.C., and Gordis, J.H., "Design Analysis of Under-Ramp Support Arm System for the Light, Medium Ship Roll-on/Roll-off (LMSR) Ramp," August 2003.

THESES DIRECTED:

Brock, G.N., "Dynamics and Control of the Roll-On/Roll-Off Stern Ramp Support System," Master's Thesis, Naval Postgraduate School, March 2004.

Christensen, J.A., "Stress Analysis of Full-Scale Model Light, Medium Ship Roll-On/Roll-Off (LMSR) Stern Ramp with Support Arm Assembly," Master's Thesis, Naval Postgraduate School, December 2003.

Echols, R.C., "Stress Analysis of Full-Scale Model Light, Medium Ship Roll-On/Roll-Off (LMSR) Stern Ramp with Combined Under-Ramp Support System and Wave Motion Compensator," Master's Thesis, Naval Postgraduate School, December 2003.

DoD KEY TECHNOLOGY AREA: Surface/Under Surface Vehicles - Ships and Watercraft

KEYWORDS: Frequency Response, Seakeeping, RORO Operations, Vibration Isolation

DRAG OPTIMIZATION OF LIGHT TRUCKS USING COMPUTATIONAL FLUID DYNAMICS
Joshua H. Gordis, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: U.S. Army Tank-Automotive and Armaments Command

OBJECTIVES: There are 80 million light trucks on the road today with suboptimal aerodynamic forms. Previous research found that several miles per gallon could be saved by specifically tailoring truck bodies for reduced aerodynamic drag. Even greater savings can be obtained if the shape of the trucks is numerically optimized. This could reduce fuel consumption in the United States by billions of gallons per year.

SUMMARY: This research developed a method for drag reduction using Computational Fluid Dynamics (CFD) and traditional numerical optimization techniques. A method for efficient design variable reduction for CFD optimization of three-dimensional shapes is also presented and applied to light trucks. The optimized form is then physically constructed and installed on a recent model pickup truck. The vehicle is tested in several configurations and the effects on fuel economy are compared to the CFD prediction. The results indicate that the CFD formulation provides an accurate predictor for improving fuel economy and drag characteristics. The prototype air dam and optimally shaped canopy generated a 21.23% savings in fuel economy. This corresponded to an improvement in fuel economy from 19 mpg to 23.17 mpg. Ultimately, this research demonstrates a practical example of geometric optimization and validates the results with a full-scale test.

CONFERENCE PUBLICATION:

Williams, N.A., Gordis, J.H., and Letherwood, M., "Drag Optimization of Light Trucks Using Computational Fluid Dynamics," *Proceedings of the 2004 SAE Commercial Vehicle Engineering Congress and Exhibition,* U.S. Army Tank-Automotive and Armaments Command.

THESIS DIRECTED:

Williams, N.A., "Drag Optimization of Light Trucks Using Computational Fluid Dynamics," Master's Thesis, Naval Postgraduate School, September 2003.

KEYWORDS: Light Truck, Aerodynamics, MPG, CFD

INVESTIGATION OF COMMERCIAL TECHNOLOGIES WITH APPLICATION TO LITTORAL COMBAT SHIP (LCS) MODULARITY
Joshua H. Gordis, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Surface Warfare Center - Panama City

OBJECTIVES: The current development of the Littoral Combat Ship (LCS) is focused on providing "modularity" for the ship. The modular ship will allow reconfiguration for different missions, e.g., mine warfare (MIW), anti-submarine warfare (ASW) and surface warfare (SUW). Reconfiguration involves the "swapping" of systems, providing a "plug-and-play" open architecture combat platform. To this end, the movement, storage, and retrieval of mission systems and subsystems to and from the ship (into and out of mission module spaces), and the launch and recovery of systems (e.g., AUV) will require materials handling technologies. The objective of this project was to investigate available commercial materials handling technologies that have potential benefit to the LCS program, in the interest of avoiding "reinventing the wheel" and saving research and development costs.

SUMMARY: A thorough investigation of commercial materials handling technologies provided a large variety of existing technologies in the following categories: materials handling, storage and retrieval, trucks and mobile equipment, containers, manufacturing industry, and robotics and automation. Many of these commercial technologies could be applied immediately to the LCS seaframe, and to other Naval applications as well.

TECHNICAL REPORT:

Gordis, J.H., "Investigation of Commercial Materials Handling Technologies with Application to LCS Modularity," Naval Surface Warfare Center (NSWC)-Panama City-PMS501, October 2004.

KEYWORDS: Littoral Combat Ship, LCS, MIW, ASW, SUW

DEVELOPMENT OF AUV TECHNOLOGIES
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Jeffrey D. Weekley, Research Associate
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Donald P. Brutzman, Associate Professor
MOVES Institute (Modeling, Virtual Environments, and Simulation)
Sponsor: National University of Singapore

OBJECTIVES: This project is sponsored by the National University of Singapore (NUS). First year work is aimed at developing the AUV WorkBench – a simulation system for mission planning and control for AUVs. The later phases will evaluate graduated nonconvexity algorithms developed using the AUV WorkBench for their performance in water trials using *ARIES*.

SUMMARY: Results - The AUV Workbench. Another impediment to the effective use of multiple AUVs is the complexity of the mission planning and analysis tools. This complexity is necessary, but each vehicle shares much of the same requirements for mission planning, rehearsal and replay and therefore each of the software tools used for these activities share commonalities. For instance, all mission planning tools must plot waypoints in one form or another. All must have some way for analyzing the data gathered on a mission. For an individual operator, it is impractical to learn all of these tools. For organizations, it may not be feasible to retain a cadre of experts, one for each tool in order to be able to field multiple vehicles. This limits the ability to tactically deploy multiple AUVs.

A common mission planning and analysis tool was proposed as one possible solution. The AUV Workbench is such a tool. It is Java-based, componentized and can be customized. Custom buttons to launch separate applications can be placed on the right side of the window, mission scripts in extensible markup language (XML) or plain text can be loaded and viewed in two-dimensional (2D) and three-dimensional (3D) views in the right panel, as well as simplified text in the upper left pane. The graphical views and the mission script are currently linked dynamically, if you change the text, the change is portrayed in the Mission Viewer. Other functionalities that are inherent in Java's Graphical User Interfaces (GUI) are included in the workbench: the ability to redraw panels, input/output, tabular design, etc.

AUV Workbench Organization Overview. The AUV workbench consists of four main control threads. These threads communicate with each other either directly or over the network for required interaction. The

individual threads are responsible for four distinct functions: mission execution; virtual world dynamics modeling and feedback; mission planning and generation; and mission visualization.

The mission execution thread runs the software from the actual AUV. It is a mirror copy of the code on board the vehicle. Utilization of the actual AUV software facilitates the development of control equations and algorithms, and enables the realistic rehearsal and fine-tuning of missions in a benign lab environment prior to attempting their execution in open water. By querying the mathematical model of the virtual world for telemetry data rather than onboard sensors, the AUV software can create for itself the illusion that it is operating in the water and the software will behave accordingly. The AUV Workbench currently contains two versions of the AUV execution software (with the primary differences being implementation programming language and useable command language options). They are compiled C code and Java. While these were both developed to run on vehicles operated by the Naval Postgraduate School (NPS), their behavior can be adapted to other vehicles by adjusting the control constants and by adding, deleting or changing control equations. The vehicle control algorithms can be tested and visualized with various mission scripts, against known hydrodynamics models. Any effort to provide precision control for an AUV requires an accurate estimation of both the vehicles physical and hydrodynamic parameters. Here, a vehicle model for controlled steering behaviors was developed and the hydrodynamic parameters were calculated from actual data obtained from operations.

