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SUMMARY OF RESEARCH 1998

Department of Aeronautics and Astronautics

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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Aeronautics and Astronautics. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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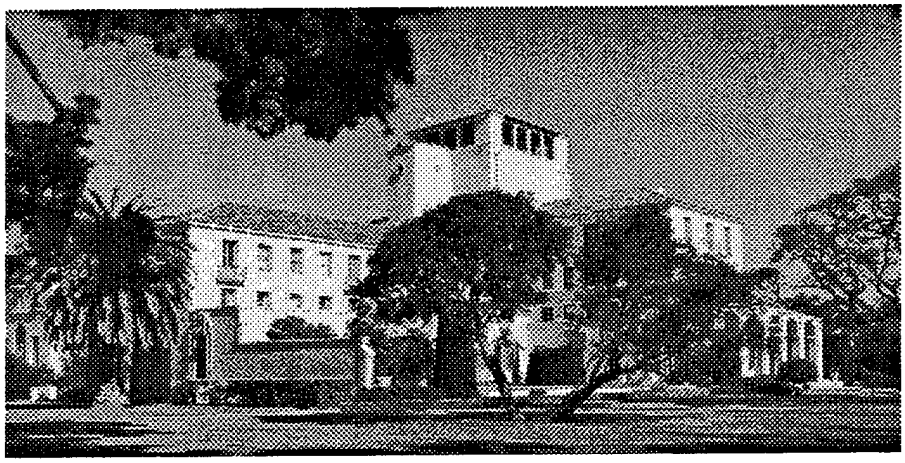
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

GERALD H. LINDSEY
CHAIR

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of U.S. and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.



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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the School's eleven academic departments, seven interdisciplinary groups, and the School of Aviation Safety. This volume contains research summaries for the projects undertaken by faculty in the Department of Aeronautics and Astronautics during 1998. Also included is an overview of the department, faculty listing, a compilation of publications/presentations, and abstracts from theses directed by the department faculty.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the NPS Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil~code09/.

INTRODUCTION

The research program at the Naval Postgraduate School exits to support the graduate education of our students. It does so by providing militarily relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, permitting them to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. This capability is especially important at the present time when technology in general, and information operations in particular, are changing rapidly. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focussed graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at NPS consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with other government laboratories and universities, provides off-campus courses either on-site at the recipient command or by VTC, and provides short courses for technology updates.

- NPS Institutionally Funded Research Program (NIFR): The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursable sponsored, (4) to contribute to the recapitalization of major scientific equipment, and (5) to cost-share the support of a strong post-doctoral program.

- Institute for Joint Warfare Analysis (IJWA) Program: The IJWA Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of research faculty.

In 1998, the overall level of research effort at NPS was 145 faculty workyears and exceeded $35 million. The Department of Aeronautics and Astronautics' effort was 10.25 faculty workyears and exceeded $2.1 million. The sponsored research program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY98, over 81% percent of the NPS research program was externally supported. In the Department of Aeronautics and Astronautics 87% was externally supported.

The department's research sponsorship in FY98 is provided in Figure 1.

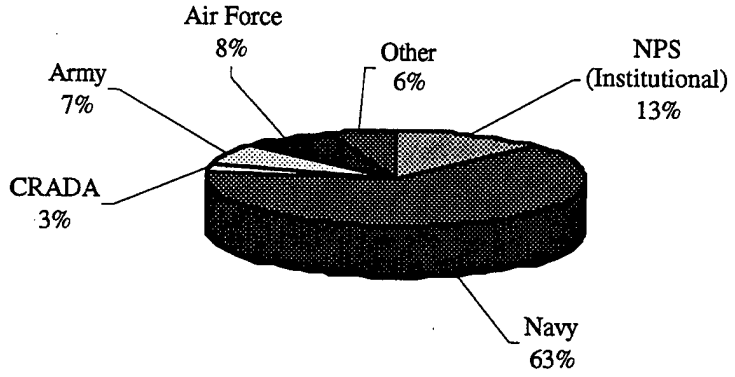

Figure 1. FY98 Sponsor Profile of the Department of Aeronautics and Astronautics

These are both challenging and exciting times at NPS and the research program exists to help ensure that we remain unique in our ability to provide graduate education for the warfighter.

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Associate Provost and Dean of Research

October 1999

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Aerodynamics

TOPICS RELATED TO ROTORCRAFT AND VERTICAL FLIGHT: The rotary wing program led by Professor Wood has four areas. These are: (1) sponsored research support of the Army's principal program, the RAH-66 *Comanche* helicopter. The prototype helicopter is now undergoing engineering flight development at Sikorsky's test center in West Palm Beach, FL. In this area, Professors Wood and Kolar (Department of Aeronautics and Astronautics), Professor Danielson (Department of Mathematics), and Professor Gordis (Department of Mechanical Engineering), are being funded by the Army RAH-66 *Comanche* Office to apply a NASTRAN structural dynamics model of the *Comanche* for exploring potential vibration and weapons system problem areas. In other areas, (2) research in ground and air resonance of soft-inplane hingeless rotor systems (Army Research Office and Sikorsky Aircraft) to eliminate the instability without requiring heavy and costly blade dampers (with AA Lecturer LCDR R. L. King); (3) technical support of Boeing Helicopters-Mesa and SatCon Technology for application of higher harmonic control for improved rotor performance; and (4) development of an improved weapons performance model (Comanche 20-mm gun) for U. S. Army Proving Ground at Yuma, AZ.

FLAPPING WING PROPULSION: In support of the Naval Research Laboratory, Professors Platzer and Jones are performing experimental and computational studies to explore flapping wing propulsion for micro-air vehicles. The numerical simulations were made with an unsteady panel code and a model with flapping wings was built and tested in the NPS low-speed wind tunnel. The measured thrust values agreed well with the prediction.

ENHANCED HELICOPTER MANEUVERABILITY: Professors Chandrasekhara, Platzer, and Jones are performing experimental and computational studies to investigate the fundamental fluid flow physics of compressible flow separation and dynamic stall onset over fixed and variable geometry airfoils, leading to innovative flow control methods. These studies are partially supported by the Army Research Office. Also, in support to the Army Research Office, Professor Chandrasekhara is performing experiments to develop flow control schemes by dynamically deforming the leading edge of an airfoil for prevention of flow separation.

Research funded by the Office of Naval Research was performed to define six possible missions for uninhabited combat air vehicles (UCAVs); a notional configuration was developed for a close-air-support (CAS) platform. Unfunded research was also conducted in waverider, Second Law (thermodynamics) aircraft design methodology and environmental security. Proposals have been submitted to funding sources associated with waverider, environmental security and UCAV systems.

Aeroelasticity

HYPERSONIC FIN FLUTTER: In support of the Naval Air Warfare Center, China Lake, Professors Platzer and Kolar performed a flutter analysis of missile fins flying at hypersonic speeds.

GUST LOAD ANALYSIS: In support of the Naval Air Warfare Center, Patuxent River, Professors Platzer and Tuncer performed computational studies to assess the gust sensitivity of the C-130J aircraft.

Propulsion

ADVANCED AIRCRAFT ENGINE AND MISSILE PROPULSION STUDIES: The validation of CFD design and analysis methods motivates advanced compressor and turbine studies. Professor Shreeve is using a transonic research compressor to validate 3D CFD design methods for advanced fans. Pressure-sensitive paint is being used as a rotor-flow diagnostic. Professor Hobson is investigating both stall in controlled-diffusion compressor blading, and tip-clearance flows in an axial turbine. His work involves both multi-component LDV measurements and CFD analysis. In a new program related to high-cycle fatigue (HCF), Professors Shreeve and Hobson are collaborating with the Naval Air Warfare Center to develop blade-excitation and measurement techniques for spin-test facilities. Small gas turbine engine variants for UAV applications are also being examined.

PLUME SIGNATURE AND PULSE-DETONATION ENGINES: Professors Netzer and Brophy are working to experimentally determine the effects of operating conditions, combustor design, fuel composition and additives on the exhaust plume sooting characteristics of liquid-fueled rocket motors. Also, they are experimentally determining the combustion requirements for sustainment of full strength detonations and the detonation characteristics of liquid-fueled, pulse detonation engines.

Flight Mechanics and Controls

UNMANNED AIR VEHICLE (UAV) TECHNOLOGY: In support of the DoD's role in the development of UAVs, Professor Howard, working with Professors Kaminer and Duren, has developed a UAV flight research laboratory at NPS using several flight platforms for the development and testing of flight control technologies and to address relevant issues of aerodynamics, flight mechanics and intelligent flight control. Projects currently in progress include autonomous flight using passive sensors, voice control of UAVs, an aircraft high-altitude drop simulation, and rotary-wing modeling. A study of key UAV marinization issues is ongoing in support of the Center for Naval Analyses.

SPACECRAFT ATTITUDE CONTROL AND SMART STRUCTURES: In this program, under the supervision of Professor Agrawal and in response to DoD requirements, the emphasis is on the development of improved control techniques for the attitude control of flexible spacecraft and vibration and shape control using smart structures. Improved control techniques have been developed using the technique of input shaping in conjunction with PWPF thrusters to minimize structural vibrations. Neural control has been used for attitude control. A finite element model has been developed to analyze composite plates with piezoelectric actuators. Analytical techniques to determine optimum actuator voltages to minimize surface error were developed. A Smart Structures Laboratory, consisting of vibration isolation platform, space truss, proof mass actuator, fiber optic, shape memory ally, and piezoelectric actuators has been developed.

ASTRODYNAMICS: In support of DoD's role to develop advanced concepts in maneuverability for future space missions, Professor Ross' research in astrodynamics is focused on theoretical and numerical aspects of modeling, analysis, simulation, guidance and control of nonlinear dynamical systems. His research on the stability of dual-spin spacecraft has lead to the development of a refined Energy-Sink theory that has narrowed the gap between theory and practice. He has also developed a new maneuver called aerobang that achieves rapid, minimum-fuel orbital plane-changes for a space plane. Professor Ross and his students continue to work with Jet Propulsion Laboratory (JPL) on advanced technologies for Mars missions. Their recent work has been in developing user-friendly software to analyze aerocaputure missions. Professor Ross and Professor Fahroo from the Mathematics Department have completed Phase I of a project to develop an algorithm for efficient solutions to nonlinear optimal control problems. In this project, they have demonstrated that one can achieve mathematically optimal solutions to a wide class of astrodynamical problems. A research team led by Professor Ross has designed a space mission project for minimizing energy requirements for deflecting Earth-crossing asteroids. Finally, Professors Baldwin and Ross, and their students have worked on a classified small satellite project.

Systems Design

MISSION DEFINITION: Research funded by the Office of Naval Research (ONR) was performed by Professor Newberry to define six possible missions for uninhabited combat air vehicles (UCAVs); a notional configuration was developed for a close-air-support (CAS) platform.

SYSTEM DEVEOPMENT: Research was conducted by Professor Newberry to refine the design methodology associated with waveriders. Aircrew-Centered and Second Law (thermodynamics) aircraft design methodology research was also initiated by Professor Newberry.

ENVIRONMENTAL SECURITY: Professor Newberry led a research effort to define the system concepts of environmental security.

DEPARTMENT SUMMARY

MULTI-DISCIPLINARY DESIGN OPTIMIZATION: Under a Cooperative Research and Development Agreement with the Boeing Company Professors Platzer and Jones are contributing to the development of advanced multi-disciplinary analysis and design methods for subsonic transport aircraft.

JOINT STAND-OFF WEAPON CAPTIVE AIR TRAINING MISSILE (JSOW CATM) PROJECT: This project involves the preliminary conceptual development of a Captive Air Training Missile (CATM) to be used in fleet operations for training pilots in the use of the Joint Stand-Off Weapon (JSOW) missile. A concept of operations for the CATM has been written, from which functional requirements are to be drawn up. Exploratory work by Professors Lindsey, Biblarz, Kaminer, Jenn and Ms. Scrivener on the conceptual design is to be done in: (1) airframe structural design and weight estimation; (2) aerodynamic analyses for flight loads and contour shaping for minimum drag; (3) flight simulation of the JSOW by the CATM carrier aircraft; and (4) exploration of communications between the CATM on the carrier aircraft and the data link pod on the control aircraft. This program has been terminated.

AIRCRAFT COMBAT SURVIVABILITY AND AIR DEFENSE LETHALITY ASSESSMENT: Professor Ball originated the study of aircraft combat survivability at NPS in 1974 and has provided technical support for the Naval Air Systems Command (NAVAIR) and the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) by: (1) developing the 11 week graduate level course AA 3251, "Aircraft Combat Survivability," in 1978 and teaching it twice a year since then; (2) creating and monitoring since 1982 the self–study course AA 3250 "An Introduction to Aircraft Combat Survivability Analysis and Design;" (3) writing a textbook in aircraft combat survivability, *The Fundamentals of Aircraft Combat Survivability and Design*, published by the American Institute of Aeronautics and Astronautics (AIAA), 1985; (4) conducting over 15 short (one week) and several shorter (three day) courses in survivability since 1978, (5) developing the NPS/NAVAIR Survivability and Lethality Assessment Center (SLAC); and (6) conducting a variety of studies on the survivability of U.S. aircraft and the lethality of air defense weapons. In CY 1998, the majority of efforts were devoted to: (1) the continued development of the second edition of the AIAA survivability textbook; (2) the presentation of another one week short course in survivability at NPS (over 100 students); and (3) two Master's theses on the survivability of aircraft. The subjects of the Master's theses were the current technology for vulnerability reduction of tilt rotor aircraft and helicopters and the analysis for the critical components and kill modes of the JSF designs.

SMART STRUCTURES

Brij. N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force

OBJECTIVE: The goal of this project is to support SRDO Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications. This is a continuing project.

SUMMARY: Research was performed in several areas related to vibration isolation, active vibration control and shape control by using smart sensors and actuators. Active vibration isolation of a 6- degree of freedom Stewart Platform was investigated by using smart struts consisting of geophone sensors and piezoelectric actuators. Adaptive feed forward control was implemented to isolate narrow band disturbances. Active vibration controls were implemented on a space truss by using force transducer as a sensor, piezoelectric strut as actuator and a proof mass actuator as a disturbing source. Techniques for the control of precision space structures by using shape memory alloy (SMA), Nickel Titanium, were developed. The experiment consisted of a composite beam with embedded SMA wires. A feed forward control was implemented to provide a control accuracy of 0.1 mm.

PUBLICATIONS:

Meyer, J., Harrington, W., Agrawal, B., and Song, G., "Vibration Suppression of a Spacecraft Flexible Appendages Using Smart Materials," *Journal of Smart Materials and Structures*, Vol. 7, pp. 95-104, 1998.

Agrawal, B. and Treanor, K., "Shape Control of a Beam Using Piezoelectric Actuators," *Journal of Smart Materials and Structures,* accepted.

THESES DIRECTED:

Johnson, S. and Vlattas, J., "Active Vibration Control of Space Truss Using Smart Struts," Master's Thesis, Naval Postgraduate School, June 1998.

Kelly, B., "Beam Shape Control Using Shape Memory Alloys," Master's Thesis, Naval Postgraduate School, December 1998.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Smart Materials, Adaptive Structures, Vibration Isolation

SPACECRAFT SYSTEMS

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Naval Warfare System Command

OBJECTIVE: The goal of this project is to develop and operate four spacecraft laboratories: FLTSATCOM Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory to support the Space Systems Engineering Curriculum in instruction and experimental research. This is a continuing project.

