Naval Engineering at the Naval Postgraduate School: Educating for tomorrow's Navy

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American Society of Naval Engineers

MARTO, PAUL J. "NAVAL ENGINEERING AT THE NAVAL POSTGRADUATE SCHOOL-EDUCATING FOR TOMORROWS NAVY." Naval Engineers Journal 88.2 (1976): 53-60.
https://hdl.handle.net/10945/59936

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NAVAL ENGINEERING AT THE NAVAL POSTGRADUATE SCHOOL—EDUCATING FOR TOMORROW'S NAVY

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received his BS degree in Engineering Science from the University of Notre Dame in 1960, his SM degree in Nuclear Engineering from Massachusetts Institute of Technology in 1962, and his ScD in 1965. He taught for two years at the Naval Postgraduate School while on active duty in the U.S. Navy, and after separation from the Service in 1967, remained as a civilian member of the Faculty where he is presently an Associate Professor of Mechanical Engineering. His engineering experience includes a number of summer positions with Gibbs & Cox, Inc., Brookhaven National Laboratory, and the NASA Lewis Research Laboratory as well as consulting experience with Lawrence Radiation Laboratory and SKF Industries, Inc. In 1972 he spent the summer visiting the Research and Technology Directorate of NAVSHIPS. Last year he was Visiting Associate Professor of Mechanical Engineering at the U.S. Naval Academy. His memberships in professional societies include ASME, ANS, ASEE, and Sigma Xi.

ABSTRACT

This paper reviews the current academic program in Naval Engineering at the U.S. Naval Postgraduate School, Monterey, Calif. Included are student qualifications for admission, degrees offered, courses available in Mechanical Engineering and Management, student thesis research areas, and complementary laboratory facilities. The evolvement of the unique qualities of this program, with its strong Naval relevance, is emphasized. Future trends in student and Faculty composition, graduate level courses, and continuing education are discussed.

INTRODUCTION

THE EDUCATIONAL PROGRAMS AT THE NAVAL POSTGRADUATE SCHOOL (NPS) in Naval Engineering in general and in Mechanical Engineering in particular are described. Specifically, the qualifications for admission, current academic programs, research activities, laboratory facilities, and future trends are reviewed.

The Postgraduate School had a modest beginning at the U.S. Navy Academy in 1909 with the enrollment of 10 officers in a Marine Engineering curriculum. Over the years, the scope and importance of the School increased, and in 1951, by order of the Secretary of the Navy, it was officially moved to Monterey, California. The goals under which the Postgraduate School was originally founded are best described by the Secretary of the Navy:

> "To conduct and direct the advanced education of commissioned officers, and to provide such other technical and professional instruction as may be prescribed to meet the needs of the Naval service; and in support of the foregoing, to foster and encourage a program of research in order to sustain academic excellence."

Presently, academic programs and direct supporting functions are administered and operated through a unique organization composed of Curricular Offices and Academic Departments. The students are grouped into nine curricular programs, one of which is the Naval Engineering Program. The Faculty and their teaching and research are organized into nine academic departments and two interdisciplinary groups, one of which is the Mechanical Engineering Department. For additional details, the readers are referred to the Naval Postgraduate School Catalogue for 1974-1976. (Available on request from Department of M.E.) The Naval Engineering Program offers courses in Mechanical Engineering and Management as described in greater detail below.

Education in Mechanical Engineering brings to the officers not only the unchanging fundamentals of mechanics and related subjects, but also, an awareness of the current and future problems and programs of the Navy. In fact, it is this Navy-oriented emphasis on teaching, research, thesis, and the entire curriculum that makes this education unique at NPS. The means used to achieve this emphasis are described below.