The virtual world dynamics thread implements the AUV hydrodynamics mathematical model. When passed a telemetry string from the AUV execution thread, the model is applied, and then a follow-on telemetry string is generated to pass back to the AUV. Additionally, a Distributed Interactive Simulation (DIS) packet is broadcast over the network to drive the visualization thread of the workbench (as well as any other DIS-enabled visualization application that may be on the network). In addition to hydrodynamics modeling, the dynamics thread contains classes that are utilized to model the vehicle's onboard sensors. Sonar data (or that from any other onboard sensor) can therefore be derived and encapsulated within the telemetry string and DIS packets to allow for the realistic feedback to the AUV execution software, and accurate mission visualization by the human operator. As with the execution software, the hydrodynamics mathematical model and sensor models currently in use were developed to model the vehicles operated by NPS, but can be arbitrarily adapted to other vehicles simply by modifying the control constants.

The visualization portion of the workbench contains a 3D viewer that utilized X3D or VRML models of the AUV and its virtual environment. By reading and interpreting the DIS packets as the come across the network, the viewer automatically animates the vehicle. It provides visual feedback on control settings, sensor effectiveness and utilization.

The final portion of the workbench provides a means of authoring and testing individual missions symbolically using the Graphical User Interface. Missions generated by the workbench take the form of a generic XML-based AUV Script Command Language (the schema currently supports mission scripting, telemetry, sensor archiving and reporting, and inter-vehicle communication). Once a mission has been generated, it is a fairly simple matter to use XSLT to convert it to any of a number of AUV command formats that are capable of running on specific vehicles. To date, transformations have been developed to convert automatically this language to command formats for two vehicles currently or previously operated by the NPS. Additionally, this generic language can be run natively by one of the two versions of execution software packaged with the AUV Workbench.

<u>Mission Planning.</u> Many AUVs share commonalities that allow for the development of a common tool for mission planning. Waypoints, speed, heading, depth, and mission duration are some common features of almost every AUV mission. There has been extensive study in what constitutes effective coverage for minefield clearance and it will not be discussed in this paper. However, there are not only common features within the mission plan, but there are also commonly found mission plans. "Mowing the Lawn" is a typical mission track and is often repeated regularly, with only minor changes made for local conditions. It has been difficult in the past to plan a mission for one vehicle, and then apply that exact same mission plan to another vehicle to allow for true comparison and experimentation. The missions must be approximated due to the differences in the planning tools. A common tool that "styles" each mission script to its appropriate vehicle would allow for experimentation and validation of archetypal missions across various vehicles.

The AUV Workbench currently supports a simple, text-based mission script, but it also supports the use of XML-based mission scripts. It can also be extended to include custom applications that can be launched in a separate process by adding buttons to the right of the panels. This becomes a very convenient way for users to bundle applications that they commonly use with AUV mission planning.

Mission Simulation. Experimental AUVs are the result of many years of effort. Other AUVs are expensive. None of them are trivial or insignificant assets. It is important, especially when doing research into new tactics and techniques, to be able to test and simulate. The AUV Workbench is valuable in this regard. A user can test, simulate and visualize missions, new control algorithms and even new vehicles in a controlled environment, safe from the rigors of the underwater environment. It allows systems and software to be thoroughly tested before they are implemented onboard an AUV. The networking capability allows even remote viewing of mission simulations by using the Distributed Interactive Simulation (DIS) protocol. (See Distributed Interactive Simulation Working Group of the Web 3D Consortium http://www.web3d.org/WorkingGroups/vrtp/dis-java-vrml/)

Network Support for Distributed Simulations. Because the AUV Workbench uses the Distributed Interactive Simulation (DIS) Protocol to generate network traffic, the missions it generates can be visualized across a local or wide area network. DIS is the Institute of Electrical and Electronics Engineers, Inc., (IEEE) recommended practice for networked simulations. (See http://standards.ieee.org/catalog/olis/compsim.html) DIS is packet-oriented and is a natural match for UDP/Multicast/Broadcast over IP.

From the DIS-Java-VRML Working Group of the Web 3D Consortium, "The primary mission of DIS is to define an infrastructure for linking simulations of various types at multiple locations to create realistic, complex, virtual "worlds" for the simulation of highly interactive activities. This infrastructure brings together systems built for separate purposes, technologies from different eras, products from various vendors, and platforms from various services and permits them to interoperate. DIS exercises are intended to support a mixture of virtual entities (human-in-the-loop simulators), live entities (operational platforms and test and evaluation systems), and constructive entities (wargames and other automated simulations). The DIS infrastructure provides interface standards, communications architectures, management structures, fidelity indices, technical forums, and other elements necessary to transform heterogeneous simulations into unified seamless synthetic environments. These synthetic environments support design and prototyping, education and training, test and evaluation, emergency preparedness and contingency response, and readiness and warfighting. (See http://www.web3d.org/WorkingGroups/vrtp/dis-java-vrml/AnnotatedReferences.html#DIS.)

The AUV Workbench produces standard data packets for DIS, called Entity State Protocol Data Units (ESPDU). These ESPDUs contain an entity's position (in x,y,z coordinates), velocity, acceleration, angular velocity, angular acceleration, and orientation. They also contain "articulation parameters," which handles things such as thruster orientation on an AUV. The *ARIES* AUV model was created using X3D-Edit. (See http://www.web3d.org/TaskGroups/x3d/translation/README.X3D-Edit.html.)

Since DIS is an IEEE standard, anyone can buy the standard and write an implementation. Some commercial implementations exist, but a free Java implementation from NPS is available. (See http://web.nps.navy.mil/~brutzman/vrtp/dis-java-vrml.)

The ESPDUs for a given entity each have a unique identifier called out in the header of the packet. The object or model in the virtual world can then "listen" for its unique identifier and is driven around the virtual world based on the entity state communicated in the data packet. The protocol has safeguards for lossy networks, such as a five-second dead reckoning and virtual world course correction for temporary periods when no packets have been received. The header information is encoded from the field values shown in Figure 5.

Server-Side Support. As AUVs and other data collectors become more ubiquitous, it will be increasingly challenging to manage all these data. On recent exercises such as Millennium Challenge '03, data was collected by handing an operator a diskette with the mission data. It was then processed by a technician and uploaded to a local computer. This process, while robust, was very labor intensive.

With XML-based mission results, this process can be automated fairly easily. In the AUV Workbench, the results are gathered from multiple sources and simply pushed up via the web to a server. Because these files contain sufficient meta-data, the server can automatically sort, file and even validate the information based on a Schema. From this web archive, mission results can be presented in easily understood ways, such as hypertext markup language (HTML) pages and X3D replay of missions. Large-scale mission repositories can be made available for research and tactical exploitation.

Real World Results. Currently, there are no data-rich AUV mission archives widely available on the World Wide Web. The data are ephemeral. Archival information is often limited to MATLAB® generated plots and HTML pages with imagery, but none of the actual mission data. This limits the ability of others to

scrutinize and analyze the data. Adopting a common AUV Tactical Mission Language would allow for the auto-generation of web-based archives.

This web-based archive could be viewed in a web browser, the data analyzed either by machine or by humans in 2D or 3D; it could be transformed via XSLT to other data formats and even imported into other mission planning tools for further experimentation. Of course, it could also be obscured and encrypted, by any means that is commonly available for other web-based information.

<u>Web-based Replay of Missions.</u> There are over 800 model components and models available there, including many AUVs and underwater mines. These models are typically formatted such that they can be automatically inserted into a computer-generated scene. As such, they can greatly aid in the analysis by creating visual cues for the analyst. (See http://www.stl.nps.navy.mil/~brutzman/Savage/contents.html.)

PUBLICATION:

Weekley, J., Brutzman, D., Healey, A., Davis, D., and Lee, D., "AUV Workbench: Integrated 3D for Interoperable Mission Rehearsal, Reality and Replay," *Proceedings of the 2004 Mine Warfare Association (MINWARA) Conference*, Naval Postgraduate School, March 2004.

