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SSC-391

EVALUATION OF MARINE STRUCTURES EDUCATION IN NORTH AMERICA

SHIP STRUCTURE COMMITTEE

1996

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An Interagency Advisory Committee

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Evaluation of Marine Structures Education in North America

This report reviews the structural engineering curriculum contained in the Ocean Engineering and Naval Architecture Departments in North American universities. The report describes undergraduate and graduate programs including marine structure courses at the various schools. Recommendations towards improving marine structural education and the role of the Ship Structure Committee are included. Improved training in ship structural design and construction will be the building block that will support the U.S. maritime industry's competitiveness in shipbuilding, maintenance, and repair.

By providing effective steps to improve the marine structural engineering curriculum in North American graduate and undergraduate programs, this report supports the Coast Guard's "Prevention Through People" program, which addresses the human error causes of marine casualties.

J. C. CARD
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

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16. Abstract

This report reviews the structural engineering curriculum contained in the Ocean Engineering and Naval Architecture Departments in North American colleges. The report includes brief descriptions of the undergraduate and graduate programs including marine structure courses at the various schools. The report queries individuals and/or organizations representing the various branches of the total marine industry that are concerned to some significant degree with structural analysis and design. Their impressions and expectations regarding the education programs, their satisfaction with their own basic knowledge of and their confidence in their current marine structural analysis and design practices, and their views on how their own or the marine industry's circumstances with respect to these matters might be bettered, were sought. The report is finalized by providing recommendations towards improving marine structural education and the role the Ship Structure Committee can play.

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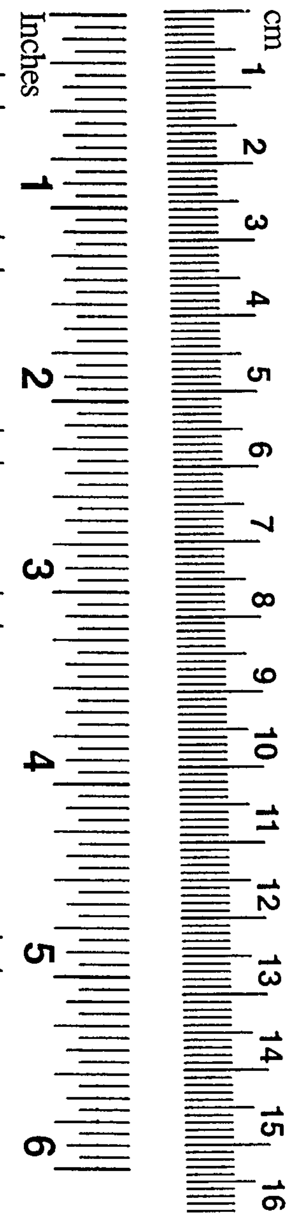


Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
	VOLUME			
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	degrees Fahrenheit	subtract 32, multiply by 5/9	degrees Celsius	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1,000 kg)	1.1	short tons	
	VOLUME			
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	degrees Celsius	multiply by 9/5, add 32	degrees Fahrenheit	°F

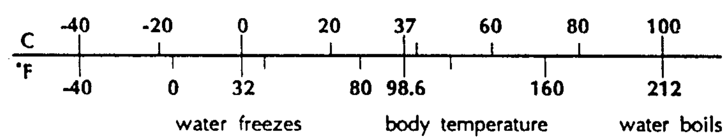


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Marine structures education, for the purposes of this study, and hence this report, includes the structures portions of both the undergraduate and the graduate programs at well-recognized schools that grant degrees in the disciplines of naval architecture and/or ocean engineering, intending they indicate that the recipients are reasonably capable of analyzing and designing ships and boats and other marine craft, and/or offshore platforms or other offshore marine systems. This does not preclude the recognition that many of those in the practice and even the teaching of marine structural analysis and design may well have earned their degrees at these same or at different schools but in other mechanics-based engineering disciplines, such as civil, mechanical, or aerospace, in applied mechanics, or perhaps at the graduate level in a narrower specialized field sometimes called "structural mechanics" or just "engineering structures." Thus the extent to which this may indeed be so is significant and will be discussed.

There is an undeniable perception that structural considerations are not at present being given adequate attention in the curricula at some of the schools of interest, and this stems at least in part from differing expectations of what understanding and capability with regard to structural analysis and design the graduates of these programs should have obtained. This is in fact a perennial problem that pervades all of higher education. It is essential that students be informed about as much of the basic knowledge pertinent to their particular field as possible and gain an understanding of the principles and underlying historical evolution of ideas and problems that have led to the distinctive definition of that field. But it is equally necessary that they acquire the capacity to contribute their efforts in practicing professionally in that field, whether that entails resolving typical current problems with existing approaches and procedures or, less often, conducting and perhaps directing research and/or development undertakings seeking to enhance and often to improve them or, more frequently, just to understand the problems themselves more fully.

These twin demands are clearly evident in engineering education. The programs at some schools have curricula that emphasize one usually at the expense of satisfactorily achieving the other at the undergraduate level, even though most schools have until recently not considered the preparation for general practice as the main focus at the graduate level. The degree to which this is so at the dozen or so schools of concern in this project will be assessed. Their programs will be evaluated primarily with respect to the content appropriate to the subject of this report, marine structural analysis and design, while noting that the generic term "ocean engineering" is unlike "naval architecture" not at all limited to the analysis and design of vessels and offshore platforms and the structures content therefore in several may not be extensive. Two of the schools are indeed military academies and the somewhat special circumstances at them must be acknowledged.

In no instances are the descriptions of and discussions about the programs and the individual courses, and sometimes even the instructors for those courses, intended to be construed as criticism, favorable or unfavorable. This study sought to determine how correct the perception mentioned above actually is, and this report will describe and discuss the material and other information that permitted some conclusions to be reached. Colleagues at all the schools were helpful in providing this material and interchanges with them have been most beneficial, and are much appreciated. Many other friends or acquaintances in the marine industry were also interviewed and/or responded to, and often elaborated on their answers to, a questionnaire sent to them or their organizations.

This report will first include brief descriptions of the undergraduate and the graduate programs at the various schools that satisfy the engineering needs of the marine industry by having created and sustained educational efforts particularly in naval architecture and/or in ocean engineering. The material that might have been included is vast indeed. But while the primary interest is in the marine structures courses, they can only be properly understood, and discussed in the next section of the report, in relation to the total content of and the other requirements imposed on these programs.

A third section of the report will review the responses to a series of questions addressed to individuals and/or organizations representing the various branches of the total marine industry that are concerned to some significant degree with structural analysis and design. Their impressions and expectations regarding the education programs, their satisfaction with their own basic knowledge of and their confidence in their current marine structural analysis and design practices, and their views on how their own or the marine industry's circumstances with respect to these matters might be bettered, were sought.

The report will be completed with a section providing the conclusions reached as a result of undertaking this project, plus some recommendations suggested by those conclusions.

NAVAL ARCHITECTURE AND OCEAN ENGINEERING PROGRAMS IN NORTH AMERICA, AND THEIR RELATION TO CURRENT TRENDS AND CONCERNS IN ENGINEERING EDUCATION

The more traditional undergraduate programs in naval architecture in the United States and Canada are currently those offered by Webb Institute, the University of Michigan, the University of New Orleans, and Memorial University in St. John's, Newfoundland. There is a Department of Naval Architecture and Marine Engineering at Michigan and their program includes both the engineering disciplines named if indeed they are considered distinctive (as they sometimes are) rather than essentially a single discipline. The program at New Orleans is administratively offered by the School of Naval Architecture and Marine Engineering and like Michigan tends to consider the two fields a single discipline. That at St. John's is entitled Naval Architectural Engineering and is administratively actually offered by the Faculty of Engineering and Applied Science. Until recently the University of California at Berkeley and the Massachusetts Institute of Technology offered similar programs, but those students at Berkeley now are enrolled in the Mechanical Engineering Department even though the Department of Naval Architecture and Offshore Engineering stills exists and its faculty offer some undergraduate courses in naval architecture, and the Department of Ocean Engineering at MIT maintains a bachelor's degree-granting program in ocean engineering that also still includes courses in naval architecture.

The other well-established undergraduate ocean engineering programs are at Florida Institute of Technology, Florida Atlantic University, Virginia Polytechnic Institute at State University, where the home department is designated the Aerospace and Ocean Engineering Department, and at Texas A&M University (at the College Station campus, not that at Galveston) where it is administratively within the Civil Engineering Department even though the degree is in ocean engineering.

The U.S. Coast Guard Academy and the U.S. Naval Academy are the only two military schools included in this study even though accredited programs are available at two of the maritime academies – in marine engineering systems at the U.S. Merchant Marine Academy and in naval architecture and, separately, in marine engineering at the State University of New York Maritime College – which both incorporate the so-called Regimental System and could therefore be considered military, or perhaps quasi-military, schools. They were not included, however, because so very few of their graduates seek careers practicing naval architecture and fewer still specializing in marine structural analysis and design. At Annapolis majors are available in naval architecture, in ocean engineering, and in marine engineering from naturally enough, the Department of Naval Architecture, Ocean, and Marine Engineering. At the Coast Guard Academy the single major in naval architecture and marine engineering, considered a single discipline much as at Michigan and New Orleans, is offered by the Engineering Department.

