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ABSTRACT

In 1947 the U.S. Navy established a Department of Aeronautics in the Naval Postgraduate School in order to better prepare naval aviation officers for the transition from piston engine powered aircraft to gas turbine powered jet aircraft. In 1987 the Department was expanded to cover astronautics. In this paper the educational objectives, programs, and developments in the major areas of concentration are briefly described for the purpose of providing easy access to the Department's history, major accomplishments and current status.

INTRODUCTION

Navy and Marine Corps aircraft are designed to operate aboard ships as part of a larger battle group. Challenges normally not considered by aircraft operating from land bases become design constraints for shipboard compatibility. Therefore, the U.S. Navy has found it necessary since the beginning of naval aviation in the 1920s under the leadership of Admiral Moffett to establish its own aircraft design bureau, the Bureau of Aeronautics (now the Naval Air Systems Command), and to involve a sufficient number of naval officers in the design, development, and testing of naval aircraft. This, in turn, necessitated officer education in aeronautical engineering beyond the baccalaureate degree. From this requirement evolved a number of courses in aeronautical engineering which led to the formal establishment of a Department of Aeronautics in the Naval Postgraduate School in 1947. It is the objective of this paper to describe the major developments since that time and to highlight some of the major accomplishments and the present status of aerospace engineering education at the Naval Postgraduate School

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DEPARTMENT HISTORY

The decisive role played by ship-based aircraft in World War II left no doubt at war's end about the need to fully transition from battle ship to carrier-based naval operations. This, in turn, required the transition from piston engine powered propeller aircraft to gas turbine powered jet aircraft. To support the technical challenges posed by this transition, Dr. Wendell Coates, an engineering professor in the Naval Postgraduate School located on the Naval Academy campus, proposed and obtained approval to establish an aeronautical engineering department in 1947. He served as its chairman until 1962 and, after the School's transfer to Monterey in 1951, was instrumental in attracting additional faculty and providing the Department with outstanding laboratories. He was succeeded by Professor Richard Bell (until 1978), Professor Platzer (until 1988), Professor Wood (until 1991), Professor Collins (until 1997), Professor Lindsey (until 1999) and Professor Platzer again since January 2000. Important additions to the Department's curricula occurred in 1979 and 1987, respectively, when the joint Naval Postgraduate School/Naval Test Pilot School and the space systems engineering/ operations curricula were implemented. Both additions reflect the Navy's recognition of the continuing need for flight test expertise and the growing use of satellites for naval operations.

EDUCATIONAL OBJECTIVES

The aeronautical engineering curricula have been fully accredited for the past fifty years; the astronautical engineering curriculum became accredited in 1995. Both curricula were reviewed again by ABET (Accreditation Board for Engineering and Technology) in October 2001 and received full six-year ABET re-accreditation in July 2002. In addition to the ABET requirements, the two curriculum sponsors, the Naval Air Systems Command and the Naval Space Systems Division, impose several additional requirements, namely:

• **Cost Effective Education:** In order to minimize the time spent on graduate studies the Department offers year-round instruction and course sequencing such that the officer students may enroll at any time during the year. Also, students who would not attempt a graduate degree because of their undergraduate background or their time away from academia are brought up to the necessary standards.

• **Broad-Based Engineering Education:** The officers need to be provided with a broad-based aeronautical or astronautical engineering education to qualify for future assignments in a variety of jobs rather than in a narrow specialty. Also, they need to be familiarized with modern computing, design, measurement and testing techniques. This calls for the availability and maintenance of modern laboratories.

• **Navy/DoD Relevant Engineering Education:** The officers need to be familiarized with problems in past and current aircraft and weapon systems developments in order to sensitize them to the current state-of-the-art and to the uncertainties involved in a typical development program. This calls for faculty with previous industrial experience and strong involvement in current Navy/DoD projects.

• **Total Systems Design Education:** It is well recognized that the success of any aircraft or spacecraft crucially depends on competent integration of all the disciplines needed for their design and development. Thus, a comprehensive capstone design project has been made a firm requirement in both curricula. Moreover, the aircraft or spacecraft, in turn, is part of a larger weapons system. Therefore, there is a need to expose the students to the Total Systems Design approach. By working together with other students and faculty in the recently established Institute for Defense Systems Engineering and Analysis, Aero/Astro students learn how air and space vehicles become part of a larger combat system that includes all aspects of war fighting.

