Division of Engineering and Weapons

CAPT Douglas H. Rau, USN
Director

Aerospace Engineering Department

Professor Daryl G. Boden
Chair

The research and publication efforts of the aerospace engineering faculty and students covered a broad range of topics in aeronautics, astronautics, rotor dynamics, and engineering education.

The capstone courses highlighted this year's research in the Aerospace Engineering Department. Following the success of the Naval Academy's first satellite, *PCSat*, all the midshipmen in the capstone design course for the Astronautical Engineering track continued work on the design of small satellites that we expect to launch in the future. The Aeronautical Engineering track students designed, built, and tested three unmanned aerospace vehicles (UAVs) for an external customer.

Students and faculty enjoyed outstanding support from the National Aeronautics and Space Administration (NASA), the Naval Network and Space Operations Command, the Naval Research Laboratory (NRL), the U. S. Air Force Space Test Program, the Naval Air Warfare Center (NAWC), the National Center for Advanced Manufacturing, the Defense Intelligence Agency (DIA), Noesis Inc, and the Boeing Corporation to accomplish their research and to support the capstone courses.

The department also joined the Conceive-Design-Implement-Operate (CDIO) Initiative. This effort has initiated pedagogical research on engineering education within the department and resulted in presentations at CDIO meetings.

Sponsored Research

MISSE5/PCSAT2 Communications System

Researchers: CDR Robert Bruninga, USN (Ret.), Midshipman 1/C Carlos Otero, USN,
Midshipman 1/C Michael Silver, USN, Midshipman 2/C Sean Jones, USN,
Midshipman 1/C Thomas Kolwicz, USN, Midshipman 1/C Harry Evans, USN,
Midshipman 1/C Edmund Henry, USN
Sponsor: Naval Research Laboratory (NRL)

PCSat2 was a follow-on opportunity to fly a modification and upgrade to our original *PCSat* communications payload on the Materials on ISS Experiment MISSE5. By modifying our *PCSat* off-the-shelf communications transponder design we were able to offer to the Naval Research Laboratory a very short-fuse rapid-response telemetry and communications package to support the command and control needs of their MISSE5 experiment while adding to our on-orbit constellation of the Naval Academy's digital communications satellites. This transponder will provide data, voice and multi-channel shared user educational access to the Amateur Satellite Service while attached to the outside of the International Space Station. All integration and testing was accomplished this year. The satellite is complete and awaiting launch on the first Space Shuttle Return to Flight mission.

Low Light Level Illumination for Enhanced Propeller Visibility

Researchers: Assistant Professor David S. Miklosovic, CDR James Jones, USN,
and Mr. Richard W. Garman (Aerospace Engineering Dept staff)
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 focuses on application materials and techniques to greatly improve the visibility of the E-2C propellers during operation. Different photo-luminescent and reflective materials and diverse adhesives have been identified to improve spinning propeller visibility.

This program seeks to develop a current-technology method for enhancing the visibility awareness of aircraft

propellers during operations to ensure crew safety. The program has the following goals:

- To validate aerodynamic performance and to reduce technical risk, of a photo luminescent propeller visual warning system, prior to actual flight testing.
- To establish and then to minimize the impact on weight and power requirements for an E-2C propeller with a photo luminescent propeller visual warning system.
- To validate these methods to be readily incorporated on existing propellers.
- To maximize durability in a rigorous marine environment (optional).
- To test and refine a photo luminescent propeller visual warning system that will be capable of withstanding the operational forces on an E-2C propeller and provide the fleet with superior performance.

USNA supported this effort with propeller endurance testing and propeller performance deficit analysis. The propeller endurance testing involved production of aircraft propellers (50-74 inches in diameter) operated at 3500 RPM, thus allowing for more realistic test conditions (without mounting full-size E-2C propellers). The propeller performance deficit analysis involved an analytic effort to predict the performance deficit due to propeller blade applications. It included a simplified 2-D analysis on the airfoil section and a 3-D analysis on the propeller to estimate thrust and torque losses due to the applications.