Academic Program

During its 66 years of operation, the program in Naval Engineering has kept abreast of the rapid technological advances in total ship and weapons system design. This had been done primarily through the Curricular Officer in Naval Engineering who is an experienced Engineering Duty Officer, as well as through an annual curricular review conducted by our sponsoring agency which is the Naval Sea Systems Command (NAVSEA). During such reviews not only are existing courses evaluated, but future programs are formulated and discussed in an effort to insure continued attainment of the Navy's professional objectives. Faculty participation in such activities as shipboard cruises, visits to shipyards, and tours (ranging from a quarter to a year in length) at NAVSEA, the Naval Research Laboratory, and the Naval Ship Engineering Center have also provided continual Naval input into our educational program. Finally, the latest technological advances in ship and weapons systems have been presented to our officer students and Faculty through a dynamic seminar program.

Today the program provides *selected* naval officers advanced education, irrespective of designator, leading, in most cases, to a Master of Science degree. Using the particularly appropriate disciplines of Mechanical Engineering and Management, emphasis is placed on developing the capability for independent and creative problem solving in future duty assignments, be they at sea in one of the technically sophisticated warships, or in the demanding business of the Navy ashore in designing, developing, building, and maintaining these ships and weapons systems.

Qualifications for Admission

U.S. Naval Officers with designators for surface, submarine, special warfare, or engineering duty, as well as officers from other U.S. services and Allied officers, can participate in this program. To qualify for admission, a baccalaureate degree with above average grades in mathematics, physical sciences, and engineering, is required. Completion of mathematics through integral calculus, engineering physics, and chemistry is considered to be minimal preparation for these programs. Officers who do not have the preparation to enter the Engineering curricula can obtain the necessary background in the Engineering Science Program. Courses in statics, dynamics, fluid mechanics, thermodynamics, electric fields, electric circuits, and electronics are desirable. Students lacking these quantitative prerequisites will be accepted in certain cases where their academic records indicate that they are exceptional students and that there are indications that they can succeed in technical studies.