EDUCATIONAL PROGRAMS

The typical graduate from the normal two-year NPS Aeronautical or Astronautical Engineering curricula is a career military officer who will, in the future, encounter many technical challenges currently unknown by both the student and the faculty. As a result, the best education is believed to consist of a program that will address the fundamentals of engineering and scientific principles, including experience in the application of these principles to unique Navy/DoD problems and issues. The NPS student population is composed of officers from the U.S. services and foreign countries. This joint, international class composition provides additional leverage in defining the challenges of the future. The department offers four curricula, which are available to U.S. and foreign military officers and U.S. government civilian employees:

- Aeronautical Engineering
- Aeronautical Engineering (Avionics)
- NPS/Test Pilot School Cooperative Program
- Astronautical Engineering

Both of the Aeronautical Engineering Programs are designed to meet specific needs of Navy technical managers with a broad-based graduate education in aerodynamics, flight mechanics, propulsion, flight structures, systems integration and/or avionics. Additionally, students receive graduate level instruction in aircraft/missile design and aero-computer science. The programs are divided into preparatory, graduate and advanced graduate phases. During the advanced graduate phase, all students receive in-depth graduate coverage through advanced electives in areas of their choice including flight dynamics, gas dynamics, propulsion, structures, avionics, and aircraft or missile design. Over the past fifty years students completing these programs varied between 20 to 60 per year.

The NPS/Test Pilot School Cooperative Program combines portions of the Aeronautical Engineering and Aeronautical Engineering (Avionics) curricula with the complete U.S. Naval Test Pilot School syllabus. After completion of the requirements at NPS, students proceed to Patuxent River for the full Test Pilot School Curriculum. This program is very competitive, and students accepted to this program are typically exceptional undergraduate engineering students and aviators who are capable of completing all the graduate education coursework in 5-6 quarters. Graduates receive the Master's degree in Aeronautical Engineering at the completion of Test Pilot School. During the past 14 years ten students per year completed this program.

The Astronautical Engineering program provides officers with a comprehensive scientific and technical knowledge of military and Navy space systems through graduate education. This curriculum is designed to equip officers with the theoretical and practical skills required to design and integrate military space payloads with other spacecraft subsystems. Graduates are being prepared by their education to design, develop and manage the acquisition of space communications, navigation, surveillance, electronic warfare and environmental sensing systems. Since its inception in 1987 the students per year who graduated from this program varied between 15 to 25.

Students are required to participate in a major design project where they contribute as a member of a design team to an aircraft, avionics, spacecraft or missile design project. At the conclusion of the design project, the students have to present their contributions to a committee of military and industry experts. Many times the NPS design team competes with other universities in American Institute of Aeronautics and Astronautics (AIAA) or American Helicopter Society (AHS) sponsored design competitions. NPS students have consistently ranked high in these competitions thus lending credence to the quality of their efforts.

Two other unique Aero/Astro courses offered at NPS are Aircraft Combat Survivability and Tactical Missile Propulsion. Aircraft Combat Survivability brings together all of the essential ingredients in a study of the survivability of fixed wing aircraft, rotary wing aircraft, and cruise missiles in a hostile (non-nuclear) environment. The technology for increasing survivability and the methodology for assessing the probability of survival in such an environment are presented in some detail. Topics covered include: current and future threat descriptions, the mission/threat analysis, combat analysis of South-East Asia and Desert Storm losses, vulnerability reduction technology for the major aircraft systems, susceptibility reduction concepts, including stealth, vulnerability, susceptibility and survivability assessment, and trade-off methodology.

Tactical Missile Propulsion covers applications and analysis of gas turbines, solid propellant rockets, ramjets, dual-combustion ramjets, scramjets, ducted rockets, and pulse detonation engines. Each propulsion system is analyzed to determine their individual characteristics including: propellant selection criteria, combustion models and behavior, performance analysis, combustor design, combustion instabilities and damping, mission and flight envelope effects on design requirements and technology requirements, use of performance and grain design codes and laboratory test firings for comparison with measured performance of rockets and ramjets. Students are also given an introduction to insensitive munitions and plume signature considerations.

Students are required to complete a thesis project in order to receive their degree. The thesis serves as an integral part of the NPS education process by giving students an opportunity to conduct individualized research in a subject of their choosing. At the completion of their thesis project, students present their work to the faculty and students. Often, the students' contribution is part of a larger research project by his/her thesis advisor, and therefore is routinely presented by the student (or his/her advisor if the student has already graduated) at scientific conferences and published in scientific journals. An exception to the thesis requirement is made for the NPS/TPS students, whose final flight test report at TPS serves in lieu of a thesis.

Interdisciplinary efforts combine faculty and students from across campus. The Department of Aeronautics and Astronautics is an integral partner in interdisciplinary projects which bring together students from across campus to participate in a "total concept" analysis. Students from the engineering disciplines provide the technical design, operations research students provide logistics and analysis, national security affairs students provide political-military perspectives, business students address manning and costs, applied science students tackle the environment. The project for 2001 was called "Crossbow" which originated with the President of the Naval War College who proposed studies to determine the feasibility and operational worth of a small, high-speed aircraft carrier concept. NPS students chose to pursue a high-speed ship design that supports an air wing composed primarily of Unmanned Air Vehicles.