Wind Tunnel Testing of Ship Motion Effect on Airwake

Researcher: Assistant Professor David S. Miklosovic
Sponsor: Naval Air Warfare Center, Code 4321

SAFEDI (Ship Aircraft Airwake Analysis for Enhanced Dynamic Interface) is an Office of Naval Research (ONR) sponsored initiative with a focus on developing computational fluid dynamics (CFD) airwake technology to enhance dynamic interface analysis, modeling, and simulation for all aircraft type and ship class combinations. One of the objectives of the program is to model the impact of ship motion on a ship's airwake using CFD. Validation data is required to provide confidence in the modeling capability. A wind tunnel test has been proposed that will enable the flow over a ship moving with single degree-of-freedom motion to be examined in a controlled environment. CFD calculations, using the same flow conditions and geometry as the wind tunnel, are being compared with the model-scale test results to determine the accuracy of the predictions. The wind tunnel measurements of the airflow over of a ship model are needed in the areas of the flight deck, the bow, the superstructure, and aft of the ship and at points along a typical helicopter approach profile.

The accomplishments of 2004 involved the fabrication of the DD-963 hull and superstructure geometry, development of the model pitch mechanism, and the specification of PIV test parameters. The wind tunnel model hull was fabricated from a male pattern geometry using 0.040"-thick carbon fiber skin. The interior was reinforced with secondary layups (up to 0.040" additional skin thickness) and bulkheads every 6" along the ship axis. The net superstructure geometry was designed to be afixed in two levels of increasing detail. While the predicted weight was 14 lbs, the final fabricated weight was about 10 lbs. A cam/shaker arm mechanism was designed and analyzed to produce the desired pitch motion. Dynamic simulations of the model and pitch mechanism produced results that were used to specify the type and size of the drive motor and to define a system that was dynamically balanced. Maximum model rotation rates and accelerations were predicted to be 13.3 rad/sec and 2394 rad/sec^2. The resulting force on the cam button was determined to be 518 lbs and the required motor torque was calculated to be 16.5 ft-lbs. Thus, the Baldor BSM100N AC servomotor with a MintDrive II motion controller was chosen to drive the model pitch mechanism during the planned wind tunnel tests. This system has proven capable of driving the dynamic pitch motion to the desire rate of 12 Hz. Two days of focused training were completed for the stereoscopic PIV system, which was delivered in February. Several trade studies were performed to identify the critical timing settings of the laser and cameras and to establish a feasible flow seeding delivery system.

Midshipman Space Technology Applications Research Satellite-1 (MidSTAR-1)

Researcher: Associate Research Professor Billy R. Smith Jr.
Sponsor: Department of Defense Space Test Program

MidSTAR is a general-purpose satellite bus capable of supporting a variety of space missions by easily accommodating a wide range of space experiments and instruments. The integration of the experiments with the satellite bus must

be accomplished with minimal changes to the satellite bus design. MidSTAR is intended to be a relatively low-cost, quick response platform accommodating small payloads approved by the Department of Defense Space Experiments Review Board (SERB) and awaiting launch through Space Test Program (STP). MidSTAR satellites will be one of two types. MidSTAR mod 1 is designed for use on the Expendable Secondary Payload Adaptor Ring developed by Air Force Research Laboratory (AFRL) for placement on Delta IV or Atlas V expendable launch vehicles. MidSTAR mod 2, still to be developed, will be designed for deployment from the Space Shuttle via the Canister All Payload Ejection (CAPE) system developed by AFRL. Both mods are Class D spacecraft, produced at minimum cost with a correspondingly higher technical risk in production and operation. Both types of spacecraft are intentionally simple in design and rugged in construction, using commercial off-the-shelf "plug-and-play" components to the greatest extent possible. Component development and circuit-board level design are accomplished only when necessary. The baseline MidSTAR mission includes a single spacecraft under the command and control of a single satellite ground (SGS) station located at USNA, Annapolis MD. (Lat. 38.98 N and 76.49 W). The ground station forwards down linked data files to the Principal Investigators via the Internet. Secondary ground control will be available on an as-needed/space-available basis through Naval Postgraduate School (NPS), Monterey CA (36.6 N, 121.89 W). Launch segment for MidSTAR mod 1 is either the Delta IV or Atlas V EELV. Launch segment for MidSTAR mod 2 is the Space Shuttle CAPE. The orbit will be tailored to payload requirements; where no requirements exist, the orbit of the primary payload or one of the other secondary payloads will be accepted. In order for the spacecraft to be seen from USNA SGS at an elevation greater than 30 degrees and range simultaneously less than 900 km, the orbit must be 500 +/- 200 km with inclination greater than 35 degrees. MidSTAR-1 is the first implementation of the mod 1 design. It has been commissioned by STP to carry the Internet Communications Satellite Experiment for SSP (no. 39 on the 2002 SERB List) and the Configurable Fault Tolerant Processor (CFTP) Experiment for NPS (no. 34 on the 2002 SERB List). MidSTAR-1 is scheduled for launch on a Lockheed-Martin Atlas V from Cape Canaveral on the STP-1 mission in September 2006.

