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SUMMARY
OF
RESEARCH
1997

Department of Aeronautics and Astronautics

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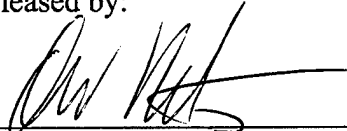This report was prepared for the Naval Postgraduate School, Monterey, CA.

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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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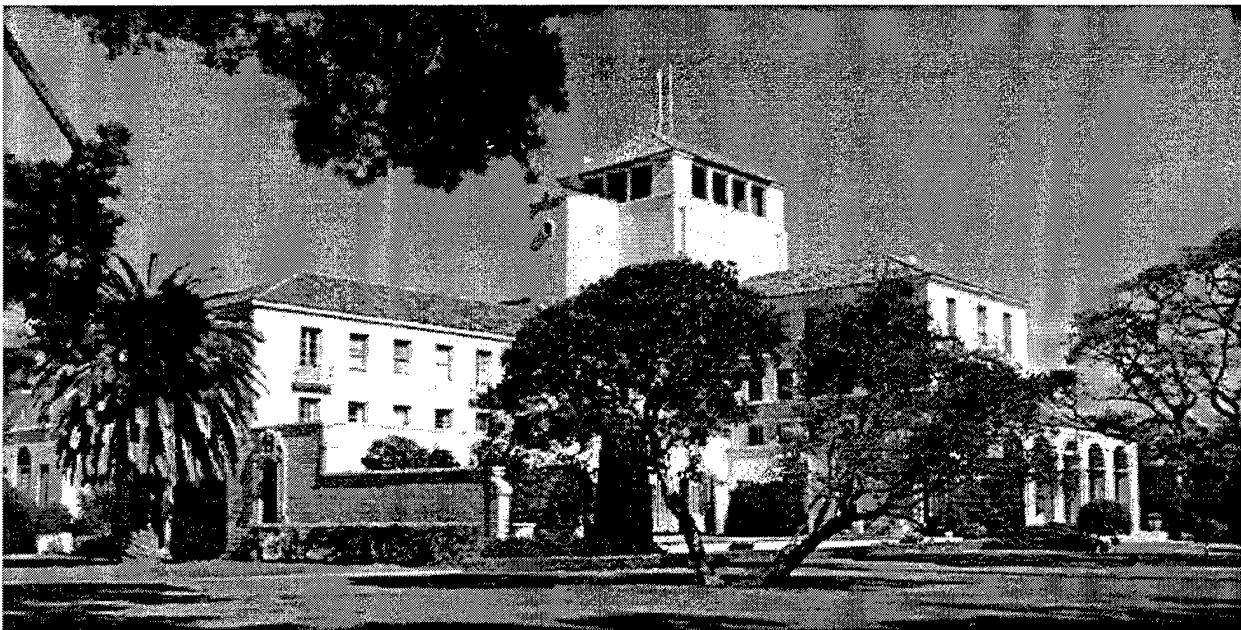71

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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

CONTENTS

PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the School's eleven academic departments, four 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 1997. 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) 656-2098 (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 1997, the overall level of research effort at NPS was 151 faculty workyears and exceeded $32 million. The Department of Aeronautics and Astronautics' effort was 9.46 faculty workyears and exceeded $1.8 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 FY97, over 87% percent of the NPS research program was externally supported. In the Department of Aeronautics and Astronautics 93% was externally supported.

The department's research sponsorship in FY97 is provided in Figure 1.
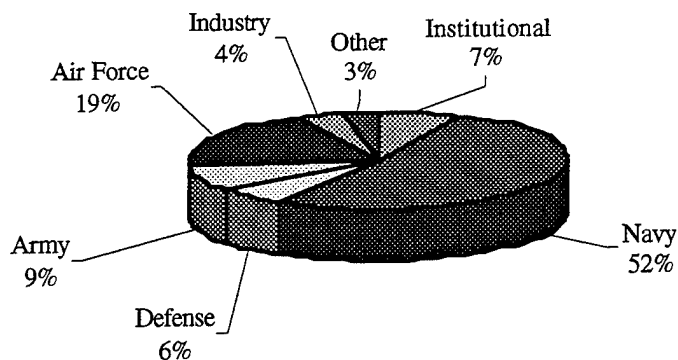
Figure 1. FY97 Sponsor Profile of the Department of Aeronautics and Astronautics

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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January 1999

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DEPARTMENT SUMMARY

Research in the Department of Aeronautics and Astronautics is focused on topics of critical importance to military users. Typically, research activity resides in the Department's five technical committees, namely, Aerodynamics, Structures, Propulsion, Flight Mechanics and Controls, and System Design. Both aircraft and spacecraft are involved. Present Departmental endeavors are described below.

Aerodynamics

HIGH-ANGLE-OF-ATTACK MISSILE AERODYNAMICS: In support of the Missile Division of the Naval Air Warfare Center, Professors Platzer and Tuncer developed a three-dimensional Navier-Stokes solution for an advanced blended airframe missile configuration.

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.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/UNIVERSITY SPACE RESEARCH ASSOCIATION (NASA/USRA) ADVANCED DESIGN PROGRAM: The primary focus of the NASA/USRA Advanced Design Program for aeronautical systems under Professor Newberry is the innovative design of deck-launched waverider configured aircraft. However, conventional aircraft, helicopter, and missile system designs were also completed. Research efforts involving interplanetary waverider-configured spacecraft using aero-gravity-assist and the LoFlyte (Mach = 5) configuration supported design class products.

TOPICS RELATED TO ROTORCRAFT AND VERTICAL FLIGHT: The rotary wing program led by Professor Wood has five 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; (2) research in ground and air resonance of soft-inplane hingeless rotor systems to eliminate the instability without requiring heavy and costly blade dampers; (3) technical support of McDonnell Douglas and SatCon Technology for application of higher harmonic control for improved rotor performance; (4) advanced engineering upgrades for rotorcraft in Special Operations Warfare; and (5) NOTAR=AE research using a 1/4 scale remotely piloted helicopter, the NPS Hummingbird I. In addition, NPS received two full scale OH-6A flightworthy helicopters from the Army National Guard in October 1995. One of the helicopters will be removed from flying status and serve as a baseline model for helicopter structural dynamics research. In this area, Professor Wood, Professor Gordis (Department of Mechanical Engineering), and Professor Danielson (Department of Mathematics) are being funded by the Army RAH-66 Comanche office to provide a backup NASTRAN dynamic model of the Comanche to be used for exploring potential vibration problem areas.

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 of 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.

Structures

P-3 ORION LIFE EXTENSION PROGRAM: Professor Wu is developing a life extension program. The strategy is to develop fatigue data for the aluminum alloy used in P-3 structures. Data collection is underway. Studying constant amplitude fatigue and spectrum fatigue will make up the second phase of testing. Results of these testing phases will be compared such that a methodology for spectrum life prediction will be available. Verifications will be performed on new samples subjected to a load history entirely in the laboratory. This will allow a lead time to forewarn any refurbishment in the fleet.

Propulsion

ADVANCED AIRCRAFT ENGINE AND MISSILE PROPULSION STUDIES: Professor Shreeve is working on a transonic fan design and validation. Experimentally, the goal is to install a new stage in the NPS transonic compressor test rig and evaluated it. Professors Shreeve and Hobson are working on an experimental validation of off-design compressor stall prediction for controlled-diffusion (CD) blading; they also are working on UAV propulsion technology, examining the potential performance of alternate engines for application in Predator and Global Hawk class UAVs. Professor Hobson is working on non-intrusive, laser Doppler velocimetry (LVD) measurements of turbine tip-leakage flows with the intent to transfer the measurement technique to operational turbines.

PLUME AFTERBURNING SUPPRESSION AND PULSE-DETONATION ENGINES: Professor Netzer and Dr. Brophy (National Research Council Post-doctoral Research Associate) are working to determine the effects of solid propellant rocket motor exhaust particulates and nozzle geometry on the suppression of plume afterburning and to obtain effective nozzle geometries which do not adversely affect thrust. 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

ADVANCED AVIONICS TECHNOLOGY: Over the past several years under the Naval Air Systems Command (NAVAIR) sponsorship, Professor Kaminer has embarked on the development and evaluation of GPS/INS integration systems. In particular, progress has been made in the development of the uniform framework for the INS/GPS integration using Kalman Filtering. The work is ongoing and strives to unify various approaches to the development of INS systems and their integration with GPS using Kalman Filtering.

CLOSED-LOOP PITCH CONTROL EFFECTOR SIZING: In this project Professor Kaminer developed a new optimization tool for obtaining the closed loop tail sizing criteria for 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.

PASSIVE SENSOR-BASED CONTROL OF NONLINEAR AUTONOMOUS SYSTEMS: 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. Preliminary results were obtained by Professors Kaminer and Duren 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.

FY97 ENGINEERING AND TECHNICAL SUPPORT FOR UNMANNED AIR VEHICLE-JOINT PROGRAM OFFICE (UAV-JPO) PHASE II CONTRACT EFFORT: Under the UAV-JPO, Professor Kaminer has provided 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." The project was kicked off at NPS in November 1997.

UNMANNED AIR VEHICLE (UAV) TECHNOLOGY: In support of the DoD's role in the development of UAVs, Professor Howard 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 and flight mechanics. A program supporting technology development for future UAVs was begun in 1997. Professors Howard, Shreeve, Kaminer, and Duren conducted studies of recuperative engine cycles of bus architecture for a common UAV architecture, and improved airframe aerodynamics. For the aerodynamic study, a panel method computer program was used to model the Predator

Unmanned Aerial vehicle at its trim flight condition. Basic stability-and-control characteristics were identified for future modeling.

INTEGRATED GUIDANCE AND CONTROL FOR AIR VEHICLES: This work by Professor Kaminer addresses the problem of integrated design of guidance and control systems for autonomous vehicles (AVs). In fact, a new methodology for integrated design of guidance and control for autonomous vehicles has been developed. The methodology proposed leads to an efficient procedure for the design of controllers for AVs to accurately track reference trajectories defined in an inertial reference frame. This methodology was applied to the design of a tracking controller for the Unmanned Air Vehicle Frog at the NPS UAV Lab.

DEVELOPMENT OF TAIL SIZING CRITERIA FOR A SUPERSONIC TRANSPORT: Professor Kaminer is also working on the development of closed loop criteria for tail sizing criteria of commercial supersonic aircraft using newly developed integrated plant/controller design methodology. The key idea is to rewrite the tail sizing and feedback requirements as Linear Matrix Inequalities. In particular, the effects of feedback specifications, such as MIL STD 1797 Level I and II flying qualities requirements, and of actuator amplitude and rate constraints on the maximum allowable cg travel for a given set of tail sizes were considered. A static state feedback controller was designed as a part of the tail sizing process. This technique is being currently integrated into a tail-sizing tool to be used by McDonnell Douglas.

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. 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. Smart Structures Laboratory, consisting of vibration isolation platform, space truss, proof mass actuator, fiber optic, shape memory ally, and piezoelectric actuators is under development.

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 such as those encountered in, but not limited to: (1) synergetic maneuvers for military space planes; (2) stability and control of single and dual-spin spacecraft; and (3) near-Earth-object interception. The research has lead to the development of a refined Energy-Sink theory that has resolved a long-standing debate on the stability of dual-spin spacecraft. In addition, Professor Ross has developed two space maneuvers: one called aerobang that achieves rapid, minimum-fuel orbital plane-changes for a space plane, and another called a singular orbit transfer which achieves suboptimal performance by continuos thrusting. Recent advances have utilized singular optimal control theory to endo-atmospheric space flight, and periodic optimal control theory to low-Earth-orbit maintenance. The application of periodic optimal control theory has provided minimum-fuel solutions to the stationkeeping problem. Currently, Professor Ross and his associates are working on developing an advanced guidance algorithm for the orbit maintenance of low-Earth-orbiting spacecraft. Research is also continuing on a space mission design project for minimizing energy requirements for deflecting Earth-crossing asteroids.

System Design

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.

In spacecraft design, under Professor Agrawal's supervision, a military communications satellite which would provide enhanced communications capacity has been considered. Also, four spacecraft laboratories have been developed, namely, FLEETSATCOM, spacecraft testing, spacecraft dynamics and control, and spacecraft design.

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, and 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.

JOINT STAND-OFF WEAPON UNITARY CAPTIVE AIR TRAINING MISSILE (JSOW-CATM) CONCEPTUAL DESIGN: On this project Professor Kaminer was responsible for the issues related to the JSOW CATM avionics system and for the development of cockpit steering commands·requirements for the carriage aircraft. The work accomplished includes development of the preliminary functional requirements for JSOW CATM avionics as well as development of JSOW 6DOF nonlinear simulation and guidance and control system for a typical JSOW profile.

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): (1) by developing the 11 week graduate level course AA 3251, "Aircraft Combat Survivability," in 1978 and teaching it twice a year since then; (2) by 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; (3) by conducting over 15 short (one week) and several shorter (three day) courses in survivability since 1978, (4) by developing the NPS/NAVAIR Survivability and Lethality Assessment Center (SLAC); and (5) by conducting a variety of studies on the survivability of U.S. aircraft. In CY 1997, the majority of efforts were devoted to: (1) the transmission of AA 3251 by Distance Learning to the NAWC-AD and NAWC-WD during the winter quarter; (2) the continued development of the second edition of the AIAA survivability textbook; and (3) six Master's theses on the survivability of aircraft. Two of the theses used MOSAIC to study the effects of flare dispensing on the survivability of the SH-60A helicopter, and two of the theses examined the effects of on-board ECM on the survivability of aircraft against proximity-fuzed SAMs. One thesis developed a robust methodology for determining the synergistic effects of combining radar signature reduction with on-board ECM, and one thesis presented the current technology for reducing the vulnerability of modern fixed-wing tactical aircraft.