SUMMARY: During 1998, significant progress has been achieved in several areas. On the FLTSATCOM telemetry and command system the VAX/VMS6.2 OS and C compiler version 5.5 were installed and implemented and COMET and ISICS were tested. The Flexible Spacecraft Simulator (FSS) was made operational. A Pulse Width Pulse Frequency (PWPF) modulator controller was implemented for thruster control, and compared with bang bang control. A new control

technique (neural network control) for attitude control of flexible spacecraft was implemented. A spacecraft design project for a space-based radar spacecraft constellation was completed. The mission requirements were two 1000km x 1000km regions of interest, with a maximum 30 minutes revisit gap, direct theater downlink/crosslink, and compatible with AFCN/ SGLS&CDL.

PUBLICATIONS:

Yale, G.E. and Agrawal, B., "A Lyapunov Controller for Cooperative Space Manipulators," *Journal of Guidance, Control, and Dynamics*, Vol. 21, No. 3, May-June 1998.

Huang, T. and Agrawal, B., "Neural Network Attitude Control of Flexible Spacecraft," IAF-98-A.6.03.

Song, G., Buck, N., and Agrawal, B., "Spacecraft Vibration Reduction Using Pulse-Width Pulse-Frequency Modulated Input Shaper," *Journal of Guidance, Control, and Dynamics,* accepted.

CONFERENCE PRESENTATION:

Huang, T. and Agrawal, B., "Neural Network Attitude Control of Flexible Spacecraft," 49th International Astronautical Congress, Melbourne, Australia, 28 September-2 October 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Spacecraft Design, Spacecraft Attitude Control, Space Manipulator

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

Muguru S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: To develop flow control schemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: During the reporting period, detailed studies were carried out to determine the best shape adaptation strategy for producing dynamic stall *vortex free* flow over an oscillating airfoil under compressible flow conditions. Further, the effect of the rate of shape adaptation was investigated which showed that the slowest rate of phase-locked deformation was the best. In addition, improper shape adaptation was found to be destructive since dynamic stall onset was triggered prematurely. These studies have now established that dynamic geometry adaptation is a powerful tool with which the airfoil vorticity field could be manipulated for successful flow control.

In order to identify the basic fluid mechanics of the problem of compressible dynamic stall, a 6-inch chord NACA 0012 airfoil has been instrumented with 120 surface heat flux gages. Presently, the integration of these gages with 30 anemometer bridge circuits and a high-speed data acquisition system is ongoing. These hot film gages provide the surface shear stress behavior of this flow.

PUBLICATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Unsteady Stall Control Using Dynamically Deforming Airfoils," *AIAA Journal*, Vol. 36, No. 10, pp. 1792-1800, October 1998.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Development of High Speed Interferometry Imaging and Analysis Techniques for Compressible Dynamic Stall," *AGARD –CP* –601, pp. 21.1-21.12, May 1998.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Competing Mechanisms of Compressible Dynamic Stall," *AIAA Journal*, Vol. 36, No. 3, pp. 387-393, April 1998.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "The Control of Compressible Dynamic Stall Using Adaptive Airfoils," *Proceedings of FLOWCON-IUTAM Symposium on Passive and Active Flow Control,* Göttingen, Germany, 7-11 September 1998.

DoD KEY TECHNOLOGY AREA: Other (Helicopter Blade Stall)

KEYWORDS: Flow Control, Helicopter Blade Stall, Smart Materials, Deforming Airfoils

RESEARCH ON AUTONOMOUS AIR VEHICLES

Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: To investigate autonomous operation of fixed and rotary wing aircraft.

SUMMARY: A small avionics package was developed, installed, and verified on a Bergen Industrial Helicopter. The avionics development included the design of an ultrasonic altimeter and mounting of a three-axis accelerometer. A small data logger based on a Motorola MC68332 processor was used to collect sensor data. A control program for the data logger was developed using the C programming language. The operation of the avionics package was validated through ground and flight testing. Concurrently with the development of the avionics package, a dynamic model of the helicopter was developed using aerodynamic parameterization and linear state-space modeling techniques. The Naval Postgraduate School designed JANRAD software was utilized to obtain the stability and control derivatives. The fidelity of the simulation model was verified by comparing the simulation responses with data collected from the avionics sensors during flight tests.

THESES DIRECTED:

Greer, Daniel S., "Avionics System Development for a Rotary Wing Aerial Vehicle," Master's Thesis, Naval Postgraduate School, June 1998.

McEwen, Matthew D., "Dynamic System Identification and Modeling of a Rotary Wing UAV for Stability and Control Analysis," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Electronics, Modeling and Simulation, Sensors, Other (Avionics)

KEYWORDS: Autonomous Vehicles, Unmanned Air Vehicles, Avionics, Robotics, UAV, VTOL UAV

VIRTUAL PROTOTYPING OF AVIONICS SYSTEMS

Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To analyze tools to develop system-level prototypes of avionics systems. These prototypes will be used for architecture design, to perform regression testing, identify problems, discover solutions, and assess the value of potential upgrades.

SUMMARY: A survey of tools for use in the design and simulation-based acquisition of avionics systems was performed. A tool for avionics system architecture design was selected and studied. A set of CAD tools developed by CPU Technology, Inc. was examined. These tools offer unique benefits for legacy avionics problems. Efforts were begun to incorporate these tools into classes within the Department of Aeronautics and Astronautics. Tools useful for requirements design were identified and incorporated into a class on Avionics Software Engineering. Additional research was performed in cooperation with the International Council on Systems Engineering (INCOSE) Model Driven System Design Working Group. This work included the identification of issues related to the characterization of model driven system design and identification of transition strategies from present document driven approaches.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Electronics, Modeling and Simulation, Sensors, Other (Avionics)

KEYWORDS: Avionics, Computer-Aided Design, Co-design, Cycle-Accurate, Software Engineering, Legacy Systems, Model Driven System Design, Prototypes, Real-Time Systems, Simulation, Simulation Based Acquisition, Systems

TURBINE TIP-LEAKAGE FLOWS

Garth V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements, in the endwall region of a turbine. The measurement technique was presented at the 33rd Joint Propulsion Conference in Seattle. The specific turbine test article is the turbine of the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME) and the particular hardware was designed and manufactured by Pratt and Whitney for NASA.

SUMMARY: An initial set of LDV measurements were taken in the tip leakage region of the turbine rotor. The turbine was relocated to the one side of the test cell to accommodate the two-component LDV. CDR Southward also modified the turbine rig to include a closed-loop cooling water system for the dynamometer. This allowed for prolonged stable operation of the turbine, which was essential for the LDV measurements. The modification entailed the inclusion of a heat exchanger in the test cell and plumbing of the water lines from the plant air package water cooling system.

LCDR McKee took over the project from CDR Southward and had to rebuild the turbine rig as an overspeed of the turbine burned the bearings. LCDR McKee repeated CDR. Southwards measurements and was about to increase the survey density when the Allis Chalmers Electric Drive Motor for the air supply system developed excessive vibrations. The motor had to be sent out for armature rebaring and rebalancing. Thirty-five thousand dollars of NPS maintenance funds was used to perform the overall of this unique supply system (the motor is the drive for the air supply system for the High Speed Turbopropulsion Laboratory and is also used to drive the Transonic Compressor Rig). LCDR McKee obtained three-hole probe measurements downstream of the rotor at different circumferential positions. These data plus the LDV data obtained were used for comparison with numerical predictions.

PUBLICATIONS:

Hobson, G.V., Ganaim Rickel, H.J., and Williams, A.J.H., "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Compressor Cascade at Stall," *ASME Journal of Turbomachinery*, Vol. 120, No. 1, pp. 170-178, January 1998.

Hobson, G.V., Wakefield, B.E., and Roberts, W.B., "Leading Edge Turbulence Amplification in a Compressor Cascade," *Journal of Rotating Machinery*, accepted.

CONFERENCE PRESENTATIONS:

Abdelhamid, H.F., Shreeve, R.P., and Hobson, G.V., "Sweep in a Transonic Fan Design," ASME 98-GT-579, 43rd IGTI Conference, Stockholm, Sweden, June 1998.

Hobson, G.V., Hansen, D.J., Schnorenberg, D.G., and Grove, D.V., "Effect of Reynolds Number on Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," ASME 98-GT-422, 43rd IGTI Conference, Stockholm, Sweden, June 1998.

THESES DIRECTED:

Southward, J.D., "Laser Doppler Velocimetry in the Space Shuttle Main Engine High-Pressure Fuel Turbopump," Master's Thesis, Naval Postgraduate School, March 1998.

McKee, J. R., "Experimental and Computational Investigation of Cold-Flow Through the Turbine of the Space Shuttle Main Engine High-Pressure Fuel Turbopump," Master's Thesis, Naval Postgraduate School, September 1998.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Turbine, Laser, Velocimetry, Tip-Leakage Flows

DEPLOYMENT OF THE APEX AIRCRAFT AT HIGH ALTITUDE

Richard M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Dryden Flight Research Center

OBJECTIVE: To assist a design team in the development of a remotely-piloted aircraft to be dropped from 100,000 feet for aerodynamic experimentation.

SUMMARY: The meteorological need for atmospheric data at high altitudes requires basic data for the design of efficient aircraft able to loiter for extended periods in this extreme environment. The Apex program is producing a high-altitude testbed aircraft to achieve trimmed flight at altitudes of over 100,000 feet to conduct aerodynamic experiments. The work this year continued the development of a 1/3-scale radio-controlled sailplane with its associated airborne sensor and data acquisition system (ASDAS). This is a continuing project.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Environmental Quality, Sensors, Modeling and Simulation

KEYWORDS: Airdata, Aerodynamics, Flight Mechanics

UNMANNED AERIAL VEHICLE (UAV) MARINIZATION

Richard M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To determine the characteristics of a UAV optimized for launch and recovery at sea. To delineate applicable technologies which currently exist to field a maritime UAV and, if lacking, what technologies are required and when they will be expected to mature.

SUMMARY: A review of UAV technologies relevant to a maritime UAV was conducted, with particular attention paid to the VTOL configuration. This effort was a combined project with the Center for Naval Analyses, who provided the lead effort. The work is continuing.

PUBLICATIONS:

Howard, R.M., "UAV Marinization Study: A Technology Assessment," Naval Postgraduate School Technical Report, NPS-AA-98-003, April 1998.

Kirk, K.M. and Howard, R.M., "Developing a Better Naval Unmanned Aerial Vehicle," Center for Naval Analyses, Occasional Papers Series, Alexandria, VA, December 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Sensors, Modeling and Simulation

KEYWORDS: UAV, VTOL, Maritime, Marinization, Unmanned Aerial Vehicle

ADVANCED AVIONICS TECHNOLOGY

Isaac I. Kaminer, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform research and development in advanced avionics technology topics relevant to NAVAIR MAST program.

SUMMARY: Over the past several years under NAVAIR sponsorship NPS has embarked on the development and evaluation of rapid flight test prototyping system for unmanned air vehicles (UAVs). During 1998 a voice control system was developed and flight tested as well as a new flight management system for autonomous UAV flight.

THESES DIRECTED:

Komlosy, John A., III, "Applications of Rapid Prototyping to the Design and Testing of UAV Flight Control Systems," Master's Thesis, Naval Postgraduate School, March 1998.

Perry, Robert C., "Integration of a Multi-Rate Position Filter in the Navigation System of an Unmanned Aerial Vehicle (UAV) for Precise Navigation in the Local Tangent Plane (LTP)," Master's Thesis, Naval Postgraduate School, March 1998.

Froncillo, Steven J., "Design of Digital Control Algorithms for Unmanned Air Vehicles," Master's Thesis, Naval Postgraduate School, March 1998.

Rivers, Timothy C., "Design and Integration of a Flight Management System for the Unmanned Air Vehicle Frog," Engineer's Thesis, Naval Postgraduate School, December 1998.

Watson, Mark T., "Vision Guidance Controller for an Unmanned Aerial Vehicle," Master's Thesis, Naval Postgraduate School, December 1998.

PUBLICATIONS:

Kaminer, I., Pascoal, A.M., Hallberg, E., and Silvestre, C., "Trajectory Tracking for Autonomous Vehicles: An Integrated Approach to Guidance and Control," *AIAA Journal of Guidance, Control and Dynamics*, pp. 29-38, January-February 1998.

Hallberg, E., Kaminer, I., and Pascoal, A.M., "Development of the Rapid Flight Testing System for Unmanned Air Vehicles," *IEEE Control Systems Magazine,* February 1999.

Hallberg, E., Kaminer, I., and Pascoal, A.M., "Development of the Rapid Flight Test Prototyping System for Unmanned Air Vehicles," *Proceedings of 1998 American Control Conference*, pp. 699-704, Philadelphia, PA, 24-26 June 1998.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Avionics, Unmanned Aerial Vehicles)

KEYWORDS: GPS, Flight Control, Rapid Prototyping

CLOSED-LOOP PITCH CONTROL EFFECTOR SIZING

Isaac I. Kaminer, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Langley

OBJECTIVE: To develop closed-loop pitch control effector sizing tool for supersonic transport.

SUMMARY: This project developed a new optimization tool for obtaining the closed loop tail sizing criteria for High Speed Civil Transport (HSCT). In particular, the tool is capable of determining the maximum cg travel for a given HSCT tail volume subject to a variety of disturbance recovery and closed loop constraints as well as structural mode considerations. The disturbances considered included vertical gust and sinusoidal inputs. The closed loop constraints included the effect of feedback specifications, such as MIL STD 1797 Level I and II flying qualities requirements. Furthermore, the HSCT actuator amplitude and rate constraints were accounted for. Moreover, the tool has the option of including the structural mode considerations.

PUBLICATION:

Kaminer, I. and Meade, P.W., "Closed Loop Pitch Control Effect or Sizing," NASA Contractor Report, 1998.

Hallberg, E. and Kaminer, I., "On the Development of the Tail-Sizing Criteria for High-Speed Civil Transport," *AIAA Journal of Guidance, Control and Dynamics,* accepted.

Hallberg, E. and Kaminer, I., "On the Development of the Tail-Sizing Criteria for High-Speed Civil Transport," *Proceedings of 1998 American Control Conference*, pp. 1635-1639, Philadelphia, PA, 24-26 June 1998.

Silvestre, C., Pascoal, A., Kaminer, I., and Healey, A., "Plant/Controller Optimization with Applications to Integrated Surface Sizing and Feedback Controller Design for Autonomous Underwater Vehicles," *Proceedings of the 1998 American Control Conference,* pp. 1640-1644, Philadelphia, PA, 24-26 June 1998.

THESIS DIRECTED:

Meade, P.W., "Analysis and Automation of Aircraft Tail-Sizing Design Tool," Master's Thesis, Naval Postgraduate School, September 1998.

PASSIVE SENSOR-BASED CONTROL OF NONLINEAR AUTONOMOUS SYSTEMS

Isaac I. Kaminer, Associate Professor
Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this proposal is to investigate sensor fusion architectures and mathematical algorithms required to support autonomous vertical take off and landing (VTOL) of uninhabited combat air vehicles on ships using passive sensors.