U.S. Naval Academy Small Satellite Program

Researchers: Midshipmen majoring in Aerospace Engineering – Astronautics Track
Advisors: Associate Research Professor Billy R. Smith Jr. and CDR Robert E. Bruninga, USN (Ret.)
Sponsor: Boeing Corporation

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.

Microcracking in Composite Laminates

Researcher: Professor Gabriel N. Karpouzian
Sponsor: National Center for Advanced Manufacturing (NCAM)

This NCAM-supported research outlines the ongoing effort to develop a Non-Destructive Evaluation (NDE)/theoretical model-driven approach to determine the extent of microcracking and the prediction of the remaining life of advanced composites used in the space environment. This involves refining high-resolution ultrasonic (UT) images to be even more predictive of physical properties of the composites. Parameters from the frequency spectrum of the UT waveforms, recorded during the imaging scan, are used to create frequency domain images. The frequency domain parameters have been used to both detect and discriminate between different defect categories in composites, such as microcracking, delaminations, and porosity. UT images have been constructed in such a way that colored regions within an image are indicative of a particular defect class, such as microcracking, at those locations. The large database of the NDE observations is used to correlate with the results of a shear-lag analysis for the stress and strain calculations in conjunction with an energy-based failure criterion. The strain energy release rate for crack initiation and propagation was adopted as the failure criterion for laminates. Micro-crack density and stiffness degradation under a progressive tensile load were determined for a laminate made of a fiber-reinforced carbon epoxy material (IM7/977-2) with a $90_4/0_8/90_4$ ply lay-up. The results show that the micro-crack initiation in the laminate began at 10% of the ultimate strength while the laminate stiffness degradation was about 6% of its un-cracked value.

Independent Research

TM-D700 Amateur Radio on the International Space Station (ARISS)

Researcher: CDR Robert E. Bruninga, USN (Ret.)

ARISS is an International Space Station follow-on to the Shuttle Amateur Radio Experiment (SAREX) which has its roots from the researcher's Summer Faculty Internship back in 1984 at NASA-Goddard. The project involves ongoing experiments flying on the Space Shuttle and now the International Space Station to provide low cost and volunteer educational opportunities for students around the world using amateur radio to communicate with astronauts and their spacecraft on orbit. This year's effort involved the detail modification and technical configuration of a TM-D700 transceiver to qualify it for space and prepare it for flight to the Station via a Russian Progress launch. As the international authority on the design and implementation of the APRS protocols in this commercial transceiver, the researcher worked with the international technical committee consisting of engineers from Japan and Russia as well as volunteer NASA engineers to meet the stringent requirements on schedule. The transceiver was launched to the station in August 2003 and has been operational since the winter 2004. The downlink from this experiment has been used for demonstrations in the Naval Academy's student satellite laboratories.

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

Researchers: Assistant Professors David S. Miklosovic
and Assistant Professor Mark M. Murray (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). Whale locomotion and maneuvering are aided by unusually large flippers that are 10-15 feet long. This research will model the Humpback flipper to varying degrees of geometrical accuracy in order to determine the function of the tubercles. It is anticipated that these raised knobs on the flipper produce 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, as 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 continuing collaborative effort with the Mechanical Engineering Department, Duke University, and West Chester University. A multi-year NSF grant is currently being pursued as a result of this independent work.

Midshipmen Research Course Projects

Design Specifications Development for Unmanned Aircraft Carrier Landings: A Simulation Approach

Researcher: Midshipman 1/C Jared Wolcott, USN
Adviser: CAPT Robert J. Niewoehner, USN

This project produced component elements for a simulation model of the T-34B airplane. The broader purpose of this effort is an engineering stability and control model which can be used to develop control laws for implementation on a T-34B. The following model components were completed: elevator and trim tab effectiveness, mathematical pilot model, and Continental IO-550 engine.