AIRCREW-CENTERED SYSTEM DESIGN (ACSD): The primary focus of the Aircrew-Centered System Design project has been the preliminary definition of attributes and characteristics of ACSD. A working group within AIAA has been established to address ACSD issues and two related sessions were held at the Ist World Congress in Los Angeles. Additional sessions are planned.

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

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

SUMMARY: The major efforts were in the development of the Smart Structures Laboratory and the validation of MRJ piezoelectric finite element model. The Ultra Quiet Vibration Isolation Platform, developed by CSA Engineering, is operational. System identification of the platform was completed. Coupling between smart struts was significant. NPS space truss was assembled and modal testing of the truss was also completed. Proof mass actuators and piezoelectric struts were procured. Active vibration control of a flexible beam using Modular Control Patch was performed. The investigation included single-mode and multi-mode vibration suppression and Positive Position Feedback control robustness. An experiment using a beam with shape memory alloy wires, fabricated by Lockheed Martin, was developed to demonstrate the active shape control. A Fiber Bragg Grating Optic sensor, manufactured by Bragg Photonics, was tested for the applications to vibration control and shape control. MRJ piezoelectric finite element model was implemented with the user-modifiable NASTRAN V.69. TRW Composite Smart Strut was used as a test article to validate the model. Experimentally, free displacement and blocked force were measured and compared with the analytical predictions from the model. Free displacement measurements were in good agreement with the analytical predictions. However, there was a significant difference between the blocked force measurements and the analytical predictions. Part of the difference is attributed to the flexibility of the test fixture, resulting in not providing ideal boundary condition for the blocked force measurements.

PUBLICATIONS:

Agrawal B. and Treanor, K., "Optimal Placement of Piezoceramic Actuators for Shape Control of a Beam," IAF-97-I.602, *Proceedings of the 48th International Astronautical Congress*, Turin, Italy, 6-10 October 1997.

Agrawal B. and Elshafei, M.A., "Shape Control of Composite Material Plates Using Piezoelectric Actuators," Vol. 3241, *Proceedings of Far East and Pacific Rim Symposium on Smart Materials, Structures, and MEMS*, Adelaide, Australia, 10-13 December 1997.

Meyer, J., Harrington, W., Agrawal, B., and Song. G., "Vibration Suppression of a Spacecraft Flexible Appendage Using Smart Materials," to appear in the *Journal of Smart Materials and Structures*, February 1998.

Agrawal, B. and Treanor, K., "Shape Control of a Beam Using Piezoelectric Actuators," to be published in the *Journal of Smart Materials and Structures*, special issue on Smart Structures for Space, September 1998.

Agrawal, B., Elshafei, M., and Song, G., "Adaptive Antenna Shape Control," accepted for publication in *Acta Astronautica Journal*.

THESES DIRECTED:

Andberg, B.K., "Modal Testing and Analysis of the NPS Space Truss," Master's Thesis, Naval Postgraduate School, September 1997.

Beavers, G.D., "System Identification of an Ultra-Quiet Vibration Isolation Platform," Master's Thesis, Naval Postgraduate School, June 1997.

Schmidt, S.P., "Active Vibration Control of Flexible Structures Using the Modular Control Patch," Engineer's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Smart Materials, Adaptive Structures, Vibration Isolation

SPACECRAFT SYSTEMS
B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: FLTSATCOM Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, significant progress has been made in several areas. In the Spacecraft Attitude Dynamics and Control Laboratory, implementation of the dSPACE Real Time Control System on the NPS Flexible Spacecraft Simulator (FSS) has been successfully completed and the FSS has been made operational. The Computational Spacecraft Design Laboratory was upgraded both in hardware and software, including Pro/ENGINEER, Pro/Mechanica, MSC/Nastran and COSMOS/M Engineer. Three spacecraft design projects were completed. The mission for the first project was to investigate three asteroids in the main belts. The project was done under AIAA/Lockheed Martin Graduate Competition and won second position. The second project was on a medium earth orbit UHF satellite constellation. This project was sponsored by the Naval Space Command and was in direct support of DoD's effort to analyze alternative solutions for the replacement of the UHF Follow-on (UFO) constellation. The third project was EHF satellite with a classified payload.

PUBLICATIONS:

Agrawal, B., Song, G., and Buck, N., "Slew Maneuvers of Flexible Spacecraft Using Input Shaping and Pulse-Width Pulse-Frequency Modulated Thrusters," IAF-97-A.2.09, *Proceedings of the 48th International Astronautical Congress,* Turin, Italy, 6-10 October 1997.

Agrawal, B., McClelland, R., and Song, G., "Attitude Control of Flexible Spacecraft Using Pulse-Width Frequency Modulated Thrusters," accepted for publication in *Space Technology Journal.*

Song, G., Buck, N., and Agrawal, B., "Spacecraft Vibration Using Pulse-Width Pulse Frequency Modulated Input Shaper," *Proceedings of AIAA Guidance, Navigation, and Control Conference,* New Orleans, LA, 11-13 August 1997.

Yale, G. and Agrawal, B., "A Lyapunov Controller for Cooperative Space Manipulators," accepted for publication in AIAA *Journal of Guidance, Control, and Dynamics.*

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Spacecraft Design, Spacecraft Attitude Control, Space Manipulator

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS
B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute of Joint Warfare Analysis-Naval Postgraduate School

OBJECTIVE: The goal of the project was to aid the military communications planners in the challenging task of providing enhanced communications capacity in the environment of shrinking budgets.

SUMMARY: During the reporting period, the NPS research team, including four students, has worked very closely with DoD Mobile User Study Joint Integrated Teams. The objectives of these Joint Integrated Teams are to define the requirements for Mobile Users, system engineering, and acquisition strategy for the future DoD UHF satellite system. The NPS team had taken an important role on two major tasks. First task was the primary responsibility for the preliminary design of MEO UHF Spacecraft system. The second task was the payload design for GEO UHF Spacecraft System. Both tasks have been completed.

THESES DIRECTED:

Homan, N.M., "A Military UHF Communications Satellite Design for the User on the Move," Master's Thesis, Naval Postgraduate School, December 1997.

Stone, C.R., "Integration of Commercial Mobile Satellite Services into Naval Communications," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Communications Satellites, Mobile Communications, Satellite Architecture

NPS AIRCRAFT SURVIVABILITY SUPPORT
Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS)
and Naval Postgraduate School

OBJECTIVE: The objective of this effort is to continue the technical and educational support provided to the JTCG/AS for the past 24 years by developing educational material, presenting short courses, and conducting research and performing analyses in aircraft combat survivability. The accomplishments during CY97 are given below.

SUMMARY: (1) Educational Materials: Professor Ball continued the development of the second edition of his AIAA textbook, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," published by the American Institute of Aeronautics and Astronautics in 1985, during CY97. Progress in CY97 consisted of improved rough drafts of the front material and Chapter 1, "An Introduction to the Aircraft Combat Survivability Discipline." The second rough draft of Chapter 3, "The Missions, the Threats, and the Treat Effects," was developed. A new Appendix entitled, "Probability Theory and Its Application to Survivability Assessment," was started, and a very large set of questions for each chapter and appendix of the textbook were developed. (2) Distance Learning: The course, AA 3251, "Aircraft Combat Survivability" was presented to the Naval Air Warfare Center, Weapons Division, China Lake, and the Naval Air Warfare Center, Aircraft Division, Pax River, during the Winter Quarter, 1996/97 as a Distance Learning course. (3) Research Projects: Several research projects were finished during CY97. These included: (a) a study of the vulnerability reduction technology used on modern tactical fixed-wing aircraft, with particular emphasis of the Joint Strike Fighter (JSF); (b) a study of the effect of on-board electronic countermeasure (ECM) equipment on missile miss distance and aircraft survivability; (c) the development of a generic endgame model that can be used to determine the increase in survivability due to an increase in missile miss distance; and (d) the development of a robust model to determine the effectiveness of signature reduction in conjunction with electronic attack in the form of on-board ECM.

CONFERENCE PRESENTATION:

Ball, Robert E., "Service Response to Live Fire Test and Evaluation Requirements," ADPA Live Fire Test and Evaluation Conference-10 Years and Counting, Lawrence Livermore National Laboratory, Livermore, CA, 13-17 January 1997.

THESES DIRECTED:

Adams, Christopher A., "Vulnerability Reduction of Modern Tactical Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

Barrie, Stephen K., "A Study of the Effects of On-Board Electronic Countermeasures (ECM) on the Combat Survivability of Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

Brennan, Sean P., "Educational Materials for the Implementation of Survivability in Combat Aircraft Design," Master's Thesis, Naval Postgraduate School, March 1997.

Flachsbart, Brian M., "A Robust Methodology to Evaluate Aircraft Survivability Enhancement Due to Combined Signature Reduction and On-Board Electronic Attack," Master's Thesis, Naval Postgraduate School, June 1997.

Rippe, Carlos M., "A Study of the Endgame Between a Proximity-Fuzed High Explosive Warhead on a Guided Missile and an Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

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

KEYWORDS: Aircraft, Survivability, Weapons, Lethality

NPS/NAVAIR SURVIVABILITY AND LETHALITY ASSESSMENT CENTER
Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVES: The objectives of this research project are: (1) to develop and improve the Survivability and Lethality Assessment Center (SLAC) within the NPS Wargaming Analysis & Research Laboratory (WARLAB), and (2) to use the SLAC to conduct survivability and lethality studies. The computer programs in the center are available to the students and faculty at NPS for research in specific survivability and lethality topics on land, sea, air, and space targets as well as research on the programs themselves.

SUMMARY: The major accomplishment in CY97 was the use of the SLAC to determine the type of air target signature modeling and target tracking that is used in the Enhanced Surface-to-Air Missile (ESAM) program.

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

KEYWORDS: Aircraft, Air Defense, Survivability, Lethality, Missiles, Guns

SPACE PROPULSION AND THERMAL CONTROL
O. Biblarz, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: This effort represents activity in applications of importance to space. The arc-jet is used for electric propulsion and PANSAT is an NPS satellite which is undergoing thermal analysis.

SUMMARY: The anode of the arc jet is usually the first component to fail in such thrustors. The anode region is defined as a highly nonequilibrium region which is composed of a nonneutral region or sheath and of an ambipolar region. A

continuum description of the anode region for steady state, isothermal conditions with two- and three-body recombination has been sought in conjunction with Professor C. L. Frenzen of the Department of Mathematics. One-dimensional description which was looked at has so far eluded any satisfactory solution. With respect to PANSAT, a thermal model of the spacecraft has been used to simulate its behavior under given thermal environments and boundary conditions so that temperature predictions can be made. This effort was undertaken in conjunction with Professor Ashok Gopinath of the Department of Mechanical Engineering and Mr. Dan Sakoda of the Space Systems Academic Group.

PUBLICATION:

Biblarz, O. and Bell, W.J., "Thermionic Arc Breakdown in Small Discharge Gaps: Model and Applications," to appear in *1998 IEEE Transactions on Industry Applications*, March/April 1998.

THESES DIRECTED:

Horner, B., "Anode Fall as Relevant to Plasma Thrusters," Engineer's Thesis, Naval Postgraduate School, June 1997.

Smith, T.R., "Thermal Analysis of PANSAT," Master's Thesis, Naval Postgraduate School, December 1997.

DoD KEY TECHNOLOGY AREA: Other (Propulsion and Energy Conversion)

KEYWORDS: Magnetoplasma-Dynamic (MPD), Electric Propulsion, Thermal Analysis, Spacecraft Thermal Control

A FUNDAMENTAL STUDY OF COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF FIXED AND ADAPTIVE AIRFOILS
M.S. Chandrasekhara, Research Professor
M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To understand the fundamental fluid flow physics of compressible unsteady flow separation and dynamic stall onset over fixed and variable geometry airfoils, leading to innovative flow control methods.

SUMMARY: The research resulted in the identification of some of the key mechanisms of compressible dynamic stall onset. These are laminar separation bubble bursting, shock-induced flow separation, and interaction of the bubble with the local supersonic flow. Primarily, all are attributable to the development of strong adverse pressure gradient over the airfoil, which needs to be mitigated for achieving flow control. This led to the concept of the Dynamically Deforming Leading Edge (DDLE) airfoil, whose leading edge curvature can be changed by as much as 320% in real-time while the airfoil oscillates, providing an airfoil that can adapt to each flow condition instantaneously. Successful preliminary tests were conducted to establish the proof-of-concept.

PUBLICATION:

Chandrasekhara, M.S., "A Fundamental Study of Compressibility Effects on Dynamic Stall of Fixed and Adaptive Airfoils," Final Report submitted to Army Research Office, September 1997.

CONFERENCE PRESENTATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Control of Flow Separation Using Adaptive Airfoils," AIAA 36th Aerospace Sciences Meeting, Reno, NV, January 1997.

Chandrasekhara, M.S., Carr, L.W., and Wilder, M.C., "Development of High Speed Imaging and Analysis Techniques for Compressible Dynamic Stall," AGARD 81st Meeting and Symposium, Seattle, WA, September 1997.