Other undergraduate programs or courses not part of this study are the relatively quite new and still small but coherent and accredited one in ocean engineering at Rhode Island, and the sequences of courses in naval architecture offered within the Mechanical Engineering Department at the University of Washington. Those at the two military academies are indeed only included because graduates who have completed these programs often do enter into the practice of naval architecture and/or ocean engineering immediately after fulfilling their service obligations or even later when retiring after often gaining service experience or possibly additional formal education that might suggest that choice is quite appropriate. These late entrants to the field have sometimes majored in engineering disciplines other than naval architecture or ocean engineering while earning their undergraduate degrees at the academies.

These dozen institutions are thus at present the principal sources of very nearly all of those naval architecture and/or ocean engineering bachelor's degree-level graduates now entering practice or continuing their studies at the graduate level, and have been (with some variations at several of the schools) the sources for the last several decades. They are also schools that have traditionally offered graduate programs in naval architecture and/or ocean engineering, and still do with the exception of the military academies and Webb – which is initiating a master's degree program in "Ocean Technology and Commerce" as this is written. Again, several other institutions do have graduate programs in ocean engineering, notably Hawaii, Miami, New Hampshire, and Rhode Island, and there is now a graduate program in naval engineering at the Naval Postgraduate School in Monterey. But limiting the study to these dozen schools and dealing with their undergraduate curricula and the corresponding graduate programs, but including also the graduate program at the Technical University of Nova Scotia, would seem sufficient to gain an adequate understanding of and to describe adequately the state of marine structures education in North America. Table 1 indicates the degrees at all levels granted by these institutions.

TABLE 1
VARIOUS DEGREE DESIGNATIONS AND LEVELS FOR PROGRAMS OF INTEREST AT INSTITUTIONS INCLUDED IN THIS STUDY.

INSTITUTION	DEGREE DESIGNATIONS AND UNITS	DEGREE LEVELS
Webb	in Naval Architecture and Marine Engineering by Webb Institute	B[1]
Michigan	in Naval Architecture and Marine Engineering by the Department of Naval Architecture and Marine Engineering	B, M[2], E[3], D[4]
New Orleans	in Naval Architectural and Marine Engineering by the School of Naval Architecture and Marine Engineering	B, M
Memorial	in Naval Architectural Engineering, also in Ocean Engineering at Graduate Level, by the Faculty of Engineering and Applied Science	B, M
Berkeley	as Ocean Engineering Option in Mechanical Engineering at undergraduate level and in Naval Architecture and Offshore Engineering at graduate level by Department of Naval Architecture and Offshore Engineering	B, M, E, D
Coast Guard Academy	in Naval Architecture and Marine Engineering by the Department of Engineering	B
Naval Academy	in Naval Architecture or in Ocean Engineering (or in Marine Engineering) by the Department of Naval Architecture, Ocean and Marine Engineering	B
Virginia Tech	in Ocean Engineering at the undergraduate level and at the Master's degree level, but in Aerospace and Ocean Engineering at the Doctor's degree level, by the Department of Aerospace and Ocean Engineering	B, M, D
MIT	in Ocean Engineering at the undergraduate level and in Ocean Engineering or Naval Architecture or as Naval Engineer at the graduate level by the Department of Ocean Engineering	B, M, E, D
Texas A&M	in Ocean Engineering by the Department of Civil Engineering	
Florida Atlantic	in Ocean Engineering by the Department of Ocean Engineering, but also Master's degree in Civil Engineering as well as Ocean Engineering	B, M, D
Florida Tech	in Ocean Engineering by the Department of Ocean Engineering	B, M, D
Nova Scotia	in Naval Architecture by the Department of Mechanical Engineering	M, D

Sources: Bulletins (Catalogs, Calendars) of the various schools (see BIBLIOGRAPHY) and personal communication.

1. B - Bachelor degree, whether B.S.E., B.Sc.
2. M - Master's degree, whether M.S.E., M.Eng., M.S., M.A.Sc.
3. E - Professional degree, Naval Engineer, Naval Architect, Ocean Engineer
4. D - Doctorate, whether D.Eng., D.Sc., Ph.D.

These programs, however, are among a number of other programs in engineering offered by the respective institutions and the departments involved are just single individual units among a number of departments with, again, Webb being the exception. Usually, a teaching department is administratively within a college, and the college one of a number within the institution as a whole. Many policies of one sort or another, certainly financial support, admission standards, and other factors are not set entirely at the discretion of the faculty members of a single department. They do largely determine the curricula of their particular programs once they are created, through even the establishment of individual courses and to some lesser extent their content generally are reviewed and approved by a college-level curriculum committee so as to avoid redundancy, insure quality, and, often today, to reduce costs and maintain some efficiency in the offerings overall. Large enrollments in any course are viewed with favor by the college administrators, and the course may even be presented with large lecture sessions being given by a professor and several so-called recitation sessions directed by relatively inexpensive teaching assistants if the enrollment is large enough and, hopefully, the subject matter is amenable to such a format. Very small enrollments, especially in undergraduate courses, often attract the attention of administrators and can lead to elimination or revision, including being offered less frequently.

Faculty members are also not entirely free to direct their own efforts as they alone may choose. Those associated with most of the programs listed in the foregoing must conduct research as well as teach, and have administrative committee assignments and/or counseling responsibilities and other service-type duties. Most presumably are permitted to do some consulting, and several of particular interest to this study as well as many others have outside activities extensive enough to warrant personal incorporation. While the concepts of tenure and academic freedom, the requirements for promotion at large universities, and other such matters are beyond the scope of this study, it is pertinent to note that younger and newer faculty members are in fact judged and rewarded largely upon the extent and level of sophistication of their publications and the number and the quality of the theses produced by the doctoral students they have directed. Both of these depend largely upon the extent and level of sophistication and thus the number and the quality of the research endeavors for which they have obtained funding. While such an arrangement is not at all inconsistent with the overall academic mission of the large research university as it exists in North America today, it has led to faculties in any given discipline that often consist mostly of the best and brightest doctoral graduates in that discipline from one of the schools having almost immediately obtained a teaching position at one of the others and thus having gained very limited if any experience or knowledge concerning professional practice in industry. While this is not entirely characteristic of any of the schools being reviewed, it is to some greater or lesser degree the situation at many of them and probably increasingly so at most. In recognition of this several have appointed as "adjunct" professors individuals with industrial experience whose presence at the schools may have been prompted by the need to hire them to take advantage of their experience to assist in conducting research, but anticipating they may also teach for perhaps several years. Others have hired local practicing naval architects and/or ocean engineers as lecturers, often for a single course for a single term. This procedure is also often followed, however, because of the lack of adequate regular faculty members, possibly because of sabbatical leaves, sickness or similar temporary circumstances; but it has all too often recently been necessary because a retired professor has not been permanently replaced, very possibly due to declining enrollment in the program. The nature of any of these programs is thus subject to temporary and even permanent modifications because of such changes in the size and composition of the faculty.

But programs must also be changed if the "service courses" which are included in the curricula are altered. These obviously include the basic courses in mathematics – typically through differential equations – and chemistry, physics, and often computer programming and usage included in all undergraduate engineering curricula, but termed service courses because they are typically given by a unit other than the departments responsible for the naval architecture and/or ocean engineering programs of interest in this study. This is usually also the situation with regard to the introductory courses in thermodynamics, electrical and material science and engineering, and mechanics – statics, dynamics, fluid mechanics, and solid mechanics (mechanics of deformable materials or bodies, strength of materials, or whatever name may be used). Changes may also be caused by revisions in composition and/or technical writing requirements or arrangements, decisions by the entire school or college with regard to the number and distribution of elective courses in the humanities and social sciences, or other similar factors.

That curricula are in a seemingly perpetual state of transition is therefore an accepted situation, in engineering education in any case, but this condition stems as much or more from the technological changes – actually the pace of technological advances – that are affecting the knowledge and understanding needed to practice in any of the engineering disciplines.

Undergraduate Programs

Adequate descriptions, for the purpose of this report, of the individual undergraduate programs dealt with can best be accomplished by reproducing here as figures the typical term-by-term course listings and/or other excerpts from their catalogs (or bulletins or calendars, as they are sometimes called) trusting that the course titles are representative enough to preclude the need to provide also each and every one of the individual course descriptions usually also contained in the catalogs. Pertinent marine structural analysis and design course descriptions, and the syllabuses for them, will be included in the next section of this report, however.