LABORATORIES

Laboratories support instructional and research programs in aerodynamics, flight mechanics, flight controls, avionics, structures and composite materials, scientific computing, aircraft and spacecraft design, gas dynamics, turbopropulsion, rocket and ramjet propulsion, and dynamics and nondestructive evaluation. The major facilities include two low speed wind tunnels with 28-by-45-inch and 3-by-5-foot test sections, a 5-by-5-foot open circuit flow visualization wind tunnel, a 15-by-20-inch water tunnel, a supersonic blow-down tunnel with a 4-by-4-inch test section, a shock tube, three test cells equipped with diagnostic apparatus for investigating solid, liquid, gaseous and hybrid rockets, solid fuel ramjets, pulse detonation engines, and gas turbine combustors, a 10-by-60-inch test section rectilinear cascade wind tunnel, a large three-stage axial research compressor, two fully instrumented transonic turbine and compressor test cells, a spin-pit for the structural testing of rotors up to 50,000 RPM, a transonic cascade wind tunnel, two flight simulators, an unmanned air vehicle research laboratory, an MTS electro-hydraulic closed-loop fatigue testing machine, a flexible spacecraft simulator, a space robot simulator, a three-axis spacecraft simulator, a Navy communications satellite, a smart structures laboratory, a flight controls laboratory, an avionics laboratory, a computation laboratory, and aircraft and spacecraft design laboratories.

MAJOR AREAS OF CONCENTRATION: HISTORY AND CURRENT STATUS

Aircraft Design

Aircraft design at the Naval Postgraduate School is taught in a team environment. Each team consists of some 6-10 students functioning as a team. The team design effort is a response to a Request-for-Proposal (RFP). One indication of the quality of the design experience is evidenced by NPS team placements in AIAA national graduate student design competitions. For example, the student teams advised by Professor Conrad Newberry placed 1st and 2nd in the 1996 AIAA/McDonnell Douglas aircraft design competition, 1st and 2nd in the 1997 AIAA/ McDonnell Douglas Aircraft Design Contest, and 3rd in the 1998 AIAA Foundation Graduate Team Aircraft Design Competition. However, not every NPS aircraft design team enters a national competition. During 1993 and 1994, for example, an M=6 waverider configured interceptor was the focus of the student design effort. For the past two years, NPS Aero/Astro design teams have developed a number of Uninhabited Combat Air Vehicle (UCAV) configurations of interest to NAVAIR and ONR.

Missile Design

Interested students may take an elective five-course sequence in missile systems. Courses in missile aerodynamics, tactical missile propulsion, missile flight analysis, and air defense lethality precede a single course in missile design. The student team advised by Professor Newberry placed 2nd in the 1997 AIAA/Northrop Grumman Missile Design Contest.

Rotary-Wing Design

The procedures for design of helicopters and other types of rotorcraft parallel that of fixed-wing aircraft design. Typically, 6-10 students work on the helicopter design project, which is a response to a Request for Proposal written by one of the three major U.S. helicopter manufacturers (Sikorsky, Boeing, and Bell). The design competition is sponsored, judged and managed by the American Helicopter Society (AHS). Student teams advised by Professor E. Roberts Wood achieved 1st place in the 1993 and 1995 AHS/NASA Student-Industry Helicopter Design Competition and 2nd place in the 1994, 1996, 1997, 1998 and 1999 AHS/NASA Student-Industry Helicopter Design Competitions.

Engine Design

An engine RFP, either a past military RFP or from a current AIAA competition, is selected for the course. For example, the JAST RFP (which evolved into the Joint Strike Fighter (JSF) program) was chosen as the design problem when the course was concurrently taught by Distance Learning to the Naval Air Warfare Center. Each student performs constraint and mission analyses, selects and sizes an engine in the first half of the course. A selection is then made from these candidate designs. In the second half of the course, the class, working as a team, carries out the preliminary design of the components. GASTURB is used in the engine selection phase. Codes developed in-house are used for the fan, compressor and turbine designs. The student team advised by Professor Raymond Shreeve placed 2nd in the 1997 AIAA/Rockwell/Rocketdyne Engine Design Contest.

Avionics Design

Associate Professor R. Duren teaches digital design and hardware/software integration through a series of small design projects and a more complex final project, such as the development of video controllers or serial communications controllers. PCs are equipped with modern CAD software and instrumentation for digital design. Designs may be entered in any combination of schematics, HDLs (Hardware Description Language) including VHDL and Verilog, or commercially available IP (Intellectual Property) modules. Hardware designs are verified using computer-aided functional and timing simulation tools. Assembly language and C programs are verified using microprocessor simulation programs and commercial software development tools. The designs are then implemented using combinations of FPGAs (Field Programmable Gate Arrays ranging from 10,000 to 1,000,000 gates) and micro-controllers. The designs are then verified using PC-based logic analyzers and digital oscilloscopes.

Spacecraft Design

Distinguished Professor Brij Agrawal teaches spacecraft design in a laboratory that uses computer-aided design tools, such as GENSAT, Aero-space Conceptual Design Center software, STK, NASTRAN, IDEAS, and MATLAB/Simulink. A student team advised by Professor Agrawal achieved 2nd place in the 1997 AIAA/Lockheed Martin Spacecraft Design Contest. During summer 2000, the students finished a preliminary design of a Bifocal Relay Mirror Spacecraft under the sponsorship of Air Force Research Laboratory (AFRL). The Bifocal Relay Mirror Spacecraft is composed of two optically coupled telescopes used to redirect the laser light from ground-based, aircraft-based or spacecraft-based lasers to a distant point on the earth or in space. The design effort identified the need to develop new technologies for beam acquisition, tracking and pointing.