THESIS DIRECTED:

Van Dyken, R.D., "Experimental and Computational Analysis of Separation Bubbles for Compressible Steady and Oscillatory Flows Over a NACA 0012 Airfoil at M∞ = 0.3 and Re = 540,000," Doctor of Philosophy Dissertation, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Helicopter Blade Stall, Unsteady Aerodynamics, Shock/Boundary Layer Interactions

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: 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: This research project initiated in April 1997 is aimed at establishing the fluid mechanics of the flow over a dynamically deforming leading edge (DDLE) airfoil under high loading conditions as it operates near stall. Preliminary studies have shown that it is possible to reattach even grossly separated flow by changing the DDLE airfoil leading edge curvature and to re-establish the vorticity field for producing lift at angles well above the maximum operating angles of attack of a fixed geometry airfoil. In view of its relevance to helicopter retreating blade stall alleviation, an oscillating airfoil will be dynamically deformed carefully as it pitches up.

PUBLICATION:

Chandrasekhara, M.S., Carr, L.W., Wilder, M.C., Paulson, G.N., and Sticht, C.D., "Design and Development of a Dynamically Deforming Leading Edge Airfoil for Unsteady Flow Control," *IEEE Publication 97CH36121*, September 1997.

CONFERENCE PRESENTATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Unsteady Stall Control Using Dynamically Deforming Airfoils," AIAA 15th Applied Aerodynamics Conference, Atlanta, GA, June 1997.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Fluid Mechanics of Wing Adaptation for Separation Control," 7th Asian Congress of Fluid Mechanics, Madras, India, December 1997.

Geissler, W., Chandrasekhara, M.S., Platzer, M.F., and Carr, L.W., "The Effect of Transition Modeling on the Prediction of Deep Dynamic Stall," 7th Asian Congress of Fluid Mechanics, Madras, India, December 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

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: Work has been performed to develop a small autonomous rotary-wing vehicle. The vehicle and a subset of the eventual avionics suite have been purchased and integration of the avionics suite has begun. The vehicle will carry a sensor suite including inertial, GPS, vision and ultrasonic sensors. Data from these sensors is transmitted to a ground-based control station where the processing and autonomous control functions reside. Control signals are transmitted from the ground station to the air vehicle. The vehicle will support research into autonomous control, vision-based navigation, and the use of passive sensors to land VTOL aircraft on ships.

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

KEYWORDS: Autonomous Vehicles, Unmanned Air Vehicles (UAV), Avionics, Robotics

TURBINE TIP-LEAKAGE FLOWS

G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsors: Naval Air Warfare Center-Aircraft Division and Naval Postgraduate School

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements, in the endwall region of a turbine. The objective of the project is to transfer the measurement technique developed on an annular turbine cascade to an operational turbine test article.

SUMMARY: 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 & Whitney for NASA.

The project during 1996-1997 consisted of the upgrade to the water cooling system of the HPFTP so that longer run times could be achieved. This entailed the commissioning of the new closed loop water cooling system on the dynamometer. The next task was to perform LDV measurements in the rotor of the turbine for the HPFTP. The first task was successfully completed and the turbine has run continuously for extended periods of time with no recirculating water problems. The turbine was also moved closer to the sidewall of the test cell to accommodate the standard optics LDV system. The move entailed lengthening the inlet piping to the turbine. A picture of the new arrangement can be viewed at the Turbopropulsion Laboratory homepage (http://www.aa.nps.navy. mil/~garth/HPFTP3.gif). The second task was initiated with the successful installation of the LDV in the test cell. Continuous LDV measurements have been over the turbine rotor in its tip region.

CONFERENCE PRESENTATION:

Hobson, G. V., Donovan, W. H., and Spitz, J. D., "LDV Measurements in the Endwall Region of an Annular Turbine Cascade Through an Aerodynamic Window," AIAA 97-3012, 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Seattle, WA, July 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

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

FAN AND COMPRESSOR STALL

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

OBJECTIVE: This is a continuing project to validate off-design and stall prediction for controlled-diffusion (CD) blading experimentally, and thereby enable the development of higher blade-loading designs.

SUMMARY: Two and three component laser-Doppler velocimetry, pressure probe, laser sheet and surface-flow visualization techniques have been applied to obtain measurements of the flow through first and second generation CD blading in a 60x10 inch rectilinear cascade wind tunnel. Second generation blading, having approximately half the solidity of the first-generation design, when operated at high incidence angles, gave rise to laminar separation bubbles at lower Reynolds numbers and trailing-edge separation at higher Reynolds numbers. Significant three-dimensional effects were found that required attention experimentally to ensure span-wise symmetry. Analytically, a three-dimensional CFD study was initiated to assess predictive capability at higher Reynolds numbers.

PUBLICATIONS:

Hobson, G.V., Chapter 17; "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Controlled-Diffusion Compressor Cascade at Stall," *Advances in Turbomachinery Fluid Dynamics and Heat Transfer,* Marcel Dekker, 1996.

Hobson, G.V. and Dober, D.M., "Three-Dimensional Fiber-Optics LDV Measurements in the Endwall Region of a Linear Cascade of Controlled-Diffusion Stator Blades," *International Journal of Turbo and Jet Engines*, Vol.14, No.1, 1997.

CONFERENCE PRESENTATIONS:

Hobson, G.V., Schnorenberg, D.G. and Grove, D.V., "Effect of Reynolds Number on Laminar Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," accepted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine & Aeroengine Congress, Users' Symposium, and Exposition, Stockholm, Sweden, 2-5 June 1998.

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 Paper 96-GT-484, 41 ASME International Gas Turbine and Aeroengine Congress, Exposition and Users Symposium, Birmingham, UK, 10-13 June 1996, (accepted for publication in the *Journal of Turbomachinery*).

THESES DIRECTED:

Carson, S.W., "The Computational Fluid Dynamic Description of Stall in a Cascade of Controlled-Diffusion Compressor Blades," Master's Thesis, Naval Postgraduate School, September 1997.

Grove, D.V., "Experimental and Numerical Investigation of Second-Generation Controlled-Diffusion Compressor Blades in Cascade," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Controlled-Diffusion Blading, LDV Measurements, Compressor Cascade Stall

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 consisted of conducting a final tail design, designing and wind-tunnel testing a wind vane for good response at the high altitude, analyzing the pressure lags in a potential air-data boom, and developing a 1/3-scale radio-controlled sailplane and performing flight simulation of it during the pullout maneuver to model the Apex launch. This is a continuing project.

OTHER: A technical report summarizing the wind-tunnel tests and pressure-lag analysis is in progress.

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

KEYWORDS: Airdata, Aerodynamics, Flight Mechanics

UNMANNED AIR VEHICLE TECHNOLOGY DEVELOPMENT
Richard M. Howard, Associate Professor
R.P. Shreeve, Professor
G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Defense Airborne Reconnaissance Office

OBJECTIVE: To support future unmanned air vehicle (UAV) development with studies of the potential performance of alternate engines for application in Predator and Global Hawk classes of UAVs, of bus architectures for a common UAV architecture, and of improved airframe aerodynamics through modeling and simulation.

SUMMARY: A panel computer program was used to model the Predator Unmanned Aerial Vehicle at its trim flight condition. An analysis was begun to study how future external modifications might impact range and endurance. In avionics, a proof-of-concept cell-phone architecture was developed as a commercial-off-the-shelf (COTS) approach to a common bus architecture for future UAVs. In propulsion, reconnaissance missions require relatively low power and/or high altitudes. Current reciprocating engines do not have the reliability of gas turbines and can not use heavy fuel. Analytical studies examined the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An experimental study sought to establish performance characteristics of small gas turbines operating with jet propulsion fuel. This is a continuing program.

OTHER: A report was provided to the Defense Airborne Reconnaissance Office by Dr. Jim Hauser under contract to NPS for the avionics study.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles, Computing and Software, Sensors, Modeling and Simulation

KEYWORDS: UAV, Avionics Architecture, Aerodynamics, UAV Propulsion, Small Gas Turbine Engines, Recuperated Turbofans

ADVANCED AVIONICS TECHNOLOGY
I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform research and development in advanced avionics technology topics relevant to the Naval Air Systems Command (NAVAIR) Maritime Avionics Subsystems and Technology (MAST) program.

SUMMARY: Over the past several years, under NAVAIR sponsorship, NPS has embarked on the development and evaluation of GPS/INS integration systems. In particular, progress has been made in the development of the uniform framework for the INS/GPS integration using Kalman Filtering. The work is ongoing and strives to unify various approaches to the development of INS systems and their integration with GPS using Kalman Filtering.

PUBLICATIONS:

Kaminer, I., Pascoal, A.M., Hallberg, E., and Silvestre, C., "Trajectory Tracking for Autonomous Vehicles: An Integrated Approach to Guidance and Control," *Proceedings of 1997 AIAA Conference on Guidance, Navigation and Control,* pp. 1133-1138, New Orleans, LA, 1997.

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

THESES DIRECTED:

Allen, P., "Incorporation of a Differential GPS in the Control of an Unmanned Aerial Vehicle for Precise Navigation in the Local Tangent Plane," Master's Thesis, Naval Postgraduate School, March 1997.

Hallberg, E., "On Integrated Plant, Control and Guidance Design," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

Papageorgiou, E.C., "Development of a Dynamic Model for a UAV," Master's Thesis, Naval Postgraduate School, March 1997.

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

KEYWORDS: GPS, Inertial Navigation, Kalman Filtering, Rapid Prototyping

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE
AIR TRAINING MISSILE (CATM) CONCEPTUAL DESIGN
I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform conceptual design studies on a captive air training missile for the JSOW Unitary Missile and to explore the possibility of extending its applicability to other missiles.

SUMMARY: This project was responsible for the issues related to the JSOW CATM avionics system and for the development of cockpit steering commands requirements for the carriage aircraft. The work accomplished includes development of the preliminary functional requirements for JSOW CATM avionics as well as development of JSOW 6DOF nonlinear simulation and guidance and control system for a typical JSOW profile.

THESIS DIRECTED:

Sardana, V., "Incorporation of Joint Standoff Weapon Steering Commands with Carriage Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Stand-off Weapons, Avionics)

KEYWORDS: JSOW CATM, Avionics, Guidance and Control

CLOSED-LOOP PITCH CONTROL EFFECTOR SIZING
I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Langley Research Center

OBJECTIVE: This project developed a new optimization tool for obtaining the closed loop tail sizing criteria for high-speed civil transport (HSCT).

SUMMARY: 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.

PUBLICATIONS:

Berglund, E. and Kaminer, I., "An Integrated Approach to Plant Optimization and Controller Design," *Preprints Robust Control Design, 2nd IFAC Symposium*, pp. 235-240, Budapest, Hungary, 25-27 June 1997.

Kaminer, I. and Hallberg, E., "Closed Loop Pitch Control Effector Sizing," National Aeronautics and Space Administration Contractor Report, 1997

Kaminer, I., Howard, R. M., and Buttrill, C., "Development of Closed-Loop Tail-Sizing Criteria for a High Speed Civil Transport," *Journal of Aircraft*, Vol. 34, No. 5, pp. 658-664, September-October 1997.

THESIS DIRECTED:

Hallberg, E., "On Integrated Plant, Control and Guidance Design," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Other (Avionics)

KEYWORDS: Closed-Loop Pitch Control

PASSIVE SENSOR-BASED CONTROL OF NONLINEAR AUTONOMOUS SYSTEMS

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

OBJECTIVE: The objective of this proposal was 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.

DoD KEY TECHNOLOGY AREA: Sensors, Other (Avionics)

KEYWORDS: Non-Linear Autonomous Systems, VTOL

FY97 ENGINEERING AND TECHNICAL SUPPORT FOR THE UNMANNED AIR VEHICLE (UAV) JOINT PROGRAM OFFICE (JPO) PHASE II CONTRACT EFFORT

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Unmanned Air Vehicle Joint Program Office

OBJECTIVE: 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 Naval Postgraduate School in November 1997.

DoD KEY TECHNOLOGY AREA: Other (Unmanned Air Vehicles)

KEYWORDS: Unmanned Air Vehicles, UAV

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

Gerald Lindsey, Professor
Oscar Biblarz, Professor
I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
David Jenn, Associate Professor
Department of Electrical and Computer Engineering
Sponsors: Naval Air Systems Command and Naval Postgraduate School

OBJECTIVE: To perform advanced conceptual design studies on the JSOW Captive Air Training Missile (CATM) in preparation for preliminary design and construction of the CATM by Raytheon Texas Instruments.

SUMMARY: Studies were conducted in six areas: (1) structural weight and gross weight estimation; (2) structural strength analysis and fatigue life estimates; (3) airframe configurations for drag minimization; (4) CATM flight control studies to determine pilot cues for flying the captive carrier aircraft during training flights; (5) restrictions on communications be-

tween controlling and carrying aircraft due to captive position of the CATM; and (6) logistical studies of inventory required and projected usage of the CATM in the fleet.

PUBLICATION:

Pomerantz, B. and Biblarz, O., "CFD Verification of Transonic Area and Similarity Rules with Missile Configurations," *Proceedings of the 37th Israel Annual Conference on Aerospace Sciences*, Israel, February 1997.

CONFERENCE PRESENTATION:

Pomerantz, B. and Biblarz, O., "CFD Verification of Transonic Area and Similarity Rules with Missile Configurations," 37th Israel Annual Conference on Aerospace Sciences, Tel-Aviv/Haifa, Israel, February 1997.

THESES DIRECTED:

Pomerantz, B., "Aerodynamic Analysis of a Modified Pylon-Mounted JSOW CATM Using Multi-Grid CFD Methods," Master's Thesis, Naval Postgraduate School, March 1997.

