Division of Engineering and Weapons

CAPT Douglas H. Rau, USN
Director

Aerospace Engineering Department

CAPT Robert J. Niewoehner, USN
Chair

The capstone courses highlighted this year's research in the Aerospace Engineering Department. The Astronautical Engineering tract students launched their prototype communications satellite, *PCSat*, on 30 September 2001, from Kodiak Island, Alaska. Amateur radio operators have used the satellite extensively worldwide since it's launch, which was the culmination of research from the previous three graduating classes. The Aeronautical Engineering tract students flew two airplanes in the American Institute of Aeronautics and Astronautics (AIAA) international remote control airplane contest in Wichita, Kansas. The airplanes were designed, built and tested throughout the academic year and were flown in competition the last week of April 2002. Students and faculty enjoyed outstanding support from the National Air and Space Administration (NASA), the Naval Space Command, the Naval Research Laboratory (NRL), the U.S. Air Force Space Test Program and the Boeing Corporation to accomplish their research in the capstone courses.

The research and publication efforts of the aerospace engineering faculty and students covered a broad range of topics from astrophysics to flight test and performance. Additional topics in flaps and leading edge research were also explored.

Sponsored Research Projects

U.S. Naval Academy Small Satellite Program

Researchers: Midshipmen majoring in Aerospace Engineering – Astronautics Track
Advisers: Professor Daryl G. Boden and LtCol Billy R. Smith, USAF
Sponsor: Boeing Astronautics

The United States Naval Academy Small Satellite Program is a series of small satellites designed, fabricated, tested, launched, and operated by midshipmen at the United States Naval Academy. *PCSat*, launched on 30 September 2001, was the first of the series.

REX II Operations

Researchers: Professor Daryl G. Boden, and CDR Robert Bruninga, USN (Ret)
Sponsor: United States Air Force Space Test Program

The United States Naval Academy Satellite Ground Station (SGS) provides operational control on the REX II spacecraft on a daily basis.

Investigation of the Effect of the Leading Edge Flap on the Dynamics of the Axial Sting Balance

Researcher: Professor Gabrielle N. Karpouzian
Sponsor: Office of Naval Research (ONR)

In the course of the dynamic wind tunnel testing of the F/A-18E model in the 16ft Transonic Wind Tunnel at Langley Research Center, it has been observed virtually from measurements that the axial force on the sting balance exhibited a large amplitude of fluctuations in an intermittent manner when the leading-edge flaps were deflected 0 degrees. In order to ascertain whether or not there is such causality, the cross-correlations between the time histories of the surface pressure measurements by the transducers on the leading edge flaps of the wing with the axial force measurements were analyzed. The results were obtained for a Mach number of 0.9 with a 10/10/5 flap schedule and for angles of attack ranging from 7 to 10 degrees. The three consecutive numbers for the flap schedule indicate leading edge flap, trailing edge flap, and aileron deflection angles in degrees,

respectively. It is shown that the power spectral densities for the axial force indicate that the dynamics of the sting balance is dominated by a single harmonic of approximately 40Hz for angles of attack 7, 8 and 9 degrees. For 10 degrees, the power spectrum exhibits the same fundamental harmonic followed by two superharmonics, 80 Hz and 120 Hz. The power spectra at the leading edge do not duplicate the same frequency content as those for the sting balance. For 7 and 10 degrees, the spectra show a cascading behavior with no distinct harmonics, whereas for 8 and 9 degrees, they contain a fundamental harmonic of 25 Hz, followed by two superharmonics, 50 Hz and 75 Hz. This shows that there is no evidence of the influence of leading edge flaps on the dynamics of the axial force component of the balance.

Leading Edge Micro-Spoiler Aircraft Control

Researchers: Associate Professor Karen A. Flack (Mechanical Engineering Department)
and Assistant Professor David S. Miklosovic
Sponsor: Office of Naval Research (ONR)