KEYWORDS: AUV, Web-Based, Browser

NAVAL POSTGRADUATE SCHOOL (NPS) *ARIES* FORWARD LOOK SONAR INTEGRATION
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Douglas P. Horner, Research Associate
Department of Information Science
Sponsor: Office of Naval Research

OBJECTIVES: The long-term goal of this project is to increase the level of autonomy in AUVs as they are being used for more complex missions than mine countermeasures. Part of this increase in autonomy will rely on obstacle detection and avoidance and will require a forward looking sonar (FLS) suitable for small vehicles. In the past year, the Naval Postgraduate School (NPS) Center for AUV Research has temporarily mounted a University of Washington Applied Physics Lab (UW: APL) Blazed Array Forward Looking Sonar (FLS) on the NPS *ARIES* AUV and has conducted several data collection tests in Monterey Bay. The goal of the collection was to provide realistic data for researchers to develop obstacle avoidance (OA) algorithms for small AUVs. In July 2004, NPS took delivery of a prototype FLS and mounted it on *ARIES*. With the FLS installed on *ARIES*, opportunities for data collection and analysis of the sonar data were increased. This also provided an opportunity to begin integrating OA algorithms aboard the *ARIES* vehicle for analysis.

SUMMARY: Results - Images were gathered using the *ARIES* AUV in both horizontal and vertical orientations. These images were analyzed and pitch stabilized for multiple ping-ping correlation for target detection and assessment. Source: LCDR D.J. Danko, USN, Naval Postgraduate School Thesis, September 2004, (http://www.cs.nps.navy.mil/research/auv/theses/danko/04Sep_Danko.pdf). This work is leading to the development of on-line real time obstacle avoidance algorithm.

Related projects include tactical decision aids (high bandwidth links using autonomous vehicles).

PUBLICATION:

Healey, A.J., "Obstacle Avoidance While Bottom Following for the *REMUS* Autonomous Underwater Vehicle," *Proceedings of the IFAC-IAV 2004 Conference*, Lisbon, Portugal, 5-7 July 2004, (http://web.nps.navy.mil/~me/healey/papers/IAV2004.pdf).

THESIS DIRECTED:

Danko, D.J., "Autonomous Underwater Vehicle Obstacle Detection and Assessment Using Forward Looking Sonar," Master's Thesis, Naval Postgraduate School, September 2004,

(http://www.cs.nps.navy.mil/research/auv/theses/danko/04Sep_Danko.pdf).

KEYWORDS: AUV, Sonar, *Aries*

PARTICIPATION IN AUTONOMOUS OCEAN SAMPLING NETWORK (AOSN) II
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Sponsor: Office of Naval Research

SUPPORT FOR AUTONOMY STUDY
Anthony J. Healey, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Undersea Warfare Center - Newport Division

SUMMARY: Conducted a study of the autonomy capabilities of potential suppliers for AUV autonomy/mission control software for future Naval autonomous underwater vehicles.

KEYWORDS: AOSN, Ocean Sampling, AUV

TACTICAL DECISION AIDS (HIGH BANDWIDTH LINKS USING AUTONOMOUS VEHICLES)
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Douglas P. Horner, Research Associate
Department of Information Science
Sponsor: Office of Naval Research

OBJECTIVES: To develop tactical decision aids (TDA) for using small autonomous underwater vehicles in very shallow water (VSW) environments. TDAs enable operators to view data gathered by these vehicles and make informed decisions as to the conduct of mine counter measures (MCM) operations. This project will examine the use of command and control vehicles to aid in reducing latency of decision making and improvements to overall MCM reliability using multiple vehicles. A large part of this work is to reduce latency of decision making using systems of autonomous underwater vehicles (AUVs) and high speed, high bandwidth communications links.

The objectives in 2004 were to demonstrate high bandwidth communications links between multiple vehicles. This included underwater, surface and aerial vehicles equipped with 802.11 wireless bridges and amplifiers. The objectives were to transfer video sized files at high rates leading to the use of full video data for target evaluation and decision making. In these experiments, forward looking sonar files were collected by the Naval Postgraduate School (NPS) *ARIES* AUV and transferred through the high bandwidth link to a command center.

SUMMARY: The operational requirements for developing this technology are

- Robust communications for command and control and data transfer are required for teams of vehicles deployed in an area to scout and report on oceanographic conditions and the mine threat.
- Collected data is voluminous and requires a high bandwidth data link.
- Data needs to be collected and distributed quickly for rapid operational planning.
- Not all vehicles may return from missions – the data still needs to be collected.

The solution offered by this technology provides unmanned systems with high bandwidth communications (currently 802.11b) using a UAV as a bridge between an AUV and a command cell located some distance

from the AUV. The technology also automates the path of the UAV to optimize the link between the groups of vehicles.

Work Completed: This year NPS participated in four exercises, the Surveillance and Target Acquisition Network (STAN)-5, 6, and 7 exercises, and the Combined Joint Task Force Experiment (CJTFEX) '04 exercise, held at Camp Lejeune, North Carolina. These exercises formed a continual series of developments that include both an opportunity for experiment as well as a demonstration of ever-increasing levels of autonomy and networking complexity and speed. The STAN experiments were funded separately by U.S. Special Operations Command (USSOCOM) and NPS and formed a natural way to multiply the results and effectiveness of the work funded by this project.

Results: *Stan-5 (February 2004 - Camp Roberts, California)* - NPS *ARIES* was fitted with 802.11b CISCO 3150, radio ethernet bridge and a similar bridge on a V6 TERN aerial vehicle. During this experiment, file transfer data was demonstrated between the *ARIES* vehicle and the TERN at various ranges. Experiments were conducted using 3 dbi, 5 dbi, omni- and directional antennae, as well as a 1 watt amplifier inside *ARIES* and the TERN. File transfer data were gathered and demonstrated at a range of 1 km, for a flight altitude of 300-500 feet with data rates between 160 and 300 Kbps.

Stan-6 (May 2004 - Camp Roberts, California) - In this experiment *ARIES* was operated in Lake Nacamiento with a tethered balloon, as well as the TERN aerial vehicle. *ARIES* was located in the Lake approximately 11 km from the Command Center at MacMillan field. The surfaced *ARIES* transmitted a video sonar data file to the TERN operated by USSOCOM, V-6 forces controlled to fly autonomously over Lake Nacamiento. File data was received at the Command Center as soon as the TERN was seen circling above the Lake. Data transfer rates were variable but averaged about 300 Kbps. Key to the success of the experiment over this range was the use of the high gain receiver and a tracking antenna (K2) at the Command Center to track the TERN. Similar experiments were conducted using a tethered balloon as the relay link. As long as the balloon was visible at MacMillan Field Command Center, the file transfer was made. High winds occasionally reduced the balloon height so that the link bandwidth was reduced when line of sight was lost. Occasional outages simply slowed the overall net rate, but the link was not destroyed.

CJTFEX-04-2 (June 2004 - Camp Lejeune, North Carolina) - A complete report of the activity during CJTFEX 04-2 is beyond the scope of this report to describe all aspects of the work. In a quick summary, the *ARIES* AUV was equipped with the Cisco AERONET 350 802.11b wireless bridge for high data rate transfer using a 1 watt compatible antenna, and an aerial vehicle TERN carried a separate bridge package. The TERN, which crashed on first flight, was substituted by a balloon. Data gathered over various ranges from the surface AUV through the balloon relay and a high gain tracking antenna (K2) showed solid performance and data rates to 300 Kbps over ranges up to 20 Km.

The NPS objectives for the *ARIES*/TERN system during CJTFEX 04-2 were to

- Demonstrate high bandwidth links for sonar and/or video file transfer between the *ARIES* AUV, the TERN UAV and the K2 Tactical Operations Center
- Demonstrate 802.11b network links for AUV and UAV assets over distances greater than 4km at 200-300 kbps.

Tests were conducted on 7 and 9 June to determine the maximum range of the 802.11b link. Tests were conducted on 6 and 8 June to determine the file transfer rates of various network configurations.