Composite Structural Integrity Assessment via High-Resolution Ultrasonic Microscopy

Researchers: Midshipman 1/C Eric D. Brege, USN, and Midshipman 1/C Clayton Sands, USN
Adviser: Professor Gabriel N. Karpouzian

This research, supported by the National Center for Advanced Manufacturing (NCAM), outlines the effort to develop a non-destructive evaluation (NDE)/theoretical model-driven approach to predict the design life based on the extent of microcracking through a composite structure. Microcracking is a phenomenon that exists when microscopic breaks occur in the matrix of a composite material. This is caused when the energy dissipated throughout the material exceeds the critical strain energy release rate. In order to quantify these energies, specimens are tested under varying loads level to failure. The microcrack density of each specimen is obtained using NDE, specifically ultrasonic acoustic microscopy. These results are correlated to a dimensionless parameter so that it can be incorporated into the theoretical model. The latter uses the shear lag approach to predict the microcrack density as a function of applied load level. Once this prediction model is complete, a portable PC-based system can be configured in order to predict the remaining life in specific composite applications.

Satellite Command and Data Handling System

Researcher: Midshipman 2/C Sean A. Jones, USN
Adviser: Associate Research Professor Billy R. Smith Jr.
Sponsor: Department of Defense Space Test Program

The mission of the Command and Data Handling System (C&DH) is to receive and execute commands; collect, store, and transmit house-keeping data; and support onboard payloads. Derived from several sources the C&DH system requirements include the requirements for the MidSTAR I mission, the experiments CFTP and ICSAT, and the systems Main Communications, EPS, and Structures.

ANDE: Atmospheric Neutral Density Experiment Satellite

Researchers: Midshipman 1/C Benjamin Aaron, USN, Midshipman 1/C Ernesto Villalba, USN,
and Midshipman 1/C Chrispena Weissenberg, USN,
Adviser: CDR Robert E. Bruninga, USN (Ret.)
Sponsor: Naval Research Laboratory (NRL)

The ANDE project began in the fall of 2002 with a group of three midshipmen and the project has been carried through to this semester for the implementation, build, test, and integration phases. The satellite has the scientific mission to measure the density of the atmosphere in space. The Naval Academy's part of the mission is the design and development construction and delivery of the communications telemetry command and control flight hardware. This semester required the full assembly of the engineering test model and the beginning of the construction of the flight hardware. The battery system alone consists of seven circuit boards containing 112 lithium primary cells. The communications system is a dual system providing telemetry command and control as well as providing a communications transponder in the Amateur Satellite Service. Launch and integration services are being provided by the Space Experiments Review Board.

RAFT: Radar Fence Transponder

Researchers: Midshipman 1/C Lauren Baker, USN, Midshipman 1/C Brandon Colvin, USN,
and Midshipman 1/C Robert Tuttle, USN
Adviser: CDR Robert E. Bruninga, USN (Ret.)
Sponsor: Naval Research Laboratory (NRL)

The RAFT project began in the fall of 2002 with a group of three midshipmen and it was carried through to this semester for the implementation, build, test, and integration phases. The RAFT satellite has the scientific mission to validate the effectiveness of the Navy Space Surveillance Radar system at detecting small spacecraft on the order of four to five inches across. The Naval Academy's part of the mission is the design and development, construction and delivery of two complete 5-inch cube satellites; one of high density and one of low density complete with a full communications telemetry

command and control transponder. One will operate in the Amateur Satellite service and the other in the Military Affiliate Radio System frequencies while also providing two-way communications to Naval Academy boats at sea. Launch and integration services are being provided by the Space Experiments Review Board.

Conference Proceedings

BRUNINGA, Robert, E., CDR, (USN, Ret.), OTERO, Carlos, Midshipman 1/C (USN), EVANS, Harry Midshipman 1/C (USN), KOLWICZ, Thomas, Midshipman 1/C (USN), SILVER, Michael, Midshipman 1/C (USN), HENRY, Edmund, Midshipman 1/C (USN), and JONES, Daniel, Midshipman 1/C (USN), "PCSAT2: Synergy in the Amateur Satellite Service," *Proceedings of the AIAA/USU Small Satellite Conference*, Logan, UT, 11 August 2003.