<u>Webb Institute</u>

Webb is unique among the programs of interest to this study, in several respects. First, all of the entering students are there to study only naval architecture and must all complete the identical sequence of courses created, and truly integrated, with that beneficial circumstance providing a distinct advantage not present elsewhere. Basic mechanics, for example, need not be introduced first in general physics courses and then essentially retaught in engineering science courses and then revisited in professional courses as is characteristic in the curricula at other schools at which the contents of the physics courses, with ABET – Accreditation Board for Engineering Education and Technology – encouragement, are usually determined by a somewhat remote physics department. At Webb material first taught in engineering science courses can be used in the various naval architecture courses that immediately follow very much as if the two courses are considered together a single entity. There are several other arrangements by which Webb can gain special efficiencies not possible at other schools, mostly including introductory material, analysis techniques, and even applications in earlier courses – in structures or hydrodynamics or marine engineering – that directly pertain to or even specifically initiate the procedures and exercises to be dealt with in a following design course. Having eight-week practical work periods in the marine industry required each year is obviously also an important bonus to the Webb curricula. Despite the lack of the much more extensive supporting infrastructure found at most of the other engineering schools, including relatively large faculties from other engineering disciplines available certainly to influence and possibly to improve and expand the educational experiences of students, it is universally acknowledged that Webb provides a thoroughly satisfactory if not exemplary education to its students. That their program is as comprehensive as it is may be due largely to efficiencies of the type listed above and more credit hours per semester and totally than required by other programs; but many believe the balance obtained between imparting knowledge and understanding, and simultaneously instilling in the graduates the capability for them to be able better to meet the expectations found in the marine industry that they also be able to carry out the routine tasks along with the more complex and demanding ones in particular, is accomplished because the faculty at Webb consists primarily of individuals with professional experience in industry and they are not distracted continually or evaluated to the same extent by the heavier other demands and expectations beyond teaching well as are their colleagues at the major research universities. The curricula at Webb is shown in the course listing in Figure 1.

SCHEDULE OF COURSES

The subjects of instruction, given during each of the four years, are listed on the following pages.

A semester hour represents one hour of recitation or two hours of drafting or laboratory work per week per semester. The term "semester hour" is identical with the term "credit hour".

Freshmen

First Semester	Sem. Hrs.	Class Hrs.
Technical Communications	2	2
Mathematics I - Calculus I	4	4
General Chemistry	3½	4
Physics I - Elementary Mechanics & Engineering Statics	4	4
Engineering Graphics	2½	5
Naval Architecture I - Introduction to Shipbuilding	1½	2
Marine Engineering I - Introduction to Marine Engineering	1½	2
	19	23

Satisfactory completion of 8 weeks practical work is required.

Second Semester		
Marine Engineering II - Shipboard Systems	3	3
The Human Experience I	3	3
Mathematics II - Calculus II	4	4
Computer Applications	2	3
Physics II - Heat, Light and Sound	3	4
Materials Science	4	5
	19	22

Sophomores

First Semester	Sem. Hrs.	Class Hrs.
Humanities Elective	3	3
Mathematics III - Differential Equations	3	3
Computer Programming	2	3
Naval Architecture II	3	4
Strength of Materials	4	4
Dynamics	4	4
	19	21

Satisfactory completion of 8 weeks practical work is required.

Second Semester		
Western Literature	3	3
Mathematics IV - Advanced Engineering Mathematics	4	4
Physics III - Electricity and Magnetism	3	4
Fluid Mechanics	3	3
Thermodynamics	3	3
Marine Engineering III - Ship Systems II	4	4
	20	21

Juniors

First Semester	Sem. Hrs.	Class Hrs.
Human Experience II	3	3
Engineering Economics	1	1
Probability and Random Processes	3	3
Marine Engineering IV - Machine Design and Transmission Systems	3	3
Electrical Engineering I - Circuits and Electronics	3	4
Naval Architecture III - Ship Resistance and Propulsion	2	2
Naval Architecture IV - Ship Structure	3	4
	19	21

Satisfactory completion of 8 weeks practical work is required.

Second Semester		
American Politics and Foreign Policy	2	2
Marine Engineering V - Steam Plants	3	3
Engineering Laboratory	2½	4
Electrical Engineering II - Machines and Controls	3	4
Naval Architecture V - Ship Hydrodynamics	4	4
Naval Architecture VI - Elements of Ship Design and Production	3	4
Thesis	½	1
	18	22

Seniors

First Semester	Sem. Hrs.	Class Hrs.
Ethics and the Profession	3	3
Ship Vibrations	3	3
Naval Architecture VII - Ship Design I	4	6
Marine Engineering VI - Diesel Engines, Plant Design and Comparative Economics	4½	5
Thesis	2½	5
	17	22

Satisfactory completion of 8 weeks practical work is required.

Second Semester		
Professional Communications	2	2
Naval Architecture VIII - Ship Design II	3½	6
Naval Architecture IX - Propeller Design and Vibrations	3	3
Naval Architecture X - Special Topics in Naval Architecture	2	2
Thesis	2½	5
Seminar	0	2
Selected Topics	3	3
	16	23

FIGURE 1. THE WEBB PROGRAM (REPRODUCED FROM THE 1995-96 "CATALOG")

The University of Michigan

The current undergraduate curriculum at Michigan, while similar in many ways to that at Webb, is almost classical in its structure and content including as it does only minor modifications over the last decade or two. It is shown in Figure 2. Two recent changes that should be noted are the insertion among the program subjects just after the introductory course entitled Marine Design, of one new one devoted to production considerations, replacing the more traditional course in hydrostatics and stability which is now covered more completely in the introductory course and in the second new course entitled Marine Hydrodynamics I. The latter course also includes most of the material previously taught in a more general fluid mechanics service course offered by the Mechanical Engineering Department, and required in most of the other mechanics-based programs such as civil and mechanical engineering but not aerospace. The traditional resistance and propulsion material is now included in the Marine Hydrodynamics II course, probably giving the impression to some that naval architecture and marine engineering is now even more predominantly concerned with hydrodynamics rather – of which more later – than the long-standing "four areas of concentration" referred to in the Technical Elective requirements. These only recently were "ship" strength, hydrodynamics, power systems, and dynamics (vibrations and rigid body motions, both of which are periodic), and are now preceded by the designation "marine" to reflect that they now are more devoted to a more systems-oriented treatment involving all types of marine systems and not just to ships and boats.

The University of New Orleans

The undergraduate program at New Orleans is very similar to that at Michigan prior to the recent changes noted above, coherent to the same degree and structured in an almost identical manner. It is illustrated in Figure 3. The individual course titles include the prefix "offshore structure and ship" (i.e., Offshore Structure and Ship Strength I and Offshore Structure and Ship Dynamics II) rather than the more generic "marine", but there does indeed seem to be somewhat more coverage of offshore platforms in several of the courses and in the overall curriculum then is the case at Michigan. There are not, however, any courses dealing specifically with some of the many other ocean engineering topics.

Required Programs

	Hours	1	2	3	4	5	6	7	8
		Sample Schedule by Term							
Subjects required by all programs (56 hrs.)									
(See under "Minimum Common Requirements," page 57, for alternatives)									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
English 125, College Writing	4	4	-	-	-	-	-	-	-
* Personal Computing	3	3	-	-	-	-	-	-	-
Chemistry 130 and 125 or 210 and 211	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; 240 with Lab 241	8	-	4	4	-	-	-	-	-
Senior Technical Communication	3	-	-	-	-	-	-	-	3
Humanities and Social Sciences (see pages 61, 65)	17	-	6	-	3	-	-	4	4
Advanced Mathematics (3 hrs.)									
Mathematics 350	3	-	-	-	-	3	-	-	-
Related Technical Subjects (16 hrs.)									
MSE 250, Prin of Eng Materials	3	-	3	-	-	-	-	-	-
ME 211, Intro to Solid Mechanics	4	-	-	4	-	-	-	-	-
ME 240, Intro to Dynamics	3	-	-	-	3	-	-	-	-
ME 235, Thermodynamics I	3	-	-	-	3	-	-	-	-
EECS 314, Cct Analy and Electronics	3	-	-	-	-	-	3	-	-
Program Subjects (38 hrs.)									
NA 270, Marine Design	3	-	-	3	-	-	-	-	-
NA 275, Marine Systems Manufacturing	3	-	-	-	3	-	-	-	-
NA 310, Marine Structures I	4	-	-	-	-	4	-	-	-
NA 320, Marine Hydrodynamics I	4	-	-	-	-	4	-	-	-
NA 321, Marine Hydrodynamics II	4	-	-	-	-	-	4	-	-
NA 330, Marine Power Systems I	4	-	-	-	-	4	-	-	-
NA 340, Marine Dynamics I	4	-	-	-	-	-	4	-	-
NA 391, Marine Lab	3	-	-	-	-	-	3	-	-
NA 470, Ship Design or NA 471, Offshore Eng Design	3	-	-	-	-	-	-	3	-
NA 475, Design Project	3	-	-	-	-	-	-	-	3
NA 481, Probal Meth in Marine Sys	3	-	-	-	-	-	-	3	-
Technical Electives (9 hrs.)									
These must include at least two of the second courses in the four areas of concentration—NA 410, Marine Struc II; NA 425, Envir Ocean Dynamics; NA 430, Mar Power Systems II; or NA 440, Mar Dynamics II	6	-	-	-	-	-	-	3	3
Another Technical Elective	3	-	-	-	-	-	-	-	3
Free Electives (6 hrs.)	6	-	-	-	-	-	3	3	-
Total	**128**	**16**	**17**	**15**	**16**	**15**	**17**	**16**	**16**

*Eng 103 (3 hrs), Eng 104 (3 hrs), Eng 106 (4 hrs), or Eng 107 (4 hrs) acceptable; Eng 106 or Eng 107 preferred, 1 hour counting as free-elective credit.