The NPS *ARIES*/TERN mission was a qualified success. The mission demonstrated the ability to create a stable 802.11b network with three nodes with a total length of 27 km. Data files were moved along the network at file transfer rates ranging at a maximum of 800 Kbps down to 160 Kbps at maximum node separation (max range).

The primary objective of these Office of Naval Research (ONR) observations was to assess the military utility and application of participating OMCM Future Naval Capabilities (FNC) systems in a real-world exercise environment. It appears that 802.11b technology does represent one means of providing a high bandwidth (200 to 800 Kbps) link between autonomous and unmanned vehicles and other network nodes using standard Windows networking. The architecture is relatively simple to set up, uses commercial-off-the-shelf (COTS) components and is relatively secure.

Stan 7 (17-20 August 2004 - Monterey Bay, California, and Camp Roberts, California) - These experiments, while far from complete, demonstrated the use of very high bandwidth data relays from a surfaced ship at 12 Km out in Monterey Bay to Camp Roberts over 100 miles away with data rates up to 6 Mbps. This ultra high speed was obtained using an orthogonal frequency-division multiplexing (OFDM)

communications protocol under the 802.16 standard. While the equipment is not yet miniaturized for deployment in small AUVs, the capability was demonstrated well offshore.

Related Work: In related work, Captain Jack Nicholson completed his Doctoral dissertation, which dealt with autonomous rendezvous between autonomous underwater vehicles for the purposes of close-in formation flying to transfer high speed data underwater at close range. High bandwidth underwater may eventually be possible at short range. Experimental work validated the use of autonomous planning and re-planning using energy and time optimal concepts. Also tied to this project was the work in obstacle avoidance control for the *REMUS* AUV under the assumptions of perfect detection of underwater obstacles. Vertical plane detection and avoidance was reported following the work of earlier thesis students.

Transitions: High-speed data transfer using 802.11 and 802.16 technologies is expected to transition into the Navy's UUV acquisition program in the future.

Related Projects: The related project is titled "NPS *ARIES* Forward Look Sonar Integration," in which a small Blazed Array is used for obstacle detection.

REFERENCES:

Healey, A.J., "Obstacle Avoidance While Bottom Following for the *REMUS* Autonomous Underwater Vehicle," *Proceedings of the IFAC IAV-2004 Conference*, Lisbon, Portugal, July 2004.

Marshall, P. and Valdez, T., "*ARIES*-TERN Network Connectivity Experiment Quicklook Report," Naval Postgraduate School, June 2004.

Marshall, P.M., Valdez, T., and Moellering, R., "Surveillance and Tactical Acquisition Network Exercise No. 7, At-Sea OFDM Network Connectivity Experiment, Quicklook Report," Naval Postgraduate School, August 2004.

PUBLICATION:

"Naval Postgraduate School Center for Autonomous Underwater Vehicle (AUV) Research 2003 Annual Report," Naval Postgraduate School Technical Report, NPS-MAE-04-002, March 2004, (http://web.nps.navy.mil/~me/healey/papers/2003 Annual Report.pdf).

CONFERENCE PUBLICATION:

Horner, D.P. and Healey, A.J., "Use of Artificial Potential Fields for UAV Guidance and Optimization of WLAN Communications," *Proceedings of the IEEE Autonomous Underwater Vehicle (AUV) 2004 Conference*, Maine, June 2004, (http://web.nps.navy.mil/~me/healey/papers/AUV2004.pdf).

THESIS ADVISED:

Nicholson, J.W., "Autonomous Rendezvous of Autonomous Underwater Vehicles," Ph.D. Dissertation, Naval Postgraduate School, September 2004

KEYWORDS: AUV, Tactical Decision Aids, *ARIES*

ADVANCED COMPRESSOR STUDIES PROJECT
Garth V. Hobson, Professor
Ronald P. Shreeve, Professor Emeritus
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Air Warfare Center, Aircraft Division

SUMMARY: An invited paper on the three-component measurements of the flow aft of the second-generation controlled-diffusion blades in cascade was presented at the 2003 American Society of Mechanical Engineers (ASME) Turbo Expo. The paper was also accepted for publication in the ASME *Journal of Turbomachinery*.

Performance measurements were completed on the Sanger transonic fan stage, with a steel casing and minimum tip gap. The measurements were taken at 50, 60, 70, 80, 90 and 100% speed lines from full open throttle to surge at all speeds. Two papers were presented at the ASME Turbo Expo 2004 in Vienna, Austria. Subsequent rotor-only testing was completed and numerical predictions of this configuration were also completed with the National Aeronautics and Space Administration (NASA) codes SWIFT (steady state) and TURBO (which has unsteady calculation capability). A complete rotor simulation with TURBO is currently underway.

REFERENCES:

Gannon, A.J., Hobson, G.V., and Shreeve, R.P., "A Transonic Compressor Stage: Part 1 Experimental Results," American Society of Mechanical Engineers (ASME) GT2004-53923, Turbo Expo 2004, Vienna, Austria.

Hobson, G.V., Carlson, J., and Caruso, T., "Three-Component Measurements of the Flow Aft of a Cascade of Controlled-Diffusion Compressor Blades," American Society of Mechanical Engineers (ASME) *Journal of Turbomachinery*, 2005, (to appear).

Hobson, G.V., Gannon, A.J., and Shreeve, R.P., "A Transonic Compressor Stage: Part 2 CFD Simulation," American Society of Mechanical Engineers (ASME) GT2004-53927, Turbo Expo 2004, Vienna, Austria.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Transonic, Compressor, Experimental, Computational

COMPRESSOR INLET DISTORTION
Garth V. Hobson, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVES: To develop and validate tools for the inlet distortion for an advanced compression system for Navy engines. To predict transfer function using the CFD code MSU-Turbo for an F414-GE-400 three stage fan and compare it to test data. To develop transient models for thermal and pressure distortion for the F414-GE-400 fan stages. To assist Naval Air Systems Command (NAVAIR) engineers in predicting performance of F110-GE-400 using the transient models. To interface with General Electric (GE)/NAVAIR on correlating the prediction to test data.

SUMMARY: The Silicon Graphics (SGI) workstations within the Department of Mechanical and Astronautical Engineering have been configured as a parallel cluster, which have been used to run various small problems with TURBO. Steady and unsteady calculations have been performed on single blade-row problems of the Naval Postgraduate School (NPS) transonic compressor, National Aeronautics and Space Administration (NASA) rotor 67 and the exit guidevane of the F414-GE-400 compressor (Step1A).
 In collaboration with Dr. Steven Gorrell at Wright Patterson Air Force Base (WPAFB), the computation of a full stator row of the F414 three-stage fan was completed on the Naval Oceanographic Office (NAVO) supercomputer cluster. A Challenge Project proposal was awarded for the computation of the whole three-stage compressor, and current calculations were performed on the Aeronautical Systems Center (ASC) Major Shared Resource Center (MSRC) at WPAFB. These calculations were performed with pressure and temperature inlet distortion profiles, which were experimentally simulated.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Fan, Compressor, Unsteady Calculations, Numerical

CROSS-FLOW FAN STUDY

Garth V. Hobson, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Aeronautics and Space Administration - Glenn Research Center

OBJECTIVES: To demonstrate the potential of the Cross-Flow Fan (CFF) for use on personal Vertical Take Off and Landing (VTOL) airplanes, as postulated by Gosset. The CFF is an underdeveloped fan, which should have significant development potential using modern computational analysis and experimental measuring techniques. Although the Vought Systems Division of LTV study yielded significant results, the optimum blade design, blade number, fan diameter and span, and size and arrangement of the high and low-pressure cavities remain to be determined. Also, the most lightweight fan using composite materials remains to be demonstrated. A further improvement could be achieved by combining the cross-flow fan with a thrust-augmenting ejector. A combined computational and experimental program was undertaken to determine and demonstrate the optimum cross-flow fan configuration.