Sardana, V., "Incorporation of Joint Standoff Weapon Steering Commands with Carriage Aircraft," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Air Vehicles

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

PLUME AFTERBURNING SUPPRESSION USING MIXING CONTROL AND COMBUSTION REQUIREMENTS FOR PULSE-DETONATION ENGINES

D.W. Netzer, Distinguished Professor
C.M. Brophy, National Research Council Post-Doctoral Research Associate
Department of Aeronautics and Astronautics
Sponsors: Office of Naval Research and the Naval Postgraduate School

OBJECTIVE: (1) To determine the effects of solid propellant rocket motor exhaust particulates and nozzle geometry on the suppression of plume afterburning and to obtain effective nozzle geometries which do not adversely effect thrust. (2) To experimentally determine the combustion requirements for sustainment of full-strength detonations and the detonation characteristics in liquid-fueled, pulse-detonation engines.

SUMMARY: A combined investigation was conducted with another research project at NPS in order to measure the effects of propellant composition and nozzle geometry on the exhaust plume signature from the UV to millimeter wavelengths. Both highly metallized and minimum smoke propellants were used with nozzles that had various expansion ratios and geometries to increase plume mixing with the ambient air. A detonation tube was designed, constructed, and utilized with gaseous fuel-air mixtures. An acrylic model was utilized to examine various liquid fuel injection methods and to determine the spatial and temporal variations of the liquid droplet size distribution. Air assist atomizers were found to produce a wide range of droplet sizes, with the largest droplets penetrating further into the tube. For radial injection these large droplets impinge on the opposing wall and for axial injection they result in highly non-uniform fuel distribution. The initial data indicated that the probable solution rests in the generation of very small droplets that can be injected with the purge air.

PUBLICATIONS:

Ruttenberg, E.C. and Netzer, D.W., "Aluminum Particle Breakup in Combustion Environments," to appear in *Journal of Propulsion and Power.*

Hill, J.A., Ruttenberg, E.C., and Netzer, D.W., "Spatial Variations in Aluminum Oxide and Zirconium Oxide Particle Sizes in Rocket Motors and Plumes," *Proceedings of the 1997 JANNAF Exhaust Plume Technology Subcommittee Meeting,* CPIA Pub. 656, Vol. I, pp. 229-240, May 1997.

CONFERENCE PRESENTATIONS:

Beals, K.A., Brophy, C.M., Fadler, D.C., and Netzer, D.W., "Plume Afterburning Suppression Using Mixing Control and Combustion Requirements for Liquid-Fueled, Pulse-Detonation Engines," 10th ONR Propulsion Meeting, Monterey, CA, October 1997.

Brophy, C.M. and Netzer, D.W., "Pulse-Detonation Engine Investigations at the Naval Postgraduate School," ONR/NPS Pulse-Detonation Engine (PDE) Workshop, Monterey, CA, 10 October 1997.

THESIS DIRECTED:

Beals, K.A., "Foundation of a Long-Term Research Effort in Liquid-Spray Detonations for Use in a Pulse-Detonation Engine," Engineer's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Rocket Plumes, Afterburning, Detonations

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: Accurate Automation Corporation has developed and is currently test flying LoFlyte, a subscale model of a hypersonic, waveriding aircraft. The Naval Postgraduate School has undertaken this Cooperative Research and Development Agreement (CRADA) to assess risks and technologies associated with transitioning the LoFlyte concept to the mission need for a tactical high-speed strike capability in the hypersonic realm.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Risk Analysis

CIVILIAN-MILITARY ENVIRONMENTAL INTERFACE ISSUES AND THEIR IMPACT ON NATIONAL SECURITY
Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: Research was conducted to further define issues in environmental security. A case study has been initiated regarding the remediation of the Fort Ord rifle ranges prior to their conversion to parkland. Funding sources are being sought to fund the case study. Funding sources are also being sought for environmental security research. One summary paper was prepared during 1997 to characterize environmental security research conducted to date.

PUBLICATION:

Newberry, C.F. and Grubbs, J.H., "Environmental Security: The Response to Environmental Threats to Societies," *Proceedings of the 1997 ASEE Annual Meeting and Exposition*, Milwaukee, WI, 15-18 June 1997.

CONFERENCE PRESENTATION:

Newberry, C.F. and Grubbs, J.H., "Environmental Security: The Response to Environmental Threats to Societies," 1997 ASEE Annual Meeting and Exposition, Milwaukee, WI 15-18 June 1997.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Environmental Quality Security, Fort Ord

OSCILLATORY AIRFOIL AERODYNAMICS
M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: To perform computational and experimental investigations of the unsteady separated flow phenomena on airfoils, of the flow control potential due to airfoil flapping, and of the flutter and gust response characteristics of airfoils, helicopter and turbomachinery blades.

SUMMARY: Water and wind tunnel experiments were performed to study the flow over double-delta wings at high incidence angles, the characteristics of separation bubbles on NACA 0012 airfoils, the influence of pressure gradients on the flow over cavities, and the ability of flapping airfoils to control flow separation. Also, boundary layer and Navier-Stokes calculations were performed to predict these flow phenomena.

PUBLICATION:

Hebbar, S.K., Platzer, M.F., and Chang, W.H., "Control of High-Incidence Flow on Double-Delta Wings Undergoing Sideslip," *Journal of Aircraft*, Vol. 34, No. 4, pp. 506-513, July-August 1997.

CONFERENCE PRESENTATIONS:

Fritzelas, A., Platzer, M.F., and Hebbar, S.K., "The Influence of Reynolds Number on the High-Incidence Flow Over Double-Delta Wings," AIAA Paper 97-0046, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Jones, K.D. and Platzer, M.F., "A Fast Method for the Prediction of Dynamic Stall Onset on Turbomachinery Blades," ASME Paper 97-GT-453, International Gas Turbine Congress, Orlando, FL, 2-5 June 1997.

Lai, J.C.S., Yue, J.W., and Platzer, M.F., "Control of Backward-Facing Step Flow Using a Flapping Airfoil," ASME Fluids Engineering Division Summer Meeting, Vancouver, Canada, 22-26 June 1997.

Margason, R.J. and Platzer, M.F., "Effect of Two-Dimensional Cavities on Boundary Layers in Adverse Pressure Gradients," AIAA Paper 97-0300, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

THESIS DIRECTED:

Van Dyken, R.D., "Experimental and Computational Analysis of Separation Bubble Behavior for Compressible, Steady and Oscillatory Flows over a NACA 0012 Airfoil," Doctor of Philosophy Dissertation, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

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

DEVELOPMENT OF AN ADVANCED MISSILE AERODYNAMIC PREDICTION METHOD
M.F. Platzer, Distinguished Professor
I.H. Tuncer, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: To develop Navier-Stokes and panel code solutions for the vortical flow over complete missile configurations in steady or maneuvering high angle of attack flight.

SUMMARY: Navier-Stokes computations were completed for subsonic flow over a complete missile configuration, including the flow into a missile engine through a flush-mounted engine inlet, using the NASA-Ames OVERFLOW code. Also, the NASA-Ames panel code PMARC was extended to compute the flow over bodies of revolution at high angle of attack.

CONFERENCE PRESENTATIONS:

Geissler, W., Platzer, M.F., Chandrasekhara, M.S., and Carr, L.W., "The Effect of Transition Modeling on the Prediction of Compressible Deep Dynamic Stall," 7th Asian Congress of Fluid Mechanics, Madras, India, 8-12 December 1997.

Platzer, M.F. and Tuncer, I.H., "Navier-Stokes Computation of High-Incidence Missile Flows," Air Force/Navy/Army Workshop on High-Angle-of-Attack Missile Aerodynamics, Eglin Air Force Base, FL, 14-17 October 1997.

Tuncer, I.H., van Dyken, R.D., and Platzer, M.F., "A Computational Study of Subsonic Flowfields over a Missile Configuration" AIAA Paper 97-0635, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Tuncer, I.H. and Platzer, M.F., "PMARC Potential Flow Solutions with Wakes over an Ogive Cylinder at High Incidence," AIAA Paper 97-1968, 28th AIAA Fluid Dynamics Conference, Snowmass Village, CO, 29 June-2 July 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

KEYWORDS: Missile Aerodynamics, Vortical Flows, Computational, Fluid Dynamics

PROJECT SUMMARIES

DEVELOPMENT OF SMALL UNMANNED AIR VEHICLES

M.F. Platzer, Distinguished Professor
K.D. Jones, Research Assistant Professor
I.H. Tuncer, 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: Computations were completed to predict the thrust of flapping/pitching airfoils and airfoil combinations as a function of frequency and amplitude of oscillation and as a function of the phase angle between flapping and pitching. Also, a wind tunnel model was designed and built to measure the thrust as a function of these parameters and a first set of measurements was completed.

CONFERENCE PRESENTATIONS:

Jones, K.D. and Platzer, M.F., "Numerical Computation of Flapping Wing Propulsion and Power Extraction," AIAA paper 97-0826, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

Tuncer, I.H., Lai, J.C.S., Ortiz, M., and Platzer, M.F., "Unsteady Aerodynamics of Stationary/Flapping Airfoil Combination in Tandem," AIAA paper 97-0659, 35th Aerospace Sciences Meeting, Reno, NV, 6-9 January 1997.

THESIS DIRECTED:

Pollard, S.J., "Evaluation of the CMARC Panel Code Software Suite for the Development of a UAV Aerodynamic Model," Master's Thesis, Naval Postgraduate School, June 1997.

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

M.F. Platzer, Distinguished Professor
K.D. Jones, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsors: McDonnell-Douglas Aircraft Company and Naval Postgraduate School

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 three-dimensional computational fluid dynamics codes for viscous subsonic/transonic flow over a wing/body/nacelle/pylon configuration and the development of new turbulence models. Also, it involves the use of a finite element code to determine the aircraft deformation under loading and to speed up the computations by means of parallelization.

CONFERENCE PRESENTATIONS:
Jones, K.D. and Platzer, M.F., "On the Prediction of Dynamic Stall on Airfoils in Low Speed Flow," 8th International Symposium on Unsteady Aerodynamics and Aeroelasticity of Turbomachines, Stockholm, Sweden, 14-18 September 1997.

Sanz, W. and Platzer, M.F., "On the Calculation of Laminar Separation Bubbles Using Different Transition Models," ASME Paper 97-GT-453, International Gas Turbine Congress, Orlando, FL, 2-5 June 1997.

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Structures)

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

LAUNCH PERIOD ANALYSIS FOR PLUTO EXPRESS
I. M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory

OBJECTIVE: This was a small exploratory research project with the objective to perform a detailed analysis of the Jupiter Gravity Assist (JGA) trajectories for the Pluto Express spacecraft, now renamed the Pluto-Kuiper Express.

SUMMARY: The Jet Propulsion Laboratory (JPL) is designing a space mission that will conduct, for the first time, a reconnaissance of the Pluto/Charon system to determine their composition, atmosphere and geological characteristics among other things. The spacecraft will also be sent to the Kuiper Belt that is at the edge of the solar system. Using the JPL software MIDAS and CATO, an analysis was performed for two nominal launch period opportunities that occur in November 2003 and December 2004. Most of the analysis was performed by Michelle Reyes as part of her thesis required for the Master of Science degree in Astronautical Engineering. The results allow JPL to make the final decision for the most feasible arrangement for launch. Initially, the JGA was supposed to have been a "back-up" plan for the trajectory design. JPL is seriously considering the JGA as the baseline trajectory. Due to the success of this project, JPL has an ongoing partnership with NPS on the Advanced Mars Mission Project.

CONFERENCE PRESENTATION:

Reyes, M.D., Matousek, S.E., and Ross, I.M., "Launch Period Analysis for the Jupiter Gravity Assist Opportunities to Pluto," to be presented at the 8th AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998.

THESIS DIRECTED:

Reyes, Michelle D., "Launch Period Analysis for the Jupiter Gravity Assist Opportunities to Pluto," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Pluto/Charon, Kuiper Belt, Jupiter Gravity Assist Trajectories

APPLICATION OF PERIODIC OPTIMAL CONTROL TO SPACE MANEUVERS
I. M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this proposal was to develop a non-linear, fuel-optimal guidance algorithm by analyzing the necessary conditions of optimality for periodic stationkeeping of low-Earth-orbiting satellites. This was a collaborative proposal with Professor Fahroo of the Department of Mathematics.

SUMMARY: In the course of investigating the extremal solutions to the problem, a new type of orbital transfer was discovered. Collaborative work with Professor Fahroo has resulted in advancing an algorithm to solve the optimization problem. The algorithm is based on a new spectral collocation method. The results show that the often-used Hohmann transfer is not the optimal maneuver for orbit maintenance. Further analysis performed by LT Karl Jensen has shown that it is will be possible to devise stationkeeping maneuvers that are fuel-optimal. These results could potentially change the orbit maintenance operations of future low-Earth-orbiting satellites. The intention is to use these results to sell the research to potential sponsors such as the National Aeronautics and Space Administration and Naval Reconnaissance Office.

PUBLICATION:

Ross, I. M., "Suboptimal Singular Orbital Transfer," *Journal of Guidance, Control, and Dynamics,* Vol. 20, No.3, pp. 605-607, May-June 1997.

CONFERENCE PRESENTATIONS:

Jensen, K. E., Fahroo, F., and Ross, I. M., "Application of Periodic Optimal Control Theory to the Orbit Reboost Problem," to be presented at the 8th AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998.

