CHAPTER 63

Naval Officer Graduate Education in Aerospace Engineering at the Naval Postgraduate School

Max F. Platzer, Distinguished Professor and Chairman
Richard W. Bell, Louis V. Schmidt, Conrad F. Newberry, Professors Emeriti
Department of Aeronautics and Astronautics
Naval Postgraduate School
Monterey, CA 93943

Abstract

Although the Naval Postgraduate School (NPS) was established in 1909 on the campus of the United States Naval Academy, the Department of Aeronautics was not established until 1947. The initial mission of the Department of Aeronautics was 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 include the field of astronautics. In this paper the educational objectives, programs, and developments in the major areas of concentration are briefly described for the purpose of providing a historical perspective on the Department’s development, 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.

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

This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.
served as its chairman until 1962 and, after the School’s transfer to Monterey, 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 aeronautical 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, Astronautical Engineering (Avionics), NPS/Test Pilot School Program, and Astronautical Engineering.

Aeronautical Engineering

Aeronautical Engineering (Avionics)

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 the number of students completing these programs varied from 20 to 80 per year.

NPS/Test Pilot School Cooperative Program

The NPS/Test Pilot School Cooperative Program combines portions of the Aeronautical Engineering and Astronautical 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.

Astronautical Engineering

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 will be 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 number of students per year who graduated from this program varied from 15 to 25.
Special Courses

The Department of Aeronautics and Astronautics provides curriculum strength in a number of areas. Some of the strengths are in rare, if not unique, courses and course sequences.

Design. Students are required to participate in a major design project where they perform as members of a design team to an aircraft, avionics, spacecraft or missile design project. At the conclusion of the design project, the student teams present their work to a panel comprised of military, science, and industrial experts. Unless the design project is completed for NAVAIR or some other branch of the Department of Defense, the design teams often elect to compete with other universities in national graduate design competitions sponsored by such organizations as the American Institute of Aeronautics and Astronautics (AIAA) or the American Helicopter Society (AHS). NPS student teams have consistently ranked high in these competitions, lending credence to the quality of their efforts.

Survivability/Lethality. Aircraft Combat Survivability and Air Defense Lethality are two courses believed to be unique to this NPS program. Both courses were developed by Distinguished Professor Robert E. Ball who is the author of the only textbook in this relatively new field of lethality and survivability.

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 operating 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; mission/threat analysis; combat analysis of Southeast Asia and Desert Storm losses.

The air defense lethality course is concerned with the design and effectiveness of anti-aircraft guns and missiles. Target detection, target signatures, warheads, fuzes, damage mechanisms, and countermeasures are considered. Total system lethality is evaluated by determining the probability of target kill given a single shot and given an encounter.

Missile Option. An elective five-course Missile Option is available for qualified students. However, most of the students who take advantage of this option are in the Combat Systems Sciences and Technology (physics) curriculum. A gas dynamic, thermodynamic, and fluid dynamic background is prerequisite for the option. The five required courses are Missile Aerodynamics, Tactical Missile Propulsion, Missile Flight Analysis, Air Defense Lethality, and Missile Design. Non-aero students taking this option often take additional elective course work in aerodynamics, performance, controls, and structures. Students taking the missile option often qualify for the Master of Science in Engineering Science degree.

The combat systems students bring an academic background in electromagnetic radiation, signal processing, explosives, warheads, combat simulation, detection and engagement elements. Most students also have some academic background in the military acquisition process. The missile option serves as a sequence of service courses for the combat systems curriculum.

Research. 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.** 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.

**Department Faculty**

Brij N. Agrawal, Distinguished Professor, Associate Fellow AIAA  
Oscar Biblarz, Professor  
Russell W. Duren, Associate Professor  
Garth Hobson, Professor, Associate Fellow AIAA  
Richard M. Howard, Associate Professor  
Isaac I. Kaminer, Associate Professor  
David W. Netzer, Distinguished Professor  
Max F. Platzer, Distinguished Professor, Fellow AIAA  
I. Michael Ross, Associate Professor, Associate Fellow AIAA  
Raymond P. Shreeve, Professor, Associate Fellow AIAA  
Michael G. Spencer, Assistant Professor  
E. Roberts Wood, Professor, Associate Fellow AIAA  

Adjunct Teaching Faculty:  
S.K. Hebar, Senior Lecturer, Associate Fellow AIAA  
Barry A. Leonard, Visiting Associate Professor  