Total Weapons Systems Design

During the 2001/2002 academic year, the Department of Aeronautics and Astronautics aircraft design teams worked with the Total Ship System Engineering (TSSE) students (ship design) and the Systems Engineering students (system requirements) to develop the CROSSBOW battle force system. CROSSBOW is essentially a small, fast carrier task force supporting global, littoral warfare scenarios. The Systems Engineering students developed the CROSSBOW ship and aircraft requirements. The TSSE students designed the small, fast carrier. The Aeronautics students designed two aircraft capable of operating from the carrier. One was designed for an armed reconnaissance (UCAV) mission; the other was designed for the intelligence, surveillance, reconnaissance and combat mission.

Aerodynamics, Aeroelasticity, V/STOL Aircraft

A better understanding of viscous flow effects throughout the whole Mach number and Reynolds number regimes has been and continues to be a serious challenge for the design and operation of various aerospace vehicles and propulsion systems. Of special importance is the prediction and measurement of the onset of flow separation (stall) on airfoils, three-dimensional wings, and helicopter and jet engine blades. For this reason Distinguished Professor Platzer has developed a computational and experimental research program to investigate steady and unsteady flow problems relevant to naval aircraft and weapons problems. To this end, he also established a joint program with the NASA Ames Research Center in 1986. Professors Bodapati and Chandrasekhara developed a special wind tunnel, located in the Fluid Mechanics Laboratory of NASA Ames Research Center, which permits the detailed measurement of the dynamic stall flow phenomena on helicopter blades using modern point diffraction interferometry and Laser-Doppler velocimetry. These measurements are complemented by Navier-Stokes computations in the NPS Computation Laboratory (which has 17 Silicon Graphics workstations and a parallel cluster of fifteen PCs running Linux), and on NASA and DoD supercomputers. Experiments are also performed in the NPS Aerodynamics Laboratory which consists of a low-speed flow visualization tunnel with a 5x5 inch test section and a 15x20 inch water tunnel. Laser Doppler velocimetry is available in both tunnels. Current projects address the computational prediction of abrupt wing stall on F-18 wings using modern Navier-Stokes codes and the development of helicopter blades capable of controlling the onset of dynamic stall. Another major project has been and is directed at the development of a micro-air vehicle which uses flapping wings requiring detailed wind/water tunnel studies and computations of the flow past flapping wings. Also, a new type of lift fan, the cross-flow fan, is being investigated experimentally and computationally to analyze the aerodynamic fan characteristics, optimize thrust and propulsive efficiency, and determine the applicability of cross-flow fans to VTOL aircraft. The current members of the aerodynamics research group are Research Professor M.S. Chandrasekhara, Senior Lecturer S.K. Hebbar and Research Associate Professor K.D. Jones. Past members and visiting researchers were J.M. Simmons, U Queensland, K. Vogeler, TU Aachen, H.H. Korst, U. Illinois, J. Ekaterinaris, KETA Greece, W. Sanz, TU Graz, F. Sisto, Stevens IT, W. Geissler, DLR Goettingen, I. Tuncer, METU Ankara, J. Lai, Australian Defence Force Academy Canberra, M. Nakashima, IT Tokyo, T. Fransson, EPFL Lausanne, S. Weber, TU Aachen, C. Dohring, German Armed Forces University Munich.

Flight Mechanics and Control

Extensive teaching and research work in these fields address real fleet-and-field problems in the areas of unmanned air vehicle performance; flying qualities; guidance, navigation and control; precision airdrop of military re-supply; use of Unmanned Air Vehicles (UAVs) for winds extraction and particle sensing for chemical/biological attack response; and integrated plant controller optimization for high speed civil transport aircraft. Current faculty supporting these efforts include Associate Professor R. Howard, Associate Professor I. Kaminer, Research Associate Professor O. Yakimenko, and NRC Associate V. Dobrokhodov. Professor Emeritus L.V. Schmidt, author of the AIAA text "Introduction to Flight Dynamics", continues to contribute his expertise. Several laboratories support this work. The Unmanned Air Vehicle Flight Research Laboratory (UAV FRL) is used to conduct flight research with scaled radio-controlled and semi-autonomous aircraft to study problems identified with fleet UAVs and to design, implement and test new concepts in flight performance, flying qualities, guidance, navigation and control. Research vehicles include fixed-wing and rotary wing platforms. Telemetry is available for transmission of data, video images, and infrared images. The Flight Controls Laboratory presently consists of four hardware-in-the-loop stations designed to conduct extensive hardware-in-the-loop studies of guidance, navigation and control systems. These stations are supported by a family of Realsim and MATLAB rapid prototyping tools.