FIGURE 2. THE MICHIGAN PROGRAM (REPRODUCED FROM THE COLLEGE OF ENGINEERING 1995-96 "BULLETIN")

FRESHMAN YEAR	CR HRS	SOPHOMORE YEAR	CR HRS
ENGL 1157, 1158	6	ENGL 2152	3
Arts Elective[1]	3	MATH 2115, 2221	6
MATH 2111, 2112[2]	10	PHYS 1062	3
PHYS 1061, 1063	4	ENME 2750	3
CHEM 1017[3]	3	CHEM 1018[3], 1023	5
CSCI 1201	3	ENCE 2311, 2350, 2351	7
ENGR 1000	1	NAME 2150, 2160	6
ENME 1781	3	Social Science Elective[1]	3
	3		3
	33		36

JUNIOR YEAR	CR HRS	SENIOR YEAR	CR HRS
ECON 2000[4]	3	Humanities Elective[1]	3
ENEE 2500, 3518, 3501	7	Social Science or Humanities Elective[1]	3
ENME 3020, 3716, 3720, 3770	10	Literature Electives[1]	6
NAME 3120, 3130, 3140, 3150, 3160	15	Biology Elective[1]	3
		ENGR 3090	1
		NAME 4150, 4155	6
		NAME Electives[5]	11
	35		33

		ANALYSIS	+	DESIGN	=	TOTAL
NAME 2150	INTRO TO SHIP & OFFSHORE STRUCTURES DES & CONSTR	2.0	+	1.0	=	3.0
NAME 2160	FORM CALC & STABILITY	3.0	+	0.0	=	3.0
NAME 3091	NAVAL ARCH DES PROJECT	0.0	+	3.0	=	3.0
NAME 3092	MARINE ENG DES PROJECT	0.0	+	3.0	=	3.0
NAME 3093	SPECIAL PROBS IN NAVAL ARCH	0.0	+	1.0	=	1.0
NAME 3095	SPECIAL PROBS IN MARINE ENG	0.0	+	1.0	=	1.0
NAME 3096	SPECIAL PROBS IN MARINE ENG	0.0	+	1.0	=	1.0
NAME 3120	OFFSHORE STRUCT & SHIP STRENGTH I	1.5	+	1.5	=	3.0
NAME 3130	MARINE ENG I (POWER SYSTEMS)	2.0	+	1.0	=	3.0
NAME 3140	COMPUTERS IN NAVAL ARCH	1.0	+	0.0	=	1.0
NAME 3150	SHIP RESISTANCE & PROPULSION	1.5	+	1.5	=	3.0
NAME 3160	OFFSHORE STRUCTURE & SHIP DYNAMICS	2.5	+	1.5	=	4.0
NAME 3900	SENIOR HONOR THESIS	0.0	+	3.0	=	3.0
NAME 4096	SPECIAL TOPICS IN NAVAL ARCH	2.0	+	1.0	=	3.0
NAME 4097	SPECIAL TOPICS IN MARINE ENG	0.0	+	3.0	=	3.0
NAME 4120	SHIP STRUCTURAL ANALYSIS & DES	2.0	+	1.0	=	3.0
NAME 4130	MARINE ENGINEERING II	0.0	+	3.0	=	3.0
NAME 4131	RELIABILITY, AVAILABILITY & MAINT OF ENG SYSTEMS	0.0	+	3.0	=	3.0
NAME 4135	INTRO TO COMPUTATIONAL FLUID DYNAMICS AND HEAT TRANSFER	0.0	+	3.0	=	3.0
NAME 4141	CURVED SURFACE DESIGN	0.0	+	3.0	=	3.0
NAME 4142	SOLID MODELING	0.0	+	3.0	=	3.0
NAME 4150	OFFSHORE STRUCTURES & SHIP DESIGN	0.0	+	3.0	=	3.0
NAME 4151	SMALL CRAFT DESIGN	0.0	+	3.0	=	3.0
NAME 4155	OFFSHORE STRUCTURES & SHIP DES PROJECT	0.0	+	3.0	=	3.0
NAME 4160	SHIP HYDRODYNAMICS II	1.0	+	2.0	=	3.0
NAME 4162	OFFSHORE STRUCTURES & SHIP DYNAMICS II	0.0	+	3.0	=	3.0
NAME 4171	ADMIRALTY LAW FOR ENGINEERS	2.0	+	0.0	=	2.0
NAME 4181	MATERIALS FOR MARINE DESIGN	1.0	+	2.0	=	3.0

FIGURE 3. THE UNIVERSITY OF NEW ORLEANS CURRICULUM (EXCERPTS FROM THE COLLEGE OF ENGINEERING 1994-95 "INFORMATION BULLETIN")

Memorial University of Newfoundland

The undergraduate program at Memorial reflects the fact that high school graduates in Canada have advanced further than is generally true in the United States and therefore their curriculum need not include for example such courses as composition and general chemistry and physics in the first year, nor the electives in the humanities and social sciences scattered throughout the curriculum that are required in the U.S. The graduates of this program are thus nearly but not quite fully equivalent in educational breadth and professional preparation to those receiving master's degrees at most of the other schools being described here. They can specialize to some extent in selecting technical electives in the last two terms, as shown in the chart in Figure 4, concentrating perhaps in production management rather than entirely in the design of ships or platforms or even submersibles. The professional content of what must still be termed an undergraduate curriculum is perhaps stronger and more varied than that offered by any of the schools in the U.S.

The University of California - Berkeley

The current undergraduate curricula in naval architecture at Berkeley is shown in Figure 5. It will evidently be changed somewhat as the program soon becomes established as another regular option in ocean engineering in the Mechanical Engineering Department, but the ocean engineering courses will then still be given by the faculty in the present Naval Architecture and Offshore Engineering Department. It would perhaps be more meaningful to include here the curriculum as it was several years ago at Berkeley – and maybe at all of the other schools, since graduates that completed those curricula are the ones now among the practicing naval architects in the marine industry – but this project is intended only to evaluate education in marine structures as it exists now and to make recommendations that could be carried out only in the future. That curriculum at Berkeley was not too different from that shown in the figure and also then included fewer professional courses than those at Webb or Michigan or New Orleans.

United States Coast Guard Academy

At the Coast Guard Academy the major of interest is accredited as in naval architecture and marine engineering combined, as noted above has been the case

CHART OF THE UNDERGRADUATE ENGINEERING CORE PROGRAM

1	2
C.S.	C.S.
1312 MECH. I	2205 CHEM. & PHY. OF ENG. MAT. I
1333 BASIC ELEC. CONC. CIRC.	2312 MECH. II
1404 LIN. ALG.	2420 STRUCT. PROGRAMM.
1412 INTERMED. CALCULUS	2421 PROB. & STATISTICS
1502 ENGIN. DESIGN I	2502 ENGIN. DESIGN II
100W SOFTWARE APPL.	

Technical Electives

7	8
7021 PRROPUL'N. EFFICIENCY	8006 FLOATING OCN. STRUC. DESIGN
7933 STRESS ANALYSIS	8048 MAINTENANCE ENGR. SYS.
7924 AUTOMATIC CONTROL	8058 SUBMERSIBLES DESIGN
7032 HYDROELASTICITY & CONTROL OF OCEAN VEHICLES	8062 MARINE PRODUCTION MANAGEMENT
	8065 SHIP OPERN. MANAGEMENT

CHART OF THE NAVAL ARCHITECTURAL ENGINEERING CURRICULUM

3	4	5	6	7	8
3102 KVAT	4102 ENGINEERING ECONOMICS	C.S.	6101 ASSESS. OF TECHNOLOGY	T.E.	F.E.
3205 CHEM & PHY. OF ENG. MAT. II	4312 MECHANICS SOLIDS I	5312 MECHANICS SOLIDS II	6041 MARINE ENG. SYS. I	T.E.	T.E.
3312 MECHANICAL III	4321 THERMO-DYNAMICS I	4342 FLUIDS I	6002 SHIP HULL STRENGTH	7002 SHIP STR. DESIGN	8000 N.A.E. PROJECT
3411 APPL. DIFF. EQUATIONS	4422 NUMERICAL METHODS	5432 ADVANCED CALCULUS	6032 SHIP HULL VIBRATIONS	7031 SHIP DYNAMICS	8014 MARINE HYDRODYNAMICS
3841 ELECT/MCH CONVRSN	4922 MECHANICAL DESIGN	5011 RESTNCE & PROPN I	6871 PHYSICAL METALLURGY	7046 MARINE ENG SYS II	8022 DESIGN OPTIMIZATION
3052 SHIP DESIGN I	4011 SHIP STATICS	5061 SHIP PRODN MGMT	6853 ELECT. FOR NON E.E.	7061 SHIP DESIGN II	8054 ADVANCED MARINE VEHICLES

NOTE: A workshop course (290W) is held on campus prior to the start of the Spring Semester

FIGURE 4. THE MEMORIAL UNIVERSITY OF NEWFOUNDLAND PROGRAM (REPRODUCED FROM THE FACULTY OF ENGINEERING AND APPLIED SCIENCE 1994-95 "CALENDAR")

Program in Naval Architecture 120 Units

Effective fall 1994, admission to the undergraduate Naval Architecture degree program was closed. Contact the Student Affairs Office for more information. Students admitted before fall 1994 should complete the following program.