SUMMARY: The 12-inch CFF was successfully run at 7,000 rpm during which performance data were measured. Flow visualization was performed at 5,000 rpm. At 6,000 rpm a thrust-to-power ratio (lbf-to-hp) of one was measured, however at 3,000 rpm a thrust-to-power ratio of two was measured. Next, a complete performance map was measured over the speed range from 2,000 to 6,000 rpm from choke (open throttle) to stall (closed throttle).
 The numerical (CFD) prediction was performed by modeling all 30 rotor blades with the rotor spinning at 3,000 rpm. Qualitative comparisons were made between the experimental and computational flow visualization. A paper documenting the experimental and numerical results was presented at the American Society of Mechanical Engineers (ASME) Turbo Expo.
    Subsequent testing was conducted on a 6-inch CFF with measurements of efficiency in excess of 75%. The increase of efficiency was achieved by modifying the exhaust duct profile. All testing to date was conducted on a 1.5-inch span CFF and future tests will be of a 6-inch span rotor.

REFERENCE:

Hobson, G.V., Cheng, W.T., Seaton, M.S., Gannon, A.J., and Platzer, M., "Experimental and Computational Investigation of Cross-Flow Fan Propulsion for Lightweight VTOL Aircraft," American Society of Mechanical Engineers (ASME) GT2004-53468, Turbo Expo 2004, Vienna, Austria, 2004.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Fan, Compressor

AN EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF OSCILLATING AIRFOIL UNSTEADY AERODYNAMICS AT LARGE MEAN INCIDENCE

Kevin D. Jones, Research Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: University of Kentucky

OBJECTIVES: To evaluate the capability of current state-of-the-art unsteady aerodynamic models to predict the oscillating airfoil response of compressor airfoils over a range of realistic reduced frequencies, Mach numbers, and loading levels through correlation with benchmark data.

SUMMARY: Initiated transition calculations with the SWG model of the National Aeronautics and Space Administration (NASA) Transonic Flutter Cascade (TFC) using the locally developed two- dimensional flow solver NSTRANS for the low angle-of-attack experimental data at an inlet Mach number of 0.5. Solutions exhibited a pressure plateau in the leading edge region following the suction peak, which was not found with the fully turbulent solution. Additionally, negligible sensitivity to variations in grid resolution was found. A study on the influence of transition onset location and the length of a suction surface

separation bubble was conducted. It was found that more downstream transition onset locations slightly lengthened the separation bubble. These studies are continuing.

PUBLICATIONS:

Jones, K.D., Bradshaw, C.J., Papadopoulos, J., and Platzer, M.F., "Improved Performance and Control of Flapping-Wing Propelled Micro Air Vehicles," *AIAA Paper No. 2004-0399*, January 2004.

Jones, K.D., Bradshaw, C.J., Papadopoulos, J., and Platzer, M.F., "Improved Performance and Control of Flapping-Wing Propelled Micro Air Vehicles," *Royal Aeronautical Society Annual Meeting, Paper 12*, 14-15 September 2004, (invited).

Jones, K.D., Nakashima, M., Bradshaw, C.J., Papadopoulos, J., and Platzer, M.F., "On Flow Separation Control by Means of Flapping Wings," *Bio-Mechanisms of Swimming and Flying, Chapter 5*, N. Kato, J. Ayers, and H. Morikawa (Eds.), Springer-Verlag, Tokyo, 2004.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Turbine, Cascade, Transition, Turbulence, Laminar Separation, Propulsion

DEVELOPMENT AND FLIGHT OF A SHIPBOARD AUTOLAND SYSTEM FOR THE SILVER FOX UAV
Isaac I. Kaminer, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Office of Naval Research

SUMMARY: A complete shipboard autoland system for Silver Fox was developed and tested in a hardware-in-the-loop simulation, followed by a series of successful flight tests. The system assumed a 5mx7m recovery net on the ship.

CONFERENCE PUBLICATION:

Kaminer, I., Yakimenko, O., Dobrokhodov, V., Lizaraga, M., and Pascoal A., "Cooperative Control of Small UAVs for Naval Applications," *Proceedings of the 43rd IEEE Conference on Decision and Control*, Paradise Island, Bahamas, 14-17 December 2004.

THESIS DIRECTED:

Lizarraga, M.I., "Autonomous Landing System for a UAV," Master's Thesis, Naval Postgraduate School, March 2004.

KEYWORDS: Autoland, Silver Fox, UAV

DEVELOPMENT OF THE MODELING AND SIMULATION TOOLS GROUND FOR GUIDED AIRDROP SYSTEMS
Isaac I. Kaminer, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Yuma Proving Grounds

SUMMARY: An eight degree of freedom (DOF) model of a generic parafoil was developed and verified using air drop data for the Pegasus parafoil. In addition, vision based algorithms for position and attitude estimation of a payload were developed and tested using preliminary video data obtained from Yuma Proving Grounds.

MECHANICAL AND ASTRONAUTICAL ENGINEERING

KEYWORDS: DOF, Airdrop, Parafoil, Pegasus, Yuma

UV AND NETWORK EXPERIMENTATION
Isaac I. Kaminer, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Postgraduate School

A TOTAL SHIP SYSTEMS ENGINEERING ANALYSIS OF THE THERMAL MANAGEMENT OF AN ALL-ELECTRIC SHIP
Matthew D. Kelleher, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Office of Naval Research

OBJECTIVES: To perform an analysis of the thermal management and cooling needs of an all-electric ship.

KEYWORDS: UV, Total Ship System, TSS, Thermal Management, All-Electric

COMPETENCY EDUCATION PACKAGE FOR AIRCRAFT STRUCTURES
Ramesh Kolar, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Air Systems Command

SUMMARY: Developed, updated, and taught short courses in aircraft fracture and fatigue and aircraft practical stress analysis for Naval Air Systems Command (NAVAIR) and Naval Aviation Depots-Cherry Point (NADEP), North Island and Jacksonville engineers and officers in structure competency.

KEYWORDS: Aircraft Fracture, Fatigue, Stress, NAVAIR, NADEP

FINITE ELEMENT MULTIDISCIPLINARY ANALYSIS OF FLIGHT VEHICLES
Ramesh Kolar, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Stirling Dynamics

INTEGRATED SOFTWARE TOOLBOX FOR AEROELASTIC MODELING AND DYNAMIC STABILITY ANALYSIS OF AIR VEHICLES
Ramesh Kolar, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Scientific Sys Co, Inc.

DAMAGE IN PARTICULATE COMPOSITES: MOLECULAR DYNAMICS AND MICROSTRUCTURAL STUDY
Young W. Kwon, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: A continuing research project from the past several years during which a numerical modeling and simulation technique was developed and evaluated against experimental results. The developed method was called a micro/macro approach. This year's effort focused on the study of the effects

of microstructures on the local damage initiation and growth, its interaction and global effect, and the molecular dynamics modeling for micro-structural variation of strain fields.

KEYWORDS: Molecular Dynamics, Microstructure, Aeroelastic

THE MECHANICAL AND MICROSTRUCTURAL CHARACTERIZATION OF COMMERCIAL AA5083 MATERIALS
Terry R. McNelley, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsors: University of Texas at Austin and General Motors Corporation

OBJECTIVES: To determine the mechanisms of elevated temperature deformation and failure under uniaxial, plane strain and biaxial deformation conditions. The microstructure dependence of the transition from grain boundary sliding to solute-drag controlled dislocation creep and the mechanisms of failure by cavity formation and growth during superplastic deformation under these various loading conditions will also be determined.