Aircraft Structures

Studies of aircraft structures include classical approaches, finite element methods, fatigue life estimations, and design of composite aircraft structures. Coverage in this discipline has been a focal point for the department since its founding, involving Distinguished Professor W. Coates, Professors C. Kahr, L.V. Schmidt, G. Lindsey, and more recently Professor E. Wu, who established a composite materials laboratory. Academic studies have been supported by laboratory experiments using test machines to demonstrate both tensile and shear stress effects upon structures, full-scale wing structures to show properties of multicell thin-wall beams under combined bending and torsion loadings, fatigue testing, and composite material behavior.

Turbo-Propulsion and Gas Dynamics

As already mentioned, the transition from piston engines to jet engine technology presented the U.S. Navy with a special challenge. Therefore, approval was obtained shortly after the Department's establishment in 1947 to construct and equip a "Turbo-propulsion Laboratory" on the new campus in Monterey. Distinguished Professor Michael Vavra was instrumental in establishing the laboratory and directing it until his death in 1975. The laboratory (TPL), now operated together with the Gas Dynamics Laboratory (GDL), comprises three large and unique buildings. The compressed-air power systems in the three buildings supply facilities operating in three different speed regimes. The low-speed building houses a large high Reynolds number cascade wind tunnel, radial cascade wind tunnel, and a large three-stage low-speed research compressor. The high-speed building contains a 1200HP air supply system and two explosion-proof test cells for transonic compressor and turbine testing; an engine-scale vacuum spin pit; a probe calibration and turbocharger test facility; control, data acquisition and computer rooms; three offices and a conference room. The Gas Dynamics Laboratory building, with a compressed air system providing 8000 cubic feet of storage at 20 atmospheres and 2000 scfm continuously, contains a variable Mach number supersonic wind tunnel, a small transonic cascade wind tunnel, two free-jets and a three-inch shock tube. Also, two micro-jet engine test stands are installed; one in a free jet.

While Prof. Vavra initially brought young postdoctoral engineers from Europe to work with him (Willi Schlachter from Switzerland and K. Papailiou from Greece), after a research charter was written for TPL in 1978, well recognized visiting professors and research investigators were invited to work with Vavra's successor, Professor R. Shreeve. Examples include Dr. Dan Adler (Technion, Israel), Mr. Roy Peacock (Cranfield, U.K.), Mr. John Erwin (NASA), Dr. H.J. Heinemann (DLR Germany), Professor Charles Hirsch (Vrije U, Belgium), Dr. Greg Walker (U. Tasmania, Australia), Professor John Kentfield (U. Alberta, Canada), Professor Ahmet Ucer (ODTU, Turkey) and Dr. Theo von Blackstrom (U. Stellenbosch, S. Africa). Dr. Atul Mathur (VPI, Virginia) spent three years at TPL. Also, research studies were performed at TPL toward doctoral degrees granted later at their home institutions; examples include Hans Zebner, Dieter Schulz and Thomas Vitting at U. Aachen; Friedrich Neuhoff at GAFU, Munich; and Ian Moyle at U. Tasmania. Postdoctoral NRC Research Associates also included Shmuel Eidelman, David Helman, Upender Kaul and (currently) Anthony Gannon. The laboratory has received recognition particularly for the development of the Dual Probe Digital Sampling (DPDS) Technique for rotor exit flows, for viscous code validation measurements in controlled-diffusion compressor cascades, for reviving interest in wave-rotors and wave engines (leading to a NASA experimental program), and for the first successful operation of an air-breathing detonation engine.

Practical instruction and advanced research in air-breathing propulsion and gas dynamics remain the charter functions of the Turbo-Propulsion Laboratory, an NPS Research Center, and the Gas Dynamics Laboratory under the direction of Professor Raymond Shreeve, working in close association with Professor Garth Hobson. Realistic (engine-scale) experimental studies are enabled by, for a university, unusually high power levels, large scale or high speeds of the test rigs. Exploiting this uniqueness, the emphasis is on developing and applying advanced measurement techniques to obtain data to validate emerging computational (CFD) predictions and new designs. In addition to the application of CFD codes to experimental test geometries, a new geometry package has been developed to optimize the aero-structural design of a compressor or fan rotor. Most recently, that package was used to obtain optimized redesigns of two turbomachinery CFD test cases; namely, the Sanger rotor being tested currently at TPL, and the NASA Rotor 67. It is anticipated that an optimized rotor design will be evaluated next in the transonic compressor rig. Also, under NASA sponsorship, a cross-flow fan investigation, proposed for a V/STOL aircraft application, is currently underway in the turbine test rig. As the highest Navy priority, high-cycle fatigue structural test techniques are being developed for use in Navy spin-pit facilities at the Naval Air Warfare Center, Patuxent River. This program is a joint program between the Navy and the Air Force. Finally, small turbo-engine variants for Unmanned Air Vehicles or missiles are being explored experimentally. Current programs are tied to Navy-critical engine Research & Technology programs, and very close coordination is maintained with the Propulsion and Power Division at the Naval Air Warfare Center, Patuxent River.