Freshman Year	***Fall***	***Spring***
Math 1A, 1B, Calculus	4	4
Chemistry 1A, General Chemistry	4	-
Physics 7A, Physics for Scientists and Engineers	-	4
Engin 28, Engineering Graphics	3	-
Nav Arch 10, Ship Systems (recommended, not required)	-	3
*Electives	4	4
Total	**15**	**15**
Sophomore Year		
Math 50A, 50B, Differential Equations, Linear Algebra, Multivariable Calculus	4	4
Physics 7B, 7C, Physics for Scientists and Engineers	4	4
Engin 36, Engineering Mechanics I	-	2
Engin 45, Properties of Materials	3	-
Engin 77, Problem Solving Using Computers [FORTRAN]	-	3
*Electives	-	6
Total	**14**	**16**
Junior Year		
Mec Eng 104, Engineering Mechanics II	3	-
Mec Eng 106, Fluid Mechanics	-	3
Mec Eng 105, Thermodynamics	-	4
Civ Eng 130, Mechanics of Materials	-	3
Nav Arch 151, Statics of Naval Architecture	4	-
Mec Eng 133, Mechanical Vibrations	-	3
Stat 25, Introduction to Probability and Statistics for Engineers	3	-
EECS 100, Electronic Techniques for Engineers	4	-
*Electives	-	3
Total	**14**	**16**
Senior Year		
Nav Arch 152A, 152B, Ship Dynamics	3	3
Mec Eng 107A, Experimentation and Measurement	3	-
Nav Arch 154, Ship Structures	3	-
Nav Arch 155A, 155B, Ship Design	4	4
Civ Eng 167, Engineering Project Management	-	3
*Electives	3	4
Total	**16**	**14**

*Electives must include six courses of at least 3 units each in the humanities and social studies selected from an approved list of courses. Of these at least one course must be a composition course taken from the current approved list of courses. See List E of the Humanities and Social Studies section on page 9. One course must also selected from Mec Eng 161, 163, or Civ Eng 120N.

FIGURE 5. THE UNIVERSITY OF CALIFORNIA - BERKELEY PROGRAM (REPRODUCED FROM THE FACULTY OF ENGINEERING 1995-96 "ANNOUNCEMENT)

at several of the other schools, but only four program-defining courses are required. And though all of the topics that are covered in the other programs are dealt with to some extent in the first two courses, their treatment just cannot be as thorough or as at several of the other schools, but only four program-defining courses are required. And though all of the topics that are covered in the other programs are dealt with to some extent in the first two courses, their treatment just cannot be as thorough or as deep. The curriculum, shown in Figure 6, culminates in a principles of design course and the capstone one entitled Ship Design/System Integration that does view the ship as a system and presumably does "integrate" economics and construction and other considerations with design decisions much as implied in the currently comprehensive and fashionable approach entitled concurrent ship design. The marine engineering content of the program is for the most part included in courses offered by the mechanical engineering staff of the Engineering Department.

United States Naval Academy

The two Naval Academy majors of greater interest to this study are those in naval architecture and in ocean engineering, that in marine engineering seemingly being less total ship or offshore platform focused and more representative of the distinct marine engineering options that once existed at several of the other schools. The ocean engineering majors must complete a series of courses, given in Figure 7, that comprehensively treat ocean systems as engineering systems and the emphasis is not as much on physical oceanographic processes and experimentation as is characteristic of some other ocean engineering curricula. Those students majoring in naval architecture complete a curriculum, also shown in Figure 7, not unlike those at Webb, Michigan, New Orleans, and Memorial in structure and sequence, and in content. They are also offered a wide array of technical electives, including for example one devoted to the naval architectural aspects of submarine design and another covering such advanced marine vehicles as hydrofoils and submersibles and ground-effect machines. The analysis and design of foils (i.e., hydrofoils) is dealt with in a course that treats marine propellers as well, using lifting line and lifting surface theories. A course entitled Advanced Methods in Ship Design and another called Analytical Applications in Ship Design and other electives clearly establish that even though the program at Annapolis is obviously only for undergraduates it does not suffer in comparison with the undergraduate programs at other schools where the existence of a graduate/research program and utilizing the same faculty in both

FALL SEMESTER		SPRING SEMESTER	
FOURTH CLASS YEAR			
0901	Academic Orientation	0903	Academic Orientation
2111	English Comp and Speech	1112	Intro to Engr and Design
3111	Calculus I	2123	Intro to Literature
5102	Chemistry I	3117	Calculus II
7102	Found of Computer Sci	5106	Chemistry II
8111	Organizational Behavior	6112	Nautical Science I
——	Physical Education	——	Physical Education
THIRD CLASS YEAR			
1202	Statics	1204	Engineering Materials Sci
2293	Morals and Ethics	1206	Strength of Materials
3211	Multivariable Calculus	2241	History of the U. S.
5262	Physics I	3215	Differential Equations
6214	Nautical Science II	5266	Physics II
8201	Leadership I	8203	Leadership II
——	Physical Education	——	Physical Education
SECOND CLASS YEAR			
1211	Dynamics	1342	Princ of Naval Architecture
1220	Electric Circuits and Machines	1353	Thermal Systems Design
1340	Fluid Mechanics	1459	Heat Transfer
1351	Thermodynamics	2263	American Government
6316	Nautical Science III	3415	Adv Engineering Math
——	Physical Education	——	Physical Education
FIRST CLASS YEAR			
1442	Principles of Ship Design	1444	Ship Design/System Integ
1453	Ship Propulsion Design	2493	Maritime Law Enforcement
2391	Legal Systems	6418	Nautical Science IV
5330	Oceanography	8311	Economics
——	Major Area Elective	——	Free Elective
——	Physical Education	——	Physical Education

FIGURE 6. THE SCHEDULE OF CLASSES AT THE U.S. COAST GUARD ACADEMY (REPRODUCED FROM THE 1994-95 "CATALOGUE OF COURSES")

Naval Architecture Major

Curriculum Requirements (In addition to the requirements of plebe year)
Professional: NL202, NL302, NL400,NN200, NS310, NS40X;
Mathematics: SM212, SM221;
Science: SP211, SP212;
Humanities: HH205, HH206 plus two electives;
Engineering: EE331, EE332, EM211, EM217, EM232, EM318, EM319, ES300, ES410;
Major: EN245, EN342, EN353, EN358, EN380, EN455, EN471, EN476, plus two major electives; one free elective.

REQUIRED COURSES:

Ocean Systems Engineering
Strength of Materials
Thermodynamics
Fluid Dynamics
Naval Materials Science and Engineering
Ship Hydrodynamics and Stability
Resistance and Propulsion
Seakeeping and Maneuvering
Ship Structures
Ship Design I & II

ELECTIVE COURSES:

Analytical Applications in Ship Design
Advanced Ship Structures
Ship Vibrations
Advanced Methods in Ship Design
Hydrofoil and Propeller Design
Advanced Marine Vehicles
Submarine Design Analysis
Engineering Economic Analysis
Independent Research Projects

Ocean Engineering Major

Curriculum Requirements (In addition to the requirements of plebe year)
Professional: NL202, NL302,NL400, NN200, NS310, NS40X;
Mathematics: SM212, SM221;
Science: SP211, SP212;

REQUIRED COURSES:

Ocean Systems Engineering
Strength of Materials
Thermodynamics
Fluid Dynamics
Naval Materials Science and Engineering
Introduction to Oceanography
Ocean Engineering Structures
Ocean Engineering Mechanics
Ocean Systems Engineering Design I & II

ELECTIVE COURSES:

Microcomputer Aided Engineering and Design
Marine Power Systems
Coastal Engineering
Underwater Work Systems
Engineering Economic Analysis
Life Support Systems
Design of Foundations for Ocean Structures
Undersea Power Systems
Design of Floating Platforms
Environmental Engineering in the Oceans
Independent Research Projects

Marine Engineering Major

Curriculum Requirements (In addition to the requirements of plebe year)
Professional: NL202, NL302, NL400,NN200, NS310, NS40X;
Mathematics: SM212, SM221, SM311;
Science: SP211, SP212;
Humanities: HH205, HH206 and two electives;
Engineering: EE331, EE332, EM211, EM217, EM232, EM319, EM324, ES300, ES410;
Major: EN245, EN361, EN362, EN380, EN443, EN460, EN463, EN467, plus two major electives; one free elective.