This research, originally supporting an Internal Laboratory Independent Research (ILIR) Program conducted by Naval Air Systems Command Branch 4321, is a collaborative effort between the U.S. Naval Academy (USNA) and the Naval Air Warfare Center (NAVAIR) to develop control paradigms using leading edge microactuated spoilers on Unmanned Combat Aerial Vehicles (UCAVs). Specifically, representative delta wing models were wind tunnel tested to determine the feasibility and efficacy of combinations of leading edge spoilers, apex/outboard fences, vortex trapping devices, and MEMS actuators for aircraft longitudinal and directional control. This program has the potential to explore novel techniques for the control of UCAV configurations that preserve aircraft stealth characteristics with only moderate decrements to agility. Data obtained at NAVAIR of a lambda wing UCAV configuration was compared to data of USNA's representative sharp edge delta wing models to determine compatibility of results and to establish baselines for trade studies. USNA wind tunnel data was benchmarked using a Vortex Lattice analysis code obtained from NASA Langley. A detailed literature search into delta wing aerodynamics and control was conducted and a baseline configuration has been established, measured, and benchmarked for a half – and a full-delta wing model. Furthermore, improvements to the USNA Closed Circuit Wind Tunnel (CCWT) have been accomplished to help upgrade it to a research quality facility. This has included developing a portable, automated data acquisition system, writing the data acquisition and reduction software, and fabricating a boundary layer splitter plate to minimize wall interference effects for floor-mounted half model testing.

E-2C Propeller Visibility Enhancements

Researcher: Assistant Professor David S. Miklosovic
Sponsor: Noesis, Inc.

In the frenzied environment of a big deck carrier during flight operations, a low visibility, spinning propeller blade creates a considerable hazard to personnel. This research focused on application materials and techniques to greatly improve the visibility of the E-2C propellers during operations. Different photo-luminescent and reflective materials have been applied using diverse adhesives and sealants to representative wind tunnel propeller models of 10-15% scale. The propellers were driven with a brushless DC motor and were tested in a wind tunnel at thrust coefficients and blade tips speeds that are representative of the E-2C flight envelope. Results showed that the representative flight conditions could be achieved with the small-scale models, but maximum values could not be attained due to limitations in the DC drive motor. The flight-operating envelope of the propeller yields a maximum thrust coefficient of approximately 0.2, but little more than 0.1 could be achieved in the wind tunnel. Approximately 60% of the power coefficient could be achieved. At these wind tunnel conditions, all films that were applied with an edge sealer remained affixed to the propeller models. This research task supported SBIR Topic N01-158, Enhanced Propeller Visibility (Phase 1). As a result of this collaboration, the Naval Academy is now leveraged to support a Phase 2 SBIR award.

Static Performance Evaluation of the Dragon Warrior Rotor

Researchers: Mr. Greg Page (Naval Research Laboratory)
and Assistant Professor David S. Miklosovic
Sponsor: Naval Research Laboratory (NRL)

Dragon Warrior is a joint effort between the Naval Research Laboratory (NRL) and the Marine Corps Warfighting Laboratory (MCWL) to develop a Humvee (HMMWV)-transportable, vertical take-off and landing (VTOL) unmanned air vehicle for U.S. Marine Corps missions. With its fully autonomous flight operation and differential GPS navigation, the Dragon Warrior will perform Reconnaissance Surveillance Target Acquisition (RSTA) and Communications Relay missions. The first full-scale prototype flight tests are scheduled beginning May 2002, with mission demonstrations beginning in 2003. The overall body length will be 84 inches with a rotor diameter of 96 inches. With a gross weight of 250 lbs and a payload capacity of 25-35 lbs, Dragon Warrior will have an estimated endurance of 3-5 hours and a dash speed of 100kt. This research involves testing the Dragon Warrior rotor on a reaction plate mounted in the Naval Academy Rotor Test Facility. Thrust and torque measurements are being taken at full-scale operational conditions.

Independent Research

Rapid Binary Gage Function for Extracting a Pulsed Signal Buried in Noise

Researchers: Associate Professor Colin P. Ratcliff (Mechanical Engineering Department),
Professor Emeritus William J. Bagaria, Associate Professor Sonia M. Garcia (Mathematics Department)
and Visiting Professor Richard P. Fahey

The type of signal studied in this research is a period pulse, with the pulse length short compared to the period, and the signal buried in noise. If standard techniques such as the Fast Fourier Transform are used to study the signal, the data records needs to be very long. Additionally, there would be a very large number of calculations. The Rapid Binary Gage Function was developed to quickly determine the period of the signal, and the start time of the first pulse in the data. Once these two parameters are determined, the pulsed signal can be recovered using a standard data folding and adding technique.