Research Faculty:  
Christopher M. Brophy, Assistant Professor  
M.S. Chandrasekha, Professor, Associate Fellow AIAA  
Kevin D. Jones, Associate Professor  
Ramesh Kolar, Assistant Professor  
Jose Sinibaldi, Assistant Professor  
Oleg Yakimenko, Associate Professor, Associate Fellow AIAA  

Emeritus Faculty:  
Robert E. Ball, Distinguished Professor, Fellow AIAA
Richard W. Bell, Professor
Allen E. Fuhs, Distinguished Professor, Fellow AIAA
Charles Kahr, Professor
Donald M. Layton, Professor
Gerald H. Lindsey, Professor
James A. Miller, Associate Professor
Conrad F. Newberry, Professor, Fellow AIAA
Louis V. Schmidt, Professor, Associate Fellow AIAA
Edward M. Wu, Professor
Robert D. Zucker, Associate Professor

Curricula

On December 22, 1951, by order of the Secretary of the Navy, the United States Naval Postgraduate School was officially disestablished at Annapolis, Maryland, and established at Monterey, California. During the period from November 21, 1951 to February 16, 1952, the entire Naval Postgraduate School at Annapolis – faculty, students and equipment, was moved to Monterey. This move, unique in character, involved the transcontinental transportation of approximately five hundred families, civilian and military, their household effects, and some three million pounds of school equipment. What had been the U.S. Naval Postgraduate School, Annapolis, was redesignated the Engineering School of the U.S. Naval Postgraduate School. The aeronautical engineering curricula have evolved over time as indicated by the following discussion.

In the 1950s the M.S. degree in aeronautical engineering required three years for completion. The first two years were taken at the Naval Postgraduate School. Qualified students then were selected to take the third year at a civilian engineering school (Princeton, Michigan, Stanford, CalTech, Stevens Institute of Technology, Cranfield Institute of Technology, etc.). The third year courses at the various civilian institutions were arranged to provide emphasis on such fields as aircraft structural analysis, aircraft propulsion, high-speed aerodynamics, seaplane design, pilotless aircraft, aircraft performance, as well as general aeronautical engineering. Completion only of the two-year curriculum provided the student with what amounted to a Master’s degree level of education. However, the Master’s degree was not awarded. The first year of the two-year program normally covered the junior and senior years of a civilian university. The second year included airplane design, flight analysis, flight testing, electronics, human engineering, principles of industrial organization etc. When practicable, a summer period was spent at a civilian institution in classes offered in industrial engineering, prior to reporting to a new duty station.

In the 1960s the requirement to take the third year at a civilian institution was dropped and the M.S. in aeronautical engineering was awarded after two years at the Naval Postgraduate School. The aeronautical engineering faculty had grown from nine in 1952 to nineteen in 1968 and the faculty became more research oriented leading to the award of the first Ph.D. degrees.

In 1979 an agreement was signed with the U.S. Naval Test Pilot School (TPS) at Patuxent River, Maryland, to offer a joint program wherein highly qualified students could enroll in a five or six-quarter aeronautical engineering program, followed by the standard one-year TPS program, qualifying the student for the award of the Master’s degree in aeronautical engineering at the completion of the TPS program. Over the years this program led to the enrollment of ten students per year in the joint NPS/TPS program.
In 1987 the Department of Aeronautics became the Department of Aeronautics and Astronautics when it started to offer a curriculum in astronautical engineering. The average number of aeronautical and astronautical engineering students in the Department substantially exceeded one hundred, but then started to drop in the 1990s together with a gradual decline in the number of tenure-track faculty to ten at the beginning of 2003.

Students typically receive their orders to report to the Department after completion of their first or second operational tour of duty, and therefore have been away from the academic environment for some four to six years. Therefore, one or two refresher quarters are offered to ease some of these students back into the academic environment. Six-week refresher courses are also available.

The requirements for entry into the aeronautical or astronautical engineering programs consist of a baccalaureate degree, or its equivalent, with an above-average Quality Point Rating, preferably in engineering or the physical sciences; mathematics through differential and integral calculus; and completion of a calculus-based physics sequence.

A typical course sequence leading to the Master of Science in aeronautical engineering is:

Quarter 1: flight structures, digital computation, differential equations, software methodology
Quarter 2: matrix analysis, gas dynamics, aerodynamics, partial differential equations
Quarter 3: flight mechanics I, aircraft navigation, digital avionics I, structural analysis
Quarter 4: propulsion, measurement techniques, aerodynamic analysis, aircraft design tools
Quarter 5: aeromechanics/aeroelasticity, flight mechanics II, flight controls, digital avionics II
Quarter 6: design course, aircraft survivability/reliability/safety engineering, thesis, elective
Quarter 8: thesis, elective, elective, elective

The aeronautical engineering/avionics curriculum offers courses in electronics, communications engineering, radar systems, avionics software engineering, digital avionics, and avionics system design.