Rocket and Ramjet Propulsion

In the mid-sixties Professor R. Reichenbach initiated research on rocket and ramjet propulsion. Over the past twenty five years his successor, Distinguished Professor D.W. Netzer, developed a very well instrumented laboratory dedicated to the systematic investigation of solid and liquid propellant rocket engines, ramjets, and pulse detonation engine systems. The Rocket Propulsion and Combustion Laboratory (RPCL) supports research programs and instructional laboratories related to advanced chemical propulsion systems. Many of the high-speed propulsion courses in the department involve experience at the laboratory investigating advanced systems and their related technologies. The laboratory has received support from a variety of government agencies, including the Office of Naval Research, Air Force Research Lab, and Naval Air Warfare Center Weapons Division as well as commercial companies such as General Electric Aircraft Engines and Pratt and Whitney. The laboratory consists of three hot-fire test cells, two cold flow testing areas, and a control room capable of monitoring experiments throughout the lab. The laboratory is capable of testing both solid and liquid rocket engines up to 500-lbs.thrust. Ramjets can be tested with vitiated air heaters which provide airflow rates up to 8 lb per second at 750 K. Gaseous and liquid-fueled pulse detonation engines can be tested up to 100 Hz operation, and comprehensive conventional and optical diagnostics are available to characterize performance and system operation. The hardware and infrastructure of RPCL is complemented by a wide range of diagnostic capabilities required for the investigation of various propulsion systems. Some of the diagnostic capabilities existing at the lab include a Phase Doppler Particle Analyzer (PDPA), Malvern particle analyzers, a copper vapor laser system for Particle Image Velocimetry (PIV), a Nd:YAG laser, high speed intensified CCD cameras, visible and infrared imaging systems, spectro-radiometers, and a wide range of additional laser systems. PC based high-speed data acquisition systems are located throughout the laboratory and are used to monitor the diagnostic systems, thermocouples, and high frequency pressure transducers. Past research visitors included D. Laredo, B. Natan, A. Gany, T. Lee and T. Milstein from the Technion, Haifa, R. McGuffin, U. Colorado. Current investigators are Research Assistant Professors C. Brophy and J. Sinibaldi.

Avionics

Starting in 1996 Associate Professor R. Duren developed a series of avionics courses, including an avionics design course, and he built up an avionics laboratory to study fleet related problems including real-time software design, fusion algorithms, software re-hosting, software engineering methods, open systems, and computer architectures. Schematic and HDL circuit design tools and modern software development tools are hosted on ten Pentium III and IV class PCs for hardware and software development. The Machine Transferable AN/AYK-14 Support Software System (MTASS/M) software development tools are hosted on a Sun SPARCstation 10. Some tools were provided by the Navy's F/A-18 Advanced Weapons Laboratory in China Lake, CA. These tools include assemblers, compilers, and simulators to develop software for the AYK-14 Mission Computer of the F/A-18 aircraft. These resources enable students to engage in research that directly assists the Advanced Weapons Laboratory in the support of the F/A-18 aircraft.

Rotary Wing Aircraft Technology

A helicopter technology course was first taught in 1969 by Professor J.A.J. Bennett, the former head of the Department of Aeronautics of Cranfield Institute of Technology. After Bennett's death in 1971 Prof. D. Layton became the major professor of rotary wing technology until the appointment of Professor E. Roberts Wood in 1988 who expanded the offerings in rotary wing technology to three courses (including a separate helicopter design course) and established a close cooperation with the NASA Ames and the Army Flight Dynamics Directorate at Moffett Field for field trips and thesis studies. Professor Wood also developed the Rotorcraft Laboratory which is designed to provide a multi-faceted approach to the problems encountered in flight by rotary wing and Vertical Take-Off and Landing (VTOL) aircraft. The testing portion of the lab consists of flight testing, structural dynamics testing, wind and water tunnel testing, acoustic testing and flight simulation. The jewels of the rotorcraft lab are the two OH-6A helicopters. Through a cooperative agreement with Mississippi State University, one helicopter is certified for use in flight testing. Cockpit components of the other helicopter are used as part of a flight simulator developed with Advanced Rotorcraft Technologies in Mountain View, CA. The fuselage of the second helicopter serves as part of the structural dynamics testing at NPS. Making use of additional test facilities at NPS, models have been developed for both the water tunnel and wind tunnel to study circulation control. In conjunction with the Physics Department at NPS, an acoustic test facility has been developed. The modeling and simulation portions of the lab consists of several computers using commercial-off-the-shelf software such as NASTRAN®, DYTRAN®, MATLAB®, Simulink®, Maple® and FlightLab® to study problems in rotor dynamics, acoustics, structural dynamics and flight performance. The Joint Army/Navy Rotorcraft Analysis and Design (JANRAD) computer program was developed at NPS to perform performance, stability and control, and rotor dynamics analysis during preliminary helicopter design efforts.