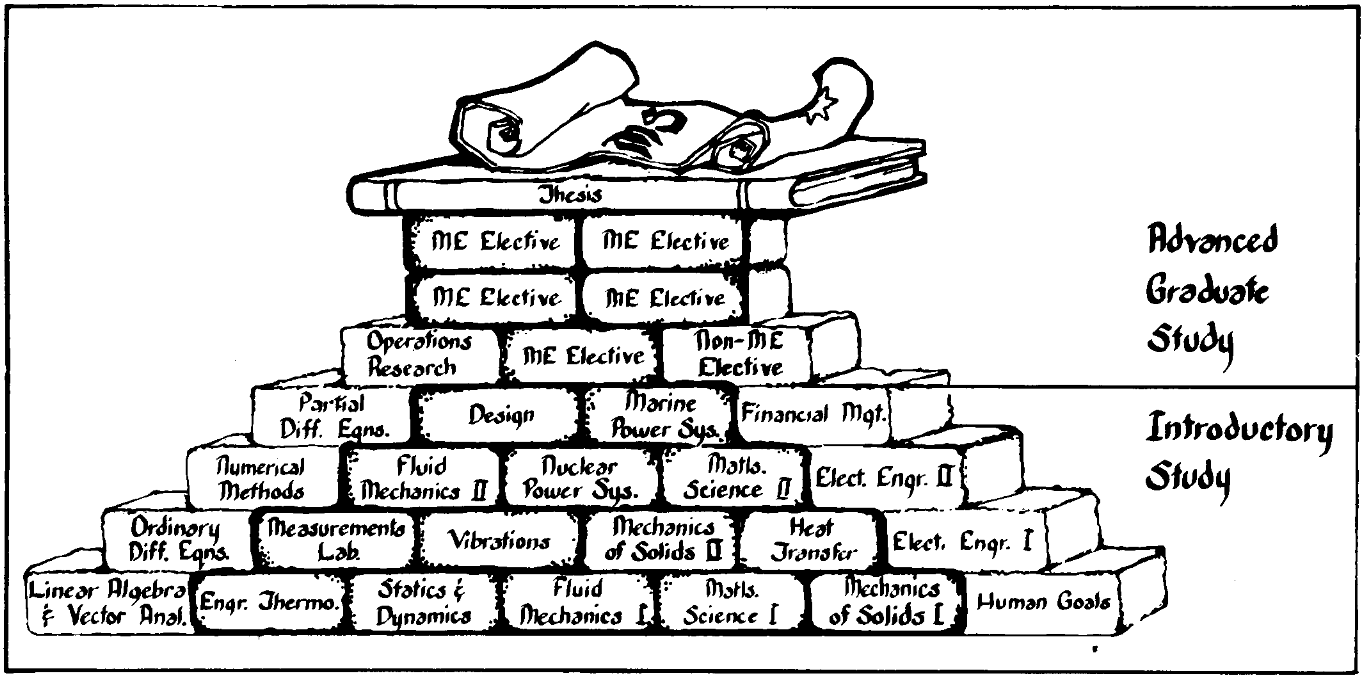

Figure 1. Schematic Representation of Graduate Program Leading to the Degree M.S. in Mechanical Engineering.

Description of Program

The academic program is divided into an introductory study portion and an advanced graduate study portion. The introductory portion consists of undergraduate level and graduate level courses which provide the necessary breadth and depth for successful pursuit of the advanced graduate level portion of the curriculum. A schematic representation of this foundation of preparatory courses is shown in Figure 1. Depending on the student's background, prior academic preparation, and length of time away from academic work, this portion of his program may vary in length from one to six quarters. Each student's transcript is evaluated for validation of as many of these introductory courses as possible — Validation in this sense means the process of certifying that a student has obtained knowledge or experience essentially equivalent to that expected from a course. No credit is allowed for a validated course, and the student is interviewed upon arrival to reach a final decision on those courses to be programmed for study. Near the end of the introductory phase of the program, students are screened for admission to advanced graduate study. Criteria for selection include academic performance, individual preference, and tour availability. Those students who are not admitted to candidacy are graduated one quarter later, and if qualified, are awarded the degree Bachelor of Science in Mechanical Engineering. Those students who are admitted to candidacy for the degree Master of Science in Mechanical Engineering elect a technical option and select an acceptable thesis topic from a variety of research areas described below. The option normally consists of five advanced graduate level electives in Mechanical Engineering, a graduate level course in Operations Research for Naval Engineers, and at least one graduate level course outside the Mechanical Engineering Department as shown in Figure 1. The option packages from which the Mechanical Engineering courses are chosen are shown in TABLE 1.

The length of the advanced graduate study portion of the program depends upon the degree program in which the student is enrolled. The Master of Science degree generally requires three quarters of additional work. The program leading to the degree Mechanical Engineer requires up to six quarters. This program is an advanced graduate curriculum which gives highly motivated students an opportunity to pursue an increased depth of graduate study beyond the Master's degree program. Additional courses are chosen from the option sequences shown in TABLE 1, and a thesis of increased depth is required.

TABLE 1

GRADUATE LEVEL COURSE OPTIONS IN MECHANICAL ENGINEERING

1. Fluid Mechanics Options

   Gas Dynamics
   Fluid Power Control of Ship Systems
   Hydrodynamics of Ocean Structures
   Viscous Flow
   Applied Mechanics of Naval and Ocean Structures

2. Propulsion Options

   Nuclear Reactor Analysis
   Marine Gas Turbines
   Reactor Engineering Design

3. Heat Transfer Options

   Conduction and Radiation Heat Transfer
   Convection Heat Transfer
   Advanced Topics in Fluid Dynamics and Heat Transfer

4. Engineering Mechanics Options

   Design of Naval Machinery
   Advanced Dynamics of Marine Systems
   Advanced Vibrations
   Advanced Mechanics of Solids
   Finite Element Methods
   Theory of Continuous Media