A typical course sequence leading to the Master of Science in astronautical engineering is:

Quarter 1: digital computation, structures, differential equations, digital logic circuits
Quarter 2: orbital mechanics, space environment, matrix analysis, controls
Quarter 3: spacecraft dynamics, signal analysis, remote sensing, guidance & control
Quarter 4: spacecraft propulsion, communications engineering, systems dynamics, vibrations
Quarter 5: attitude dynamics & control, electromagnetic waves, microprocessors, astrodynamics
Quarter 6: spacecraft design tools, space power, military space applications, thesis
Quarter 7: spacecraft design I, spacecraft communications, thermal control, smart structures
Quarter 8: spacecraft design II, elective, elective, thesis

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**

The major curriculum areas of concentration include disciplinary, research, and design components. Typically students select only one area of design (from the four areas available in aeronautical engineering) and one area of research.

**System Design**

Since the inception of the Department, system design has been recognized as an important ingredient for the education of aeronautical engineering duty officers. After graduation, naval officers may be assigned to class desks or program acquisition offices. NAVAIR sponsored research by Professor Ulrich Haupt in the mid-70s addressed the basic needs of aircraft design education in the United States [1,2]. The quality of the NPS curriculum design component can, in part, be measured by student success in national graduate design competitions, contributions to advanced system development at the Naval Air Systems Command (NAVAIR), and national recognition of outstanding system design instruction. Depending upon their particular program, students will be involved in one or more system design projects. These projects may be aircraft, missile, rotary wing, engine, avionics, spacecraft, and/or weapons system design.

**Aircraft Design.** For more than a decade, Professor Newberry taught aircraft design at the Naval Postgraduate School in a team environment. Each team consists of some 6-10 students functioning as an Integrated Process and Product Development Team (IPPDT). The two-quarter course design effort takes place in a special Aeronautics Design Laboratory containing computers, software, design literature, and work spaces. It should be noted that the same design laboratory is used by aircraft, missile, rotary wing, and end engine design teams (without mutual interference). The aircraft design team effort is in response to a Request-for-Proposal (RFP) generated by a variety of sources, e.g., NAVAIR, national AIAA graduate design team competitions, or sponsored research. Each design team addresses aerodynamic, structural, propulsion, stability & control, performance, total ownership cost, survivability, system effectiveness, weight, armament, deployment, utilization, maintainability, manufacturing, and system parameter trade-off issues impacting the subject aircraft system. At the completion of the project, the students present their design effort to an evaluation panel consisting of representatives from NAVAIR, NASA, industry, and academe; the composition of the panel varies from presentation to presentation. The student design effort is documented in a comprehensive report which, when applicable, is submitted for national competition judging.
One indication of the quality of the design experience is evidenced by NPS team placements in AIAA/McDonnell Douglas national graduate student design competitions. Aircraft design team placements during the 1990s were 2nd and 3rd in 1992-93, 1st in 1993-94, 1st and 2nd in 1994-95, 1st and 2nd in 1995-96, 1st and 2nd in 1996-97 and 3rd in 1997-98.

From 1990 to 2002, the aircraft design teams were directed by Professor Newberry. He was honored with the Fred Merryfield Award of the American Society for Engineering Education (ASEE) for excellence in teaching engineering design in 1997.

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 for two student design teams supporting independent NPS waverider research [3].

From 1999 through 2001, NPS aircraft design teams supported NAVAIR advanced UCAV planning studies. This support resulted in a number of NPS graduate student team generated Uninhabited Combat Air Vehicle (UCAV) configurations of interest to NAVAIR and ONR. This UCAV design experience also enabled NPS aircraft design students to support the NPS Systems Engineering CROSSBOW Project discussed below.

**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. Generally, an NPS missile design team will consist of from six to ten students, but due to the elective nature of the missile option sometimes results in a team as few as five members. The team functions as an IPPDT.

The missile design effort is in response to an RFP generated by the naval or military service, NASA, a national academic design competition, or some defense related source. Each design team addresses aerodynamic, structural, propulsion, stability & control, trajectory, performance, cost, storage, weight, system effectiveness, lethality, warhead, deployment, utilization, manufacturing, and systems parameter trade-off issues impacting the subject missile configuration. As in the aircraft design project, the students present their design effort to an evaluation panel and document their work in a comprehensive report. When applicable, the report is submitted for national design competition judging.