Aircraft Combat Survivability

An essential aspect in the education of the warfighter is the study of aircraft combat survivability. The core of the survivability discipline was developed during the past twenty years by Distinguished Professor Robert E. Ball who published a book on this topic in 1984 (recently greatly expanded in a second edition). The course on aircraft survivability emphasizes the operational considerations and analytical methodologies necessary to design aircraft, both fixed-wing and rotary-wing, that are survivable in the combat environment. The resources available to educate the war fighter include the Survivability and Lethality Assessment Laboratory, Distance Learning and Short Courses, and a variety of multi-discipline survivability and lethality related graduate courses at NPS.

Spacecraft Systems, Attitude Control and Smart Structures

Starting in 1988 Distinguished Professor Brij Agrawal developed several unique laboratories to provide hands-on experience in the design, analysis, and testing of space systems and subsystems and to enable experimental research on current problems on DoD spacecraft. He also succeeded to attract several postdoctoral researchers, namely, H. Bang (South Korea), G. Song (U of Houston), G. Ramirez (Tennessee TU), H. Chen (Columbia U) and M. Romano (U of Milan). The Spacecraft Attitude, Dynamics and Control Laboratory is used to perform research on developing improved control techniques for attitude control of flexible spacecraft and flexible robotic manipulators. The emphasis has been to develop improved control laws for fast slew maneuvers of flexible spacecraft. The laboratory has three simulators to validate the improved control techniques experimentally: Flexible Spacecraft Simulator (FSS), Space Robot Simulator (SRS), and Three-Axis-Spacecraft Simulator (TASS). The FSS simulates attitude motions of the spacecraft in one axis. The SRS consists of a two-link manipulator with rigid and flexible links. The TASS simulates a free floating spacecraft with a platform that incorporates rate gyros, sun sensors, and magnetometers, three reaction wheels and a laptop computer. The platform floats on a spherical air-bearing stand, thus giving the simulator three degrees of freedom for attitude control. The simulator also has an optical payload consisting of a fast steering mirror, jitter control system, and camera for acquisition, tracking and pointing. The integrated system is used as a simulator of a relay mirror spacecraft. The Smart Structures Laboratory is used to perform research on active vibration control, vibration isolation, and fine pointing by using smart sensors and actuators. This laboratory has three main experiments: Ultra Quiet platform (UQP), Positioning Hexapod and the NPS Space Truss. The UQP is used for testing control algorithms for vibration isolation of an imaging payload. It has six piezo-ceramic actuators and a geophone sensor. The Position Hexapod is used for testing control algorithms for both vibration isolation of an imaging payload and fine steering. It is based on the arrangement of six self-supporting electromagnetic voice coil actuators with in-line accelerometers and position sensors. The NPS Space Truss is used for testing control algorithms for active structural control and vibration isolation. The overall dimension of the truss is 3.76 m long, 0.35m wide and 0.7 m tall. It has piezo-ceramic struts as actuators and a linear proof mass actuator as source of disturbance. The FLTSATCOM Laboratory consists of a qualification model of the Navy communications satellite, FLT-SATCOM, and ground TT&C system. This laboratory is kept operational in cooperation with Naval Satellite Operational Center, for use by students in classes and by NAVSOC for analyzing on-orbit anomalies. Commands are sent to the satellite for wheel spin-up, firing of thrusters and rotation of solar array drive. The Satellite Servicing Laboratory is a new laboratory used to develop and operate a servicing spacecraft simulator to conduct research into autonomous rendezvous, docking and control of a small manipulator vehicle. The servicing spacecraft simulator floats on a granite table using air pads to provide a frictionless 2-D simulation of on-orbit operations. A new joint NPS and Air Force Research Laboratory (AFRL) Optical Relay Spacecraft Laboratory was dedicated in June 2002. This laboratory is used for both instruction and research on acquisition, tracking, and pointing of flexible military spacecraft. The test bed consists of a spacecraft attitude simulator, which can simulate spacecraft three-axis motion, and an optical system simulating a space telescope. The simulator has three reaction wheels and thrusters as actuators; rate gyros and sun sensors; on-board processor; batteries; and it is supported on a spherical air bearing. The optical system consists of a laser source, a fast steering mirror, jitter sensor, and a video camera as a tracking sensor.

Spacecraft Guidance, Control and Optimization

Associate Professor M. Ross is the Program Director for Spacecraft Guidance, Control and Optimization at NPS. Over the last decade, this program has attracted several postdoctoral associates and visiting faculty and currently supports cross-cutting research across NPS. The Space Technology Battlefield Laboratory and the Astrolab support the program in various aspects pertaining to the research on the high-speed precision guidance and control of space vehicles and ballistic missiles developed the NPS Astrolab and the Space Technology Battlefield Laboratory to study high-speed precision guidance and control of space vehicles and ballistic missiles. Prof. Ross and his colleagues achieved a significant breakthrough by a revolutionary approach to the design of feedback laws. In this approach, the "laws" are determined on-line with an adaptive nonlinear model instead of the traditional off-line design and implementation. This system can adapt to changing mission objectives while maintaining optimal performance. Two software packages have been developed at NPS in this field. DIDO is the implementation of a pseudo-spectral method invented at Astrolab. It is a one-of-a-kind method to provide automatic "adjoint sensitivities" or co-vector information for complex non-smooth problems. ACAPS is software developed for the Jet Propulsion Laboratory for the preliminary design of interplanetary aero-assisted missions. It has also been used by Raytheon to support JPL missions.