Analytic and Experimental Aerodynamic Characterization of a Multiple-Bladed Flapped Autorotational Deceleration

Researcher: Assistant Professor David S. Miklosovic

This research supports a collaborative development program for the Rotary-wing Decelerator Vehicle (RDV), a precision-guided aerial delivery system for the U. S. Armed Forces. Based on an unpowered auto-rotating rotor, this system will significantly surpass the capabilities of conventional fabric canopies for precision aerial delivery of equipment and supplies. The principle advantages of this system include: increased aircraft/airborne force survivability, improved airdrop accuracy, reduced losses, autonomous guidance. The research approach involves applying established analytic methods to predict autorotor performance and conducting wind tunnel tests of a 1/10-scale model rotor. Different control surfaces are considered by measuring the effectiveness of statically configured devices in the wind tunnel to determine the optimum configuration for a full-scale model. This work is being done in collaboration with Dr. Dan Stilwell of Virginia Tech University. The research has spawned a midshipman independent study project and led to a white paper solicitation from USD Acquisition, Technology, and Logistics.

Roughness Effects on Lift and Drag of a Laser Centerboard

Researchers: Assistant Professor David S. Miklosovic and
Assistant Professor Michael P. Schultz (Naval Architecture and Ocean Engineering Department)

Recent research at the U.S. Naval Academy demonstrated that surface roughness has a first-order effect on the hydrodynamics drag of flat plates. In an effort to apply these results to a geometry having an imposed pressure gradient, wind tunnel tests were conducted on production laser centerboards modified for mounting purposes. The centerboard has a symmetric

NACA 0009 airfoil section and a sweep of about 15 degrees and was tested at the same Reynolds numbers experienced during sailing. After baseline tests were performed with a "production-quality" surface finish, a rough paint coating was successively sanded down to finer finishes. The results showed very minor improvements in the drag and the lift-to-drag ratio as the surface finish became smoother, but the magnitude of change was barely above the sensitivity of the instrumentation. This was attributed to the large percentage of turbulent flow over the conventional airfoil section at Reynolds numbers around 1 million. Plans to test a laminar flow section on a centerboard model are being considered.

Wind Tunnel Measurements of the Effects of Tubercles on a Humpback Whale Flipper

Researchers: Assistant Professor David S. Miklosovic and
LCDR Mark M. Murray, USN (Mechanical Engineering Department)

Humpback whales are baleen whales, with stocky bodies that are 40-50 feet long. The body is not as streamlined as other rorquals, but is quite round, narrowing to a slender peduncle (tail stock). Unusually large flippers (10-15 feet in length) aid whale locomotion and maneuvering. This research modeled the humpback flipper to varying degrees of geometrical accuracy in order to determine the function of the tubercles. It was anticipated that these raised knobs on the flipper produced lift improvements at high angles of attack and drag improvements at low Reynolds numbers. The flipper was modeled in acrylic using three geometries: as an idealized smooth wing, a smooth wing with a sinusoidal leading edge profile, and a scaled casting of an actual humpback flipper. Wind tunnel tests are being conducted at nearly the same Reynolds numbers experienced in the ocean (1-2 million). This work is a collaborative effort with the Mechanical Engineering Department and Duke University and is in progress.

Research Course Projects

Abrupt Wing Stall and Spectrum Methods

Researcher: Midshipman 1/C Jerrod S. Hair, USN
Adviser: Professor Gabriel N. Karpouzian

Abrupt Wing Stall (AWS) is an uncommanded, abrupt rolling motion caused by a sudden loss of lift over one wing prior to the other. It was discovered on the U.S. Navy F/A-18E fighter during high-speed maneuvers (Mach 0.8-0.9) at angles of attack ranging from 7 – 10 degrees. Though an empirical solution was found and applied to mitigate the problem, the physics underlying the phenomenon is not yet well understood. Wind tunnel unsteady pressure data were taken over the wing of an F/A-18E model in an attempt to identify the cause of AWS. The data were analyzed using spectral methods for Mach 0.8. The power spectrum reached a maximum value at zero frequency and then decayed in a cascading manner towards higher harmonics, a well-known behavior of energy transfer from large eddies to smaller ones in a turbulent boundary layer. The peak spectra measured at each chordwise location on the wing were plotted against angle of attack. The coalescence of the peak spectra at two or more consecutive locations indicated shock-induced boundary-layer separation. The separation line on the port side of the wing did not coincide with that on the starboard side, thus creating a sudden rolling moment.