Fahroo, F. and Ross, I. M., "A Spectral Collocation Method for Solving Optimal Periodic Control Problems," to be presented at the AIAA Guidance, Navigation and Control Conference, Boston, MA, 10-12 August 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Orbit Maintenance, Low-Earth-Orbiting Satellites

HIGH CYCLE FATIGUE (HCF)/SPIN TEST RESEARCH
R.P. Shreeve, Professor
G.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 the Naval Air Warfare Center-Aircraft Division (NAWCAD).

SUMMARY: This is a new project. 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. Several 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 is a production-sized pit in which blade excitation techniques will be evaluated and demonstrated, eventually at full scale. Once proven, the system will be installed on the Navy's production pits at NAWCAD. Close collaboration between NPS and NAWCAD will be maintained. In addition, other research projects to support the Navy's participation in the HCF initiative will be explored.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, Blade Excitation

TRANSONIC FAN DESIGN AND VALIDATION
R. P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: This is a continuing project to advance aircraft engine fan technology. Experimentally, the goal is to install a new stage, designed by N. Sanger at NASA using CFD methods, in the transonic compressor test rig, and to evaluate all aspects of the performance using advanced measurement techniques. Code versus measurement comparisons will be documented, and the test facility and instrumentation will be proven for use in the evaluation of innovative designs. Analytically, the goal is to develop a new geometry package suitable for use in designing blading to incorporate sweep.

SUMMARY: A prototype transonic fan stage was installed and a first set of stage performance-map measurements were obtained to 80% of design speed. Code calculations showed good agreement. The stage was remanufactured following failure of the spinner attachment, and a refined fillet design was incorporated. The development of the pressure sensitive paint (PSP) measurement technique to map the rotor surface pressure was continued using a separate turbine-driven test rig. The development of a new geometry package to allow rotor design to incorporate sweep, and eventually allow aero-structural-manufacturing optimization, was successfully demonstrated using the NASA rotor as a baseline.

PUBLICATION:

Abdelhamid, H.F. and Shreeve, R.P., "Three-Dimensional Geometry Package for Axial Compressor Blading; Initial Code Listing," Naval Postgraduate School Technical Report, NPS-AA-97-001, September 1997.

CONFERENCE PRESENTATIONS:

Abdelhamid, H.F. and Shreeve, R.P., "Sweep in a Transonic Fan Design: Part 1. 3D Geometry Representation," submitted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine and Aeroengine Congress, Users' Symposium and Exposition, Stockholm, Sweden, 2-5 June 1998.

Abdelhamid, H.F., Shreeve, R.P., and Hobson, G.V., "Sweep in a Transonic Fan Design: Part 2. Flow and Stress Analyses," submitted for presentation at the ASME Turbo Expo '98-Land, Sea, & Air-43rd Gas Turbine and Aeroengine Congress, Users' Symposium and Exposition, Stockholm, Sweden, 2-5 June 1998.

Seivwright, D.L. and Shreeve, R.P., "Flat Plate in a Highly-Underexpanded Sonic Jet," AIAA 97-0066, AIAA 35th. Aerospace Sciences Meeting and Exhibit, Reno, NV, 15-18 January 1997.

THESES DIRECTED:

Abdelhamid, H.F., "Incorporation of Sweep in a Transonic Fan Design Using a 3D Blade-Row Geometry Package Intended for Aero-Structural-Manufacturing Optimization," Doctor of Philosophy Dissertation, Naval Postgraduate School, September 1997.

Gahagan, S.G., "Pressure-Sensitive Paint Measurement on Rotor Blading," Master's Thesis, Naval Postgraduate School, March 1997.

Grossman, B.L., "Testing and Analysis of a Transonic Axial Compressor," Master's Thesis, Naval Postgraduate School, September 1997.

Quinn, K.J., "Pressure-Sensitive Paint Measurement Technique Development for Turbomachinery Application," Engineer's Thesis, Naval Postgraduate School, December 1997.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Transonic Compressor Design and Test, Pressure-Sensitive Paint, Swept Fan Geometry Package

UNMANNED AIR VEHICLE (UAV) PROPULSION TECHNOLOGY
R. P. Shreeve, Professor
G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Defense Airborne Reconnaissance Office

OBJECTIVE: To examine the potential performance of alternate engines for application in Predator and Global Hawk 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. Analytical studies examine the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An experimental study seeks to establish performance characteristics of small gas turbines operating with JP fuel.

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

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

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
Sponsor: U. S. Army Aviation and Troop Command-Comanche Program Manager's Office

OBJECTIVE: For Professors Wood, Danielson, and Gordis to continue their work in support of the ongoing development of the Army's RAH-66 Comanche helicopter. Tasks include vibration and structural dynamics analysis and correlation of calculated results with results of ground vibration tests. It is important that NPS maintain a "current" dynamic NASTRAN model of the Comanche. A current model permits NPS to respond quickly to requests from the Program Manager's Office to carry out parametric investigations of RAH-66 vibrations in cooperation with the Army and Sikorsky in which NPS results can be quickly compared to those of other principals and applied to the aircraft if desired.

SUMMARY: Described is a summary of engineering work conducted at the Naval Postgraduate School in 1997 for the Comanche Program Manager's Office, in support of the Army-Boeing-Sikorsky RAH-66 Comanche Helicopter Program. The prototype helicopter is currently undergoing flight test envelope expansion at Sikorsky Aircraft's Flight Test Facility at West Palm Beach, FL.

    The RAH-66 Comanche's stealth design requires the use of radar absorbing material (RAM) on the outer skin of the aircraft. The reduced stiffness properties of RAM produce insufficient tail torsional stiffness, necessitating the use of non-radar absorbing graphite on the outer skin of the prototype's tail section. An investigation was carried out to determine the structural design modifications required to increase the tailcone's stiffness to allow the use of RAM on the outer skin and still meet all structural requirements. The reference or baseline case is a finite element model that was constructed to represent the prototype aircraft. The goal is to identify stiffness-enhancing structural design changes, with minimum increase in weight, which allow the use of RAM while preserving the stiffness of the prototype aircraft.

Nine structural modifications to the tailcone were developed conceptually, then analyzed. NASTRAN analysis showed that the total effect of these modifications was to increase the torsional stiffness by 12 percent with respect to the baseline aircraft with graphite on the outer mold line. It is shown that the addition of radar absorbing material (RAM) to the outer skin of this modified model costs only a six percent reduction in torsional stiffness from baseline values as compared to a 24 percent reduction in tailcone stiffness for adding the same amount of RAM were these structural modifications not incorporated in the design. In other words, the design modifications developed in this work increased the torsional stiffness by 18 percent with respect to the baseline aircraft with Kevlar on the outer mold line (OML).

These results were presented verbally to the Army and in detail in the thesis work carried out by MAJ Tobin and MAJ Shoop. A summary of the year's work is given in the referenced report by Professors Wood, Danielson, and Gordis.

NPS students participated actively in this program. U.S. Army CPT Pat Mason joined the Sikorsky Dynamics Group under Mr. Bob Blackwell for a 1997 summer internship in which he worked on Comanche vibrations. At the end of the summer, Sikorsky sent him to West Palm Beach to witness the Comanche flight test program and he even had the opportunity to fly as co-pilot in the S-76 helicopter that serves as the chase aircraft for the Comanche. MAJ Vince Tobin, who had interned at Sikorsky during the summer of 1996, completed his thesis on the Comanche and graduated in June with distinction. MAJ Brian Shoop extended the work of MAJ Tobin to encompass the tailcone aft of the landing gear bay bulkhead. He completed his thesis and graduated in September.

PUBLICATION:

Wood, E. R., Danielson, D. A., and Gordis, J. H., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Report submitted to Comanche Program Manager's Office.

PRESENTATIONS:

Wood, E.R. and Danielson, D.A., "NPS Helicopter Program and Comanche Work," San Francisco Bay Area Chapter of the American Helicopter Society, Moffett Field, CA, 20 February 1997.

Wood, E.R., "Helicopter Programs at NPS," Los Angeles Chapter of American Helicopter Society, Los Angeles, CA, 15 May 1997.

THESES DIRECTED:

Shoop, B. P., "Structural Design Analysis of the Tail Landing Gear Bay and the Vertical/Horizontal Stabilizers of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, September 1997.

Tobin, V. M., "Analysis of Potential Structural Design Modifications for the Tail Section of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes and Structures, Computing and Software, Modeling and Simulation, Manufacturing Science and Technology, Other (Design)

KEYWORDS: Helicopter, Rotorcraft, Dynamics, Structures

ADVANCED HELICOPTER TECHNOLOGY FOR SPECIAL OPERATIONS
E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute for Joint Warfare Analysis-Naval Postgraduate School

OBJECTIVE: To provide proof-of-concept helicopter modifications to Special Operations OH-6A derivative helicopter for increase in agility and power available and decrease in vibration and noise using intermittent higher harmonic control (HHC). To conduct a limited full-scale HHC flight test program for verification.

SUMMARY: From 1976 through 1985, NASA and the Army sponsored extensive research in HHC for helicopters. The resulting OH-6A flight test program (1982-84) showed large payoffs in noise, performance and vibration. For noise, it has been shown that HHC provides the capability to reduce and tailor the main rotor noise signature. For performance, it has been shown that HHC has the potential to provide a 10% improvement in hover, increasing up to a 20% improvement at 60 knots. For vibration, up to 90% reduction at n/rev can be realized throughout the aircraft. Since the 1985 time frame, there has not been any flight testing, but basic research into HHC has continued at leading aeronautical laboratories in both the U.S. and Europe (NASA, U.S. Army, DFLR, and ONERA).

This program makes the case that for military and research purposes, HHC flight testing should be resumed again. The agency to conduct the flight test evaluation is Special Operations Command. Whereas the initial OH-6A program focused on vibrations the proposed future program will incorporate three HHC derivative active control systems in one aircraft. The three derivative systems are: (1) low noise-stealth, (2) low vibrations, and (3) performance. Since components of the prototype system still exist, costs can be kept low by modifying a helicopter that is an operational OH-6A derivative.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Aerospace Propulsion and Power, Battlespace Environments, Computing and Software, Sensors, Modeling and Simulation, Other (Active Controls, Stealth)

KEYWORDS: Helicopters, Stealth, Rotary Wing, Special Operations Warfare, Joint Warfare Modeling and Simulation

GROUND/AIR RESONANCE SIMULATION OF HELICOPTER ROTOR SYSTEMS BASED ON FULL NON-LINEAR EQUATIONS OF MOTION
E. Roberts Wood, Professor
LCDR Robert L. King, Lecturer
Department of Aeronautics and Astronautics
Sponsor: Sikorsky Aircraft and National Rotorcraft Technology Center

OBJECTIVE: Professor Wood and LCDR King continued the original thesis work of LT Christopher S. Robinson in the area of nonlinear helicopter rotor dynamics. As hingeless helicopter main rotors become more commonplace, a need has arisen for a rotor simulation tool that will 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.

SUMMARY: This research has reported on a new method for formulating the full non-linear equations of motion for ground/air resonance stability analysis of helicopter rotor systems. A full set of non-linear equations was developed by Lagrangian approach using the well-known MAPLE" symbolic processing software for expanding the equations. The symbolic software was further utilized to automatically convert the equations of motion into C, Fortran or MATLAB" source code formatted specifically for numerical integration. The compiled C or Fortran code was then accessed and numerically integrated by the dynamic control simulation software, SIMULINK". SIMULINK" then applied a Runga-Kutta integration scheme to generate time history plots of blade and fuselage motion. The method was used to explore the effects of damping non-linearities, structural non-linearities, active control, individual blade control (IBC), and damper failure on air/ground resonance. Damping levels were determined from the time history plots by a MATLAB" program, which used the Moving Block Technique for determining critical damping levels from the coupled rotor-fuselage response.

For validation, the analysis was compared with Coleman's classic theory and was also applied to representative cases that included: (1) The classic instability on isotropic supports; (2) The case of one blade damper inoperative; and (3) The case of one blade damaged by a ballistic strike.

PUBLICATIONS:

Robinson, C.S., Wood, E.R., and King, R.L., "Analysis Of Helicopter Rotor Instabilities Using Symbolic Processing and Control System Dynamics Software," *Proceedings of the 23rd European Rotorcraft Forum*, Paper No. 12, Dresden, Germany, 16-18 September 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Ground/Air Resonance Simulation of Helicopter Rotor Systems Based on Full Non-Linear Equations of Motion," *Proceedings of the Seventh International Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems*, Washington University, St. Louis, MO, 14-16 October 1997.

CONFERENCE PRESENTATIONS:

King, R.L., "Presentation of NPS Ground/Air Resonance Work to Date," U.S. Army Aeroflightdynamics Laboratory, Moffett Field, CA, June 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Analysis of Helicopter Rotor Instabilities Using Symbolic Processing and Control System Dynamics Software," Paper No. 12, 23rd European Rotorcraft Forum, Dresden, Germany, 16-18 September 1997.

Robinson, C.S., Wood, E.R., and King, R.L., "Ground/Air Resonance Simulation of Helicopter Rotor Systems Based on Full Non-Linear Equations of Motion," Seventh International Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, Washington University, St. Louis, MO, 14-16 October 1997.

THESIS DIRECTED:

Robinson, C.S., "Modeling and Analysis of Helicopter Ground Resonance Utilizing Symbolic Processing and Dynamic Simulation Software," Engineer's Thesis, Naval Postgraduate School, March 1997.