SUMMARY: Superplastic forming of aluminum alloys has become an established technology for aerospace systems and is being used increasingly in transportation and other applications. The commercial alloy AA5083 is an aluminum-magnesium-manganese that provides a combination of elevated temperature forming characteristics, corrosion resistance, weldability, and post-forming mechanical properties that make it suitable for a wide range of components. This alloy is currently being utilized in an innovative application, termed Quick Plastic Forming (QPF) by General Motors Corporation, which involves forming of sheet metal parts by differential gas pressure at elevated temperature. There are two particular difficulties in advancing this technology: 1) empirically developed methods for production of fine-grained AA5083 sheet material result in high cost, and 2) available sheet materials often exhibit widely different ductility values at elevated temperature even when their grain sizes, textures and grain boundary characteristic are essentially identical. In this research program, newly developed orientation imaging microscopy and related microtexture methods are being employed to investigate grain size refinement during thermomechanical processing and transitions from grain boundary sliding to dislocation deformation mechanisms. Of particular concern are the relationships among alloy constitution, deformation mechanism, and failure by the formation and coalescence of cavities. The influence of stress state will be considered as well by including materials deformed under balanced biaxial tension and plane strain conditions as well as under uniaxial tension.

PUBLICATIONS:

Oh-ishi, K., Boydon, J.F., and McNelley, T.R., "Processing, Deformation and Failure in Superplastic Aluminum Alloys: Applications of Orientation Imaging Microscopy," *Journal of Materials Engineering and Performance*, Vol. 13(6), pp. 710-19, 2004.

Oh-Oishi, K., Boydon, J.F., and McNelley, T.R., "Texture Development and Dynamic Recrystallization in AA5083 During Superplastic Forming at Various Strain Rates," *Advances in Supeplasticity and Superplastic Forming*, E. Taleff, P.A. Friedman, P.E. Krajewski, R.S. Mishra and J.C. Schroth (Eds.), Warrendale, PA: TMS, pp. 119-26, 2004.

Kulas, M.A., Green, W.P., Taleff, E.M., Krajewski, P.E., and McNelley, T.R., "Deformation Mechanisms in Superplastic AA5083 Materials," *Metallurgical and Materials Transactions*, (accepted).

PRESENTATIONS:

McNelley, T.R., "Deformation and Failure Mechanisms in Superplastic AA5083 Materials," General Motors QPF Program Annual Review, GM Technical Center, Warren, MI, 19 August 2004.

Oh-Oishi, K., Boydon, J.F., and McNelley, T.R., "Deformation Mechanisms and Cavity Formation in Superplastic AA5083," Symposium: Advances in Superplasticity and Superplastic Forming, TMS Annual Meeting, Charlottesville, NC, 14-18 March 2004, (invited).

Oh-ishi, K., Boydon, J.F., and McNelley, T.R., "Processing, Deformation and Failure in Superplastic Aluminum Alloys: Applications of Orientation Imaging Microscopy," Symposium on Superplasticity and Superplastic Forming, AEROMAT2004, Seattle, WA, 7-10 June 2004, (invited).

THESES DIRECTED:

Deffenbaugh, K.L., "Grain Size Control in AA5083: Thermomechanical Processing and Particle Stimulated Nucleation," Master's Thesis, Naval Postgraduate School, June 2004.

Fowler, R.M., "Identification of Deformation Mechanisms During Bi-Axial Straining of Superplastic AA5083," Master's Thesis, Naval Postgraduate School, June 2004.

DoD KEY TECHNOLOGY AREAS: Materials and Processes

KEYWORDS: Aluminum, Superplasticity, Recrystallization, Grain Boundaries, Thermomechanical Processing

MICROSTRUCTURE EVOLUTION AND CONTROL DURING FRICTION STIR PROCESSING (FSP) OF CAST NIAL BRONZE MATERIALS
Terry R. McNelley, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Defense Advanced Research Projects Agency

OBJECTIVES: To determine the effect of friction stir processing (FSP) on the microstructure and properties of a cast NiAl bronze (NAB) material utilizing various micro-analytical methods as well as conventional mechanical testing. Of particular concern is to determine the mechanisms of microstructure refinement during FSP and the temperature distributions associated with this process.

SUMMARY: NAB materials are copper-based alloys that are widely used to produce cast components for marine applications due to excellent corrosion resistance; good fracture toughness combined with moderate strength; low coefficients of friction and good wear characteristics; non-sparking behavior; high damping capacity; and good fatigue resistance. Many cast components produced in NAB involve thick sections and the slow cooling rates contribute to coarse microstructures and reduced physical and mechanical properties. Porosity is a particular problem. In many NAB applications it would be desirable to have a means to reduce the porosity as well as alternative methods available to selective strengthen the surface layers of cast components. During FSP, friction between a rotating tool and the surface of the material results in a 'stirring' action that, in turn, produces adiabatic heating and local softening. The tool rotation results in very large deformations in the softened regions, and thus microstructure refinement and homogenization leading, in turn, to improved strength and ductility in processed material. FSP may also result in closure of porosity and redistribution of inclusions thus conferring improved corrosion resistance. The influence of FSP on NAB materials will be examined by various methods including conventional scanning electron microscopy, orientation imaging microscopy, transmission electron microscopy, and related characterizations of the physical and mechanical properties of processed materials.

PUBLICATIONS:

Oh-ishi, K. and McNelley, T.R., "The Influence of Friction Stir Processing Parameters on Microstructure of As-Cast NiAl Bronze," *Metallurgical and Materials Transactions A*, (accepted).

Oh-Ishi, K. and McNelley, T.R., "Microstructural Modification of As-Cast NiAl Bronze by Friction Stir Processing," *Metallurgical and Materials Transactions A*, Vol. 35A, pp. 2951-61, 2004.

PRESENTATIONS:

McNelley, T.R. and Oishi, K., "Friction Stir Processing: Nickel-Aluminum Bronze," Defense Advanced Research Projects Agency (DARPA) Program Review of Friction Stir Processing, Naval Surface Warfare Center-Carderock Division, Bethesda, MD, 13 January 2004.

McNelley, T.R., Oishi, K., Zhilyaev, A., and Williams, R., "Friction Stir Processing: Nickel-Aluminum Bronze," Defense Advanced Research Projects Agency (DARPA) Program Review of Friction Stir Processing, Rockwell Scientific Company, Thousand Oaks, CA, 12 August 2004.

THESES DIRECTED:

Jamison, J.D., "Modeling of Thermal and Mechanical Effects During Friction Stir Processing of Nickel-Aluminum Bronze," Master's Thesis, Naval Postgraduate School, September 2004.

Pierce, F.A., "The Isothermal Deformation of Nickel Aluminum Bronze in Relation to Friction Stir Processing," Master's Thesis, Naval Postgraduate School, June 2004.

Williams, R.A., "A Microstructural and Mechanical Property Correlation of Friction Stir Processed Nickel Aluminum Bronze," Master's Thesis, Naval Postgraduate School, September 2004.

DoD KEY TECHNOLOGY AREA: Materials and Processes

KEYWORDS: Nickel Aluminum Bronze, Friction Stir Processing, Castings, Propellers, Stir Zone, Thermomechanically Affected Zone, Shear Deformation

ULTRA-FINE AND NANO-GRAIN MICROSTRUCTURES BY SEVERE PLASTIC DEFORMATION
Terry R. McNelley, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Supervisor of Shipbuilding, U.S. Navy

OBJECTIVES: To determine mechanisms by which ultra-fine grain structures form in severely deformed materials, such as those processed by equi-channel angular (ECA) pressing

SUMMARY: Ultra-fine grain sizes in the sub-micrometer or even nanometer range can be achieved in metallic materials by imposing extremely large plastic strains during deformation processing. Such grain refinement will result in drastic improvements in strength/toughness combinations for structural applications, as well as in improved ductility during elevated temperature forming. Methods such as ECA pressing are required in order to impart stains large enough to produce such refinement. ECA pressing is accomplished by pressing a billet of material through a die having two channels, of equal cross-section, that intersect at an angle. In such a circumstance, the billet experiences simple shear without change in cross-sectional area and so the process is amenable to repetition. Billet rotation between successive pressing operations allows the shear plane orientation to be changed in order to achieve further control of microstructural refinement. The characteristics of the grain structures and, especially, the nature of the grain boundaries produced by such processing have remained in question. However, grain-to-grain misorientations may be readily determined by newly developed computer-aided electron backscatter pattern (EBSP) analysis methods.