REQUIRED COURSES:

Ocean Systems Engineering
Strength of Materials
Thermodynamics
Fluid Dynamics
Naval Material Science and Engineering
Engineering Mathematics
Marine Power Systems
Thermal Engineering
Reactor Physics I & II
Marine Engineering Design I & II

ELECTIVE COURSES:

Resistance and Propulsion
Ship Vibrations
Undersea Power Systems
Computer Methods in Nuclear Engineering
Nuclear Energy Conversion
Independent Research Projects

FIGURE 7. PROGRAM AT THE U.S. NAVAL ACADEMY (REPRODUCED FROM THE 1993-94 "CATALOG" AND A NAOME DEPARTMENT PAMPHLET)

preparing undergraduate courses and teaching them concurrently with their efforts on behalf of the graduate/research program often has some benefit in attaining and maintaining a somewhat higher level of quality and treatment than would otherwise be possible.

Virginia Polytechnic Institute and State University

At Virginia Tech the program designated as being in ocean engineering, shown in Figure 8, does concentrate more on the engineering aspects of marine vehicles and marine structures than on the ocean environment and such physical processes as estuary hydrodynamics and sediment transport, although the students are required to complete a course in physical oceanography offered by the Geological Sciences Department. Enough traditional naval architectural considerations are included in the undergraduate curriculum generally and in several courses specifically to suggest that graduates of this program should indeed be as well prepared for practicing professionally in the same areas of the marine industry as are those from programs advanced as being for those interested in becoming naval architects. Marine design is treated as a process based on many the same considerations that would be involved if the system of concern were for operation in the atmosphere or in space; and many of the prerequisite analysis courses in for example dynamics and structures, that must be completed before the capstone design course in the fourth year, present the material in such a basic manner that it is more universally applicable even though the particular applications are in just aerospace or ocean engineering.

Massachusetts Institute of Technology

The MIT bachelor's degree program in ocean engineering known as Course XIII is defined in Figure 9, but the format shown as it is presented in their bulletin does not include a representative or suggested schedule of the courses to be taken each term (as given for the other schools) and hence the sequential structure can only be envisioned by combining the courses in the subjects included as General Institute Requirements with those 11 courses listed for this specific program plus some number of approved elective courses – restricted and unrestricted. It is apparent, however, that individual students can with faculty guidance fashion a program that could be somewhat more specialized than is the situation at any of the other schools considering the very large number of courses offered by the Ocean Engineering and

First Year

First year students are admitted in General Engineering, the common freshman engineering program for engineerng curricula. This program provides time for the students to adjust to the college and to select the branch of engineering in which they are most interested. At the end of the year—after additional counseling, contacts with the various departments, and satisfactory progress—students make a selection and, if academically eligible, are transferred to the curriculum of their choice.

FIRST YEAR

First Semester		
Chem 1035: General Chemistry	3	(3)
Chem 1045: General Chemistry Lab	2	(1)
EF 1005: Introduction to Engineering	3	(2)
Engl 1105: Freshman English	3	(3)
Math 1205: Calculus I	3	(3)
Math 1114: Linear Algebra	2	(2)
Elective		(1)
	Credits	(15)
Second Semester		
Chem 1036: General Chemistry	3	(3)
Chem 1046: General Chemistry Lab	2	(1)
EF 1006: Introduction to Engineering	3	(3)
ESM 1004: Statics	3	(3)
Engl 1106: Freshman English	3	(3)
Math 1206: Calculus I	3	(3)
Math 1224: Vector Geometry	2	(2)
	Credits	(18)

Ocean Engineering Program

SECOND YEAR

First Semester		
ESM 2004: Mechanics of Deformable Bodies	3	(3)
Math 2224: Multivariable Calculus	3	(3)
Phys 2175: Physics I	3	(3)
ISE 2014: Engineering Economy	2	(2)
ESM 3074: Computational Methods	3	(3)
Core elective *		(3)
	Credits	(17)
Second Semester		
ESM 2304: Dynamics	3	(3)
Math 2214: Differential Eqs.	3	(3)
Phys 2176: Physics II	3	(3)
EE 3064: Electrical Theory	3	(3)
AOE 3204: Ship Hydromechanics	3	(3)
Core elective *		(3)
	Credits	(18)

THIRD YEAR

First Semester		
AOE: 3014 Aero/Hydrodynamics	3	(3)
AOE: 3024 Thin Walled Structures	3	(3)
AOE: 3034 Vibration and Control	3	(3)
ME: 3134 Thermodynamics	3	(3)
Math: 4564 Operational Methods	3	(3)
Geol: 4104 Physical Oceanography	3	(3)
	Credits	(18)
Second Semester		
AOE 3054: Instrumentation and Lab	4	(2)
AOE 3214: Fundamentals of Ocean Engineering	3	(3)
AOE 3224: Ocean Structures	3	(3)
AOE 3234: Ship Dynamics	3	(3)
AOE 4244: Marine Engineering	3	(3)
Math Elective	3	(3)
	Credits	(17)

FOURTH YEAR

First Semester		
AOE 3044: Boundary Layer and Heat Transfer	3	(3)
AOE 4065: Design	5	(3)
AOE 4214: Wave Mechanics	3	(3)
AOE 4254: Ocean Engineering Lab	3	(1)
Technical Elective		(3)
Core elective *	3	(3)
	Credits	(16)
Second Semester		
AOE 4066: Design	5	(3)
Technical Electives		(6)
Core elective *		(3)
Free Electives and/or core area 7		(3)
	Credits	(15)

* All students must take 6 credits each from Areas 2 and 3 of the University Core Curriculum. The College of Engineering requires that 6 of these 12 credits be at or above the 2000 level and 6 must be in a single discipline. Students graduating in 1998 or later must also satisfy Area 7 or the Core. Some Area 7 courses may simultaneously satisfy Core Area 2 or 3 or other elective needs.

FIGURE 8. THE PROGRAM AT VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY (REPRODUCED FROM THE 1994-95 "UNDERGRADUATE COURSE CATALOG AND ACADEMIC POLICIES")

Bachelor of Science in Ocean Engineering Course XIII

CLASS OF 1997 or later: See Notes on Course XIII below.

General Institute Requirements (GIRs)	Subjects
Science Requirement	5
Humanities, Arts, and Social Sciences Requirement[1]	8
Restricted Electives in Science and Technology (REST) Requirement** [two subjects can be satisfied from among 2.01, 6.071, 18.03, and 13.010 or 13.016 in the Departmental Program]	3
Laboratory Requirement [can be satisfied by 13.017 and 13.018 in the Departmental Program]	1
Total GIR Subjects Required for S.B. Degree	**17**

PLUS

Departmental Program	Units

Subject names below are followed by credit units and by prerequisites if any (corequisites in italics)

Required Subjects[2] 135

18.03	Differential Equations, 12, REST; 18.02*
13.010	Introduction to Ocean Science and Technology, 12, REST; 8.01, 18.02
13.012	Fluid Mechanics for Ocean Engineers, 15; 13.010, 18.03
2.01	Mechanics of Solids, 12, REST; 8.01, 18.02
13.014	Marine Structures and Materials, 12; 2.01, 18.03
13.013J	Dynamics, 12; *2.01*, 2.02, 18.03*
13.015	Mathematical Methods in Ocean Engineering, 12; 18.03
13.016	Introduction to Geometric Modelling and Computation, 12, REST; 8.01, 18.02
6.071	Electronics and Instrumentation, 12, REST; 18.01, 8.02
13.017	Design of Ocean Systems I, 12, LAB; 2.01, 13.016, *13.012*
13.018	Design of Ocean Systems II, 12, LAB; 6.071, 13.017

Restricted Electives 48

The student with the help of the faculty advisor must propose a program of not less than 48 units in an area of ocean engineering. This program must be approved by the Ocean Engineering Undergraduate Program Committee and must include at least 12 units of an individual research or design project.

Departmental Program units that also satisfy the GIRs	**(36)**
Unrestricted Electives	**48**
Total Units Beyond the GIRs Required for S.B. Degree	**195**

No subject can be counted both as part of the 17-subject GIRs and as part of the 195 units required beyond the GIRs. Every subject in the student's departmental program will count toward one or the other, but not both.

Notes on Course XIII

CLASS OF 1997 or later: The Science Requirement increases to six subjects with the addition of Biology as a GIR, and the REST Requirement decreases from three subjects to two, keeping the total number of GIRs constant at 17.

[1]14.01 or another economics subject is strongly suggested in the Humanities, Arts, and Social Sciences Requirement if another subject in the field of economics and management is not included in the elective program.