5. Material Science Options

   Properties, Problems and Failures of Structural Materials
   Corrosion in the Marine Environment
   Mechanical Behavior of Engineering Materials in Ship Systems

A new academic program recently developed at NPS is called Systems Acquisition Management. Officers in Naval Engineering who are academically qualified and who desire to expand on their education with a balance between technical and management courses, may apply for the dual Master's degree program in Mechanical Engineering and Systems Acquisition Management. Officers pursue both degrees concurrently and, in addition to the courses in Mechanical Engineering outlined earlier, pursue courses in the Management areas listed in TABLE 2. This program requires the same length of time as the Engineer degree program.

The degree of Doctor of Philosophy is available to a limited number of officers who demonstrate superior academic performance. The degree normally requires about two years of study after the student qualifies for award of the Master of Science and it is limited to a total program not to exceed four years in residence.

TABLE 2

MANAGEMENT COURSE AREAS FOR DUAL MASTER'S DEGREE PROGRAM

1. Financial Management

   Managerial Accounting
   Management Economics
   Public Expenditure Policy and Analysis

2. Personnel

   Individual and Group Behavior
   Personnel Management and Labor Relations

3. Quantitative Methods

   Survey of Operations Analysis and Systems Analysis
   Systems Effectiveness
   Systems Analysis

4. Life-Cycle Management

   Introduction to Systems Acquisition
   Fundamentals of Defense Project Management
   Production Management
   Systems Engineering Management
   Defense Contract Administration
   Logistic Support
   Procurement

Student and Faculty Research Areas

The Department of Mechanical Engineering is presently composed of sixteen (16) faculty members whose research backgrounds and interests provide a variety of topics for student theses as shown in Figures 2 through 7. Areas of expertise include fluid dynamics, heat transfer, solid mechanics, and material science. Some members of the Department are also actively engaged in the analysis of nuclear reactors and high energy lasers. In addition, the Department has also interacted with other Departments on interdisciplinary group projects, such as a study of the effects of atmospheric disturbances upon high energy laser propagation.

In the area of fluid dynamics, faculty members are particularly interested in missile aerodynamics, wave/body interactions in the ocean, unsteady flow about bluff bodies, vortex breakdown phenomena, fluidics, and drag reduction.

In the area of heat transfer, interest is maintained in conduction, natural and forced convection, boiling, and condensation. Particular expertise has been developed in heat pipe technology and liquid crystal thermography.

The Material Science group is interested in the damping capacity of alloys, shape-memory effects in certain alloys, corrosion prevention and high temperature deformation mechanisms in dispersion-strengthened alloys.

In the area of solid mechanics, interest is maintained in the design and analysis of piping systems, transient thermal stresses, shock and vibration, inelastic analysis of structures, and structural optimization. A particular expertise has

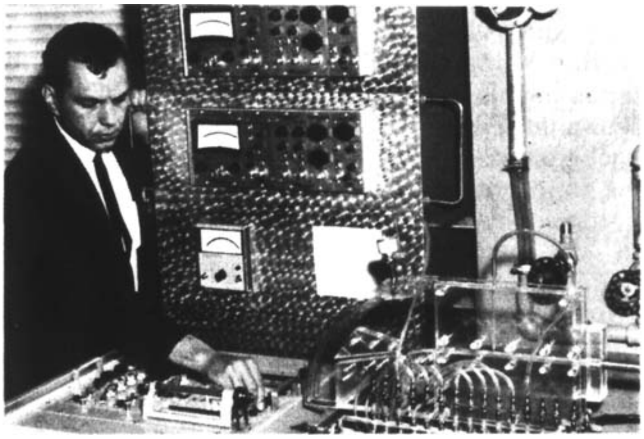

Figure 2. An Officer Investigating the Phenomenon known as the Coanda Effect – Attachment of a Jet to Curved Surfaces.