PUBLICATIONS:

McNelley, T.R. and Swisher, D.L., "Deformation Banding and Grain Refinement During ECAP of Aluminum," *Ultrafine Grained Materials III*, Y.T. Zhu, T.G. Langdon, R.Z. Valiev, S.L. Semiatin, D.H. Shin, and T.C. Lowe (Eds.), Warrendale, PA: TMS, pp. 89-94, 2004.

McNelley, T.R. and Swisher, D.L., "Grain Refinement Mechanisms During Equi-Channel Angular Pressing," *LiMAT2003 International Conference on Light Metals for Transportation Systems*, W.E. Frazier, Y.D. Han, N.-J. Kim and E.-W. Lee (Eds.), Center for Advanced Aerospace Materials, Pohang University of Science and Technology, Pohang, Korea, Session IV, Paper 7, March, 2004.

Salem, A.A., Horita, Z., Langdon, T.G., McNelley, T.R., and Semiatin, S.L., "Effect of Strain Path on Microstructure Evolution During Severe Plastic Deformation of Al," *Ultrafine Grained Materials III*, Y.T. Zhu, T.G. Langdon, R.Z. Valiev, S.L. Semiatin, D.H. Shin, and T.C. Lowe (Eds.), Warrendale, PA: TMS, pp. 81-9, 2004.

PRESENTATIONS:

McNelley, T.R., Swisher, D.L., Oh-Ishi, K., and Zhilyaev, A.P., "Development of Microtexture and Grain Boundaries During ECAP of Pure Al," Third International Symposium on Ultra-fine Grained Materials, TMS Annual Meeting, Charlottesville, NC, 14-18 March 2004.

Salem, A.A., Horita, Z., Langdon, T.G., McNelley, T.R., and Semiatin, S.L., "Effect of Strain Path on Microstructure During SPD of Al," Third International Symposium on Ultra-fine Grained Materials, TMS Annual Meeting, Charlottesville, NC, 14-18 March 2004.

DoD KEY TECHNOLOGY AREA: Materials and Processes

KEYWORDS: Aluminum, Grain Refinement, Nano-Grain Materials, Recrystallization, Grain Boundaries, Materials Processing

ADVANCED MARINE GAS TURBINE TECHNOLOGY PROGRAMS
Knox T. Millsaps, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Surface Warfare Center - Carderock Division

SUMMARY: Supported the Advanced Technology Group Manager (Code 91) in the Marine Gas Turbine Branch of Naval Surface Warfare Center (NSWC), Carderock Division, for the life cycle support of the ship service and main propulsion gas turbines. This work included providing analysis and methodologies for the detection and localization of compressor fouling for condition-based maintenance.

KEYWORDS: Marine Gas Turbine, MSWC, CBM

COURSE MATERIAL FOR COMMERCIAL AIRCRAFT SURVIVABILITY: TOOLS FOR DECISION ANALYSIS
Knox T. Millsaps, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Department of Homeland Security

SUMMARY: Provided course materials on commercial aircraft vulnerability to terrorist action for CS3660 - Critical Infrastructure Protection. This material included an overview of the threats, an analysis of current vulnerabilities, and analysis tools to enable policy-makers to take off various options for improving commercial air transportation resilience.

KEYWORDS: Decision Analysis, Commercial Aircraft, Terrorism, Survivability

DESIGN AND VALIDATION OF REDUCED SIGNATURE EXHAUST SYSTEM FROM THE LHAR II MAIN PROPULSION ENGINES

MECHANICAL AND ASTRONAUTICAL ENGINEERING

Knox T. Millsaps, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Surface Warfare Center - Carderock Division

SUMMARY: Supplied design and engineering services to support reducing infrared plume and surface thermal signatures on the LHAR II naval combatants.

KEYWORDS: Reduced Signature Exhaust, LHAR II, Plume, Infrared

ADVANCED TOTAL SHIP SYSTEM ENGINEERING AND OPTIMIZATION
Fotis A. Papoulias, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: ADV Tech Institute

OBJECTIVES: To educate American youth about career opportunities in naval architecture and marine engineering (NA&ME) through a pre-college program for ship design.

KEYWORDS: TSS, NA&ME, Youth Program, Ship Design

ROBUST DISTRIBUTED CONTROL OF SHIPBOARD SYSTEMS
Fotis A. Papoulias, Associate Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Office of Naval Research

SUMMARY: Supported work performed by Nutech Solutions, Inc. on robust distributed control of shipboard systems, utilizing a multi-agent approach, for the Office of Naval Research.

KEYWORDS: TSS, Nutech, Robust Distributed Control, Multi-Agent

CROSS-FLOW FAN FOR VERTICAL TAKE OFF AND LANDING (VTOL) AIRCRAFT
Maximilian F. Platzer, Distinguished Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Aeronautics and Space Administration - Glenn Research Center

AUTONOMOUS DOCKING AND SPACECRAFT SERVICING
Marcello Romano, Research Assistant Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory (Space Vehicle Directorate)

OBJECTIVES: This on-going research aims to advance the knowledge in the field of autonomous proximity navigation, autonomous docking, and servicing between two spacecraft. The capability of successfully dock and transferring fuel between two unmanned spacecraft may bring to breakthrough applications for both Department of Defense (DoD) and civilian missions. The research focuses on the dynamics, control and autonomy aspects and is centered about the Autonomous Docking and Spacecraft Servicing (AUDASS) test-bed. This test-bed, which is in the advance design and integration phase, consists of two spacecraft vehicle simulators, which float via air-pads on a flat surface, in order to simulate in two-dimensions the micro-gravity conditions.

SUMMARY: During FY04, autonomous proximity navigation of the chaser vehicle simulator in the proximity of the fixed target vehicle was achieved using an advance custom-developed vision sensor.

PUBLICATION:

Romano, M., "Ongoing Research Using an On-the-Ground Simulator of Autonomous Docking and Spacecraft Servicing," *Dynamics and Control of System and Structure in Space*, Riomaggiore, Italy, July 2004.

CONFERENCE PUBLICATION:

Romano, M., "An On-the-Ground Simulator of Autonomous Docking and Spacecraft Servicing for Research and Education," *The International Society for Optical Engineering (SPIE) Spacecraft Platforms and Infrastructure Symposium, SPIE,* 5419-19, Orlando, FL, April 2004.

STUDENT PARTICIPATION:

LT Tracy Shay, involved in designing an upgrade chaser vehicle simulator.

LT Diallo Wallace, involved in developing a vision sensor for docking with a passive satellite.

LT David Friedman, involved in studying and testing control laws for the docking maneuver.

DoD KEY TECHNOLOGY AREAS: Space Platform, Autonomous Operation

KEYWORDS: Spacecraft Docking, Space Robotics, Machine Vision, On-the-Ground Testing

DEPLOYMENT OF MULTIPLE SPACECRAFT: COORDINATION, CONTROL AND OPTIMIZATION
I. Michael Ross, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Reconnaissance Office

PSEUDOSPECTRAL METHODS FOR OPTIMAL TRAJECTORIES BY IMPLICIT SIMULATION (OTIS)
I. Michael Ross, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Aeronautics and Space Administration - Glenn Research Center

SUMMARY: Advised the Optimal Trajectories by Implicit Simulation (OTIS) upgrade team at the National Aeronautics and Space Administration (NASA) on matters regarding the use of pseudospectral methods for trajectory optimization.

KEYWORDS: OTIS, NASA, Pseudospectral, Trajectory

RAPID TRAJECTORY GENERATION FOR ENTRY VEHICLES
I. Michael Ross, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Air Force Research Laboratory

SUMMARY: Investigated the use of pseudospectral methods for real-time trajectory generation for entry vehicles.