SUMMARY: Preliminary results were obtained on the synthesis of time-varying and nonlinear filters that integrate vision, GPS and inertial sensors to provide an accurate estimate of ship's position with respect to the aircraft as well as of the ship's inertial velocity.

PUBLICATIONS:

Pascoal, A.M., Kaminer, I., and Oliveira, P., "Design of the Complementary, Time-Varying Filters Using Linear Matrix Inequalities," *Proceeding of the 1998 IEEE Conference on Control Applications*, Trieste, Italy, 1998.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: UCAV, Unihabited Combat Air Vehicles, Sensor Fusion

FY-98 ENGINEERING AND TECHNICAL SUPPORT FOR UNMANNED AERIAL VEHICLE (UAV) JOINT PROJECT OFFICE (JPO) PHASE II CONTRACT EFFORT

Isaac I. Kaminer, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To provide engineering and technical support to UAV JPO in managing the Phase II of the SBIR proposal "Low-Cost Fault Tolerant Controls for Unmanned Air Vehicles."

SUMMARY: The project was kicked off at NPS in November of 1997.

DoD KEY TECHNOLOGY AREA: Other (Unmanned Aerial Vehicles)

KEYWORDS: UAV, Controls

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE AIR TRAINING MISSILE (CATM) CONCEPTUAL DESIGN STUDIES

Gerald H. Lindsey, Professor
Oscar Biblarz, Professor
Isaac I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
David. C. Jenn, Associate Professor
Department of Electrical and Computer Engineering
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform conceptual design studies on the Captive Air Training Missile to be used for the JSOW Unitary missile.

SUMMARY: This program has been terminated by NAVAIR. On 6 May 1998 an all day presentation to the sponsor took place at NPS. Representatives from NAVAIR, including CAPT Johnson the program manager, and the Naval Air Warfare Center-Weapons Division were briefed on the research accomplishments. The presentations included a report on the overall program (G.H. Lindsey), a report on CATM weight and airframe design (S. Scrivener), a report on JSOW flight simulations (I.I. Kaminer), a report on antenna shielding and communication (D.C. Jenn), a report on aerodynamics and drag reduction (O. Biblarz), and a report on steering commands for carriage aircraft (LCDR M. Overs). Overall, six students did their thesis work in this project at the master's level and one at the engineer's level. Three other students were involved on

a project basis. These students made significant contributions to the research and to the problem formulation as all of them could bring in their pilot experience.

CONFERENCE PRESENTATION:

Biblarz, O., Pomerantz, B., and Lindsey, G.H., "Transonic Missile Drag Area-Rule and Afterbody Role Verification with CFD," 36th Aerospace Sciences Meeting and Exhibit, AIAA 98-0527, Reno, NV, 12-15 January 1998.

THESIS DIRECTED:

Overs, M., "JSOW CATM Steering Command Analysis for the Carriage Aircraft," Master's Thesis, Naval Postgraduate School, March 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Conventional Weapons

KEYWORDS: Missile, Missile Design, CATM, JSOW, Pilot Training

THE EFFECTS OF ROCKET MOTOR OPERATING CONDITIONS ON EXHAUST PLUME SOOT CONCENTRATIONS

David Netzer, Distinguished Professor
Christopher Brophy, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force Research Lab

OBJECTIVE: To obtain the optical properties, physical size, and mass loading of soot present in a liquid-fuel/gaseous oxygen rocket engine operation at fuel rich conditions and to evaluate the effects of additives on those properties.

SUMMARY: The investigation succeeded in the development and operation of a liquid-fueled rocket engine with uniform exhaust soot loading under fuel-rich conditions. A multiple-wavelength extinction technique was used to obtain the optical properties of the soot. The transmission measurements and obtained optical properties were then used in conjunction with a thermodynamic equilibrium code to determine the overall soot loading in the exhaust.

PUBLICATIONS:

Silva, S., Brophy, C.M., and Netzer, D.W., "Measurement of Soot in Oxygen/Kerosene Exhaust Plumes," *Proceedings of the 24th JANNAF EPTS*, Kennedy Space Center, FL, 9-13 November 1998.

Nickerson, G.R., Johnson, C.W., and Brophy, C.M., "Prediction of Soot Produced in Kerosene Fueled Rocket Engines," *Proceedings of the 35th JANNAF Combustion Subcommittee*, Tucson, AZ, 7-11 December 1998.

CONFERENCE PRESENTATIONS:

Silva, S., Brophy, C.M., and Netzer, D.W., "Measurement of Soot in Oxygen/Kerosene Exhaust Plumes," 24th JANNAF EPTS, Kennedy Space Center, FL, 9-13 November 1998.

Nickerson, G.R., Johnson, C.W., and Brophy C., "Prediction of Soot Produced in Kerosene Fueled Rocket Engines," 35th JANNAF Combustion Subcommittee, Tucson, AZ, 7-11 December 1998.

THESIS DIRECTED:

Silva, S., "Soot Particle Size and Concentration Determination From a Kerosene/Gaseous Oxygen Rocket Plume," Master's Thesis, Naval Postgraduate School, December 1998.

DoD KEY TECHNOLOGY AREA: Other (Missile Signatures)

KEYWORDS: Missile, Propulsion, Signature, IR, Soot

AIRCRAFT/MISSILE/SPACECRAFT DESIGN

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To improve the conceptual design process for aircraft, missiles, and spacecraft.

SUMMARY: Current design methodology tends to emphasize performance parameters that can be related to the design process through an application of the First Law of Thermodynamics. This research is intended to improve the conceptual design process by introducing Second Law concepts into the conceptual design methodology. The Second Law concept of energy availability, or exergy, is used to evaluate the overall effectiveness of the vehicle design as well as the effectiveness of each major subsystem.

THESIS DIRECTED:

Gleeson, David A., "A Second Law Approach to Aircraft Conceptual Design," Master's Thesis, Naval Postgraduate School, September 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Modeling and Simulation

KEYWORDS: Simulation, Modeling, Cost, Design, Performance, Exergy, Energy

ENVIRONMENTAL SECURITY

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To quantify the attributes of environmental security related to national policy, population well being, technology, warfighting, and education.

SUMMARY: Research has been conducted to clarify the role of national policy, population well being, technology, warfighting, and education in the definition of environmental security.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Battlespace Environments, Biomedical, Chemical and Biological Defense, Clothing, Textiles and Food, Conventional Weapons, Command, Control, and Communications, Environmental Quality, Civil Engineering, Human Systems Interface, Manpower, Personnel and Training, Materials, Processes, and Structures, Sensors, Surface/Under Surface Vehicles – Ships and Watercraft, Ground Vehicles, Manufacturing Science and Technology, Modeling and Simulation

KEYWORDS: Environmental Security, Warfighting, Air Pollution, Water Pollution, Noise Pollution, Solid/Hazardous Waste Disposal, National Policy

WAVERIDER CONFIGURED AIRCRAFT/SPACECRAFT DESIGN

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To define waverider configured aircraft/spacecraft concepts and technology for tactical or exploratory missions.

SUMMARY: Research was conducted to assess, develop, and evaluate methodologies which might prove useful in the development of waverider configured aircraft/spacecraft.

THESIS DIRECTED:

Huff, Michael R., "A Labview© Based Wind Tunnel Data Acquisition System," Master's Thesis, Naval Postgraduate School, September 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Battlespace Environments

KEYWORDS: Waverider, Aircraft, Spacecraft

AIRCREW-CENTERED SYSTEM DESIGN

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To define the attributes and characteristics of an Aircrew-Centered System Design (ACSD) discipline.

SUMMARY: A number of initiatives related to this discipline have been implemented to alleviate problems which arise as modern tactical aircraft and cockpits have come to overwhelm the aircrew. Further initiatives have been identified to further ameliorate aircrew workload and/or information overload. These recent and future initiatives are briefly summarized herein: (1) One ACSD paper session was held at the 3rd AIAA/SAE World Aviation Congress held in Anaheim, California, 28-30 September 1998. This session was focused on human factors; and (2) Two ACSD paper sessions were held at the 36th AIAA Aerospace Sciences Meeting and Exhibit held in Reno, Nevada, 11-14 January 1999. One session was focused on situation awareness and the second was focused on sensor fusion integration.

DoD KEY TECHNOLGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Space Vehicles, Battlespace Environments, Command, Control, and Communications, Computing and Software, Electronic Warfare, Human System Interface, Sensors, Surface/Under Surface Vehicles-Ships and Watercraft, Ground Vehicles, Manufacturing Science and Technology, Modeling and Simulation

KEYWORDS: Aircrew-Centered, System Design, Situation Awareness, Displays, Mission Planning, Sensor Fusion, Human Factors.

UNINHABITED COMBAT AIR VEHICLES (UCAV) MISSION DEFINITION

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: To define six missions that have the potential of being performed by uninhabited combat air vehicles.

SUMMARY: Uninhabited combat air vehicles (UCAVs) represent a class of military aircraft that have the potential to perform a variety of military missions with a smaller, more agile (maneuverable) and less expensive platform than is possible with inhabited systems. Profiles (i.e., range, velocity, and attitude) were developed for intelligence, surveillance, and reconnaissance (ISR); battle damage assessment (BDA); mobile/moving/fixed targeting (MMFT); anti-surface warfare (ASW); suppression of enemy air defenses (SEAD); and close-air-support (CAS) missions. A very brief request-for-proposal was also developed for the CAS mission. Finally, a student design team developed a notional configuration that would meet the requirements of the CAS mission.

PUBLICATIONS:

Newberry, Conrad F., "UCAV Mission Definition," Naval Postgraduate School, Monterey, California, 18 December 1998.

Anderson, C. Scott, et al., "PUMBAA-A Close Air Support UCAV," Naval Postgraduate School, Monterey, California, 24 September 1998.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Battlespace Environments, Command, Control, and Communications, Computing and Software, Conventional Weapons, Electronics, Electronic Warfare, Environmental Quality, Human Systems Interface, Materials, Processes, and Structures, Sensors, Surface/Under Surface Vehicles – Ships And Watercraft, Manufacturing Science and Technology, Modeling and Simulation

KEYWORDS: UCAV, Close-Air-Support, VTOL, Cost, Battlespace, Mission Profile

RISK ANALYSIS OF MISSION NEED STATEMENT FOR TACTICAL HIGH-SPEED STRIKE CAPABILITY

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Accurate Automation Corporation

OBJECTIVE: To assess the risks and technologies associated with transitioning the LoFLYTE concept to mission need for a tactical high-speed strike capability in the hypersonic realm.

SUMMARY: Engineering models were used to assess the required time response, overpressure loads and heat transfer characteristics associated with a high speed strike capability and a risk assessment associated with these technologies.

PUBLICATION:

Newberry, Conrad F., "Risk Analysis for a High Speed Missile," Naval Postgraduate School, Monterey, California, June 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicle, Battlespace Environment, Conventional Weapons, Materials, Processes, and Structures, Modeling and Simulation

KEYWORDS: Hypersonic, Overpressure, Time Response, Heat Transfer, Missile

SUBSONIC AIRCRAFT AND UNMANNED AIR VEHICLE AERODYNAMICS

Max F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: To perform computational investigations of the steady and unsteady aerodynamic and aeroelastic characteristics of subsonic aircraft and of unmanned air vehicles.

SUMMARY: Navier-Stokes calculations were performed to predict the flow over wing-body-canard aircraft configuration at high angles of attack. Also, the effect of airfoil geometry and flow compressibility on airfoil flutter was studied using panel, Euler, and Navier-Stokes codes.

PUBLICATIONS:

Tuncer, I.H., van Dyken, R.D., and Platzer, M.F., "Navier-Stokes Analysis of Subsonic Flowfields Over a Missile Configuration," *Journal of Spacecraft and Rockets*, Vol. 35, No. 2, pp. 127-131, March-April 1998.

Ekaterinaris, J.A. and Platzer, M.F., "Computational Prediction of Airfoil Dynamic Stall," *Progress in Aerospace Sciences,* Vol. 33, pp. 759-846, 1998.

Tuncer, I.H., Platzer, M.F., and van Dyken, R.D., "Computational Investigations of Subsonic High Angle of Attack Missile Flows," *Proceedings of NATO RTO Meeting on Missile Aerodynamics*, RTO-MP-5, pp.28-1 to 28-9, Sorrento, Italy, 11-14 May 1998.

CONFERENCE PRESENTATION:

Jones, K.D. and Platzer, M.F., "Airfoil Geometry and Flow Compressibility Effects on Wing and Blade Flutter," AIAA Paper 98-0517, 36th Aerospace Sciences Meeting, Reno, NV, 12-15 January 1998.

THESES DIRECTED:

Alexandris, G. "Supersonic Flow Past Two Oscillating Airfoils," Master's Thesis, Naval Postgraduate School, June 1998.

Kakkavas, C., "Computational Investigation of Subsonic Torsional Airfoil Flutter," Master's Thesis, Naval Postgraduate School, December 1998.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Aerodynamics, Separated Flows, Aeroelasticity, Flow Control, Oscillatory Flows

DEVELOPMENT OF SMALL UNMANNED AIR VEHICLES

Max F. Platzer, Distinguished Professor
Kevin D. Jones, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Research Laboratory

OBJECTIVE: The objective of the proposed effort is the exploration and demonstration of flapping wing propulsion for small unmanned air vehicles.

SUMMARY: A mechanical flapping-wing device was built, allowing for the systematic evaluation of flapping wing performance over a broad parameter space. The mechanism flaps two airfoils with variable pitch and plunge amplitude and

variable phasing, and allows for the inclusion of additional stationary wings. The thrust was measured with a laser device and compared with the numerical results obtained with a previously developed inviscid unsteady panel code. Also, a micro-air vehicle using two flapping airfoils was built and preliminary tests of this vehicle were initiated.

PUBLICATIONS:

Jones, K.D., Dohring, C.M., and Platzer, M.F., "Experimental and Computational Investigation of the Knoller-Betz Effect," *AIAA Journal*, Vol. 36, No. 7, pp. 1240-1246, 1998.

Platzer, M.C., Lai, J.C.S., and Dohring, C.M., "Flow Separation Control by Means of Flapping Foils," *Proceedings of the International Symposium on Seawater Drag Reduction*, Newport, RI, 22-23 July 1998.

CONFERENCE PRESENTATIONS:

Lai, J.C.S., "The Jet Characteristics of a Plunging Airfoil," AIAA Paper 98-0101, 36th Aerospace Sciences Meeting, Reno, NV, 12-15 January 1998.

Tuncer, I.H., Lai, J.C.S., and Platzer, M.F., "A Computational Study of Flow Reattachment Over a Stationary/Flapping Airfoil Combination in Tandem," AIAA Paper 98-109, 36th Aerospace Sciences Meeting, Reno, NV, 12-15 January 1998.

Dohring, C.M., Fottner, L., and Platzer, M.F., "Experimental and Numerical Investigation of Flapping Wing Propulsion and Its Application for Boundary Layer Control," International Gas Turbine and Aeroengine Congress, ASME Paper 98-IGTI-46, Stockholm, Sweden, 2-5 June 1998.

Lai, J.C.S. and Platzer, M.F., "The Characteristics of a Plunging Airfoil at Zero Free-Stream Velocity," ASME Fluids Engineering Summer Meeting, ASME Paper FEDSM98-4946, Washington, DC, 22-25 June 1998.