An Experimental Analysis of Camber Effects of a 6-Bladed Flapped Auto-Rotational Aerodynamic Decelerator

Researcher: Midshipman 1/C Jamie Bartz, USN
Adviser: Assistant Professor David S. Miklosovic

In an effort to evaluate the feasibility of implementing an articulated autorotor as an aerodynamic decelerator, this research delineated a series of wind tunnel tests on a scale rotor model. These tests were conducted in the U.S. Naval Academy Eiffel Wind Tunnel, which can accommodate a 24-inch rotor disk on the installed sting balance system. Results from this work provided basic sizing guidelines for full-scale decelerators and validated analytic methods involving the modified momentum method for this mode of rotor operation. To this end, this research encompassed the following three phases: the design of a 1/10-scale articulated flapping-blade autorotor model, the execution of the wind tunnel test matrix, and the comparison of experimen-

tal results with analytic predictions. As a result of the various model and test configurations, it was concluded that adding effective camber through the use of outboard flaps to the rotor blades has huge performance benefits over the baseline rotor configuration. The optimal flap configuration for the use in an autorotation capacity was in the range of 2-4 % camber. The 2% camber configuration produced the highest drag, and the 4% camber configuration resulted in the highest autorotation rate and therefore the lowest advance ratio. Given the conclusion of this research, for a larger scale rotor to be built, the ideal design would implement a 4% increase in camber due to the flaps. By creating a rotational aerodynamic decelerator similar in concept to this model with articulated blades, easy adjustments during flight could be made via computer input, which could effectively control drag characteristics.

Publications

Journal (Refereed) Manuscripts

PISACANE, Vincent L., Professor, "Space Systems and Design," *Encyclopedia of Physical Science and Technology*, Third Edition, pp. 15, 463-483; 2002.

This article presents an introduction to spacecraft design by describing each of the major subsystems that constitute a spacecraft system. The intent is to expose the reader to the fundamental functions and important characteristics of each subsystem. Through this, it is anticipated that the reader will gain an appreciation of the sophisticated development, launch and operations that are required for a successful mission. Sufficient references are provided for the interested reader to find additional information on any of the topics discussed. The topics covered include: systems engineering, astrodynamics, propulsion, launch systems, atltitude determination, attitude control, power systems, thermal control, structures, and telemetry, tracking and command.

PISACANE, Vincent L., Professor, (co-author), "Precision Bone and Muscle Loss Measurements by Advanced Multiple Projection (AMPDXA) Techniques for Space Flight Applications," *Acta Astronautica*, pp. 45, 3-10, 447-450, 2001.

An advanced multiple projection, dual energy, x-ray absorptiometer (AMPDXA) scanner system in under development. The AMPDXA is designed to make precision bone and muscle loss measurements necessary to determine the deleterious effects of micro gravity on astronauts as well as develop countermeasures to stem their bone and muscle loss. To date, a full size test system has been developed to verify principles and the results of computer simulations. Results indicate that accurate predictions of bone mechanical properties can be determined from as few as three projections, while more projections are needed for complete, three dimensional reconstruction.

ROGERS, David F., Professor, "An Engineering Flight-Test Course Emphasizing Flight Mechanics Concepts," *American Institute of Aeronautics and Astronautics (AIAA) Journal of Aircraft*, Vol 39, pp. 79-83 (2002).

To provide real-world experience for aeronautical engineering students at the U. S. Naval Academy, a flight-test engineering course was developed and implemented. The course used flights both in an actual aircraft and in a motion based simulator. Cost, scheduling, manpower, and safety were the principal considerations in obtaining approval. Using a rented aircraft and limiting the course enrollment to 12 students contained cost. The availability of an experienced pilot in the chosen aircraft also contributed to cost containment. Data acquisition was accomplished using handheld and standard onboard instrumentation. Selecting benign flight-test profiles contributed to safety. Experimental results were excellent, and the course was well received by students.

ROGERS, David F., Professor, and RATCLIFF, Colin P., Associate Professor (Mechanical Engineering Department), "Balanced Fuel Injector Effects on In-flight Aircraft Engine Vibration," *American Institute of Aeronautics and Astronautics (AIAA) Journal of Aircraft*, Vol 39, pp. 440-444 (2002).

