SMART STRUCTURES

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

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

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

PUBLICATIONS:

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

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

THESES DIRECTED:

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

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

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Smart Materials, Adaptive Structures, Vibration Isolation

SPACECRAFT SYSTEMS

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

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

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

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

PUBLICATIONS:

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

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

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

CONFERENCE PRESENTATION:

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

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Spacecraft Design, Spacecraft Attitude Control, Space Manipulator

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

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

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

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

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

PUBLICATIONS:

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

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

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

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

DoD KEY TECHNOLOGY AREA: Other (Helicopter Blade Stall)

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

RESEARCH ON AUTONOMOUS AIR VEHICLES

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

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

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

THESES DIRECTED:

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

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

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

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

VIRTUAL PROTOTYPING OF AVIONICS SYSTEMS

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

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

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

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

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

TURBINE TIP-LEAKAGE FLOWS

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATIONS:

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

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

THESES DIRECTED:

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

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

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

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

DEPLOYMENT OF THE APEX AIRCRAFT AT HIGH ALTITUDE

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

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

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

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

KEYWORDS: Airdata, Aerodynamics, Flight Mechanics

UNMANNED AERIAL VEHICLE (UAV) MARINIZATION

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

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

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

PUBLICATIONS:

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

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

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

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

ADVANCED AVIONICS TECHNOLOGY

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

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

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

THESES DIRECTED:

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

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

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

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

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

PUBLICATIONS:

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

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

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

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

KEYWORDS: GPS, Flight Control, Rapid Prototyping

CLOSED-LOOP PITCH CONTROL EFFECTOR SIZING

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

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

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

PUBLICATION:

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

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

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

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

THESIS DIRECTED:

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

PASSIVE SENSOR-BASED CONTROL OF NONLINEAR AUTONOMOUS SYSTEMS

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

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

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

PUBLICATIONS:

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

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: UCAV, Unihabited Combat Air Vehicles, Sensor Fusion

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

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

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

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

DoD KEY TECHNOLOGY AREA: Other (Unmanned Aerial Vehicles)

KEYWORDS: UAV, Controls

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

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

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

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

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

CONFERENCE PRESENTATION:

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

THESIS DIRECTED:

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

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Conventional Weapons

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

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATIONS:

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

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

THESIS DIRECTED:

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

DoD KEY TECHNOLOGY AREA: Other (Missile Signatures)

KEYWORDS: Missile, Propulsion, Signature, IR, Soot

AIRCRAFT/MISSILE/SPACECRAFT DESIGN

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

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

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

THESIS DIRECTED:

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

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

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

ENVIRONMENTAL SECURITY

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

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

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

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

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

WAVERIDER CONFIGURED AIRCRAFT/SPACECRAFT DESIGN

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

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

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

THESIS DIRECTED:

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

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

KEYWORDS: Waverider, Aircraft, Spacecraft

AIRCREW-CENTERED SYSTEM DESIGN

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

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

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

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

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

UNINHABITED COMBAT AIR VEHICLES (UCAV) MISSION DEFINITION

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

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

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

PUBLICATIONS:

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

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

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

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

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

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

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

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

PUBLICATION:

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

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

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

SUBSONIC AIRCRAFT AND UNMANNED AIR VEHICLE AERODYNAMICS

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

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

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

PUBLICATIONS:

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

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

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

CONFERENCE PRESENTATION:

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

THESES DIRECTED:

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

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

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics)

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

DEVELOPMENT OF SMALL UNMANNED AIR VEHICLES

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATIONS:

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

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

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

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

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

DISSERTATION DIRECTED:

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

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Hydrodynamics)

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

ADVANCED MULTIDISCIPLINARY ANALYSIS AND DESIGN OPTIMIZATION METHODS FOR SUBSONIC TRANSPORT AIRCRAFT

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

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

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

PUBLICATIONS:

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

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

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

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

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

THESIS DIRECTED:

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

DoD KEY TECHNOLOGY AREA: Other (Aerodynamics/Structures)

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

FIN FLUTTER ON HYPERSONIC MISSILES

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

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

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

DoD KEY TECHNOLOGY AREA: Other (Aeroelasticity)

KEYWORDS: Aeroelasticity, Missile Technology, Hypersonic Flow

GUST LOAD ANALYSIS

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

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

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

DoD KEY TECHNOLOGY AREA: Other (Aeroelasticity)

KEYWORDS: Aeroelasticity, Aircraft Technology, Subsonic Flow

USING SLBMs FOR LAUNCHING SMALL SATELLITES

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

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

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

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

PUBLICATION:

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

CONFERENCE PRESENTATION:

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

DoD KEY TECHNOLOGY AREA: Space Vehicles

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

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

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

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

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

PUBLICATION:

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

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Space Systems Engineering, Space Mission Architect

ADVANCED FAN AND COMPRESSOR DEVELOPMENT STUDIES

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATIONS:

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

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

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

THESIS DIRECTED:

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

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

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

HIGH CYCLE FATIGUE (HCF)/SPIN TEST RESEARCH

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

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

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

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, Blade Excitation

UNINHABITED AERIAL VEHICLE (UAV) PROPULSION TECHNOLOGY

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

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

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

THESES DIRECTED:

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

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

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

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

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

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATION:

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

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

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

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

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

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

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

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

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

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

PUBLICATIONS:

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

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

CONFERENCE PRESENTATION:

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

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

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

WEAPONS PERFORMANCE MODEL FOR RAH-66 *COMANCHE* HELICOPTER

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

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

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

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

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

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

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

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

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

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

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

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

THESIS DIRECTED:

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

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

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