Tuncer, I.H., Walz, R., and Platzer, M.F., "A Computational Study on the Dynamic Stall of a Flapping Airfoil," AIAA Paper 98-2519, 16th AIAA Applied Aerodynamics Conference, Albuquerque, NM, 15-18 June 1998.

DISSERTATION DIRECTED:

Dobring, Claus, "The Thrust of Flapping Airfoils and Its Application for Boundary Layer Control," Doctor of Philosophy Dissertation, German Armed Forces University, Munich, Germany, May 1998.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Hydrodynamics)

KEYWORDS: Unsteady Aerodynamics, Unmanned Air Vehicles, Flapping Wing Propulsion

ADVANCED MULTIDISCIPLINARY ANALYSIS AND DESIGN OPTIMIZATION METHODS FOR SUBSONIC TRANSPORT AIRCRAFT

Max F. Platzer, Distinguished Professor
Kevin D. Jones, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: McDonnell-Douglas Aircraft Company

OBJECTIVE: To contribute to the development of advanced multidisciplinary analysis and design optimization methods for subsonic transport aircraft.

SUMMARY: This work entails the use/extension of two/three-dimensional computational fluid dynamics codes for inviscid or viscous subsonic flow over airfoils or aircraft configurations with emphasis on speeding up the computations by means of parallelization.

PUBLICATIONS:

Tuncer, I.H. and Platzer, M.F., "Potential Flow Solutions With Wakes Over an Ogive Cylinder," *Journal of Spacecraft and Rockets,* Vol. 35, No. 3, May-June 1998.

Jones, K.D. and Platzer, M.F., "On the Prediction of Dynamic Stall Onset on Airfoils in Low-Speed Flow," *Proceedings of the International Symposium on Unsteady Aerodynamics and Aeroelasticity of Turbomachines*, Kluwer Academic Publishers, pp. 797-812, 1998

Sanz, W. and Platzer, M.F., "Numerical Investigation of the Stall Onset Behavior of the GA(W)-1 Airfoil," *Computers and Fluids*, Vol. 27, Nos. 5-6, pp. 681-687, 1998.

Tuncer, I.H. and Platzer, M.F., "Computational Study of Subsonic Flow Over a Delta Canard-Wing-Body Configuration," *Journal of Aircraft*, Vol. 35, No. 4, pp. 554-560, July-August 1998.

Jones, K.D., "On the Parallelization of the PMARC Code," end-of-contract report to Boeing, 1 September 1998.

THESIS DIRECTED:

Pollard, S.J., "Development and Verification of an Aerodynamic Model for the NPS FROG UAV Using the CMARC Panel Code Software Suite," Engineer's Thesis, Naval Postgraduate School, September 1998.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Structures)

KEYWORDS: Aerodynamics, Computational Fluid Dynamics, Structures, Finite Element Modeling, Design Optimization

FIN FLUTTER ON HYPERSONIC MISSILES

Max F. Platzer, Distinguished Professor
Ramesh Kolar, Lecturer
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: The objective of this work is to perform an exploratory flutter analysis of the fins on the proposed Navy Hypersonic Weapons Technology Missile.

SUMMARY: A report was delivered which summarized the flutter analysis using piston theory aerodynamics in combination with a two-degree-of-freedom bending/torsion model.

DoD KEY TECHNOLOGY AREA: Other (Aeroelasticity)

KEYWORDS: Aeroelasticity, Missile Technology, Hypersonic Flow

GUST LOAD ANALYSIS

Max F. Platzer, Distinguished Professor
Ismail H. Tuncer, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Patuxent River

OBJECTIVE: The objective of this project is to perform an exploratory assessment of the gust load sensitivity of the Lockheed C-130J aircraft to Navy missions.

SUMMARY: The panel code PMARC was used to compute the aerodynamic loads on the C-130J wing.

DoD KEY TECHNOLOGY AREA: Other (Aeroelasticity)

KEYWORDS: Aeroelasticity, Aircraft Technology, Subsonic Flow

USING SLBMs FOR LAUNCHING SMALL SATELLITES

I. Michael Ross, Associate Professor
Department of Aeronautics and Astronautics
Craig Baldwin, Navy Space Systems Academic Chair
Space Systems Academic Group
Sponsor: Naval Space Command

OBJECTIVE: Space support to the warfighter may be enhanced significantly by providing a launch on demand capability to support the growing and dynamic C4ISR requirements. The purpose of this proposal is to study how SLBMs may be used to launch small communication satellites in Earth orbit. The proposal includes a conceptual design of a small communication satellite that can be launched using the Trident missile.

SUMMARY: A five-member team of three faculty members (Professors Baldwin, Ross and Fahroo) and two students (CDR Gleason and LT Molinari) was formed to solve the problem. The problem is divided into two major sub-problems: launch trajectory optimization to put the maximum payload in low earth orbit (LEO), and orbital analysis (payload types, constellation requirements, mass constraints etc.). A computer code for the launch trajectory optimization was written in MATLAB. It is based on discretizing a generic launch profile and optimizing the discrete points for the Trident data. The Trident I (C4) data was modeled as a proof-of-concept.

The orbital analysis has progressed to the point of identifying potential orbits, payload ideas and lifetime requirements. The students are trying out these ideas by means of the standard simulation package called the Satellite Tool Kit (STK). The launch and orbit analysis will be patched together at the end of this quarter. Preliminary small satellite design is underway and will be completed next quarter. The end of this analysis will help identify the orbit and constellation requirements to achieve certain DoD objectives.

PUBLICATION:

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method," *Journal of Guidance, Control and Dynamics,* submitted.

CONFERENCE PRESENTATION:

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method," AIAA Guidance, Navigation and Control Conference, Boston, MA, 10-12 August 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: SLBM, Trident II, Launch Vehicles, Small Spacecraft

CURRICULUM DESIGN FOR CENTER FOR SPACE MISSION ARCHITECTURE AND DESIGN (CSMAD)

I. Michael Ross, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory

OBJECTIVE: The Jet Propulsion Laboratory (JPL) is in the process of setting up a Center for Space Mission Architecture and Design (CSMAD). One of the missions of CSMAD is the education and training of selected engineers. The primary focus of this education is to broaden the knowledge of technical experts in fields other than their own so that they can become "mission architects." The purpose of this proposal is to help JPL develop a curriculum that will accomplish their objectives.

SUMMARY: To accomplish the broad objectives, the following questions were identified: 1) What are the academic and professional credentials of the technical experts at JPL who are interested in becoming mission architects? 2) What are the necessary Educational Skill Requirements (ESRs) that must be met in order that JPL will declare someone is a Space Mission Architect, and 3) What are the time-constraints (i.e. duration of the curriculum)? The first question was answered by preparing a questionnaire for distribution at JPL. Essentially, the objective of this survey was to identify potential students' experiences (in space projects) that may already contribute towards the goals of a mission architect. This data was used in the curriculum design. The second question was answered by defining the ESRs. These ESRs were obtained by iteration with a number of JPL technical staff through CSMAD. The final question is still being answered in an ongoing project. JPL has been provided with a tentative description of the curriculum (i.e., a matrix) and the ongoing project will flesh it out.

PUBLICATION:

Ross, I.M., McLaughlin, W.I., Anderson, C.H., and Gowler, P.P., "Curriculum Design for CSMAD: Final Report," Jet Propulsion Laboratory, 20 September 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Space Systems Engineering, Space Mission Architect

ADVANCED FAN AND COMPRESSOR DEVELOPMENT STUDIES

Raymond P. Shreeve, Professor
Garth V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: To develop or validate tools for the design of advanced compression systems for Navy engines. Three tasks are ongoing: (i) to obtain experimental measurements and observations of CD blade stall for CFD code validation; (ii) to develop a geometry package geared to the design (by CFD analysis) of swept transonic blading; and (iii) to install and test an advanced transonic axial stage, and thereby establish the means to economically evaluate more advanced designs.

SUMMARY: (i) Second-generation CD stator blading has been tested in a large rectilinear cascade wind tunnel under near-stalling conditions, and LDV and flow visualization techniques were used to map and understand the flow field. The project was interrupted by the failure of the wind tunnel power supply, which has since been replaced. The data obtained at three

different Reynolds numbers is being used to validate 3D Navier-Stokes code predictions, and preparations are being made to obtain similar data at an increased incidence angle. (ii) A Bezier-surface representation of axial transonic blading was found to require the specification of only 32 control points and two parameters. Forward and aft sweep were introduced without changing blade shape, and the effect of sweep on aerodynamic performance and rotational stresses were easily determined. (iii) An advanced transonic stage design was tested to 80% speed before a bolt failure led to the loss of the stage. The numerically-machined blisks and spinner were quickly replaced, and testing will resume when the build is complete. The ability to make pressure-sensitive paint measurements of the rotor blade surface pressure is being developed using a small turbine-driven disk rotor.

PUBLICATIONS:

Hobson, G.V., Ganaim Rickel, H.J., and Williams, A.J.H., "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Compressor Cascade at Stall," *Journal of Turbomachinery*, Vol. 120, No. 1, pp. 170-178, January 1998.

Hobson, G.V., Wakefield, B.E., and Roberts, W.B., "Leading-Edge Turbulence Amplification in a Compressor Cascade," *Journal of Rotating Machinery*, accepted.

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Hobson, G.V., Hansen, D.J., Schnorenberg, D.G., and Grove, D.V., "Effect of Reynolds Number on Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," ASME Paper 98-GT-422, 43rd ASME Gas Turbine and Aeroengine Technical Congress, Exposition and User's Symposium, Stockholm, Sweden, 2-5 June 1998.

Abdelhamid, H.F. and Shreeve, R.P., "Sweep in a Transonic Fan Rotor: Part 1. 3D Geometry Package," ASME Paper 98-GT-578, 43rd ASME Gas Turbine and Aeroengine Technical Congress, Exposition, and User's Symposium, Stockholm, Sweden, 2-5 June 1998.

Abdelhamid, H.F., Shreeve, R.P., and Hobson, G.V., "Sweep in a Transonic Fan Rotor: Part 2. CFD and Stress Analyses," ASME Paper 98-GT-579, 43rd ASME Gas Turbine and Aeroengine Technical Congress, Exposition, and User's Symposium, Stockholm, Sweden, 2-5 June 1998.

THESIS DIRECTED:

Baumann, P.D., "Investigation of Pressure and Temperature Sensitivities of a Pressure-Sensitive Paint," Master's Thesis, Naval Postgraduate School, September 1998.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Controlled-Diffusion Blading, LDV Measurements, Compressor Cascade Stall, Swept Transonic Rotor Design, Pressure-Sensitive Paint (PSP)

HIGH CYCLE FATIGUE (HCF)/SPIN TEST RESEARCH

Raymond P. Shreeve, Professor
Garth V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: To reactivate the Spin-Pit Facility at the Turbopropulsion Laboratory (TPL) and conduct a program to develop blade excitation and measurement techniques to be used on the Navy's Rotor Spin Facility at Naval Air Warfare Center-Aircraft Division (NAWCAD).

SUMMARY: The National High Cycle Fatigue (HCF) Initiative has identified a potentially important role for spin testing in the development cycle of new engines, and in eliminating HCF problems in existing engines. Blade-excitation techniques have been proposed for use in vacuum pits but no satisfactory system has yet been proven. The Spin-Pit Facility at TPL was reactivated in 1998 to enable blade excitation techniques to be evaluated and demonstrated at full scale. A technique proposed by Hood Technologies will be attempted first in 1999. Once proven, a practical system can be transitioned immediately to the Navy's production pits at NAWCAD. Close collaboration between NPS and NAWCAD is maintained. Related projects to support the Navy's participation in the HCF initiative are also explored.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, Blade Excitation

UNINHABITED AERIAL VEHICLE (UAV) PROPULSION TECHNOLOGY

Raymond P. Shreeve, Professor
Garth V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To examine the potential performance of alternate engines for application in Predator and Global Hawk, and in other classes of UAVs.

SUMMARY: Reconnaissance missions require relatively low power and/or high altitudes. Current reciprocating engines do not have the reliability of gas turbines and cannot use heavy fuel. An analytical study examined the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An on-going experimental study, using both turbocharger components and micro-gas turbine engines, seeks to establish performance characteristics of small gas turbines operating with JP fuel.

THESES DIRECTED:

Jensen, M.L., "Uninhabited Aerial Vehicles: A Study of Recuperated-Cycle Gas Turbine Application," Master's Thesis, Naval Postgraduate School, March 1998.

Rivera, G.D., "Turbochargers to Small Turbojet Engines for Uninhabited Aerial Vehicles," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: UAV Propulsion, Small Gas Turbine Engines, Recuperated Turbofans

RESEARCH IN DAMPER -FREE ROTOR DESIGN BASED ON MAPLE®-GENERATED NONLINEAR SIMULATION

E. Roberts Wood, Professor
LCDR Robert L. King, USN, Lecturer
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: Recent work at NPS has resulted in a new and powerful tool for exploring ground and air resonance stability with the goal of eliminating lead/lag dampers on helicopters. The analysis takes advantage of new advances in mathematical analysis such as Waterloo's Maple® for symbolic manipulation, Mathworks' Simulink® for control system simulation and the Moving Block Analysis or Hilbert Transform Method for accurate determination of damping values from

simulation time histories. The resulting combined analysis tool is no longer hampered by the usual limitations that would restrict the method to small amplitudes and angles, linear springs, linear dampers and prescribed ordering schemes for variables. Instead, new features have been incorporated that for the first time use the full equations of motion to permit detailed studies of such topics as: (1) Nonlinear flexbeam constraint at blade root – stiffening approach versus stiffening approach; and (2) active feedback control – provided both by swashplate input HHC) and/or non-swashplate input (IBC).

SUMMARY: The approach is to apply nonlinear dynamics, control theory, and enhanced computer graphics to provide a general rotor stability and analysis tool. Further research will enhance, simplify and verify the present code, then model the incorporation of material non-linearities at the blade root, exploring the effect on the stability solutions generated. The significance of this new research for the helicopter designer is that the allowance of non-linearities at the blade root may result in an acceptable bounded response in the parameter region where linear theory would predict instability. Evidence of the latter may be found in numerous aircraft lost in the documented cases of ground resonance. Modern soft-inplane rotors, such as that first introduced in the MBB BO-105, have the additional possibility of encountering this lead/lag instability in flight.

PUBLICATIONS:

Robinson, C.S., Wood, E.R., and King, R.L., "Simulation of Helicopter Dynamic Mechanical Instability by MAPLE®-Based Nonlinear Lagrangian Derivation," *Proceedings of AIAA/AHS/ASME/ASCE 39th Structures, Structural Dynamics, and Materials Conference,* AIAA Paper No. 98-2005, Long Beach, CA, 20-23 April 1998.

Robinson, C.S., Wood, E.R., and King, R.L., "Full Nonlinear Simulation of Coupled Rotor-Fuselage Response Using Symbolically Derived Equations of Motion," *Proceedings of American Helicopter Society 54th Annual Forum and Technology Display,* Washington, DC, 20-22 May 1998.