Figure 3. Officers and Their Advisor Discussing the Use of Liquid Crystals to Map the Temperature Distribution on a Heated Cylinder Cooled by Air.

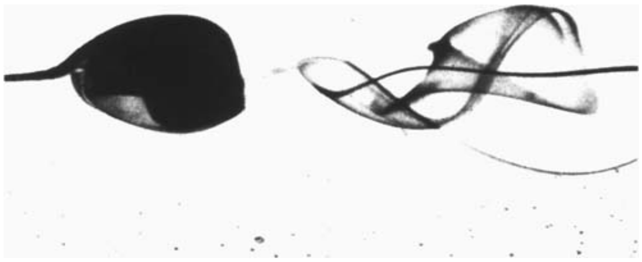

Figure 4. Vortex Breakdown Phenomenon as Observed in a Swirling Flow in a Diverging Tube.

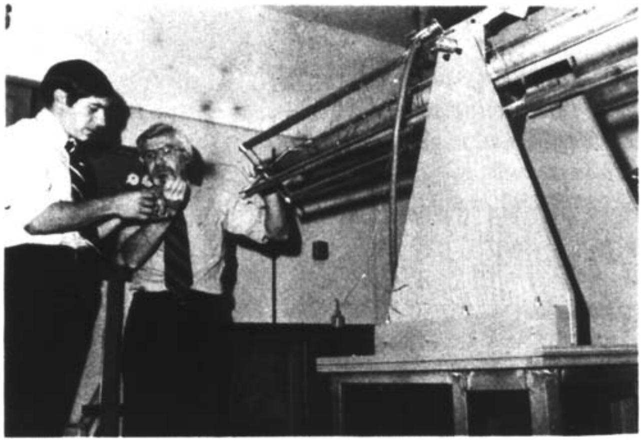

Figure 5. An Officer and His Advisor Inspecting the Instrumentation on a Gas-Loaded Heat Pipe.

Figure 6. Laser Gyro Platform Being Loaded Aboard RV/ACANIA in the Electo-Optics Laser Technology Project.

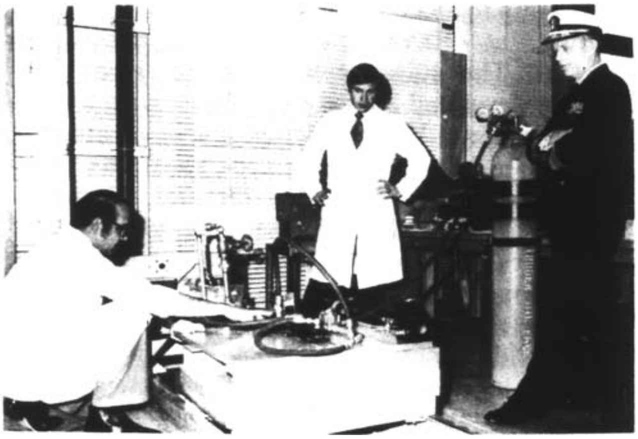

Figure 7. Officers Explaining the Experimental Operation of a Simulated Liquid Propellant Gun Feed System to VAdm. J.B. Wilson, USN, Chief of Naval Education & Training.

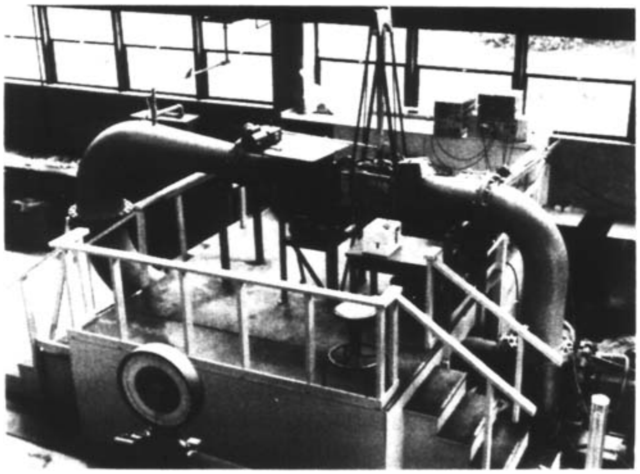

Figure 8. A Medium Size Water Tunnel Used for Polymer Drag Reduction and Unsteady Flow Investigations About Bluff Bodies.

been developed in the application of finite element methods (including the development of a variety of finite element computer codes) to engineering problems.