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

KEYWORDS: Rotorcraft, Helicopter, Ground/Air Resonance, Damperless, VTOL, MAPLE, SIMULINK, Nonlinear Simulation and Control

TESTING AND ANALYSIS FOR P-3 AIRCRAFT
Edward Wu, Professor
Department of Aeronautics and Astronautics
Sponsors: Naval Air Systems Command and Naval Postgraduate School

OBJECTIVE: The overall objective of these P-3 structural integrity programs is t provide increased reliability against failure during the service lifetime. Since fatigue testing, which is time consuming and destructive, cannot be conducted on a large scale, the existing methodology is based on the statistics of few samples. Many assumptions of uncertain validity are required to utilize such statistical data. A probabilistic approach developed by Coleman utilizing a convolution integral to assess damages resulted from different load history. The Naval Postgraduate School can contribute to the life extension program through the evaluation of conventional methodology and the formulation of modern damage accumulation to supplement the conventional fatigue analysis from constant amplitude load history to spectrum load history and to extend the prediction to include the life variability.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: P-3, Structural Integrity, Fatigue Analysis

BASIC SCIENCE AND DATABASE FOR COMPOSITE RELIABILITY AND LIFE PREDICTION
Edward Wu, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: To provide analytical and experimental databases for the definitive modeling of an appropriate composite reliability function addressing both strength and strength aging of composites materials and structures.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Composites, Composite Reliability

PUBLICATIONS/PRESENTATIONS

JOURNAL PAPERS

Chandrasekhara, M.S., Carr, L.W., Wilder, M.C., Paulson, G.N., and Sticht, C.D., "Design and Development of a Dynamically Deforming Leading Edge Airfoil for Unsteady Flow Control," IEEE Publication 97CH36121, pp. 132-140, September 1997.

Hebbar, S.K., Platzer, M.F., and Chang, W.H., "Control of High-Incidence Vortical Flow on Double-Delta Wings Undergoing Sideslip," *Journal of Aircraft*, Vol. 34, No. 4, pp. 506-513, July-August 1997.

Hobson, G.V. and Dober, D.M., "Three-Dimensional Fiber-Optics LDV Measurements in the Endwall Region of a Linear Cascade of Controlled-Diffusion Stator Blades," *International Journal of Turbo and Jet Engines*, Vol.14, No.1, 1997.

Kaminer, I., Howard, R. M., and Buttrill, C., "Development of Closed-Loop Tail-Sizing Criteria for a High Speed Civil Transport," *Journal of Aircraft*, Vol. 34, No. 5, pp. 658-664, September-October 1997.

Natan, B. and Netzer, D.W., "Boron Carbide Combustion in Solid-Fuel Ramjets Using Bypass Air. Part II: Theoretical Analysis," *Propellant, Explosives and Pyrotechnics*, 22, 6-10, 1997.

Newberry, C.F., "A Multidisciplinary Environmental Science and Engineering Master's Degree Program: A Proposed NPS/DoD Partnership," *Naval Engineers Journal*, Vol. 109, No. 2 pp. 29-1, March 1997.

Ross, I.M., "Extremally Steered Singular Thrust-Arcs for Space Flight in an Atmosphere," *Acta Astronautica, Journal of the International Academy of Astronautics*, Vol. 39, No. 8, pp. 569-577, October 1996 (appeared in CY 1997).

Ross, I. M., "Extremal Angle of Attack Over a Singular Thrust Arc in Rocket Flight," *Journal of Guidance, Control and Dynamics*, Vol. 20, No.2, pp. 391-393, March-April 1997.

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INCORPORATION OF SWEEP IN A TRANSONIC FAN DESIGN USING A 3D BLADE-ROW GEOMETRY PACKAGE INTENDED FOR AERO-STRUCTURAL MANUFACTURING OPTIMIZATION

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A new 3D blade row geometry package was developed and implemented. In the new representation the blade is described by six Bezier surfaces two of which represent the pressure and suction surfaces with sixteen points each. The leading and trailing edges are each represented by two Bezier surfaces. Only one extra parameter is required (in addition to the pressure and suction surfaces parameters) to define each of the leading and trailing edge surfaces. Blade geometry manipulation in this format is easily implemented. A change to one surface location affects the surrounding area inversely proportional to the distance from the moved point, creating a smooth variation in geometry, free of waviness. The geometry generated is easy to handle with CAD/CAM programs without any conversion or approximation. The representation was applied to an existing transonic fan geometry to investigate effects of sweep. Results were obtained for the effect of forward and backward sweep on the aerodynamic performance, and the associated effect on centrifugal stress levels was obtained. The investigation demonstrated the suitability of the package to be incorporated into a multi-disciplinary design optimization process.

VULNERABILITY REDUCTION OF MODERN TACTICAL AIRCRAFT

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Survivability engineers and Program Managers (PMS) must ensure that modern combat aircraft will be both mission effective and affordable by "designing in" survivability. Survivability means avoiding hits and when hit, withstanding the hits. Vulnerability has been defined as the inability of an aircraft to withstand the damage caused by a hostile environment. Most current tactical aircraft incorporate many vulnerability reduction features to reduce the likelihood of an aircraft kill given a hit (Pk/h), thereby increasing the aircraft's survivability. The goal of vulnerability reduction is to prevent critical damage "hit" caused failures, to mitigate cascading threat effects, and to allow for graceful degradation of an aircraft. The next-generation tactical aircraft under development is the Joint Strike Fighter (JSF). The JSF must be designed not only to avoid being hit, but also to survive when hit. This thesis presents the latest vulnerability reduction designs, features, and guidelines that can be used to reduce the vulnerability of the JSF.

INCORPORATION OF A DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) IN THE CONTROL OF AN UNMANNED AERIAL VEHICLE (UAV) FOR PRECISE NAVIGATION IN THE LOCAL TANGENT PLANE (LTP)

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The purpose of this thesis is to incorporate the Global Positioning System (GPS) and Inertial Navigation System (INS), for the guidance of an unmanned aerial vehicle (UAV) seeking precise navigation in a Local Tangent Plane (LTP). By applying

the Differential Positioning technique, GPS position data becomes more accurate. This position can then be referenced to a known location on the ground in order to give the aircraft's position in the Local Tangent Plane.

The FOG-R UAV at the Naval Postgraduate School will be used for autonomous flight testing using a Texas Instruments TM5320C30 Digital Signal Processor (DSP). This DSP is hosted on an IBM compatible PC, and is controlled via Integrated System's AC100 control system design and implementation software package.

The GPS receiver used throughout this thesis is a Motorola PVT-6 OEM. Another identical GPS receiver is used as a reference station, thus providing the Differential capability. The objectives of this thesis are to: ensure the system is able to accept current location from the GPS and convert it to LTP, display the LTP coordinates (numerically and graphically), and be able to easily change the origin coordinates. Finally, the achieved accuracy of the differential setup is examined.

A STUDY OF THE EFFECTS OF ON-BOARD ELECTRONIC COUNTERMEASURES (ECM) ON THE COMBAT SURVIVABILITY OF AIRCRAFT (U)
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On-board electronic countermeasures increase aircraft survivability by reducing the likelihood that the aircraft will be hit by a radar guided missile. The cost of developing and maintaining ECM equipment must be justified by the increase in survivability since these actions require money and incur aircraft design penalties, such as increased weight. By examining ECM's effect on missile miss distance using statistical parameters, a quantifiable increase in miss distance due to ECM may be determined. Consequently, this thesis gathers and examines available data (from computer simulations, hardware-in-the-loop tests, and open-air tests) on the effects of ECM on missile miss distance. When combined with the missile warhead's lethality in an endgame study, an overall value for the increase in survivability may be determined.

FOUNDATION OF A LONG-TERM RESEARCH EFFORT IN LIQUID SPRAY DETONATIONS FOR USE IN A PULSE DETONATION ENGINE
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The pulse detonation engine (PDE) concept, which may provide increased performance for high speed tactical missiles, is reviewed. For the PDE technology to realize its full potential, high-energy-density, liquid-hydrocarbon fuels must be detonated reliably with air. The present project has initiated a long-term effort to characterize critical detonation properties of liquid fuel sprays in air. A modular, stainless-steel detonation tube, and an acrylic replica were designed and built to measure detonation wave and liquid-spray characteristics. Air-assist atomizing nozzles were tested with both qualitative and quantitative diagnostics to characterize forward and reverse-flow injection of water sprays into simulated PDE combustors. Laser-illuminated, stop-action video data recorded poor axial penetration of the injected spray near the head end of the combustor. Malvem 2600 Particle Analyzer data showed Sauter mean diameters between 10 and 60 microns. Laser transmittance and Malvern measurements both indicated that considerable fuel mass was either lost from the open tube end or deposited on the tube wall before the desired detonation time, indicating that improvements are required for the fuel injection process. The transient nature of the injection limited the usefulness of a phase-doppler particle analyzer. Two fuel-injection configurations were characterized with comparable particle mass concentrations, but significantly different levels of homogeneity throughout the detonation tube.

DETERMINATION OF HUB FORCES AND MOMENTS OF THE
RAH-66 COMANCHE HELICOPTER

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Efforts to establish a better understanding of the performance of the RAH-66 *Comanche* helicopter were performed as part of an engineering internship with the Sikorsky Aircraft Comanche Dynamics group in Trumbull (Stratford), Connecticut. Test data from whirl stand testing and the *Comanche* Propulsion System Testbed (the ground test vehicle replacement) was evaluated. Fixed and rotating frame measurements were used to determine hub moments and forces generated by cyclic inputs. Flapping response phase to control input was also determined. Other mast loads were examined to determine the cause for greater than anticipated hub forces. Edgewise bending of the rotor blades was found to be a significant contributor to hub forces.

A STUDY OF THE EFFECTS OF COUNTERMEASURE DISPENSER
LOCATION ON INFRARED DECOY EFFECTIVENESS (U)

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The latest generation of infrared guided missiles employs a wide variety of techniques designed to discriminate between the target aircraft and flares. As a result, every aspect of a flare design and employment has become increasingly important. In response to the threat, countermeasure designers are having to rethink countermeasure design and employment.

This study focuses on one aspect of the problem facing countermeasures designers, that of dispenser location. To that end the effectiveness of the current SH-60B Seahawk dispenser locations will be compared to those of the planned SH-60R. Each configuration will employ pyrotechnic and pyrophoric flares against a counter-countermeasures capable threat in hovering, non-maneuvering and maneuvering scenarios.

EDUCATIONAL MATERIALS FOR THE IMPLEMENTATION
OF SURVIVABILITY IN COMBAT AIRCRAFT DESIGN

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This thesis presents the educational objectives, and the means to achieve the objectives, essential for the implementation of aircraft combat survivability in design. Achieving the educational objectives forms the basis of a student's knowledge and proficiency within the aircraft survivability discipline. To realize the goal of this thesis, the specific educational objectives for aircraft survivability had to be reviewed, refined, and further developed. The educational objectives, adopted in this thesis, include the course objectives established in the Aircraft Combat Survivability course taught at the Naval Postgraduate School (NPS), in additional to objectives obtained from the results of a survivability survey conducted at NPS as a part of this thesis. The educational materials, developed herein, reinforce the fundamental concepts of aircraft combat survivability through demonstration, implementation, application, and analysis of realistic design problems. Once firmly ingrained, the essential elements are then incorporated in a detailed survivability program. The program utilizes a generic aircraft and generic mission which allow students the chance to study any aircraft of interest. In addition, working the

program will give students the opportunity to apply many of the concepts of survivability to a complete survivability program, from conceptual design to production. The intent of this work is to provide students, of the aircraft survivability discipline, additional educational materials designed to enhance their knowledge and proficiency of aircraft survivability in design.

MINIMUM VARIATION MANEUVERS USING INPUT SHAPING AND PULSE-WIDTH, PULSE FREQUENCY MODULATED THRUSTER CONTROL

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Minimizing the modal vibration induced by on-off thrusters is a challenging problem for designers of flexible spacecraft. This thesis presents the first study of Pulse-Width, Pulse-Frequency (PWPF) modulated thruster control using the method of command input shaping. Input shaping for systems with linear actuators has been successfully developed to reduce modal vibrations. Recently, this method has been extended to systems with on-off actuators to some degree. However, existing approaches require complicated non-linear optimization and result in bang-bang control action. Bang-bang thruster operation on flexible spacecraft is propellant-intensive and causes frequent thruster switches. In this thesis, a new approach integrating command input shaping with PWPF-modulated thruster control is developed to minimize residual vibration in maneuvers and to reduce propellant consumption. To realize this approach, an in-depth analysis of the PWPF modulator is first conducted to recommend parameter settings. Next, command input shapers are designed and integrated with the PWPF modulator. Simulation verifies the efficacy of this technique in reducing modal vibration. Lastly, robustness analyses are preformed and demonstrate the method's insensitivity to frequency and damping uncertainty.

DRAG STUDY AND PERFORMANCE TRADEOFFS OF A PITCHLOCKED PROPELLER ON THE P3 ORION AIRCRAFT

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A result of many malfunctions of the propeller system on the Lockheed P3 Orion is called pitchlock, a feature of the propeller pitch control mechanism that prevents low blade angles and high drag loads. Pitchlock can have serious negative impacts on the range of the aircraft, which is a critical consideration on a long-range patrol mission. The U.S. Navy P3 Fleet Replacement Squadron Fleet NATOPS Department requested an investigation of the pitchlock situation and the subsequent impact on the aircraft range. Two vortex/blade element propeller analysis computer codes were used to investigate pitchlocked, windmilling propellers. The blade angle of a decoupled propeller was predicted accurately, yet negative thrust predictions varied widely. A lack of engine data prevented use of the computer codes to investigate the coupled situation. Available negative thrust and windmilling rpm data verified by the codes was demonstrated to be useful in determining the pitchlock blade angle, the drag of the pitchlocked propeller in a windmilling condition with the engine shutdown, and the airspeed which must be decelerated to in order to prevent decoupling when the engine is shut down. Maximum range performance could not be addressed due to the lack of engine performance data.