[2]Students must receive a grade of C or better in core subjects which serve as prerequisites for other departmental core subjects before continuing in the departmental program.

*Alternate prerequisites are listed in the subject description.

**The REST Requirement was formerly called the Science Distribution Requirement. See Chapter II for further details on this and other Institute requirements.

Bachelor of Science in Ocean Engineering Course XIII-C

Course XIII-C is an Engineering Internship Program that enables students to combine professional experience with their academic work, while at the same time providing for part of their educational expenses. The four-year program leads to the Bachelor of Science in Ocean Engineering. Students in the internship program may also apply for admission to the Graduate School to obtain the Bachelor of Science concurrently with the Master of Science at the end of their fifth year. This program is part of the Engineering Internship Program, described in detail in the School of Engineering section.

All MIT sophomores in good standing can apply for entrance to the program. Alternating periods at the Institute and at cooperating work sites are arranged so that graduation is not delayed beyond the normal date.

The companies and laboratories participating in the internship program cover all important aspects of ocean engineering. Assignments with these organizations provide opportunities to participate in activities such as construction, testing, design, development, research, and technical planning.

The Course XIII-C program leading to the Bachelor of Science in Ocean Engineering is accredited by the Accreditation Board for Engineering and Technology.

The Course XIII-C curriculum is identical to Course XIII, except that 13.771 Engineering Internship (12 units) is taken in place of the12 units of individual research or design project in the restricted electives. Further details may be obtained from the department.

FIGURE 9. THE PROGRAM AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY (REPRODUCED FROM THE 1993-94 "BULLETIN, COURSES AND DEGREE PROGRAMS ISSUE")

the other departments at MIT, even though many of these would not normally be open to undergraduates. It should be noted that the required program courses include one entitled Fluid Mechanics for Ocean Engineers and another named Introduction to Geometric Modeling and Computations that are among those offered by the Ocean Engineering Department and by its faculty members, even though the general topics are obviously of interest to the programs in other engineering disciplines. The luxury of a larger faculty at MIT and elsewhere evidently permits such tailoring of the presentation of basic material to the needs of a single program, and the benefit derived is obvious. It should also be noted that the solid mechanics course required is that offered by the Mechanical Engineering Department, however, as is that in electronics and instrumentation, much as they are at other schools. The "units" assigned to each course are the total of the number of hours of lecture or recitation, the number for laboratory or field work, and for preparation, one unit normally representing fourteen total hours of work for the term. The Design of Ocean Systems I and II courses are thus three plus four plus five and one plus four plus seven, respectively, and are similar to the capstone design sequence in most other programs of interest here in that the design process is taught in the first but in the second, at MIT, the student design projects are not usually ships or platform but smaller systems (such as experimental apparatus) and are often actually constructed and operated.

Texas A&M University

While the undergraduate curriculum in ocean engineering at Texas A&M is representative of those programs designated as in ocean engineering elsewhere, including as it does courses in wave mechanics and other aspects of physical oceanography along with those in basic coastal engineering and even hydroacoustics, it also includes the mathematics and mechanics and the other engineering science subjects that are included in the early years in naval architecture and/or marine engineering curricula or those of aerospace or civil or mechanical engineering. It is shown in Figure 10. Perhaps because of the close relationship with civil engineering there and the basic structures courses required for that discipline, however, ocean platforms of various types are the focus of several individual courses and the one entitled Dynamics of Offshore Structures introduces loading prediction and the concepts of linear structural dynamics as well as dealing with mooring and towing analyses for example. The Basic Coastal Engineering course, OCEN 400, deals with

Undergraduate Degree Program

B.S. in Ocean Engineering

Freshman Year

First Semester	Cr*
CHEM 102 Fund. of Chem II[3]	3
CHEM 112 Fund. of Chem Lab II[3]	1
ENDG 105 Engineering Graphics	2
ENGL 104 Comp. & Rhetoric	3
MATH 151 Engr. Mathematics I[3]	4
Directed elective[1]	3
Military, air or naval science[4]	
PHED 199	1
	17

Second Semester	Cr*
ENGR 109 Engineering Prob. Solving & Computing	3
MATH 161 Engineering Math II	3
PHYS 218 Mechanics	4
Directed elective[1]	6
Military, air or naval science[4]	
PHED 199	1
	17

Sophomore Year

First Semester	
MATH 251 Engr. Math III	3
MEEN 212 Engr. Mech. I	3
OCNG 401 Intro. to Oceanography	3
PHYS 208 Electricity & Optics	4
Directed elective[1]	3
Military, air or naval science[4]	
PHED 199	1
	17

Second Semester	Cr*
CVEN 205 Engr. Mech. of Mtls.	3
MATH 308 Differential Equations	3
MEEN 213 Engineering Mech. II	3
OCEN 201 Intro. to Ocean Engr.	2
Directed electives[1]	6
Military, air or naval science[4]	
PHED 199	1
	18

Junior Year

First Semester	Cr*
CVEN 311 Fluid Dynamics	3
CVEN 336 Fluid Dyn. Lab	1
CVEN 345 Theory of Structures	3
GEOL 320 Geol. for Civil Engrs.	3
MEEN 327 Thermodynamics	3
Directed elective[1]	3
	16

Second Semester	Cr*
CVEN 302 Comp.Appl.in Engr.& Con.	2
CVEN 365 Geotechnical Engr.	3
ENGL 301 Technical Writing	3
OCEN 462 Hydromechanics	3
OCNG 410 Intro. to Phys. Ocn.	3
OCEN 300 Ocean Engr. Wave Mech.	3
	17

Senior Year

First Semester	Cr*
ELEN 306 Elec. Circuits & Instrum.	4
OCEN 301 Dyn. of Offshore Structures	3
OCEN 400 Basic Coastal Engr.	3
OCEN 401 Underwater Acoustics for Ocean Engineers	3
OCEN 481 Seminar	1
Technical elective[2]	3
	17

Second Semester	Cr*
CVEN 321 Materials Engr.	3
OCEN 407 Des. of O.E. Facilities	4
OCEN 410 Ocean Engr. Lab.	1
Directed elective[1]	3
Technical electives[2]	6
	17

*

FIGURE 10. THE PROGRAM AT TEXAS A&M UNIVERSITY (REPRODUCED FROM AN UNDATED BOOKLET "OCEAN ENGINEERING AT TEXAS A&M UNIVERSITY")

such usual coastal engineering topics as seawalls and breakwaters but also is concerned with offshore pipelines and dredging and control of oil spills – topics included in what are designated as elective ocean engineering courses at only several of the other schools. There is a single course entitled Principles of Naval Architecture available as an elective, and the content is much like the introductory courses at the other schools but does seem to be the only one dealing specifically with ships.

Florida Atlantic University

The other two ocean engineering undergraduate programs, at Florida Tech and Florida Atlantic, are reasonably similar to that at Texas A&M as comparison of Figures 11 and 12 with Figure 10 will demonstrate, but Figure 11 shows that the curriculum at Florida Atlantic does allow for specialization in any of the five areas of concentration by means of four technical electives. This is an arrangement common in many undergraduate civil engineering programs, one of the areas always being in structures, another almost always in materials, and the rest varying with the different schools but more and more including recently one named environmental engineering. It should be noted that the area in fluids (parallel to one often found in civil engineering named hydraulics or hydrological engineering) at Florida Atlantic includes two courses called Ship Hydrodynamics I and II, and these and several of the structures courses do indeed include considerations of ships and offshore platforms as well as submarines and submersibles. The basic mechanics courses – in statics, strength of materials, dynamics, and fluid mechanics – and those in engineering materials and thermodynamics, the basic engineering science courses required in all undergraduate programs in the mechanics-based disciplines, are offered by Department of Ocean Engineering at Florida Atlantic and hence can presumably include some ocean engineering applications. The undergraduate enrollment is evidently large enough to permit this, and the benefits are obvious. Note also in considering Figure 11 that at Florida Atlantic the fall and spring terms are regular semesters but the summer term is only about six weeks in length.