Experimental Facilities

The Mechanical Engineering Laboratories include extensive facilities for the support of student and faculty research, as well as a variety of general use equipment for various courses. These facilities are described relative to the various research areas of specialization.

Fluid Mechanics

The major facilities related to the area of fluid mechanics consist of a recirculating water tunnel; a small, as well as a large, U-shaped water tunnel; a subsonic wind tunnel; a 75 foot long wave channel; two vortex-breakdown apparatus; and a number of smaller supporting equipment for calibration, flow visualization, and preliminary exploration. The water tunnel, shown in Figure 8, is of medium size, is powered by a 45HP motor, and is used mostly to investigate the effect of polymers on drag-reduction and the problems related to cable strumming. The U-shaped water tunnels are designed to generate harmonically oscillating flow about bluff bodies for the purpose of investigating wave loading on ocean structures. The small tunnel operates at Reynolds

NUMBERS up to 35,000. The larger one is capable of operating at REYNOLDS NUMBERS close to 1,000,000. The subsonic wind tunnel is of low turbulence level and is used to study such problems as the flow about bodies at high angles of attack, heat transfer from cylinders in the proximity of a plane wall, wind loading on structures, etcetera. The wave channel is about three feet wide and is used mostly to measure the wave forces on cylinders and other models of ocean structures. The vortex breakdown apparatus, believed to be the only kind in the world, generates swirling flows at various rates of rotation and enables one to investigate the causes of vortex breakdown often observed over delta-wing aircraft and other swirling flows.

Heat Transfer

The major facilities related to the area of heat transfer and gas dynamics consist of a BOEING MODEL 502 Gas Turbine (rated HP = 175 and rated rpm = 36,000); a General Motors Single Cylinder (displacement = 53 cubic inch) Diesel Engine with electric dynamometer; several gas loaded heat pipes; one *rotating* heat pipe, several everted heat pipes, and associated equipment such as pressure calibration system and temperature calibration system (including a liquid-nitrogen controlled constant temperature oil bath and a platinum resistance thermometer); and a quartz-crystal thermometer. The gas turbine is used both for educational and research purposes. The heat pipes have been specially constructed for a variety of research projects to determine the performance characteristics of rotating and non-rotating heat pipes.

Solid Mechanics and Materials

The major facilities related to the area of solid mechanics, materials, and structures consist of a fatigue machine; two universal testing machines; a Cambridge SF-10 Scanning Electron Microscope shown in Figure 9; a Princeton GammaTech Energy Dispersive X-Ray Analyzer; a GEM-7 Transmission Electron Microscope; two Instron Machines (one 2,000 lb. capacity and programmable; the other 20,000 lb. capacity); an X-Ray diffraction machine; and an MTS programmable fatigue machine with a capacity of 50,000 lbs. These facilities are used both for teaching and research.

Supporting Elements

The operation of all the facilities cited above is backed by numerous mechanical and electronic equipments, such as a Fairchild High-Speed Camera, a variety of photographic equipment, various calibration systems, transducers, etcetera. Electronic equipment includes various amplifier-recorder systems, a Varian computer, about 20 analog computers, Dymec Data Acquisition System, various oscilloscopes, RMS meters, three sets of hot-wire and hot-film anemometer systems, a tape recorder, etcetera. These systems have been operated and maintained, and a variety of test sections have been built using a well equipped machine shop with support personnel. In addition, it is important to note that both students and staff share all the major facilities of the Naval Postgraduate School, including an IBM-360 computer system and an Educational Media Facility to provide photo, drafting, and printing support.