CONFERENCE PRESENTATION:

King, R.L., "Nonlinear In-Plane Flexbeam Stiffness Provides Rotor System Stability Without Lag Dampers," Lichten Award Presentation, NASA Ames Research Center, CA, 17 December 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation, Other (Dynamics and Control)

KEYWORDS: Stability, Control, Dynamics, Rotorcraft, Rotary-Wing, Helicopter, Simulation, MATLAB

DAMPER FREE ROTOR DESIGN METHODOLOGY BASED ON FULL ORDER MAPLE® GENERATED EQUATIONS OF MOTION AND SIMULINK NONLINEAR SIMULATION

E. Roberts Wood, Professor
LCDR Robert L. King, USN, Lecturer
Department of Aeronautics and Astronautics
Sponsor: Sikorsky Aircraft Corporation
(National Rotorcraft Technology Center/Rotorcraft Industry Technology Association)

OBJECTIVE: The objective of the present work is to explore the potential of eliminating the snubber damper on hingeless rotor designs and replacing it with a flexbeam that has been modified to possess nonlinear properties. This work is well suited to the new NPS rotor simulation analysis that can accurately model nonlinear mechanical properties so that these nonlinearities may be exploited to the helicopter's advantage. Tasks in this research included the formulation of a MAPLE®-based symbolic processing program that formulated nonlinear equations of motion given energy expressions for helicopter rotor model degrees of freedom. SIMULINK® based computer simulations were developed from the equations of motion derived by the symbolic processor. The resulting simulation is being used to analyze the effects of nonlinear material properties on aeromechanical rotor stability.

SUMMARY: This research presented results of a parametric study of damperless helicopter rotor blade lead/lag motion. Simulations of hub and blade lag motion were performed in the SIMULINK® modeling environment using the symbolically derived equations of motion mentioned. Without including auxiliary lag dampers in the blade dynamics, this analysis incorporated nonlinear flexbeam stiffness properties to limit inplane motion of the blade. A parametric study was then performed simulating soft inplane rotors with lag natural frequencies from 0.3Ω to 0.7Ω and damping ratios for hub motion from <1% to 10%. For lead/lag motion, each blade in the study was modeled with a conventional linear restoring spring in parallel with a cubic restoring spring, found in the literature as a Duffing-type spring.

Since ground and air resonance are characterized by coupling of fuselage motion with lead/lag motion of the rotor blades in their plane of rotation, the classic frequency shifts of a Duffing type blade constraint offer an intriguing option to conventional lead/lag dampers as a potential solution to the rotorcraft ground/air resonance problem.

With Duffing-type nonlinear stiffness employed in the flexbeam of the blades, stable lead/lag motion was successfully achieved in coupled rotor-fuselage simulations that are otherwise very unstable. Built-in linear structural lag damping of 1% was assumed for the flexbeam in all cases.

Parametric studies were then conducted with the linear spring rate held constant but where the Duffing spring rate was gradually increased. Simulation time histories showed that the linear system, while initially unstable, became increasingly stable as the spring constant of the nonlinear Duffing spring was gradually increased. Additional analysis has been performed at rotor rotational frequencies above the center of instability.

PUBLICATIONS:

Robinson, C.S., Wood, E.R., and King, R.L., "Simulation of Helicopter Dynamic Mechanical Instability by MAPLE®-Based Nonlinear Lagrangian Derivation," *Proceedings of AIAA/AHS/ASME/ASCE 39th Structures, Structural Dynamics, and Materials Conference,* AIAA Paper No. 98-2005, Long Beach, CA, 20-23 April 1998.

Robinson, C.S., Wood, E.R., and King, R.L., "Full Nonlinear Simulation of Coupled Rotor-Fuselage Response Using Symbolically Derived Equations of Motion," *Proceedings of American Helicopter Society 54th Annual Forum and Technology Display,* Washington, DC, 20-22 May 1998.

CONFERENCE PRESENTATION:

King, R.L., "Nonlinear In-Plane Flexbeam Stiffness Provides Rotor System Stability Without Lag Dampers," Lichten Award Presentation, NASA Ames Research Center, CA, 17 December 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation, Other (Dynamics and Control)

KEYWORDS: Stability, Control, Dynamics, Rotorcraft, Rotary-Wing, Helicopter, Simulation, MATLAB

WEAPONS PERFORMANCE MODEL FOR RAH-66 *COMANCHE* HELICOPTER

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Proving Ground-Yuma

OBJECTIVE: Using the NASTRAN structural dynamic model of the RAH-66 helicopter, determine biases between sensor LOS and weapon pointing to the target for specified conditions as a function of the flight envelope. Biases are to be applied as fire control corrections. Weapons of interest are 1.75-inch rockets and 20-mm nose mounted gun. Sensors include FCR, TV, and FLIR.

SUMMARY: This analysis is being conducted using the Boeing-Sikorsky finite element model of the Army's RAH-66 *Comanche* helicopter. The purpose of the work is to quantify errors in gun accuracy due to dynamic response of the airframe

structure as it is subjected to gun firing recoil loads. In addition, related movement at the weapon sensor locations will be predicted to provide information on tracking and aiming errors. These results will ultimately be applied as corrections to the system's fire control computer.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Conventional Weapons, Human Systems Interface, Sensors, Modeling and Simulation

KEYWORDS: Attack Helicopter, Fire Control Computer, Weapons System Accuracy, Air Vehicle Environment, Sensors, Modeling and Simulation, Structural Dynamic Response, MSC NASTRAN, Gun Firing Recoil Loads

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 *COMANCHE* HELICOPTER

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Donald A. Danielson, Professor
Department of Mathematics
Joshua H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsors: U.S. Army Comanche Program Office and Naval Postgraduate School

OBJECTIVE: Professors Wood, Danielson, and Gordis continued their work in support of the ongoing development of the Army's RAH-66 *Comanche* helicopter. Tasks included static and dynamic analyses. A dynamic NASTRAN finite element model provided the basis for the analyses and is maintained at NPS to support the ongoing Comanche flight test development program. The objective of the analyses is the optimization of the airframe for dynamic response.

SUMMARY: Research for 1998 comprised two parts: For the first part, developmental flight testing of the Comanche helicopter had revealed high vibrations caused by buffeting of the aircraft empennage. From the flight test aircraft differential pressure transducer and accelerometer data, the spectral content of the response was determined. Then, using a NASTRAN model of the aircraft, the frequency response functions between selected points on the aircraft's tail and the flight test accelerometer locations were calculated. Finally, various assumptions as to the location and distribution of empennage air loads were made, and the magnitude of these airloads, and the relative importance of primary airframe modal responses to these airloads, were determined.

Efforts of the NPS Comanche team for the second half of 1998 were directed to a new area, that of designing the tailboom to withstand the high pressure blast emitted from a 23 mm HEI (High Explosive plus Incendiary) round. For the new work, special software, MSC/DYTRAN is required. DYTRAN is a three dimensional code that is well suited for analyzing short, transient dynamic events that involve large deformations, a high degree of nonlinearity, and interactions between fluids and structures. Typical applications include: (1) response of structures to explosive and blast loading; (2) high-velocity penetration; and (3) weapons design calculations that involve self-forging fragments.

DYTRAN makes Lagrangian and Eulerian solvers available to enable modeling of both structures and fluids. Meshes within each solver can be coupled together to analyze fluid-structure interactions. Solid, shell, beam, membrane, spring, and rigid elements are used within the Lagrangian solver to model the structure, and the three-dimensional Eulerian elements can then be used in addition to create Eulerian meshes.

THESIS DIRECTED:

Mason, Patrick H., "Identification of Random Loads Impinging on the RAH-66 *Comanche* Helicopter Empennage Using Spectral Analysis," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Simulation, Manufacturing Science and Technology, Materials, Processes, and Structures

KEYWORDS: Helicopters, Airframe Dynamics, Random Aerodynamic Excitation, Dynamic Plasticity, Computer Software

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Tuncer, I.H. and Platzer, M.F., "Potential Flow Solutions With Wakes Over an Ogive Cylinder," *Journal of Spacecraft and Rockets*, Vol. 35, No. 3, May-June 1998.

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PUBLICATIONS/PRESENTATIONS

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SUPERSONIC FLOW PAST TWO OSCILLATING AIRFOILS

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Supersonic flow past two oscillating airfoils with supersonic leading edge locus is analyzed using an elementary analytical theory valid for low frequencies of oscillation. The airfoils may have arbitrary stagger angle. This approach generalizes Sauer's solution for a single airfoil oscillating at small frequencies in an unbounded supersonic flow.

It is shown that this generalization can provide an elementary theory for supersonic flow past two slowly oscillating airfoils. This aerodynamic tool will facilitate the evaluation of pressure distributions and consequently the calculation of moment coefficient. Torsional flutter boundaries are computed. The results for the pitch-damping coefficient are the same when compared with previous analysis. For arbitrary frequencies a linearized method of characteristics was outlined.

The elementary theory that has been developed in the thesis can be used for flutter evaluation of aircraft carrying external stores. The result of the thesis is the derivation of the pitch-damping coefficient which is necessary to predict the flutter conditions.

DoD TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Flutter Analysis, Structures

INVESTIGATION OF THE PRESSURE AND TEMPERATURE SENSITIVITIES OF A PRESSURE SENSITIVE PAINT

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In the development of a surface pressure measurement system for transonic compressor rotors, it has been shown that Pressure Sensitive Paint (PSP) is also temperature dependent. In the present study, the sensitivities to pressure and temperature were examined experimentally using an electronically-gated, intensified Charged-Coupled-Device (CCD) video camera, frame-grabber software and an eight-inch diameter calibration chamber. Using a signal generator, in a procedure that matched the requirements of the rotor application, multiple low-intensity-level camera exposures were integrated and captured to produce a single usable image. Ten captured images were averaged to increase the image's signal-to-noise ratio and the result was used to produce an image ratio with respect to a static (ambient pressure/temperature) reference condition. Calibration tests of constant temperature/variable pressure and constant pressure/variable temperature were completed. The results were then compared with data obtained using the same paint and an automated, single-exposure calibration procedure at NASA Ames Research Center. It was shown that the calibration data could be used to derive the static pressure field produced over a high-speed test rotor using PSP and the same image-capture system used in the calibration. In preparation for a bench test of the procedure, a uniform-stress, high-speed test rotor disk, fitted with a shock generator was driven at speeds in excess of 30,000 RPM. Recommendations are made toward the goal of obtaining quantitative pressure measurements on transonic compressor rotors.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Pressure Sensitive Paint, PSP, Charged Couple Device Camera, CCD, Photoluminescence, Imaging, Luminescence, PTOEP, UV Illumination, Detection, Emission, Aerodynamics, Measurements, Temperature and Pressure Calibration

COMPARATIVE ANALYSIS OF SELECTED RADIATION EFFECTS IN MEDIUM EARTH ORBITS

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Satellite design is well developed for the common Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) and Highly Elliptical Orbits (HEO), i.e., Molniya, cases; Medium Earth Orbit (MEO) satellite design is a relatively new venture. MEO is roughly defined as being altitudes above LEO and below GEO. A primary concern, and a major reason for the delay in exploiting the MEO altitudes, has been the expected radiation environment and corresponding satellite degradation anticipated to occur at MEO altitudes. The presence of the Van Allen belts, a major source of radiation, along with the suitability of GEO and LEO orbits, has conventionally discouraged satellite placement in MEO. As conventional Earth orbits become increasingly crowded, MEO will become further populated.

This thesis investigates the major sources of radiation (geomagnetically trapped particles, solar particle events and galactic cosmic radiation) with respect to specific Naval Research Laboratory (NRL) designated MEO (altitudes between 3,000 nautical miles (nmi) and 9,000 nmi; inclination angle of 15 degrees). The contribution of each of these components to the total radiation experienced in MEO and the effects of the expected radiation on a representative spacecraft are analyzed in comparison to a baseline LEO orbit of 400 nmi and 70 degrees inclination. Dose depth curves are calculated for several configurations, and show that weight gains from necessary expected shielding are not extreme. The radiation effects considered include proton displacement dose and solar cell degradation.

KEYWORDS: Radiation, Medium Earth Orbit, Space

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Battlespace Environments

DESIGN OF AN ATTITUDE DYNAMICS AND CONTROL SUBSYSTEM FOR A MEDIUM EARTH ORBIT SATELLITE

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The Department of Defense has a continuing need for satellite communications to satisfy the demand for information exchange for strategic, operational, and tactical warfighters. There is currently a Deputy Undersecretary of Defense for Space (DUSD (Space)) transition planning effort to develop a satellite communications architecture for the 2007-2010 time frame. During this time all three current satellite systems; UFO, DSCS, and MILSTAR, are expected to degrade rapidly. As part of the DUSD - Space effort the U.S. Navy was tasked to form a Mobile Users Study to establish a framework for completing the detailed requirements and engineering work needed to develop the UHF/Mobile User transition plan. Then, as part of the Navy effort, the Naval Postgraduate School's Astronautical Engineering class SE-61 under Professor Brij Agrawal's guidance designed a proposed medium Earth orbit communications satellite. This thesis is a design of the Attitude Dynamics and Control Subsystem for the subject medium Earth orbit MUS communications satellite. The thesis describes and explores the five major steps in designing an Attitude, Dynamics, and Control Subsystem. It also focuses on key ADCS related areas that are peculiar to a MEO satellite as compared to a GEO satellite.

KEYWORDS: Attitude Dynamics and Control Subsystem, ADCS, Medium Earth Orbit, MEO, Satellite Design, Spacecraft Design, Communications Satellite

DoD KEY TECHNOLOGY AREA: Command, Control, and Communications

INVESTIGATION INTO THE TUMBLING CHARACTERISTICS OF THE TIER III MINUS UNMANNED AIR VEHICLE (UAV)

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A free-to-pitch wind tunnel analysis of a 1/25-scale model of the Tier III Minus DarkStar Unmanned Aerial Vehicle (UAV) was conducted to better quantify the susceptibility of the aircraft to entering a potentially catastrophic autorotative pitching motion known as tumbling. The objective of the experimental portion of the study was to determine total and dynamic moment coefficients as well as pitch damping coefficients for incorporation into a three-degree-of-freedom computer simulation. The simulation, based on the experimentally-obtained data, revealed that the Tier III Minus would tumble with the proper initial conditions of high angle of attack and/or pitch rate. Also investigated were the effects of uncommanded control surface deflection and wind shear. The simulation revealed a tendency to enter a tumble for control deflections of between -5 and -15 degrees. The results of the wind shear simulation revealed a resistance to tumbling for encountering FAR Part *25* design gusts of 38 and 66 ft/s.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Tier III Minus, Unmanned Aerial Vehicle, UAV, Tumbling

AN ANALYSIS OF LIMITATIONS IN ACTIVE CANCELLATION OF RADAR SIGNALS

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Acoustic noise suppression has been achieved by rebroadcasting a phase-inverted copy of an incident signal, such that the two signals cancel. The same effect applies in theory to electromagnetic signals, allowing the cancellation of radar signals. This effect would supplement existing "stealth" technologies. The electromagnetic equivalence theorem provides for a straightforward theoretical analysis, and several numerical analyses demonstrate cancellation on simple wire models. The limitations of the cancellation are covered with respect to bandwidth, canceler spacing, and two canceler unit failure (error) modes. Sucessful cancellation is demonstrated for two canceler densities up to approximately 50 MHz, and a significant reduction in canceler effectiveness results when the two failure modes are tested.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Electronic Warfare, Sensors

KEYWORDS: Radar, Electromagnetic Field Cancellation, Radar Cancellation, Scattering Analysis

DESIGN AND BUILD OF EVA COMPATIBLE, BOLT/MOTOR BRACKET ASSEMBLIES FOR THE R-SLC SYSTEM AND ANALYSIS FOR FOLLOW-ON REDUCED GRAVITY TESTING

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The Robotic-Sidewall Logistics Carrier (R-SLC) is a design solution for putting small payloads (military and non-military) on orbit while meeting the requirement to transfer experiment and logistics equipment between the Space Shuttle and the International Space Station (ISS) by robotics rather than through the conduct of extra vehicular activities (EVA). The concept, design, and fabrication were all conducted by students and faculty at the Naval Postgraduate School (NPS) and the Boeing Defense and Space Group (Boeing).