KEYWORDS: Pseudospectral, Trajectory, Entry Vehicles

REAL-TIME OPTIMIZATION FOR SLEW-MANEUVER DESIGN AND CONTROL

MECHANICAL AND ASTRONAUTICAL ENGINEERING

I. Michael Ross, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: National Reconnaissance Office

SUMMARY: This was an unclassified project. The objective of this multi-year, multi-faculty research was to develop, simulate and ground-test the feasibility of a revolutionary real-time-optimization algorithm for spacecraft slew maneuvers. This research has a potentially large payoff for military spacecraft that require rapid maneuvering. This research focused on the development of the algorithm and the software, while a companion proposal by Professor Loomis, et al., focused on the development of the flight-ready processor on which the algorithm can be hosted. At the end of the third year, the expected outcome of this research work is a laboratory demonstration of this advanced attitude maneuver for NPSAT1, a Naval Postgraduate School (NPS) satellite.

KEYWORDS: Spacecraft Slew Maneuver, NPSAT1

THE BEHAVIOR OF AIRCRAFT WAKES IN GROUND EFFECT
Turgut Sarpkaya, Distinguished Professor Emeritus
Department of Mechanical and Astronautical Engineering
Sponsor: National Aeronautics and Space Administration - Langley Research Center

SUMMARY: This was fundamental/applied fluid dynamics research regarding the roll-up of aircraft vortex wakes in ground effect. The objectives were to identify, review, and contrast the existing models; identify the areas that need improvement; propose a new model with rationale for expected improvement; and work with the National Aeronautics and Space Administration (NASA) on the selection of in-ground-effect flight test cases for evaluating both existing and candidate models.

KEYWORDS: Aircraft Wakes, NASA, Ground Effect

BOW WAVES AND SHIP WAKES
Turgut Sarpkaya, Distinguished Professor Emeritus
Department of Mechanical and Astronautical Engineering
Sponsor: Office of Naval Research

SUMMARY: This was the continuation of a comprehensive experimental investigation of bow waves and ship wakes. The quantification of the dynamics of bow waves in incident waves and the determination of the integral-length scale of turbulence and the decay of turbulent kinetic energy in the wakes of grids and partly submerged bodies in flow of controlled contamination (with dissolvable and non-dissolvable surfactants) constitute the essence of the investigation.

KEYWORDS: Bow Waves, Wakes, Turbulence, Contamination

MODEL OF DYNAMICS AND DECAY OF WAKE VORTICES IN PARALLEL RUNWAYS
Turgut Sarpkaya, Distinguished Professor Emeritus
Department of Mechanical and Astronautical Engineering
Sponsor: National Aeronautics and Space Administration - Langley Research Center

SUMMARY: There is a need for a flexible and absolutely safe separation standard that would permit efficient flight operations. A model (AVOSS) was previously developed and successfully field-tested. The need to resort to parallel runways to further improve flow traffic gives rise to problems such as the wake transport from one runway to the other before it decays, the vortex bouncing and lofting onto the adjacent lane during landing, and other phenomena induced by environmental conditions. These may lead to very dangerous situations. The analysis of the existing data from the San Francisco and Frankfurt/Main Airports and the development of a sound theoretical model constituted the essence of this research.

DDG81 SHIP-SHOCK TRIAL SIMULATION
Young S. Shin, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Sea Systems Command

SUMMARY: Performed shock and vibration analysis in support of DDG-81 class shock follow-on actions, including DDG-81 flight IIL ship shock modeling and simulation. The results were compared with ship shock trial test data (shots 1 and 2) to identify potential problem areas and to investigate damage potential from the standpoint of survivability and vulnerability of the ship.

FORCE PROTECTION IN THREAT ENVIRONMENTS: WEAPONS EFFECTS ON TARGET AND DAMAGE MODELS
Young S. Shin, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Defense Threat Reduction Agency

OBJECTIVES: To look into the details on the integrated munitions effects on targets (structural systems) and, as a result, to identify the critical technology needs, to apply the Integrated Munitions Effectiveness Assessment (IMEA) software system to model weapon effects on an integrated structure system, and to develop additional features in IMEA modules, weapons effects and damage models.

IMEA AND HARDENED-TARGET MODULE COMPARATIVE STUDIES
Young S. Shin, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Defense Threat Reduction Agency

OBJECTIVES: To ensure compatibility of Integrated Munitions Effectiveness Assessment (IMEA) and JMEM Air-to-Surface Weaponeering System (JAWS), thereby assisting in the accreditation of IMEA by Joint Technical Coordinating Group; to develop a common target set to provide a framework to compare future development of each tool and preserve commonality of results; and to investigate subject specific features of IMEA that cause concern among the weaponeering community, such as runt time, fuze options and confidence levels of the results.

SHIP SHOCK TRIAL MODELING AND SIMULATION
Young S. Shin, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Sea Systems Command

SUMMARY: Performed LPD17 ship shock trial modeling and simulation, conducted shock and vibration analysis in support of DDG class shock follow-on actions, including DDG-81 flight IIA ship shock modeling and simulation, identified potential problem areas, and investigated damage potential from the standpoint of survivability of a ship system.

MECHANICAL AND ASTRONAUTICAL ENGINEERING

KEYWORDS: Ship Shock, Vibration, DDG Class

SHOCK AND VIBRATION ANALYSIS SUPPORT OF DDG-81 SHIP SHOCK FOLLOW-ON ACTIONS
Young S. Shin, Professor
Department of Mechanical and Astronautical Engineering
Sponsor: Naval Sea Systems Command

OBJECTIVES: To perform shock and vibration analysis in support of DDG-81 class shock follow-on actions, including DDG-81 flight IIA ship shock modeling and simulation. The results are to be compared with ship shock trial test data (shots 1 and 2) to identify potential problems areas and to investigate damage potential from the standpoint of survivability and vulnerability of the ship.

KEYWORDS: Shock, Vibration, DDG-81

HIGH-CYCLE FATIGUE (HCF)/SPIN TEST RESEARCH
Raymond P. Shreeve, Professor Emeritus
Garth V. Hobson, Professor
Department of Mechanical and Astronautical Engineering
Sponsors: Naval Air Warfare Center - Aircraft Division, Naval Postgraduate School

OBJECTIVES: To develop high-cycle fatigue (HCF) spin-test techniques using an engine-scale vacuum spin-pit. Following the successful implementation of air-jet excitation (AJE), oil-jet excitation (OJE) and eddy-current excitation (ECE) techniques using two small rotors, goals are to apply similar techniques to full-scale engine rotors, and to perform tests to evaluate blade damping techniques. The program was conducted in close association with Naval Air Warfare Center - Aircraft Division (NAWCAD), and with the participation of Hood Technology Corporation, jointly funded by the Air Force.

SUMMARY: A test program to evaluate stick dampers in the XTE 66 LPT-2 turbine rotor was completed. Both ECE and AJE were used to excite the rotor at high engine orders. The second program was conducted to evaluate ECE as an excitation technique for titanium fans, using a developmental F119 first stage blisk. The third program, which is ongoing, is the evaluation of visco-elastic dampers in the fan blades of the AE3007 engine, which powers the Global Hawk. Oil jet excitation has been used, however erosion of the titanium blades were encountered after prolonged testing. Oil mist nozzles are currently being evaluated to alleviate the erosion problem.
 Mist spray patterns have been characterized in a vacuum chamber, using laser Doppler velocimetry to measure the droplet velocity as a function of pressure and temperature as well as the spray cone angle. These results will enable the tuning of spray patterns in the spin pit.

PRESENTATION:

Shreeve, R.P., Seivwright, D.L., and Hobson, G.V., "HCF Spin-Testing with Oil-Jet Excitation," 9th High-Cycle Fatigue (HCF) Conference, 2004.

THESIS DIRECTED:

Moreno, O.R., "Investigation and Development of Oil-Injection Nozzles for High-Cycle Fatigue Rotor Spin Test," Master's Thesis, Naval Postgraduate School, March 2005.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, Gas-Turbine Blade Excitation

DEPARTMENT OF MECHANICAL AND ASTRONAUTICAL ENGINEERING

2004
**Faculty Publications
and Presentations**

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