Uneven fuel/air mixtures between cylinders in flat horizontally opposed fuel injected aircraft engines can contribute to vibration. A comparative in-flight study using standard fuel injector nozzles and balance flow fuel injector nozzles was conducted on a Teledyne Continental Motors IO 520 BB aircraft engine installed in Beech Bonanza under typical cruise flight conditions. The results indicate that balanced flow fuel injector nozzles reduce engine vibration for most fuel/air flow ratios.

ROGERS, David F., Professor, (Guest Editor), Pierre Etienne Bezier (1910-1999), in memoriam, *CAD*, Vol. 34, pp. 489-491, 2002.

Pierre Etienne Bezier was the technical father of Bezier curves and surfaces and children, i.e., NURBS. The editorial reviews Bezier's early history and the influence he had on the development of computer aided design and manufacturing at the Naval Academy.

Conference Proceedings

KARPOUZIAN, Gabriel, N., Professor, "Abrupt Wing Stall Analysis of an F/A-18E Model in Unsteady Transonic Flow," *Proceedings of International Forum on Aeroelasticity and Structural Dynamics*, Vol 3, pp. 217-228, June 2001.

Study of the Abrupt Wing Stall (AWS) problem of an 8% scale of an F/A-18E wind tunnel model is presented. Spectral Analysis is applied to the time histories of the unsteady wing surface pressure distributions measured in the transonic dynamic wind tunnel of Langley Research Center. A part of the data used in this study corresponds to a Mach number of 0.9 and angle of attack ranging from 7 to 10 degrees. The analysis shows that the pressure spectra over the wing surface are dominated by large eddies of fixed size with varying energy content, accompanied with turbulent fluctuations of such intensity indicative of flow separation. The vortex-shock-boundary-layer interactions manifest themselves in the pressure spectra according to the energy content level in the eddies. On the inboard side of the wing, a well-behaved flow over most of the wing section is revealed in the pressure spectra, with some separation present in the aft region of the shock. However, on the outboard section of the wing, the shock appears to oscillate back and forth over a distance of 10-15 % chord. Behind the shock, vortex breakdown occurs inducing massive flow separation over a sizeable portion of the wing surface. It is conjectured that the intermittent behavior of the complex flow field over the outboard wing sections may be responsible for the AWS phenomenon.

Newsletters

ROGERS, David F., Professor, "Turn Performance – Altitude Effects," *Newsletter of the World Beechcraft Society*, Sept./Oct. 2001, pp. 14-15.

Discusses the effects of altitude on the ability to maintain a level turn. Determines the available range of true air speeds for sustained level turns at various bank angles up to altitudes of 17,000 feet.

ROGERS, David F., Professor, "Vortex Generator Flight Test – Cruise Performance Effects," *Newsletter of the World Beechcraft Society*, March/April 2002, pp.12-13.

Discusses the effects of the addition of vortex generators to the wing, ailerons and vertical stabilizer of a single engine light general aviation aircraft. Before and after flight tests were used. A reduction in cruise velocity was observed throughout the tested cruise speed range. For example at 65% power at a pressure altitude of 6000 feet, a reduction of 4.4 knots indicated airspeed was observed.

ROGERS, David F., Professor, "Vortex Generator Flight Tests - Stall Effects," *Newsletter of the World Beechcraft Society*, Jan/Feb 2002, pp. 14-16.

Discusses the effects of the addition of vortex generators to the wing, aileron, and vertical stabilizer of a light, single engine, general aviation aircraft. Using before and after comparison flight test of 3-8 MPH, a reduction in stall velocity was observed. The flying qualities of the aircraft when fully stalled both power on and power off were somewhat degraded.

ROGERS, David F., Professor, "Speed Stability," *Newsletter of the World Beechcraft Society*, Nov/Dec 2001, p. 13.

Discusses classical aircraft speed stability on both the front side and the backside of the power available and power required curves.

Presentations

MIKLOSOVIC, David S., Assistant Professor, "Leading Edge Micro-Spoiler Aircraft Control," Brief to Naval Air Warfare Center (NAVAIR 4.3.2), Patuxent River, MD, 19 October 2001.