> PCSAT2 is a follow-on digital communications payload to the highly successful PCsat that was launched on 30 September 2001. PCSAT2 evolved from our success with the off-the-shelf command control and telemetry design and the Navy' s availability of a solar cell experiment that was to fly as an external payload on the International Space Station this year. Due to the Navy's short fuse and only nine months development time available, the Navy payload was going to be only a passive sample-return mission with no external communications capability. But combining this mission with our rapid response communications system led to synergistic advantages for both parties and a resulting communications experiment what was perfect for operating within the rules of the Amateur Satellite Service.

BRUNINGA, Robert, E., CDR, (USN, Ret.), Leung, Sunny, and Montenbruck, Oliver, "GPS Tracking of Microsatellites – PCsat Flight Experience," *Proceedings of the 5th International ESA Conference on Spacecraft Guidance, Navigation and Control Systems*, Frascati, Italy, 22-25 October 2002

> An experimental GPS receiver was flown on the USNA PCsat satellite to study the operation and performance of the GPS receiver in low Earth orbit. A series of tracking experiments were carried out over 12 months. Data on the hot and warm start capabilities and times to first fix of 60 seconds to 3 minutes were achieved. On average the receiver tracked 10-11 GPS satellites out of the 12 possible channels. The large number of tracked satellites from an elevation angle of –15 degrees led to a favorable geometry for the single point navigation solution where an average PDOP value of unity was observed. The onboard navigation solution yielded a 3D RMS of about 10-15m due to the presence of measurement outliers.

Book Chapters

NIEWOEHNER, R. J., CAPT, USN, "Flutter Flight Testing" in *Pilots Handbook for Critical and Exploratory Flight Testing*, Society of Experimental Test Pilots, 2003.

> This manual was developed as part of the national Centennial of Flight to replace a 30-year-old edition. Contributors represented the country's most experienced test pilots. Its purpose was to provide an archival volume documenting lessons learned from a century worth of flight test engineering. The editor described the Flutter chapter as the most technically substantial of the manual.

Technical Reports

KARPOUZIAN, Gabriel N., Professor, Kostoff, Ronald N., and Malpohl, Guido, "Abrupt Wing Stall Text Mining Using Bibliometrics and Database Tomography," Technical Report No: NAWCADPAX/TR-2003/164, October 2003.

> Database Tomography (DT) is a textual database analysis system consisting of two major components: 1) algorithms for extracting multi-word phrase frequencies and phrase proximities (physical closeness of the multi-word technical phrases) from any type of large textual database, to augment 2) interpretative capabilities of the expert human analyst. DT was used to derive technical intelligence from an Abrupt Wing Stall database derived from the Science

Citation Index (SCI) database. Phrase frequency analysis by the technical domain experts provided the pervasive technical themes of the Abrupt Wing Stall database, and the phrase proximity analysis provided the relationships among the pervasive technical themes. Bibliometric analysis of the Abrupt Wing Stall literature supplemented the DT results with author/journal/institution publication and citation data.

Presentations at Professional Meetings and Conferences

BODEN, Daryl G., Professor, "U.S. Naval Academy's Adoption of the CDIO Syllabus," Conceive-Design-Implement-Operate (CDIO) Meeting, Stockholm, Sweden, 10-17 January 2004.

BODEN, Daryl G., Professor, "U.S. Naval Academy's Adoption of the CDIO Syllabus," CDIO Meeting, Annapolis, MD, 2-4 June 2004.

NEIWOEHNER, Robert J., CAPT, USN, "Flight Test Engineering", Kansas University's Aerospace short-course, Kansas City, MO, 23 March and 9-11 June 2004.

SMITH, Jr., Billy R., Associate Research Professor and Currie, D., "Laser Relativity Satellite: A Search for the Dragging of Inertial Frames (the Lense-Thirring Effect)," 2003 AMOS Technical Conference, Maui, HI, 8-12 Sept 2003.

SMITH, Jr., Billy R., Associate Research Professor and Currie, D., "High-impact Science with University Satellites: U.S. Naval Academy's Contribution to the Laser Relativity Satellite (LARES)," AIAA Space 2003 Conference, Long Beach, CA, 23-25 Sept 2003.

SMITH, Jr., Billy R., Associate Research Professor, "U.S. Naval Academy Small Satellite Program: PCSAT and SAPPHIRE One-year Reports," AIAA Space 2003 Conference, Long Beach, CA, 23-25 Sept 2003.