Using as much off-the-shelf technology as practical for the design, the R-SLC will provide a lightweight, stand-alone means to more cost effectively carry small payloads aloft in the Shuttle cargo bay. This hardware will be fully Remote Manipulator System (RMS) compatible for on orbit removal and retrieval operations. Transferring or deploying payloads via the RMS reduces the requirement for astronauts to conduct EVA operations. EVA operations will only be required where system failure of power or robotics occurs.

This thesis project, specifically the bolt/motor bracket assemblies of the R-SLC, will integrate some off-the-shelf parts with three primary hardware elements specifically designed for this assembly. This innovation will provide the means to attach an EXPRESS pallet adapter to a side wall carrier so that it is removable and replaceable during EVA contingency operations. Special considerations were given to human factors engineering during the design process in order to accommodate the suited astronaut in a zero-gravity environment. Part two of this thesis encompasses the hazard and structural analyses of specifically designed flight support equipment and planning for a reduced gravity flight test aboard the NASA KC-135A aircraft in order to validate EVA compatibility.

DoD KEY TECHNOLOGY AREA: Other (Manned Space Flight)

KEYWORDS: Orbiter, Robotics, Logistics, Space Shuttle, ISS

DESIGN OF DIGITAL CONTROL ALGORITHMS FOR UNMANNED AIR VEHICLES

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Recent advances in the design of high performance aircraft, such as fly-by-wire controls, complex autopilot systems, and unstable platforms for greater maneuverability, are all possible due to the use of digital control systems. With the aid of modern control tools and techniques based on state-space methods, the aerospace engineer has the ability to design a dynamic aircraft model, verify its accuracy, and design and implement the controller within a matter of a few months. This work examines the digital control design process utilizing a Rapid Prototyping System developed at the Naval Postgraduate School. The entire design process is presented, from design of the controller to implementation and flight test on an Unmanned Air Vehicle (UAV).

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Unmanned Aerial Vehicles, Rapid Prototyping Systems, Hardware-in-the-Loop Simulation, AROD, FROG, MATRIX, SystemBuild

A SECOND LAW APPROACH TO AIRCRAFT CONCEPTUAL DESIGN

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With advancements in the fields of propulsion, aerodynamics, structures, materials and controls, the routine exploration of hypersonic, atmospheric flight has become a more feasible concept. Thus, there is a need for efficient and effective hypersonic configurations. Current studies in configuration efficiency and effectiveness seem to be concentrated in aircraft subsystem design, especially propulsion systems, rather than at the conceptual aircraft system design level. This thesis attempts to initiate the process of incorporating the Second Law of Thermodynamics into the conceptual aircraft design process. The methodology for this process involves the use of the thermodynamic variable exergy, also known as availability. The ultimate goal of the process introduced by this thesis is to be able to define an aircraft configuration design space based upon both the First and Second Laws of Thermodynamics.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: Conceptual Design, Configuration, Second Law of Thermodynamics, Exergy, Availability

AVIONICS SYSTEM DEVELOPMENT FOR A ROTARY WING UNMANNED AERIAL VEHICLE

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The Naval Postgraduate School has developed a successful Rapid Flight Test Prototyping System (RLFTPS) for the development of software for remote computer control of fixed wing Unmanned Aerial Vehicles (UAV). This thesis reviews the work accomplished to mount sensors on a small remote controlled helicopter with instrumentation compatible with the RFTPS: an inertial measurement unit, a Global Positioning System (GPS) receiver, an altitude sensor and associated power supply and telemetry equipment. A helicopter with sufficient lift capability was selected and a lightweight aluminum structure was built to serve as both an avionics platform for the necessary equipment and also as a landing skid. Since the altitude sensors used for fixed wing UAVs, such as barometric sensors and GPS, do not provide sufficient accuracy for low altitude hover control, a lightweight, precision altimeter was developed using ultrasound technology. Circuitry was developed to drive a Polaroid 6500 Series Ranging Module and process the output data in a form compatible with the RFTPS avionics architecture. Flight testing revealed severe vibrations throughout the helicopter. An alternative avionics package of reduced size was constructed to house the sonic altimeter and a three-axis accelerometer. Subsequent test flight results and recommendations for further research are provided.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Electronics, Sensors

KEYWORDS: Unmanned Aerial Vehicles, Avionics, Sonic Altimeter

A MILITARY UHF COMMUNICATIONS SATELLITE DESIGN FOR THE USER ON THE MOVE

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Initial proposals for commercial PCS at L/S band were based on LEO and MEO satellites; some more recent commercial initiatives have been based on GEO satellites with large deployable antennas to provide low data rate services to handheld units. This thesis addresses the feasibility of a UHF military satellite design capable of providing service to handheld units. More specifically, this thesis focuses on the key payload design aspects and technology considerations required to design a GEO satellite with a large deployable antenna that forms multiple beams, and employs on-board signal processing to demodulate and route signals between beams. Several design excursions based on cutting edge technologies in their final stages of R&D are discussed (e.g., Digital Beam Forming, and Turbo coding) along with their system impacts.

KEYWORDS: Satellite Personal Communications, Communications on the Move, Processing Payload, Digital Beam Forming, Waveform Coding, Spacecraft Design

DoD KEY TECHNOLOGY AREA: Command, Control, and Communications

PERFORMANCE ENHANCEMENTS TO JOINT ARMY/NAVY ROTORCRAFT ANALYSIS AND DESIGN (JANRAD) SOFTWARE AND GRAPHICAL USER INTERFACE (GUI)

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The Joint Army/Navy Rotorcraft Analysis and Design (JANRAD) computer program was developed at the Naval Postgraduate School to perform performance, stability and control, and rotor dynamics analysis during preliminary helicopter design efforts. This thesis is the continuation of a previous work in which a Graphical User Interface (GUI) was developed and implemented as the front end to the JANRAD program. Due to the complexity of the GUI design, only the performance module of JANRAD was completed by the prior student. This thesis expands the capabilities of the performance module, and the JANRAD code, by adding graphical output of performance results, improved rotor sizing capabilities, resources for user defined blade elements and non-linear blade twist, airfoil meshing capabilities, and additional reference airfoil data corrected for compressibility effects. It also contains the basic architecture for the stability and control module GUI. Additionally, utilizing actual I.JH-60A Black Hawk airfoil and test flight data as inputs, JANRAD version 5.0 was run to validate its output with the test flight results, and those produced in a prior thesis by JANRAD version 3.1 (1995). Excellent agreement was demonstrated in all flight regimes. Utilizing airfoil data corrected for compressibility effects, high altitude runs resulted in much better correlation with test flight results than those experienced in 1995 using uncorrected airfoil data. A JANRAD Users Guide was updated and is included as Appendix A to this thesis.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Helicopter, Graphical User Interface, Performance, Preliminary Design, Stability and Control, UH-60A, JANRAD

A LABVIEW© BASED WIND TUNNEL DATA ACQUISITION PROGRAM

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The Naval Postgraduate School (NPS) Aerolab® Low Speed Wind Tunnel located in Halligan Hall of the Naval Postgraduate School has been in operation since 1953. Although the tunnel is well maintained, its data acquisition system has not kept pace with modern technology. An effective but affordable solution for acquiring data was needed. It was determined that a software package known as LabVIEW© provides a low cost, data acquisition solution that will enhance the capabilities of the wind tunnel, while at the same time making it more user friendly to faculty and students. The focus of this thesis is the design of a VI that will collect and plot force and moment data from a six-component strain gauge balance and yield real time, non-dimensional, force and moment coefficients in six degrees of freedom. Wind tunnel tests consisting of a sweeps in the NPS Aerolab® low-speed wind tunnel were conducted to verify $(L/D)I_{sp}$ optimized, $M_\bullet = 6$, conical-flow waverider data obtained in 1994 using a different data acquisition system. Results of current testing substantiate the validity of the 1994 test data. Analysis of the current data set resolved pitching moment concerns related to the 1994 data.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Battlespace Environments, Computing and Software, Conventional Weapons, Human Systems Interface, Sensors, Modeling and Simulation

KEYWORDS: Strain Gauge Balance, LabVIEW©, VI, Data Acquisition, Wind Tunnel, Waverider, Lift, Drag, Aeromoments

FUEL-OPTIMAL LOW-EARTH-ORBIT MAINTENANCE

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First-order solutions indicate that a forced Keplerian trajectory (FKT) obtained by thrust-drag cancellation is as fuel-efficient as a Hohmann transfer. Further analysis has shown that the FKT is not Mayer-optimal. Therefore, there must exist another trajectory that matches or exceeds the efficiency of the Hohmann transfer. The application of this result to the fuel-optimal orbit maintenance problem implies that periodic reboosts must be more efficient than an FKT profile. This research begins with the formulation of an optimal periodic control (OPC) problem to determine the minimum fuel-reboost strategy. The problem is numerically solved by a spectral collocation method. The optimization code is further modified to increase accuracy and reduce sensitivity to initial guesses. The results of this effort identified a trajectory for a sample satellite that was 3.5% more efficient than an ideal impulsive Hohmann transfer over the same period of time. From the optimal code, a maximum thruster size is also identifiable for a set of initial conditions. The optimal trajectory can save as much as 10% of the propellant budget when compared to finite-bum Hohmann transfers.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Space Vehicles, Modeling and Simulation

KEYWORDS: Orbital Maintenance, Orbital Mechanics, Hohmann Transfer, Orbit Reboost, Orbit Transfer, Forced Keplerian Trajectory, Optimization, Periodic Control

UNMANNED AIR VEHICLES: A STUDY OF RECUPERATED-CYCLE GAS TURBINE APPLICATION

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The DoD's Unmanned Air Vehicle (UAV) medium and high altitude/endurance programs require reliable and fuel-efficient propulsion systems, which suggests the use of turboprop technology. Operational UAVs use commercial reciprocating engines or high-bypass turbofan engines. Current engine types were reviewed and the potential performance of the gas-turbine cycle with recuperation, which would improve thermal efficiency and specific fuel consumption, was examined. The recuperated cycle was noted to have particular advantages for smaller engines. A study was performed using the GasTurb and GECAT engine codes, using component level efficiencies appropriate for small-scale turbomachinery and heat exchangers, to estimate the potential performance of a recuperated turboshaft/turboprop-powered UAV system in comparison to the present reciprocating engine system. It was shown that the use of a recuperated turboprop in a *Predator-type* UAV would result in extended range, increased power availability, and an altitude capability in excess of those attainable currently with spark-ignition engines. Such a recuperative gas-turbine engine would also provide better reliability than the reciprocating engines currently used by UAV platforms.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: UAV, Propulsion, Gasturb, GECAT, NEPP, Turboprop, Turboshaft, Recuperation

ACOUSTICAL EMISSION SOURCE LOCATION IN THIN RODS THROUGH WAVELET DETAIL CROSS CORRELATION

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Flaws in structural elements release strain energy in the form of stress waves that can be detected through acoustical emission techniques. The transient nature of a stress wave is analytically inconsistent to Fourier Transforms, and the wave characteristics under the effects of dispersion and attenuation deviate from the formal basis of the Windowed Fourier Transform. The transient solid body elastic waves contain multiple wave types and frequency components which lend themselves to the time and frequency characteristics of Wavelet Analysis. Software implementation now enables the exploration of the Wavelet Transform to identify the time of arrival of stress wave signals for source location in homogeneous and composite materials. This investigation quantifies the accuracy and resolution of two existing source location methods and develops a third technique using the Discrete Wavelet Transform on a windowed portion of the stress wave signal. A refined method for the spatial location of material damage induced stress waves can be used to directly monitor the safe-life of structures and provide a quantitative measure for the risk assessment of critical and aging structures.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Materials, Processes, and Structures

KEYWORDS: Acoustical Emission, Composites, Structures, Wavelet Analysis

ACOUSTICAL EMISSION SOURCE LOCATION IN THIN RODS THROUGH WAVELET DETAIL CROSS CORRELATION

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Advisor: Edward M. Wu, Department of Aeronautics and Astronautics
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Flaws in structural elements release strain energy in the form of stress waves that can be detected through acoustical emission techniques. The transient nature of a stress wave is analytically inconsistent to Fourier Transforms, and the wave characteristics under the effects of dispersion and attenuation deviate from the formal basis of the Windowed Fourier Transform. The transient solid body elastic waves contain multiple wave types and frequency components which lend themselves to the time and frequency characteristics of Wavelet Analysis. Software implementation now enables the exploration of the Wavelet Transform to identify the time of arrival of stress wave signals for source location in homogeneous and composite materials. This investigation quantifies the accuracy and resolution of two existing source location methods and develops a third technique using the Discrete Wavelet Transform on a windowed portion of the stress wave signal. A refined method for the spatial location of material damage induced stress waves can be used to directly monitor the safe-life of structures and provide a quantitative measure for the risk assessment of critical and aging structures.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Materials, Processes, and Structures

KEYWORDS: Acoustical Emission, Composites, Structures, Wavelet Analysis

MODAL ANALYSIS AND ACTIVE VIBRATION CONTROL OF THE NAVAL POSTGRADUATE SCHOOL SPACE TRUSS

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This thesis examines active control of the Naval Postgraduate School (NPS) Space Truss using a piezoceramic stack actuator. Preceding the development of an active control mechanism for the NPS space truss, modal testing was performed to identify the modal properties of the truss. An impact hammer provided excitation to the truss and accelerometers measured the trussí response. Two data acquisition systems, dSPACE and an Hewlett Packard spectrum analyzer, were used independently to gather and analyze data. For active control, an active strut, consisting of a piezoceramic stack, a force transducer, and mechanical interfaces, was substituted in place of a critical diagonal strut and acted as a control actuator. The frequency response of the system was determined and an integral plus double-integral force feedback control law was designed and implemented. A linear proof mass actuator was employed to excite one of the trussí vibrational modes. The controller then suppressed the vibration along the length of the structure resulting in power attenuation on the order of 10-15 dB. Various combinations of velocity and position feedback gains were investigated in order to optimize the control action. Additional testing was also performed to determine the controllerís sensitivity over a frequency band.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Active Vibration Control, Piezoceramic Actuators, Modal Testing, Modal Analysis