RESEARCH

The research projects carried out by Aeronautics and Astronautics faculty mostly are focused on topics of critical importance to military users and, typically, are funded by various Navy and other DOD sponsors. These externally funded projects ensure a continued close interaction between the faculty and the sponsors and thus provide the students with valuable insight into current naval aircraft and weapons development, maintenance, and operational problems during their formal courses and, especially, during their thesis project studies. The total externally funded research amounted to $ 2.86 million in FY2001, where more than 50% of the funds came from various Navy laboratories, 20% from Army laboratories, 12% from the Air Force, the remainder from NASA and other agencies. In FY2002 the externally funded research increased to over $3.5 million. Output from these projects is documented in 28 journal publications and 82 conference papers published during the past three years. Additional information is available from the individual professors and from the NPS Research Office.

COST EFFECTIVENESS CONSIDERATIONS

These days most universities struggle with the significantly higher costs involved in maintaining engineering schools compared to, say, business management schools. This "bean counting" approach is widely practiced in evaluating federal government activities. In the NPS context the argument is often used that the naval officers only need to have a thorough management education to oversee the procurement of aircraft and weapons built in the private sector. To counter this argument we present a few specific examples which should help to elucidate the fallacy of this argument.

CDR D. Lott analyzed the previously unrecognized P-3C static aeroelastic wing behavior using a finite element analysis to show the cause of wing leading edge rib section failure

CDR J. Clifton was the first to accurately model the unsteady motion of the 20,000 foot long trailing antenna wire when towed by the orbiting E-6A aircraft during TACAMO missions in the presence of wind gradients

After his PhD studies, CDR R. Niewoehner served as Navy chief test pilot during part of the F/A-18 E/F flight test program where he was responsible for the Navy's share of the envelope expansion flying, including flutter, flying qualities, and high angle-of-attack/spin testing. This included both discovery and resolution of the Super Hornet's well publicized transonic wing drop. Note that the F/A-18 E/F program was the Navy's largest development program of the 1990's and in 2000 the program received the Collier award for innovative contributions to aeronautics.

DISTINGUISHED GRADUATES

Over the years, the Department of Aeronautics and Astronautics has graduated many naval and other officers who reached the rank of Admiral and made important contributions to the development of naval/military aviation. In addition, the Department is especially proud that the following six graduates became APOLLO astronauts:

- COL Gerald Carr, USMC
- CAPT Edgar D. Mitchell, USN (sixth man on the moon)
- CAPT Eugene A. Cernan, USN (last man on the moon)
- CAPT Ronald E. Evans, USN
- COL Robert Overmyer, USMC
- CAPT Paul J. Weitz, USN (Skylab2)

The following twenty-two astronauts became SPACE SHUTTLE astronauts:

- COL Jack R. Lousma, USMC
- CAPT Michael J. Smith, USN
- CAPT David C. Leestma, USN
- COL David C. Hilmers, USMC
- CAPT Michael L. Coats, USN
- CAPT Winston E. Scott, USN
- CAPT Kenneth S. Reightler, USN
- CDR Michael J. Foreman, USN
- CDR Kent V. Rominger, USN
- LCOL Jeffrey N. Williams, USA
- CDR Michael E. Lopez-Alegria, USN
- CDR Brent W. Jett, Jr., USN
- CDR Scott D. Altman, USN
- LCDR Robert L. Curbeam, USN
- LCDR William C. McCool, USN
- LCDR Lisa N. Nowak, USN
- LCDR Christopher J. Ferguson, USN
- LCDR Stephen N. Frick, USN
- LCDR Mark E. Kelly, USN
- LCDR John B. Herrington, USN
- LCDR Alan G. Poindexter, USN
- LCDR Kenneth T. Ham, USN

SUMMARY AND OUTLOOK

On 17 December 2002 a Memorandum of Understanding was signed by the Secretaries of the Navy and Air Force to transfer the NPS aeronautical engineering programs to the Air Force Institute of Technology effective January 2003. The astronautical engineering program remains at NPS. Hence this decision consolidates the graduate aeronautical engineering education for Air Force and Navy officers in one institution only and thus terminates the unique Navy/Marine Corps oriented aeronautical engineering programs described in this paper. It remains to be seen whether this decision is in the Navy's near- and long-term interest because of the continuing need to offer interdisciplinary systems studies which require aeronautical engineering expertise. Also, it remains to be seen whether the NPS leadership recognizes the need to maintain the unique NPS aeronautical engineering laboratories to support such interdisciplinary systems studies.

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