WIND TUNNEL TEST OF THE TIER III MINUS
UAV FOR TUMBLING INVESTIGATIONS

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Static and dynamic low-speed wind tunnel tests were conducted to determine the aerodynamic characteristics of a 1/25-scale Tier III Minus model. These experiments were the initial study for on-going research to investigate the tumbling susceptibility of the Tier III Minus planform. Static force and moment data were obtained for 0° to 360° angle of attack with the use of an internal strain-gage balance. Dynamic forced-oscillation tests were performed to obtain pitch damping data. Static results were as predicted and compared favorably with generic planform data collected by other investigators. However, dynamic testing failed to produce reliable pitch-damping information. Based on the geometric design of the Tier III Minus and the static pitching moment data, it is likely that the platform will experience tumbling given the proper initial conditions. However, computer simulation is required for further analysis.

A STUDY OF THE EFFECTS OF GEOMETRIC VARIATIONS
ON THE FLOW CHARACTERISTICS IN THE FASTHAWK COMBUSTION CHAMBER

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A water tunnel study was conducted in support of the FASTHAWK combustor design. Five combustion chamber configurations (including a combustion can, aerogrid, turbulator and swirl devices at the dump plane) were evaluated with Laser Doppler Velocimetry (LDV) to measure profiles of turbulence intensity and axial velocity. Laser sheet flow visualization was used to analyze flow patterns of seven different combustion can designs and nozzle exit swirl.

The baseline, swirl, and aerogrid configurations produced similar flow characteristics, moderate turbulence intensity, and a large primary recirculation zone. The latter was unsuitable for short (L/D < 1.0) combustors. The combustion can and turbulator configurations were similar to one another with respect to axial velocity profiles and both produced a primary recirculation zone with L/D significantly less than 1.0. The turbulator configuration also produced significantly higher turbulence intensities throughout the combustion chamber, greater than any of the other configurations. The evaluation of the combustion can designs revealed the greatest impact on flow patterns results from the axial location of hole rows and that fuel injection is optimum when done near the downstream end of the primary recirculation zone.

THE CONTROL OF BIFURCATIONS WITH ENGINEERING APPLICATIONS

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This dissertation develops a general method for the control of the class of local bifurcations of engineering interest, including saddle-node, transcritical, pitchfork, and Hopf bifurcations. The method is based on transforming a general affine single-input control system into quadratic normal form through coordinate transformations and feedback. (The quadratic normal form includes the quadratic order Poincare normal form of the uncontrolled system as a natural subset.) Then, linear and quadratic state feedback control laws are developed which control the shape of the center manifold of the transformed

system. It is shown that control of the center manifold allows the quadratic and cubic order terms of the center dynamics to be influenced to produce non-linear stability. Specific matrix operations necessary to transform a general affine single-input control system into quadratic normal form are provided. Specific control laws to stabilize a general system experiencing a linearly unstabilizable saddle-node, transcritical, pitchfork, or Hopf bifurcation are also provided.

A ROBUST METHODOLOGY TO EVALUATE AIRCRAFT SURVIVABILITY
ENHANCEMENT DUE TO COMBINED SIGNATURE REDUCTION
AND ONBOARD ELECTRONIC ATTACK
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This thesis examines the effect of combining radar signature reduction and onboard electronic attack (EA) capability on the survivability enhancement of a generic joint strike fighter (JSF). The missions of a generic JSF are examined, and a tactical scenario for an air-to-air mission and a strike mission are presented. The principles of signature reduction and EA using onboard Electronic Countermeasures (ECM) are reviewed. The effect of signature level and of jammer effective radiated power (JERP) on the ability of a radar to detect the JSF are determined individually. Finally, an approach for combining the two survivability enhancement features is described, in the context of the two tactical JSF scenarios, and an EXCEL spread-sheet program entitled RCS-JERP is developed using unclassified radar and EA equipment data. Although all of the material in this thesis and in RCS-JERP are unclassified, the principles, methodology, and spreadsheet can be applied to specific (and classified) scenarios by utilizing the specific radar data, applicable mission threat analyses, and the effectiveness of the specific EA techniques employed.

PRESSURE-SENSITIVE PAINT MEASUREMENTS ON
A ROTOR DISK SURFACE AT HIGH SPEEDS
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Measurement of the static-pressure distribution over the surface of a rotor disk was attempted using pressure-sensitive paint (PSP). A uniform-stress, high-speed rotor disk, fitted with a shock generator, was built, installed, and operated at speeds in excess of 20,000 RPM by a Hamilton-Standard turbine-driven fuel pump. A once-per-revolution trigger signal was converted to a transistor-to-transistor logic (TTL) format and used to gate an intensified charged-coupled device (CCD) video camera. 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 reference condition. Finally, a pseudo-coloring process was used to develop a color image that related intensities to both temperature and pressure distributions in accordance with the Stern-Volmer relation. Paint stripping and temperature dependence prevented the measurement of pressure at transonic speeds. The test-bed facility and acquisition techniques developed here could now be used to overcome those limitations.

AIRCREW CENTERED SYSTEM DESIGN ANALYSIS
CONSIDERATIONS FOR THE MH-53E HELICOPTER

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An analysis was made of the aircrew centered system design aspects for the MH-53E helicopter. These aircrew centered design features included changes in the cockpit, aircraft weight and drag coefficient. The cockpit evaluation compared the current MH-53E cockpit configuration with design changes currently under review by the Navy. This evaluation suggests that the proposed cockpit design display change may reduce aircrew load stress and improve mission effectiveness. Changes in subsystem components may either increase or decrease the weight of the MH-53E. Similarly, changes in crew tasking may result in a need for more or less fuselage volume size. Therefore, the sensitivity of MH-53E performance to generic changes in weight and drag was investigated in order to make source assessment of equipment and crew tasking changes upon MH-53E mission effectiveness.

A SYSTEM ANALYSIS OF A NEW ASCM SIMULATOR

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This research applied a Systems engineering approach to identity the technical characteristics for an improved ALQ-170(V) Anti-Ship Cruise Missile (ASCM) simulator. This simulator pod attaches to a F/A-18C Hornet to provide ASCM defense training. The new simulator provides a fully coherent, multi-polarization, broad band simulator that emulates all current and postulated ASCM threats through the year 2020.

A set of requirements were developed from the Operational Requirements Document (ORD) for the ALQ-170 Performance Enhancement Program (PEP) and fleet messages. Five design alternatives were examined through a number of trade-off studies in order to identify a preferred configuration. Multiple Attribute Utility Theory (MAUT) was used to score the five alternatives to determine the best possible replacement for the ALQ-170. The preferred configuration provides true "dial-a-threat" capability whereby any one of over 125 known ASCM threats are simulated upon operator command.

TESTING AND ANALYSIS OF A TRANSONIC AXIAL COMPRESSOR

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A test program to evaluate a new transonic axial compressor stage was conducted. The stage was designed (by Nelson Sanger of NASA Lewis) relying heavily on CFD techniques while minimizing conventional empirical design methods. The stage was installed in the NPS Transonic Compressor Test Rig and instrumented with fixed temperature and pressure probes. A new PC-based data acquisition system was commissioned and programmed for stage performance measurements. These were obtained at 50, 60, 65, 70, and 80% of the design speed before failure of the spinner retaining bolt led to the loss of the stage. The flow through the rotor was analyzed and the rotor performance predicted using a 3-dimensional viscous code (RVC3D). The predicted rotor performance agreed qualitatively and was numerically consistent with the measured stage performance.

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF SECOND-GENERATION, CONTROLLED-DIFFUSION, COMPRESSOR BLADES IN CASCADE

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This thesis contains a detailed experimental and numerical investigation of second-generation, controlled-diffusion compressor-stator blades at an off-design inlet-flow angle of 39.5° Investigation of the blades took place in a low-speed cascade wind tunnel using various experimental procedures. The objective of the wind tunnel study was to characterize the flow field in and around the blades at the off-design angle, and to investigate flow separation near the mid-chord for a high Reynolds number of 640,000. It was known from previous studies that boundary layer thickness on the end walls were of different thicknesses. Thus, prior to taking data, an adjustment to the end wall boundary layer thickness was attempted by insertion of an aluminum trip strip far upstream of the blades. Rake probe surveys were performed upstream and downstream of the blades in order to obtain spanwise upstream and downstream total pressure profiles. Surface flow visualization was performed on the blades using a titanium dioxide and kerosene mixture. Blade surface pressure measurements were obtained using a 40-hole instrumented blade from which coefficients of pressure were calculated. A standard optics, two-component laser-Doppler velocimeter was used to characterize the flow field upstream, in the boundary layer on the suction side of the blades, and in the wake region. A numerical investigation was conducted using the rotor viscous code 3-D developed by Dr. Roderick Chima of NASA Lewis Research Center.

Overall, good agreement between flow visualization, blade pressure measurements, laser measurements, and numerical modeling was obtained.

ON INTEGRATED PLANT, CONTROL AND GUIDANCE DESIGN

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Two theoretical methods and the development of a guidance, navigation and control rapid prototyping system address the issue of considering the integral participation of feedback early in the design process. The first method addresses the problem of sizing the horizontal tail on a statically unstable transport aircraft. Dynamic constraints including recovery from a severe angle of attack excursion and penetration of a vertical wind shear are formulated in terms of the solution to a convex minimization problem utilizing LMIs and used to size the horizontal control surfaces. The second method addresses the problem of tracking inertial trajectories with applications for unmanned air vehicles. This problem is posed and solved within the framework of gain scheduled control theory leading to a new technique for integrated guidance and control systems with guaranteed performance and robustness properties. Finally, a rapid prototyping system for the flight test of GNC algorithms for unmanned air vehicles is designed that affords a small team the ability to quickly take a new concept in guidance, navigation, and control from initial conception to flight test.

CONVENTIONAL AND PROBABILISTIC FATIGUE LIFE PREDICTION METHODOLOGIES RELEVANT TO THE P-3C AIRCRAFT

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This thesis investigates conventional and probabilistic methodologies for predicting the fatigue life of critical components in the P-3C aircraft. A probabilistic damage convolution model was developed with the intent of providing quantitative predictions of life-variability. Traditional methodologies, which are based nominally on median values, lack the capacity to adequately assess variability. Aluminum 7075-T6 was tested using a fatigue Material Test System. A fatigue database was compiled from tests conducted at the Naval Postgraduate School and from literature sources.

NUMERICAL INVESTIGATION OF TUMBLING CHARACTERISTICS OF THE TIER III MINUS UAV

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In light of today's high cost military aircraft and the desire for zero fatalities in military conflict, the Unmanned Aerial Vehicle (UAV) has become increasingly more important, and with the recent use of UAVs in Operation Desert Storm, improvements in the current technologies are both indicated and desirable. However, with today's increase in threat sophistication, there has also been a recent surge of interest in the design of low observable, or stealth, aircraft. An example of a current stealth UAV is the Tier III Minus DarkStar. The DarkStar is a joint venture between the Defense Advanced Research Project Agency (DARPA), Defense Airborne Reconnaissance Office (DARO), and the Lockheed Martin (Skunk Works)/ Boeing Aircraft manufacturing teams. The DarkStar is also a tailless flying-wing aircraft and being of a flying-wing planform makes the design potentially susceptible to tumbling, a sustained autorotative pitching motion. Using the full-scale aircraft geometry, a three degree-of-freedom motion simulation program was run using coefficient data obtained from a 1/25-scale wind-tunnel model. Initial indications show that the Tier III Minus is capable of tumbling under initial conditions of high angle of attack and/or high pitch rate with average nose-down pitch rates of around -460 deg/sec.

DEVELOPMENT, CORRELATION, AND UPDATING OF A FINITE ELEMENT MODEL OF THE OH-6A HELICOPTER

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This thesis is part of the helicopter research program established at the Naval Postgraduate School (NPS). NPS currently has two OH-6A light observation helicopters which were obtained from the U.S. Army. One of these is dedicated to ground vibration testing and dynamics research.

Previous research on the OH-6A at NPS established baseline vibration test data. The data includes natural frequencies, principal mode shapes and damping characteristics. This thesis continues previous research of the OH-6A and develops a detailed finite element model to be used in future helicopter dynamics research at NPS.

The model is based on an MSC/NASTRAN finite element model of a similar aircraft obtained from the McDonnell Douglas Helicopter Company. Both the nose and empennage were modified to represent the structural characteristics of the test article. Due to lack of structural design data, model mass updating was performed using previously obtained test data and a design sensitivity approach. The updated model natural frequencies agree well with the test data.

DEVELOPMENT OF A DYNAMIC MODEL FOR A UAV

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Moments of inertia were experimentally determined and the longitudinal and lateral/directional static and dynamic stability and control derivatives were estimated for a fixed wing Unmanned Air Vehicle (UAV). High fidelity, non-linear equations of motion were derived and tailored for use on the specific aircraft. Computer modeling of these resulting equations was employed both in Matlab/Simulink and in Matrix$_x$/Systembuild. The resulting computer model was linearized at a specific flight condition, and the dynamics of the aircraft were predicted. Several flight tests were conducted at a nearby airfield and the behavior of the aircraft was compared to that of the computer model. The longitudinal dynamics as depicted by the short period mode were found to be almost identical with those predicted by the non-linear computer model. The phugoid mode was also observed and found to be in close agreement. In the lateral/directional dynamics, flight test was employed to improve the model and the parameters were modified to obtain a better match. Ultimately a reasonably accurate non-linear model was achieved as required for purposes of control and navigation system design.