VULNERABILITY REDUCTION TECHNOLOGY FOR ROTARY WING AIRCRAFT

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Aircraft Survivability is made up of two elements, aircraft susceptibility and aircraft vulnerability. Susceptibility is the inability of an aircraft to avoid being damaged by the elements of an enemy's air defense, and vulnerability is the inability of an aircraft to withstand the damage caused by the enemy's air defense. This thesis is written as a tool for the designer of future military helicopters and tiltrotor aircraft. The vulnerability of modem rotary wing aircraft, the vulnerability reduction concepts, and the technologies used to reduce vulnerability are examined. This thesis describes the threats that may be encountered by modern aircraft, the damage that those threats can cause, the aircraft component/system kill modes, the Loss of essential functions, and concludes with a vulnerability reduction checklist for the designer of rotary wing aircraft.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Rotary Wing Aircraft, Vulnerability, Reduction Concepts, Aircraft Survivability

ALUMINUM 7075-T6 FATIGUE DATA GENERATION AND PROBABILISTIC LIFE PREDICTION FORMULATION

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The life extension of aging fleet aircraft requires an assessment of the safe-life remaining after refurbishment. Risk can be estimated by conventional deterministic fatigue analysis coupled with a subjective factor of safety. Alternatively, risk can be quantitatively and objectively predicted by probabilistic analysis. In this investigation, a general probabilistic life formulation is specialized for constant amplitude, fully reversed fatigue loading utilizing conventional breakdown laws applied to the general probability damage function. Experimental data was collected both as a benchmark database, as well as an example of the implementation of probabilistic fatigue life prediction. Fully reversed, sinusoidal fatigue testing under load control was carried out at load levels giving high cycle fatigue lives from 1×10^4 to 5×10^6 cycles. The life range is longer than currently available in the literature, thereby increasing the confidence of predictions in the long-life domain, as well as the number of replications at each load level thereby extending the statistics. The load level data sets are interpreted by the probabilistic damage function for life location as well as life shape parameters using maximum likelihood analysis. Homologous life ranking and the minimum entropy hypothesis are investigated as well.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes, and Structures

KEYWORDS: Aluminum 7075-T6, Fatigue Life Prediction, Fatigue Database, Probability, Reliability, Damage Accumulation, Maximum Likelihood Analysis

APPLICATIONS OF RAPID PROTOTYPING TO THE DESIGN AND TESTING OF UNMANNED AIR VEHICLE (UAV) FLIGHT CONTROL SYSTEMS

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The modern engineer has a myriad of new tools to assist in the design and implementation of ever increasingly complex control systems. A promising emerging technology is rapid prototyping. By totally integrating the development process, a Rapid Prototyping System (RPS) takes the designer from initial concept to testing on actual hardware in a systematic, logical sequence. At the Naval Postgraduate School (NPS), the concept of rapid prototyping has been applied to the discipline of flight control.

The NPS RPS consists of a commercially available rapid prototyping software suite and open architecture hardware to permit the greatest possible range of control and navigation projects. The RPS is crucial in that it allows students to participate in projects from the initial concept to the flight-testing phase of the design process. This thesis describes in detail two of these projects: the development of an Airspeed Controller using the RPS tools and the integration of a Voice Control System developed by ViA, Inc., of Northfield, Minnesota. Both projects demonstrate the inherent flexibility and risk reduction of the rapid prototyping approach to system design.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Rapid Prototyping, Unmanned Air Vehicles, Flight Control Systems

DEVELOPMENT OF GRAPHICAL USER INTERFACE (GUI) FOR JOINT ARMY/NAVY ROTORCRAFT ANALYSIS AND DESIGN (JANRAD) SOFTWARE

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A Graphical User Interface (GUI) was developed and implemented as the front end of the NPS software Joint Army/Navy Rotorcraft Analysis and Design (JANRAD). The original JANRAD computer program was developed to aid in the analysis of helicopter rotor performance, stability and control, and rotor dynamics. An interactive program, JANRAD was capable of accurately and quickly solving helicopter design problems at the preliminary design level. The addition of the GUI greatly simplified the use of the program but added considerable complexity to the original MATLAB® M-File code. Because of the increased complexity, only the Performance Analysis module of the program was modified. The use of several new features of MATLAB® version 5.1, such as the GUIDE® and Structure functions, simplified the construction of the GUI environment and enhanced the tie between the user interface and performance calculation routines. Although initiated from the MATLAB® command line, the program can now be worked entirely from the "Windows" environment. The performance routines were modified extensively to connect the user input with the existing analysis routines. However, the fundamental method of analysis remains unchanged. Several cases of Sikorsky UH-60A Black Hawk input data were run and results compared with those from JANRAD version 3.1 (1995). The results correlated exactly. A Users Guide was developed and is included in Appendix A.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software

KEYWORDS: Helicopter, Graphical User Interface, Performance, Preliminary Design

SOLID MODELING FOR ROTARY WING DESIGN AT NPS WITH AUTOCAD R13

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This thesis is intended to be a reference for solid modeling and Computer Aided Design (CAD) tailored specifically for the Naval Postgraduate School's capstone helicopter design course, AA 4306. The goal is to present the use of AutoCAD R13 software as a central design tool throughout the conceptual design phase of the American Helicopter Society (AHS) Graduate Design Competition project. The specifics of AutoCAD that are essential to performing the design project are explored through examples of model construction and lessons learned from the 1997 VIPER design effort. The usage of solid modeling as a design tool for design team integration is investigated. It is intended for this work to allow future classes to acquire sufficient proficiency with CAD and solid modeling. Maximizing the practical usage of CAD techniques in a single quarter will provide for an improved learning experience in a more realistic design environment.

KEYWORDS: AutoCAD, Design, Solid Modeling, Helicopter, Rotary Wing

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation

IDENTIFICATION OF RANDOM LOADS IMPINGING ON THE RAH-66 COMANCHE HELICOPTER EMPENNAGE USING SPECTRAL ANALYSIS

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The Army RAH-66 Comanche Helicopter is currently undergoing developmental flight testing. The empennage of the aircraft is experiencing buffeting where the horizontal and vertical tail vibrate at resonant frequencies. These high buffet loads are manifested in higher than anticipated fitting loads, particularly on the tail, and vibrations in the crew stations and at the nose cone where the targeting sensors are located. Significant effort has been devoted to identifying the sources of excitation and the nature of the structural response. This thesis determines the location and magnitude of empennage vibratory airloads. Because the nature of the excitation is a random function, spectral analysis is used. To obtain the loads, a three-step process was utilized. First, from aircraft differential pressure transducers and accelerometers, the spectral content of the response and excitation was determined Then, using a NASTRAN model modified to replicate the flight test aircraft, frequency response functions were determined between selected points on the aircraft's tail and the accelerometers. Finally, using this information, a solution was obtained for the vibratory airloads. Having provided information on the nature of the driving forces, structural modifications can be made that move the natural frequencies away from the frequencies of the applied airloads.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: RAH-66 Comanche Helicopter, Random Vibrations, Comanche Tail Section, Structural Analysis, Spectral Analysis, NASTRAN Analysis

DYNAMIC SYSTEM IDENTIFICATION AND MODELING OF A ROTARY WING UAV FOR STABILITY AND CONTROL ANALYSIS

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This thesis presents a method for the dynamic system identification and simulation model development of a small rotary wing Unmanned Aerial Vehicle (UAV). Using aerodynamic parameterization and linear state-space modeling techniques, the Bergen Industrial UAV was modeled for computer simulation to analyze its inherent stability and control characteristics. The NIPS designed JANRAD software was utilized to determine the stability and control derivatives used in the simulation model. The identification of the UAV dynamic model will aid in the development of closed-loop controllers capable of autonomous UAV control. The fidelity of the simulation model was verified by comparing the simulation responses with data collected from on-board sensors during test flights.

DoD KEY TECHNICAL AREA: Air Vehicles

KEYWORDS: Unmanned Aerial Vehicles, Stability and Control, Modeling, Simulation, System Identification, Helicopter, JANRAD

DEVELOPMENT OF GRAPHICAL USER INTERFACE (GUI) FOR JOINT ARMY/NAVY ROTORCRAFT ANALYSIS AND DESIGN (JANRAD) SOFTWARE

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A Graphical User Interface (GUI) was developed and implemented as the front end of the NPS software Joint Army/Navy Rotorcraft Analysis and Design (JANRAD). The original JANRAD computer program was developed to aid in the analysis of helicopter rotor performance, stability and control, and rotor dynamics. An interactive program, JANRAD was capable of accurately and quickly solving helicopter design problems at the preliminary design level. The addition of the GUI greatly simplified the use of the program but added considerable complexity to the original MATLAB® M-File code. Because of the increased complexity, only the Performance Analysis module of the program was modified. The use of several new features of MATLAB® version 5.1, such as the GUIDE® and Structure functions, simplified the construction of the GUI environment and enhanced the tie between the user interface and performance calculation routines. Although initiated from the MATLAB® command line, the program can now be worked entirely from the "Windows" environment. The performance routines were modified extensively to connect the user input with the existing analysis routines. However, the fundamental method of analysis remains unchanged. Several cases of Sikorsky UH-60A Black Hawk input data were run and results compared with those from JANRAD version 3.1 (1995). The results correlated exactly. A Users Guide was developed and is included in Appendix A.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software

KEYWORDS: Helicopter, Graphical User Interface, Performance, Preliminary Design

FLIGHT TESTING AND REAL-TIME SYSTEM IDENTIFICATION ANALYSIS OF A UH-60A BLACK HAWK HELICOPTER WITH AN INSTRUMENTED EXTERNAL SLING LOAD

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Helicopter external air transportation plays an important role in today's world for both military and civilian helicopters, external sling load operations offer an efficient and expedient method of handling heavy, oversized cargo. With the ability to reach areas otherwise inaccessible by ground transportation, helicopter external load operations are conducted in industries such as logging, construction, and fire fighting, as well as in support of military tactical transport missions. Historically, helicopter and load combinations have been qualified through flight testing, requiring considerable time and cost. With advancements in simulation and flight test techniques, there is potential to substantially reduce costs and increase the safety of helicopter sling load certification. Validated simulation tools make possible accurate prediction of operational flight characteristics before initial flight tests. Real-time analysis of test data improves the safety and efficiency of the testing programs. To advance these concepts, the U.S. Army and NASA, in cooperation with the Israeli Air Force and Technion, under a Memorandum of Agreement, seek to develop and validate a numerical model of the UH-60 with sling load and demonstrate a method of near real-time flight test analysis. This thesis presents results from flight tests of a U.S. Army Black Hawk helicopter with various external loads. Tests were conducted as the U.S. first phase of this MOA task. The primary load was a container express box (CONEX), which contained a compact instrumentation package. The flights covered the airspeed range from hover to 70 knots. Primary maneuvers were pitch and roll frequency sweeps, steps, and doublets. Results of the test determined the effect of the suspended load on both the aircraft's handling qualities and its control system's stability margins. Included were calculations of the stability characteristics of the load's pendular motion. Utilizing CIFER® software, a method for near real-time system identification was also demonstrated during the flight test program.

KEYWORDS: Helicopter, External Loads, Sling Loads, Flight Testing, CIFER, Real-time Data Analysis, Helicopter Handling Qualities, Helicopter Stability Margins, UH-60A, Black Hawk

DoD TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF COLD-FLOWTHROUGH THE TURBINE OF THE SPACE-SHUTTLE MAIN ENGINE HIGH-PRESSURE FUEL TURBOPUMP

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Computational predictions and experimental measurements were made on the Naval Postgraduate School's cold-flow turbine test rig. The test turbine was the Space-Shuttle Main Engine, high-pressure Fuel Turbopump, Alternate Development Model, designed and manufactured by Pratt & Whitney. The flow-field around the first-stage rotor end-wall region was measured using a laser-Doppler velocimetry (LDV) system. Measurements were taken at two axial locations over the rotor blade tip and at three radial locations from the end-wall casing. Three circumferential velocity profile measurements were taken downstream of the first-stage using a three-hole pressure probe. All measurements were taken at a referred rotational speed between 4781 and 4904 rpm. A computational fluid dynamics model of the combined first-stage stator and rotor was developed. Predicted velocity data from this model were extracted for comparison to the rotor exit plane probe measurements.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Computational Fluid Dynamics, Laser-Doppler Velocimetry, High-Pressure Fuel Turbopump Turbine, Space-Shuttle Main Engine

ANALYSIS AND AUTOMATION OF AN AIRCRAFT TAIL-SIZING DESIGN TOOL

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The numerical input/output behavior of a previously developed tail-sizing design tool for the High Speed Civil Transport (HSCT) aircraft is described and analyzed. HSCT, under development by NASA with industry partners, is an engineering design model of a future supersonic transport aircraft intended for the commercial passenger aviation market. Tail sizing, in the context of HSCT design, constitutes determining the maximum aft center-of-gravity that the aircraft can accept, given fixed limits on horizontal tail volume, maximum horizontal tail actuator deflection, and maximum actuator deflection rate, while remaining controllable in response to disturbances. Considerations regarding application of the tail-sizing design tool to the problem of FAR gust recovery for this longitudinally unstable aircraft, and limitations thereof are identified and discussed. An algorithm to automate the tool to produce specified outputs is developed and is implemented in MATLAB‰. The automated tool is then applied to the problem of recovery from a series of gust profiles. A set of tests is conducted to verify and validate the features of the tool. The tool is shown to be valid and accurate over a limited range of flight conditions and gust inputs. The limitations of the tool are identified and methods for extending its capabilities in the future, if necessary, are proposed. Features of previously developed graphical user interface (GUI) and data analysis software are extended, and new GUI and analysis software is developed.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

KEYWORDS: High Speed Civil Transport (HSCT), Automatic Flight Control, Linear Matrix Inequalities (LMI)

AN EXPERIMENTAL INVESTIGATION OF VORTEX BREAKDOWN IN TUBES AT HIGH REYNOLDS NUMBERS

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This thesis deals with non-cavitating swirling flows with vortex breakdown in various tubes. Phenomenological and quantitative investigations were carried out at Reynolds numbers ($Re_D = U_0 D_0/n$) as high as 300,000. It was shown that a high Re_D vortex transitions to its new state (breaks down) via a rapidly spinning spiral form, as demonstrated with 4,000 frame per second video, short exposure time (6 ns) imaging, and Digital Particle Image Velocimetry. Of the known types, the spiral emerges as the fundamental breakdown form, and the axisymmetric bubble may now be regarded as a relatively low Re_D occurrence that is bypassed at sufficiently high Re_D. Some new phenomena were observed at high Re_D: Extremely

rapid spiral rotation (over 1,000 revolutions per second), core bifurcation, and reversals in the sense of the spiral windings. Familiar features of breakdowns, such as the transition from jet-like to wake-like axial velocity profiles and the rapidly expanding vortex core, were observed in extensive time averaged velocity and turbulence profiles ascertained with Laser Doppler Velocimetry. However, a mean stagnation point and recirculation were absent in the highest Re_D flow. The core meandering and stagnation point darting in the turbulent flow field were quantified and discussed in detail.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Vortex Breakdown, Turbulence, Laser Doppler Velocimetry, Particle Image Velocimetry, Swirling Flow, Spectra

ENVIRONMETAL TESTING OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT)

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Any complex and expensive system requires testing to ensure adequate performance. Communications satellites require extensive testing for two additional reasons: they operate in an environment considerably different from that in which they were built and, after launch, they are inaccessible to routine maintenance and repair. The objectives of testing is not necessarily to duplicate the space environment but to approach it sufficiently so that any spacecraft that passes the tests will operate successfully in its designed space environment. The major features of the space environment that are difficult to simulate exactly are zero gravity, high vacuum, solar radiation, particle radiation and extreme temperatures. This document describes the environmental test program and the test results for the PANSAT program. PANSAT is the acronym for the Petite Amateur Navy Satellite, which is a small communications satellite under development by the Space Systems Academic Group at the Naval Postgraduate School. PANSAT subsystems were subjected to thermal vacuum and random vibration testing as part of the overall environmental test program. Satellite launch, as a Shuttle secondary payload via the Space Transportation System (STS) Small Self-contained Payload (SSCP) program, is planned for October 1998.