From 1990 to 2002, Professor Conrad F. Newberry directed the NPS missile design teams. One measure of the quality of the missile design experience is provided by their placements in the national AIAA/Northrop Grumman missile design competitions, namely 1st and 2nd in 1992-93, 2nd and 3rd in 1993-94, 2nd in 1996-97. Due to decreasing student demand the sequence was offered infrequently during the late 1990s.

**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 1995 AHS/NASA Student-Industry Helicopter Design Competition and 2nd place in the 1996, 1997, 1998 and 1999 AHS/NASA Student-Industry Helicopter Design Competitions.
Engine Design. The engine design experience consists of a one quarter course. 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. Digital design and hardware/software integration is taught by Associate Professor Russell Duren 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. The spacecraft design is taught in a dedicated laboratory that uses computer-aided design tools, such as GENSAT, Aerospace Conceptual Design Center software, STK, NASTRAN, IDEAS, and MATLAB/ Simulink. A student team advised by Professor Brij 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.

Weapons (Total) System 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, SEA ARCHER. The Aeronautics students designed two aircraft capable of operating from the SEA ARCHER. SEA ARCHER was designed for an armed reconnaissance (UCAV) mission; SEA SPECTRUM was designed for the intelligence, surveillance, reconnaissance and combat (ISRC)UCAV mission. SEA SPECTRUM also has the capability to operate unassisted from an LHA.

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 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. Ekaterinariais, KETA Greece, W. Sanz, TU Graz, F. Sisto, Stevens IT, W. Geissler, DLR Goettingen, I. Tuncer, METU Ankara, J. Lai, Australian Defense 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 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 (VPL, 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 Neuhoft 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**

High-speed propulsion systems on both military and commercial platforms require a thorough understanding of the existing gas dynamic and chemical processes within these systems. Propulsion systems commonly investigated include solid propellant and liquid propellant rocket engines, ramjets, and pulse detonation engine systems. The Rocket Propulsion and Combustion Laboratory (RPCL) was established by Dr. Roy Reichenbach. Since joining the Naval Postgraduate School in 1968 it was further developed by his successor, Distinguished Professor David Netzer, who is currently supported by two research assistant professors, Dr. Christopher Brophy and Dr. Jose Sinibaldi. 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, copper vapor laser system for Particle Image Velocimetry (PIV), 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.

**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 A/K-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 since 1969 by Professor J.A.J. Bennett, the former head of the Department of Aeronautics of Cranfield Institute of Technology. Following the death of Professor Bennett in 1971, instruction in rotary wing technology continued under Prof. Donald Layton. After the appointment of Professor E. Roberts Wood in 1988 he 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, 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 NPS Distinguished Professor Robert E. Ball who published a book on this topic in 1984 (recently
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 gyro 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 developed the NPS Astrolab and the Space Technology Battlefield Laboratory to study high-speed precision guidance and control of space vehicles and ballistic missiles. He 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
CAPT 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

Each year, the NPS Department of Aeronautics and Astronautics and the AIAA Point Lobos Section jointly make an award to the best student in both the aeronautics and astronautics programs. The Admiral William Adger Moffett Award is presented annually to the outstanding aeronautical engineering officer student on the basis of academic excellence, including thesis, and career potential. The Astronaut Michael J. Smith CAPT, USN, Astronautics Award is presented annually to the outstanding astronautical engineering student on the basis of academic excellence, including thesis, and career potential.

Over the years, the Department of Aeronautics and Astronautics has graduated many naval and other officers who reached the rank of Admiral. Many have made important contributions to the development of naval/military aviation.

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 astronautical engineering graduates received the Michael Smith Award:

**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 astronautical engineering programs to the Air Force Institute of Technology effective 1 January 2003. The astronautical engineering program remains at NPS for the time being. Hence this decision consolidates the graduate astronautical engineering education for Air Force and Navy officers in one institution only and thus terminates the unique Navy/Marine Corps oriented astronautical 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 astronautical engineering expertise. Also, it remains to be seen whether the NPS leadership recognizes the need to maintain the unique NPS astronautical engineering laboratories to support such interdisciplinary systems studies.

**Books/Contribution to Books**


References


Dedication

This paper is dedicated to the memory of Dr. Wendell M. Coates, Distinguished Professor and founder of the Department of Aeronautics, and to Dr. Michael H. Vavra, Distinguished Professor and founder of the Turbopropulsion Laboratories.