EVALUATION OF THE CMARC PANEL CODE SOFTWARE SUITE FOR THE DEVELOPMENT OF A UAV AERODYNAMIC MODEL

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The CMARC panel code is evaluated to verify its accuracy and suitability for the development of an aerodynamic model of the Naval Postgraduate School (NPS) FROG Unmanned Air Vehicle (UAV). CMARC is a DOS personal computer based version of the NASA Panel Method Ames Research Center (PMARC) panel code. The core processing algorithms in CMARC are equivalent to PMARC. CMARC enhancements include improved memory management and command line functionality. Both panel codes solve for inviscid, incompressible flow over complex three-dimensional bodies using potential flow theory. Emphasis is first placed on verifying CMARC against the PMARC and NPS Unsteady Potential Flow (UPOT) panel codes. CMARC boundary layer calculations are then compared to experimental data for an inclined prolate spheroid. Finally, a complex three-dimensional panel model is developed for aerodynamic modeling of the FROG UAV. CMARC off-body flow field calculations are used to generate static-source and angle-of-attack vane position corrections. Position corrections are provided in look-up table and curve fit formats. Basic longitudinal and lateral-directional stability derivatives are also developed with CMARC data. CMARC derived stability derivatives are sufficiently accurate for incorporation into an initial aerodynamic model. Adjustments through analysis of flight test data may be required. Future CMARC studies should concentrate on the development of the damping and control power derivatives.

AERODYNAMIC ANALYSIS OF A MODIFIED, PYLON-MOUNTED JSOW/CATM USING MULTI-GRID CFD METHODS

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Computational Fluid Dynamics (CFD) has become a major tool in aerodynamic analysis throughout the aerospace industries, complementary to traditional methods such as wind tunnel testing, and analytical calculations. In this research, an attempt was made to integrate the Similarity and Area Rules with CFD methods. Both tools, the Similarity/Area-Rule and CFD are used to derive the characteristics of complicated aerodynamic shapes in the transonic Mach number regime. It was found that the Similarity Rule can only be verified qualitatively. On the other hand, the Area Rule can be more completely verified. The aim was to find ways to minimize the drag of the training configurations of the Air-to Ground (A/G) weapon, Joint-Standoff-Weapon (JSOW), in its Captive-Air-Training-Missile (CATM) configuration. By analyzing the combination of CATM and Pylon, it was found that the drag of this configurations depends on the average slop of the area cross-section distribution of the afterbody. The CFD tools used were state-of-the-art grid generation code GRIDGEN, and multi-grid integration code PEGSUS; the configurations were run with the OVERFLOW solver using Euler, as well as Navier-Stokes solutions. For drag optimization, Euler solutions give adequate results, the need for NS solution can be restricted to more intensity viscous analysis.

MODELING AND ANALYSIS OF HELICOPTER GROUND RESONANCE UTILIZING SYMBOLIC PROCESSING AND DYNAMIC SIMULATION SOFTWARE

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This thesis develops a technique for formulating the full nonlinear equations of motion for a coupled rotor-fuselage system utilizing the symbolic processing software MAPLE®. The symbolic software is further utilized to automatically convert the equations of motion into C, Fortran or MATLAB® source code formatted specifically for numerical integration. The compiled source code can be accessed and numerically integrated by the dynamic simulation software SIMULINK®. SIMULINK® is utilized to generate time history plots of blade and fuselage motion. These time traces can be used to explore the effects of damping nonlinearities, structural nonlinearities, active control, individual blade control, and damper failure on ground resonance. In addition, a MATLAB® program was developed to apply the Moving Block Technique for determining modal damping of the rotor-fuselage system from the time marching solutions.

A STUDY ON THE INFRARED SUSCEPTIBILITY OF THE SH-60B SEAHAWK TO THE SA-16 GIMLET IR SAM (U)

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The survivability of a helicopter in a hostile man-made environment is a function of the aircraft's vulnerability and susceptibility. Because vulnerability is determined in the aircraft's design, susceptibility is the primary concern of the aircrew and mission planners.

The Navy's SH-60B Seahawk was initially designed for the primary mission of Undersea Warfare (USW) in the benign open ocean environment. It has since evolved into a multi-mission platform with the added roles of Antisurface Warfare (ASUW) and ASUW attack. Furthermore, the helicopter must now confront the potential threats associated with the littorals, those coastal regions characterized by high sea and air traffic.

This thesis will investigate the susceptibility of the SH-60B Seahawk to the Russian SA-16 infrared missile, a man-portable air-defense system (MANPAD). The digital computer program MOSAIC (Modeling System for Advanced Investigation of Countermeasures) will be used to evaluate the SH-60B's current infrared countermeasure systems.

INCORPORATION OF JOINT STANDOFF WEAPON STEERING COMMANDS WITH CARRIAGE AIRCRAFT

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A combined student/faculty team at the Naval Postgraduate School has been working on the conceptual design of the Unitary Joint Standoff Weapon (JSOW) Captive Air Training Missile (CATM). Previous work included modeling the JSOW's guidance and control system using the MATLAB/Simulink software package. This thesis, covering the next step in the design process, involves developing algorithms to display timely and realistic course changes to the pilot of the carriage aircraft. The carriage aircraft and algorithms were modeled using MATLAB/Simulink and XMATH/Systembuild software packages. A six-degree of freedom input device allows pilots to "fly" the carriage aircraft in a computer simulation of the JSOW CATM-aircraft interface. Steering commands are displayed on a virtual cockpit, designed by another team member using Designer's Workbench software.

ACTIVE VIBRATION CONTROL OF FLEXIBLE STRUCTURES USING THE MODULAR CONTROL PATCH (MCP)

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Active vibration control has been increasingly used as a solution for spacecraft structures to achieve the degree of vibration suppression required for precision pointing accuracy that is not easily achieved with passive damping. This thesis examines the effectiveness and suitability of the Modular Control Patch (MCP) to achieve active vibration control on flexible structures. The MCP was developed by TRW for the United States Air Force and uses a digital signal processor to implement control algorithms. The objective of the MCP program was to design a miniaturized multi-channel digital controller suitable for space-based vibration control. Three different control laws: Positive Position Feedback (PPF), Strain Rate Feedback (SRF), and Integral control were realized using the MCP. These control laws were used independently and in combination in order to discover the most effective damping for the first two modal frequencies on a cantilevered aluminum beam. Two PPF filters in parallel provided the most effective mulit-mode damping. Further experiments tested the robustness of the PPF control law implemented by the MCP. Increasing the compensator damping greatly improved PPF robustness and expanded its capability as an effective controller.

STRUCTURAL DESIGN ANALYSIS OF THE TAIL LANDING GEAR BAY AND THE VERTICAL/HORIZONTAL STABILIZERS OF THE RAH-66 COMANCHE HELICOPTER

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The RAH-66 Comanche's stealth design requires the use of radar-absorbing material (RAM) on the outer skin of the aircraft. The reduced stiffness properties of RAM produce insufficient tail torsional stiffness, necessitating the use of non-radar-absorbing graphite on the outer skin of the prototype's tail section. This thesis investigates structural design modifications to increase the tail section's stiffness to allow the use of RAM on the outer skin and still meet all structural requirements. An original model represents the prototype aircraft at first flight. The goal is to create a model using RAM on the outer skin that matches the structural stiffness of the original model. This thesis builds on earlier work conducted at the Naval Postgraduate School (NPS). Two new design modifications to the tailcone are developed. The best modification increases the torsional stiffness of a baseline model by six percent. Integrating earlier NPS modifications increases torsional stiffness by 12 percent. When RAM is applied to the outer skin of the modified model, torsional stiffness is reduced by only six percent from the baseline as compared to a 24 percent reduction with no modifications. Additional modifications to the vertical and horizontal stabilizers further increase structural stiffness and reduce weight.

INTEGRATION OF COMMERCIAL MOBILE SATELLITE SERVICES INTO NAVAL COMMUNICATIONS

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Mobile Satellite Services (MSS) need to be integrated into Naval Communications. DoD SATCOM military-owned systems fall well short of meeting DoD SATCOM requirements in general and mobile SATCOM specifically. This thesis examines DoD SATCOM requirements, especially those affecting communications on the move. From these requirements, three systems—Inmarsat, Iridium and Globaistar—are identified and evaluated for potential use in Naval Communications. An overview of space communications and each of the three systems is provided to identify general operational capabilities, system strengths, and system weaknesses. The Naval narrowband functional requirements process is explored and DoD SATCOM and Commercial MSS ability to satisfy those requirements is assessed. Potential Naval MSS communications missions are examined and possible DoD enhancements are considered for each system as well as the impact these enhancements will have on each system. Recommendations are provided as to which Naval communications missions are best suited for these enhanced MSS.

ANALYSIS OF POTENTIAL STRUCTURAL DESIGN MODIFICATIONS FOR THE TAIL SECTION OF THE RAH-66 COMANCHE HELICOPTER

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The Army RAH-66 Comanche Helicopter made its first flight in January of 1996. Its current structural configuration, however, does not meet the Army's requirements for radar signature. Structural configurations of the tailcone that meet radar cross-section requirements tend to lack sufficient structural stiffness due to the presence of Kevlar in place of graphite on the outer mold line. This thesis investigates potential structural design modifications to the Comanche tailcone that would move the design closer to meeting both its structural and radar signature requirements. Structural geometry modifications with baseline (current configuration) materials increased torsional stiffness by six percent. Geometry modifications using radar signature-compliant materials reduced torsional stiffness by 15 percent. The geometry changes analyzed produce structural performance improvements insufficient to allow the use of radar-compliant materials without further geometry changes.

EXPERIMENTAL AND COMPUTATIONAL ANALYSIS OF SEPARATION BUBBLE BEHAVIOR FOR COMPRESSIBLE, STEADY AND OSCILLATORY FLOWS OVER A NACA 0012 AIRFOIL ($M\bullet = 0.3$, $Re_c = 540{,}000$)

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In this thesis, the separation bubble behavior and its effect on the steady and dynamic stall characteristics of a thin airfoil in a compressible flow at a transitional Reynolds number was studied. For such flows, laminar separation occurs near the airfoil leading edge, but turbulent reattachment occurs within a short distance downstream, forming a separation bubble in the underlying region. Two experimental techniques, point diffraction interferometry (PDI) and laser doppler velocimetry (LDV), were used to acquire detailed flowfield information that showed the development of the leading-edge separation bubble and its subsequent bursting at higher angles of attack. The initiation of the stall process from the leading-edge separation bubble as opposed to trailing-edge flow reversal pointed to the need for transitional flow analysis. Both in the boundary layer and Reynolds-averaged, Navier-Stokes (N-S) analysis methods, transition models were incorporated to determine the location and extent of the transition zone that best modeled the measured separation bubble behavior. Computed results for steady flow gave remarkable agreement with the measurements. The computations compared favorably with the measurements for an airfoil oscillating in pitch about the quarter-chord point during the airfoil upstroke. However, the computations did not predict the light stall and vorticity-shedding process that was measured during the airfoil downstroke.

DEVELOPMENT AND COMPARISON OF THE SH-60B USAGE SPECTRUM
BASED ON HEALTH AND USAGE MONITORING SYSTEM DATA
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One possible bridge between continued high helicopter readiness rate requirements and restricted maintenance budgets is the Health and Usage Monitoring System (HUMS). This system, installed on one U.S. Navy SH-60B helicopter, is designed to monitor and record flight control positions, aircraft flight regimes and aircraft drive system vibrations in an effort to provide early notification of potential component failure and to provide a vibration trend analysis basis for component replacement. Currently, the U.S. Navy bases SH-60B helicopter component replacement on a predicted aircraft usage spectrum, which calls for component replacement after a fixed number of aircraft flight hours.

This research develops an aircraft usage spectrum from the detailed flight and aircraft parameter data recorded by HUMS and compares it with the current U.S. Navy SH-60B usage spectrum. Using the HUMS usage spectrum, component replacement times are calculated for four of the most frequently replaced SH-60B components and these results are compared with currently used replacement times for these components.

MODELING IN THE DESIGN AND ANALYSIS OF A
HIT-TO-KILL ROCKET GUIDANCE KIT
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This thesis presents several computer models used in the design and analysis of a Hit-to-Kill Rocket Guidance Kit (HRGK). The HRGK—proposed as an inexpensive add-on kit—has the potential of converting unguided 2.75" diameter rockets into precision weapons against non-tank targets. A Naval Postgraduate School design team recently participated in a nationwide graduate student competition for the design of such a kit. The design and analysis process led the author to develop and use various computer models and simulations. This thesis documents three distinct types of computer models found useful in the design.

The first, operational effectiveness modeling, established the cost effectiveness of the NPS HRGK. The second was related to the preliminary sizing of various design aspects—ensuring the proper flow-down of system requirements into design specifications. The third was a six-degree of freedom (6DOF) simulation, developed to perform detailed analyses of the HRGK's performance.

Although the models presented in this thesis pertain to the HRGK, the basic principles apply to the design or evaluation of other missile systems, and this thesis provides general insights regarding the benefits and limitations of computer modeling in missile design.

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