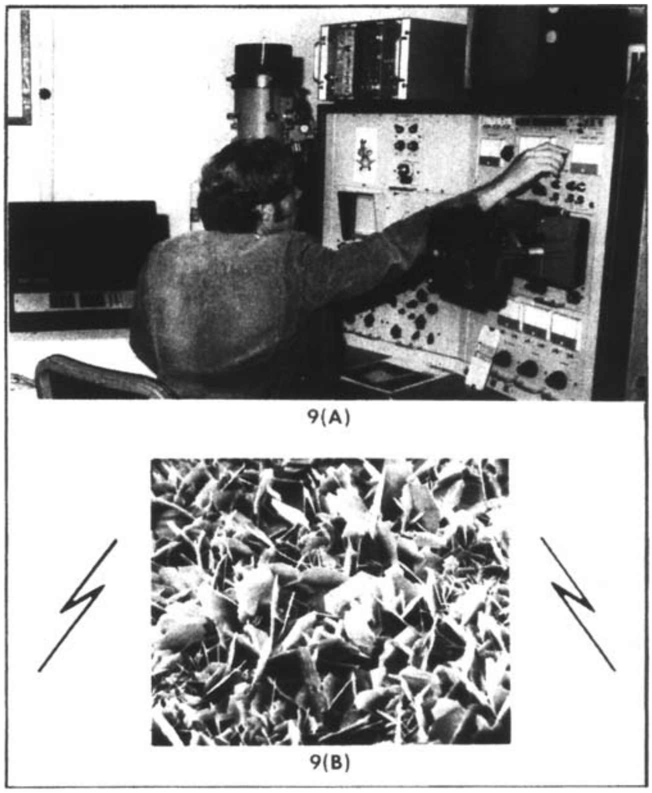

Figure 9. [A] A Faculty Member Operating the Scanning Electron Microscope (SEM). [B] A SEM Photograph (2500X) of a Zinc Corrosion Product.

FUTURE TRENDS

In keeping with an everchanging, more sophisticated NAVY, educational trends in Naval Engineering at NPS will continue to provide flexibility and adaptability to the needs of the Naval service. These trends can best be described in terms of new courses and laboratory facilities, developments in educational technology, teaching philosophy, and faculty and student composition.

Several new graduate level courses are being introduced into the Mechanical Engineering program which are briefly described below. Each of these courses is designed to provide the students with the opportunity to develop the requisite skills to understand and operate modern complex engineering systems.

Marine Gas Turbines deals with thermodynamic analyses of gas turbine cycle variations as well as the internal aerodynamics of compressor, turbine and combustor design. It considers the matching of engine and propeller characteristics along with operational control and instrumentation, fuel systems and inlet and exhaust silencing systems. The details of machinery arrangement, installation, and maintenance are discussed. It compares propulsion of hydrofoil, surface effect, and conventional surface ships with an overview of current Naval research and development in these areas.

Naval Weapons Engineering will deal with gun internal ballistics including gun propellant combustion and one-dimensional, time-dependent gas flow. It will consider gun external ballistics such as flat-earth trajectory equations with aerodynamic forces, and blast damage effects in air and water. A comparison of guns versus missiles will be made. New weapons developments will be presented including high energy laser technology, its advantages and limitations.

Synthesis and Design in Naval Engineering will describe various categories of marine vehicles, such as single hull, multiple hull, submarine, surface effect, hydrofoil and wing-in-ground effect vehicles. Consideration will be given to all major facets of marine vehicle synthesis including structures, hull forces, propulsion, electronics, armament, crew, etc. Selected Naval Engineering components will be designed through special projects. The details of vehicle optimization will be presented together with sensitivity analysis and design "trade-offs."