KEYWORDS: Environmental Testing, PANSAT, Spacecraft Testing

DoD KEY TECHNOLOGY AREA: Space Vehicles

INTEGRATION OF A MULTI-RATE POSITION FILTER IN THE NAVIGATION SYSTEM OF AN UNMANNED AERIAL VEHICLE (UAV) FOR PRECISE NAVIGATION IN THE LOCAL TANGENT PLANE (LTP)

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Differential Global Positioning System (DGPS) provides highly accurate position information but at update rates of one Hz which is inadequate for precise aircraft terminal maneuvering such as take-off and landing. During this period between updates an accurate position estimate in Local Tangent Plane (LTP) can be made using complementary filtering of the DGPS position and indicated airspeed. Use of indicated airspeed as the filter velocity input necessitates the transformation from body to inertial (LTP) reference frame using Euler angle information available from the Inertial Measuring Unit (IMU) or DGPS. This filter provides accurate estimates of both vehicle position and existing wind. These filter outputs of

position and wind can then be used as inputs to a trajectory controller to ultimately enable autonomous launch and recovery of an Unmanned Aerial Vehicle.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Differential Global Positioning System, Unmanned Aerial Vehicles, Inertial Measuring Unit, Euler Angles,Complementary Filter

DEVELOPMENT AND VERIFICATION OF AN AERODYNAMIC MODEL FOR THE NPS FROG UAV USING THE CMARC PANEL CODE SOFTWARE SUITE

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The CMARC panel-code is evaluated for the development of an aerodynamic model of the Naval Postgraduate School FROG Unmanned Air Vehicle (UAV). CMARC is a personal computer hosted panel-code software suite for solving inviscid, incompressible flow over complex three-dimensional bodies. A panel model of the NPS FROG UAV is developed to obtain stability derivative data at the cruise flight condition. Emphasis is placed on comparing the CMARC data to aerodynamic models obtained from classical design techniques and parameter estimation. Linearized longitudinal and lateral-directional state-equation models are used to compare the dynamic response of each data set. In addition, CMARC is used to generate static-source and angle-of-attack sensor position corrections. Position corrections are provided in look-up table and curve-fit formats. The aerodynamic model obtained with CMARC demonstrated higher fidelity dynamic longitudinal response than the classical design model. Dynamic lateral-directional response is similar to that obtained from classical design techniques. Adjustment through comparison with flight-test data is still required to optimize the CMARC model. Future studies should concentrate on improving CMARC modeling of fuselage side force through the addition of wake separation lines. Additionally, the propeller disk should be modeled in an attempt to capture the effects of increased dynamic pressure over the horizontal and vertical tail surfaces.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

KEYWORDS: Unmanned Aerial Vehicles, UAV, CMARC Panel Method, Ames Research Center, PMARC, Panel Code, Stability Derivatives, Boundary Layer Code, Aircraft Dynamic Response

A PATCHED-CONIC ANALYSIS FOR OPTIMALLY DEFLECTING EARTH-CROSSING ASTEROIDS

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The threat of collision between an asteroid or a comet and the Earth has been well documented. Mitigation of such a threat can be accomplished by destruction of the threat or by perturbing the threat object into a safe orbit. Following a summary of proposed mitigation techniques, this thesis investigates the impulse required to safely perturb a threatening Earth-Crossing Asteroid (ECA). While previously published analysis included only two-body approximations to the impact geometry, this thesis adds the effect of the Earth's gravitational field to more closely approximate reality. The results indicate that third-body effects are strongest on ECA's in a nearly circular heliocentric orbit, where the minimum required DV can be several times larger than that calculated using two-body approximations. To determine the minimum DV required for mitigation,

MATLAB,'s sequential quadratic programming (SQP) algorithm is applied to a constrained optimization problem. Third-body effects were added to a previously published two-body optimization by modifying the boundary conditions. With knowledge of the minimum DV requirements, the capability of current impulsive mitigation technology is analyzed. For asteroids of median density in co-planar orbits, a single 24 Mt nuclear explosive impulse applied earlier than 3 years before impact can effectively mitigate a threat with diameter of 6 km. The capability significantly decreases with shorter warning times.

KEYWORDS: Earth-Crossing Asteroid, Near-Earth Object, NEO Hazard Mitigation, Deflection, Asteroid, Comet, Impact Hazard, Optimum

DoD KEY TECHNOLOGY AREA: Space Vehicles

QUANTITATIVE STRUCTURAL RELIABILITY ASSURANCE THROUGH FINITE ELEMENT ANALYSIS

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Risk assessment of aging aircraft components can be achieved by operational de-rating using a safety factor subjectively selected from experience and heuristics. This investigation involves synthesizing currently available, maturing computer-aided methods into a format of objective quantitative risk assessment. The methodology is applied to quantify the effect of corrosion on P-3C main landing gear lower drag struts. This kind of synthesis is appropriate wherever structural operational risk is a concern. The P-3 has undergone many modifications since the 1950s and the lower drag struts are being scrapped due to internal surface corrosion. The corrosion process is random, resulting in pits varied spatially and in severity. These corrosion attributes are merged into a one random variable probability model. The casual relation of the corrosion to structural load is analyzed by finite elements. The structural configuration model input is provided by computer-aided drafting, verified by physical measurement. The effect of corrosion on current strut population reliability, as well as the future, is computed. The conclusion is that even under severe corrosion, compressive buckling is not an issue. All the other failure modes (compressive yielding, tensile yielding, and fracture by fatigue) can be assured by one cold temperature proof test.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Column Buckling, Corrosion, Finite Element Analysis, Probability, Reliability Assurance, Risk Assessment

SPACE-BASED RADAR AND ITS IMPACT ON AIRCRAFT SUSCEPTIBILITY

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Since the U.S. does not have the largest military force in the world, it relies on force multipliers to achieve victory. One of these force multipliers is stealth technology. However, when stealth technology is used in modern military aircraft, usually only the forward sector of the aircraft is treated and/or shaped. This forward sector treatment is effective against static, ground-based radars. However, the aircraft may be very susceptible to a look-down type of radar. This thesis addresses the viability of using space-based radar to detect stealth aircraft.

Many papers have been written on how to use space-based radar to detect and track targets. However, these papers neglect to develop the satellite constellation that would be necessary to provide continuous radar coverage. These papers also do not address how susceptible stealth aircraft would be to space-based radar. The approach of this thesis was to select a target area, in the case Iraq, and develop two satellite constellations that could provide the required radar coverage. The next step was to determine if the system would be able to detect and track stealth targets.

Based on the analysis, one satellite in geosynchronous orbit can detect stealth aircraft. However, because the satellite is 35,786 km away, the power requirements, as well as the spot size are too large to track stealth aircraft. On the other hand, a constellation of 32 satellites in low earth orbit (1000 km) can both detect and track stealth aircraft. In conclusion, if the U.S. does not start applying stealth technology to the upper surface of stealth aircraft, they will be susceptible to space-based radar.

KEYWORDS: Space, Radar, Satellite

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Sensors

HYPERSPECTRAL POLARIMETRY FOR SATELLITE REMOTE SENSING

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The study of polarization of reflected light and its angular dependence is well documented. However, most measurements have been panchromatic in nature, i.e., they were taken over a broad wavelength region. A few polarization measurements have examined polarization at several specific narrow wavelength bands. These measurements can be classified as multi-spectral. Thus, previous efforts to characterize an object using polarization have not investigated a hyperspectral polarization signature.

This thesis determines the hyperspectral polarization signature of several common materials that are significant to the military. A range of materials was examined including camouflage fabrics, military paints, rubber, plastic, taggant, and glass. It is shown that a hyperspectral polarization signature, when combined with a hyperspectral reflectance signature may enhance present capabilities to detect, classify, and identify objects of military significance. This technique appears especially promising for dark objects, shiny surfaces, synthetic fabrics, and unpainted metal.

This combined approach could be realized in a hyperspectral polarimetric imaging satellite. The utility of designing such a sensor and many key design considerations are examined. Preliminary analysis suggests sensor designs for low earth and geosynchronous orbiting spacecraft may be feasible. Sensor data rate and signal-to-noise ratio will be the limiting factors in these designs.

KEYWORDS: Hyperspectral Imagery, Polarization, Polarimetry, Satellite Remote Sensing

DoD KEY TECHNOLOGY AREA: Sensors

TURBOCHARGERS TO SMALL TURBOJET ENGINES FOR UNINHABITED AERIAL VEHICLES

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Three test programs were conducted to provide the preliminary groundwork for the design of a small turbojet engine from turbocharger rotor components for possible Uninhabited Aerial Vehicle applications. The first program involved the performance mapping of the Garrett T2 turbocharger centrifugal compressor. The second program involved the bench testing of a small turbojet engine, the Sophia J450, at 115000 RPM, and comparing the results to another small turbojet, the JPX-240, from previously documented research. The compressor radii of the two engines were identical but greater than that of the Garrett compressor. The two engines, despite their physical similarities, had different fuel requirements. The J450 used heavy fuel (fuel pump required) while the IPX used liquid propane (pressurized fuel tank required). The third program involved the performance prediction of the J450 using GASTURB cycle analysis software. The compressor map generated from the Garrett T2 test was imported into GASTURB and used to predict the J450 performance at 94000, 105000, 115000, and 123000 RPM. The performance predictions agreed reasonably well with actual J450 performance.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: Centrifugal Compressor, Turbomachinery, Uninhabited Aerial Vehicles (UAV), GASTURB, SMOOTHC, Turbojet, Turbocharger

THERMAL ANALYSIS OF PANSAT

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The thermal control system of a spacecraft is designed to maintain all spacecraft components within their specified operating temperature limits throughout all phases of a spacecraft's mission. In order to verify and aid in such a design process, a thermal analysis of the system must be conducted. A thermal model of the spacecraft is used to simulate its behavior under given thermal environments and boundary conditions so that temperature predictions can be made.

The focus of this thesis is to develop and analyze thermal models of PANSAT which describe its thermal behavior while it is in orbit and also prior to its insertion in its orbit (while it is still in the shuttle). The results of these analyses will serve to help in the thermal design and performance of PANSAT. This thesis completes the thermal model prerequisites of the STS 95 space shuttle mission hitchhiker program for PANSAT. The emphasis of this thesis is to develop a model that will allow the prediction of the temperatures of all the electrical components including the temperature sensitive electrical components of PANSAT such as batteries over a complete orbit of the satellite.

KEYWORDS: Thermal Analysis, Spacecraft Thermal Control

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Modeling and Simulation

LASER DOPPLER VELOCIMETRY IN THE SPACE-SHUTTLE MAIN ENGINE HIGH-PRESSURE FUEL TURBOPUMP

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Modifications were made to the Naval Postgraduate School cold-flow turbine test rig to enable integration of a two-component laser-doppler velocimetry (LDV) system. The test turbine was the Space-Shuttle Main Engine, High-Pressure Fuel Turbopump, Alternate-Turbopump Development Model, manufactured by Pratt & Whitney. Flow field measurements were obtained, using the LDV system, in the first-stage rotor end-wall region of the test turbine, at three axial locations and at three depths from the end wall. For each survey location, velocity ratios, absolute flow angle, turbulence intensities, and correlation coefficients were examined. The laser data exhibited distinct trends with axial position, depth from the end wall, and with circumferential position. In addition to the laser data, velocity profiles were determined at the first-stage stator inlet and rotor exit planes, using a three-hole pressure probe. Both laser and probe data were taken at referred rotational speeds in the range 4815 to 4853 rpm. Phase-locked measurements were recorded using a once-per-revolution signal from a magnetic pick-up as a trigger. TSI Phase-resolved software version 2.06 was used for laser data acquisition and reduction.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Space Vehicles

KEYWORDS: Turbine, Data Acquisition, Laser Doppler Velocimetry, Space Shuttle Main Engine, High Pressure Fuel Turbopump

IDENTIFICATION OF CRITICAL COMPONENTS AND COMBAT KILL MODES OF NOTIONAL JOINT STRIKE FIGHTER AIRCRAFT DESIGNS

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The U.S. Navy is a partner with the U.S. Air Force in the new Joint Strike (JSF) program. In the JSF program, two conventional fixed wing versions, one land-based and one carrier-based, and a Short Take-Off and Vertical Landing (STOVL) version are being developed. Of interest to the Navy is the difference in the vulnerability of the carrier-based version and the STOVL version. An aircraft's vulnerability is the inability of the aircraft to withstand the damage caused by hits by enemy weapons. The first step in a vulnerability study of an aircraft is the identification of the critical components on the aircraft and the ways these components can be killed. The critical components on an aircraft are those components whose kill either individually or jointly, result in an aircraft kill. This thesis examines a notional design of a typical fighter/attack CV aircraft and two notional designs of a STOVL aircraft and identifies the critical components and their kill modes for each design. Comparing the set of critical components for each of the three designs reveals the potential differences in the vulnerability of the designs.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Other (Aircraft Survivability)

KEYWORDS: Vulnerability, Survivability, Kill Modes, Vulnerability Reduction, Vulnerability Reduction Technology, Joint Strike Fighter

INVESTIGATION OF THE EFFECTS OF VARIOUS NOZZLE CONFIGURATIONS ON SOLID-ROCKET-PLUME INTENSITIES AND SPECTRA

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Subscale rocket motors were fired and the plume signatures were measured in the infrared (IR) and ultraviolet (UV) wavelength regimes. Band-averaged and spectral data were recorded using an SR5000 IR spectrometer (2.5 to 5.5 μm range), an Agema 870 IR thermal imaging camera (3.5 to 5 μm range), and the Naval Postgraduate School UltraViolet Imaging Spectrometer (NUVIS) (325 to 405 nm range). Rocket motor nozzle geometries were varied to determine the effects of over- and under-expansion on the plume band-averaged intensity and spectra. Four different solid rocket propellants were used: X-61, NWC-278, AC-13, and AC-14. The enhanced mixing nozzle, used in conjunction with the X-61 propellant, reduced the plume signature in both the UV and IR regions. The total UV intensity of the plume decreased by about 30% and varied as function of distance from the rocket nozzle. The intensity difference was more pronounced at shorter wavelengths (325-385 nm) than at longer wavelengths (385-405 nm). The difference in power was not as large in the IR region (about 7%). Intensity results from the analysis of the NWC-278, AC-13, and AC-14 runs were inconclusive. Data from the NUVIS and Agema instruments were used to create spectra for each of the propellants. While distinct features were discernible in the UV spectra, they could not be identified with a specific atom or molecule. The IR spectra were characterized by several molecular bands attributed to a combination of CO_2, H_2O, and HCl.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Sensors

KEYWORDS: Solid Propellant Rocket, Rocket Plume Spectra, Rocket Plume Intensity, Plume Signature

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