A trend in today's manpower-conscious NAVY is toward automated engine rooms. By exploiting the capability of present day sensors, servos, microprocessors, and software, the crew aboard a ship can be significantly reduced. To participate in this trend, the Mechanical Engineering Department is designing an automated engine room. Although the control will be of either the small diesel or the gas turbine and not of a full size marine propulsion unit, the features will be realistic. Involved in the automated engine room will be instantaneous control of the engine, provisions for monitoring emergencies, consideration of engine health monitoring, and other functions. Students will be involved in the design.

A new tool has been developed for visualization of the vibration modes of complex geometric shapes. The technique is holography. A laboratory space is being converted to provide the darkroom environment necessary for real-time holographic interferometry. Plans are also being developed to improve the experimental facilities for measurement of hull forces and wave interaction studies.

Educational trends encompass the utilization of teaching aids, such as computer graphics, videotaped lectures, and a variety of electronic software including video cassette tapes and sound-on-slide projectors. These methods are being experimented with at NPS for inclusion in future courses. More importantly, new teaching methods, such as programmed instruction and the personalized system of instruction (PSI), are being developed for delivery to officers at their current duty stations for completion during off-duty hours or work/study periods. These courses have been selected primarily from courses normally contained in the introductory portion of the academic degree programs, and should, therefore, serve to provide a smooth transition from previous education and experience to advanced graduate level programs. Some of the PSI courses deal with Engineering Thermodynamics, Introductory Fluid Mechanics, Statics, Dynamics, Individual and Group Behavior, and Financial Accounting in Management.

In addition, the Continuing Education Program at NPS will provide extended educational services to the NAVY. The development of professionally relevant short courses will contribute toward increasing the professional efficiency of the officers and will also combat technical obsolescence. As such, the offerings will cover both fundamental engineering and managerial subjects, as well as topics of special interest. The following short courses are being tentatively planned by Mechanical Engineering: Military Applications of High Energy Lasers; Cooling of Electronic Equipment; Properties, Problems, and Failures of Structural Materials; Marine Gas Turbines; Finite Element Computer Codes; and Advanced Marine Vehicles.

As to the Faculty and its composition, it is anticipated that the number of faculty members will be somewhat reduced and the ratio of the officer instructors to the civilian faculty will be increased. Opportunities for visiting military and civilian faculty from other Naval Shore Activities will be expanded. The net result of this change in the faculty structure will be to put the students in greater touch with current NAVY problems. Furthermore, such a change is expected to bring the research activities of the Faculty and the students closer to practical and relevant problems of the NAVY.

As to the student composition, no serious changes are anticipated. Some of the programs described earlier, such as PSI and Continuing Education, will prepare the students better for a graduate level of study at NPS with a shorter period of residence. It also appears that the ratio of the foreign students to U.S. Naval officers will decrease due to the desire of many countries to open their own postgraduate institutions on the basis of their observation of the success and quality of NPS.

CONCLUSIONS

The foregoing has attempted to bring into focus the unique qualities of the NPS curriculum and the strong ties between the needs of the NAVY and the relevant evolution of the programs in Mechanical Engineering. This evolution has been directed to teach officers to be analytical, to think independently, and to relate what they learn in the classroom and laboratories to the NAVY around them. This is evident with an increased emphasis on open classroom discussions, on thesis topics which have a strong bearing on the needs of the NAVY, and on self-paced learning. Such an education allows the students to bring Navy-related problems based on past experience into abstract classroom situations. This cultivates their desire to explore not only the present but also future problems and programs of the NAVY. The Naval Engineering Program at NPS also enables a variety of USN and Allied officers to be together and to interact with each other both in technical and social areas.

The Naval Engineering Program, as well as NPS, will steadily evolve in the years ahead with dedication to the needs of the NAVY. This belief is based on the unique qualities of this institution as well as on a dynamic past and on the support of the Secretary of the Navy.