Florida Institute of Technology

Florida Tech's undergraduate program is in some ways less comprehensive than that at Texas A&M and Florida Atlantic, but with a somewhat smaller faculty and somewhat fewer students the basic engineering science courses, for example, are with

The preferred program for four-year students is listed below:

First Fall Term

College Writing I (Gordon Rule)	ENC 1101	3
General Chemistry I	CHM 2045	3
General Chemistry I Lab	CHM 2045L	1
Calculus I (Gordon Rule)	MAC 3311	4
CORE course....		
Reason and Value (GR)	PHI 1030	3
Introduction to Ocean Engineering	EOC 3000	1
	subtotal	15

First Spring Term

General Physics I	PHY 3040	4
General Physics I Lab	PHY 3040L	1
Calculus II (Gordon Rule)	MAC 3312	4
College Writing II (Gordon Rule)	ENC 1102	3
PASCAL	COP 2210	3
	subtotal	15

First Summer Term

Macroeconomics	ECO 2013	3
Statics	EOC 3105	3
CORE course...		
Fine Arts	ARH 2000, or MUL 2010, or THE 3000	3
	subtotal	9

Second Fall Term

Engineering Ethics	PHI XXXX	3
Calculus III	MAC 3313	4
General Physics II	PHY 3041	4
General Physics II Lab	PHY 3041L	1
CORE course...		
History of Civilization (GR)	WOH 2012	3
	subtotal	15

Second Spring Term

Dynamics	EOC 3113	3
Strength of Materials	EOC 3150	3
Engineering Math I	MAP 3305	3
General Chemistry II	CHM 2046	3
General Chemistry II Lab	CHM 2046L	1
	subtotal	13

Second Summer Term

Engineering Math II	MAP 4306	3
Engineering Graphics	EGS 1111	3
Network Analysis and Electrical Machines	EEL 3004	3
	subtotal	9

Third Fall Term

Thermodynamics	EML 3141	3
Marine Geochemistry	OCG 3001	3
Vibrations	EOC 3114	3
Numerical Meth. or	MAD 3400 or	3
Probability & Statistics	STA 4032	3
Analog Electronics	EEL 3003	3
	subtotal	15

Third Spring Term

Fluid Mechanics	EOC 3123	3
Materials	EOC 3200	3
Acoustics	EOC 3306	3
Technical Elective 1		3
	subtotal	12

Third Summer Term

CORE course...		
World Geography	GEA 2000	3
Technical Elective 2		3
Microeconomics	ECO 2023	3
	subtotal	9

Fourth Fall Term

Phys. Oceanography & Wave Mechanics	EOC 4422	3
Ocean Engineering Systems Design *	EOC 4804	3
Digital Electronics	EEL 3341	3
Technical Elective 3		3
	subtotal	12

Fourth Spring Term

Ocean Thermal Systems	EOC 4193	3
Ocean Engineering Systems Design Project	EOC 4804L	3
Technical Elective 4		3
Ocean & Environmental Data Analysis	EOC 4631	3
	subtotal	12
	TOTAL	136

Technical Electives

Complete at least four technical electives, three of which must be from a single area of specialization as indicated in the following:

FLUIDS

Ship Hydrodynamics I	EOC 4503
Ship Hydrodynamics II	EOC 4510
Underwater Sound Prop.	EOC 4308C
Env. Eng. & Aquatic Pollution	OCC 4060

MATERIALS

Batteries and Fuel Cells	EOC 4202
Marine Materials & Corrosion	EOC 4204C
Advanced Engineering Materials	EOC 4201C
Ocean Structures	EOC 4410C

ENVIRONMENTAL ENGINEERING

Env. Eng. & Aquatic Pollution	OCC 4060
Marine Geotechnique	EOC 4220
Vibration, Shock, & Noise Con.	EOC 4115C
Ship Hydrodynamics I	EOC 4503

ACOUSTICS AND SIGNAL PROCESSING

Underwater Sound Prop.	EOC 4308C
Vibration, Shock, & Noise Con.	EOC 4115C
Ship Hydrodynamics I	EOC 4503
Env. Eng. & Aquatic Pollution	OCC 4060

STRUCTURES

Marine Geotechnique	EOC 4220
Ocean Structures	EOC 4410C
Design of Marine Steel Struct.	EOC 4414
Design of Marine Concrete Str.	EOC 4415

FIGURE 11. THE CURRICULUM AT FLORIDA ATLANTIC UNIVERSITY (REPRODUCED FROM THE 1994-95 "UNDERGRADUATE CATALOG")

DEGREE REQUIREMENTS

Candidates for a Bachelor of Science in Ocean Engineering must complete the minimum course requirements outlined in the following curriculum. Deviation from the recommended program may be made only with the approval of the student's faculty advisor and the concurrence of the department head.

For definition of electives for engineering programs, see the *Undergraduate Information and Regulations* section of this catalog.

Freshman Year

Fall

			Credits
BUS	1301	Basic Economics*	3
CHM	1101	General Chemistry 1	4
COM	1101	Composition and Rhetoric	3
MTH	1001	Calculus 1	4
OCN	1001	Oceanography and Environmental Systems	3
			17

Spring

COM	1102	Writing about Literature	3
MTH	1002	Calculus 2	4
OCE	1001	Introduction to Ocean Engineering	3
PHY	1001	Physics 1	4
PHY	2091	Physics Lab 1	1
			15

**Or Social Science Elective*

Sophomore Year

Fall

			Credits
HUM	2051	Civilization 1	3
MAE	2081	Statics	3
MTH	2001	Calculus 3	4
PHY	2002	Physics 2	4
PHY	2092	Physics Lab 2	1
CSE	xxxx	Restricted Elective (Computer Science)	3
			18

Spring

HUM	2052	Civilization 2	3
MAE	2082	Dynamics	3
MAE	3082	Deformable Solids	3
MTH	2201	Differential Equations and Linear Algebra	4
OCN	xxxx	Restricted Elective (Oceanography)	3
			16

Junior Year

Fall

			Credits
COM	2223	Scientific and Technical Communication	3
OCE	3010	Engineering Materials	4
OCE	3030	Fluid Mechanics	3
OCE	3033	Fluid Mechanics Lab	1
OCN	3401	Physical Oceanography	3
		Free Elective	3
			17

Spring

ECE	4991	Electrical Circuit	3
MAE	3191	Engineering Thermodynamics 1	3
OCE	3521	Hydromechanics and Waves	3
OCE	3522	Water Wave Lab	1
OCE	4541	Ocean Engineering Design	3
OCE	4571	Fundamentals of Naval Architecture	3
			16

Summer

OCE	4911	Marine Field Project	1
OCE	4912	Marine Field Project	2
OCE	4913	Marine Field Project	3
			6

Senior Year

Fall

			Credits
CVE	3015	Structural Analysis and Design	3
OCE	4525	Coastal Engineering Structure	3
OCE	4545	Hydroacoustics	3
OCE	xxxx	Restricted Elective (Ocean Engineering)	3
		Humanities Elective	3
			15

Spring

CVE	4000	Engineering Economy and Planning	3
OCE	4518	Protection of Marine Materials	3
OCE	4542	Ocean Engineering Systems Design	3
		Humanities or Social Science Elective	3
		Technical Elective	3
			15

TOTAL CREDITS REQUIRED 135

FIGURE 12. THE PROGRAM AT THE FLORIDA INSTITUTE OF TECHNOLOGY (REPRODUCED FROM THE 1993-94 "UNIVERSITY CATALOG")

the exception of fluid mechanics offered by and taught by faculty from other departments. There is a required course in Fundamentals of Naval Architecture, however, and elective courses in preliminary ship design and another devoted to the design of high-speed small craft that are available for undergraduates. But, despite quite a number of graduate courses also devoted to various aspects of ships and platforms, the bachelor's degree graduates are probably not usually as well prepared to practice naval architecture as graduates from one or two of the other programs that are presented as being in ocean engineering. For the most part those who have created these programs do not now nor did they ever see them as variations of the existing programs in naval architecture and/or marine engineering, with their graduates also being educated for careers at say ship design firms or shipyards, but the presence of naval architects among the faculty members for all of these programs and the fact that a platform of some sort is essential in almost any conceivable ocean system has led to material concerning or common to naval architecture being included in their curricula. Similarly, many aspects of ocean engineering beyond those that relate to the design of floating platforms and other offshore systems are now included in the courses offered at the schools and in the units that have housed the traditional naval architecture and/or naval architecture and marine engineering programs.

Graduate Programs

Graduate programs in the U.S. and Canada in naval architecture and/or naval architecture and marine engineering or in ocean engineering are not as amenable to fixed or even reliable description as have been the undergraduate programs. Curricula are not usually published in terms of listings of required courses and almost never in suggested sequential term requirements. Further, several levels and types of degrees are available: master's degrees in engineering, master of science and master of science in engineering degrees, what are termed professional degrees leading to the titles of Naval Architect or Ocean Engineer or Naval Engineer (and Marine Engineer as well, a matter of no great interest in this report), and doctoral degrees of engineering and of philosophy. Some schools have programs leading to combined bachelor's and master's degrees as a single integrated curriculum, and there is a continuing trend that seeks to establish the master's degree rather than the bachelor's degree as the true measure by which a graduate might rightfully deem himself or herself an engineer professionally qualified to enter practice utilizing today's high technology procedures and well aware of the vast increase in knowledge and capability that can now be applied in resolving engineering problems.

Several among the dozen schools included above do not offer graduate study; as indicated above, Webb is only about to initiate a master's degree program, and neither the Coast Guard Academy nor the Naval Academy have graduate programs. But the Technical University of Nova Scotia in Halifax does, and therefore it and the remaining programs, in the same order as above, will be discussed. There is no accreditation normally sought by graduate programs, and while several other programs could perhaps be included these ten are considered, as before, adequate for the purposes of this study.

The University of Michigan

The Michigan graduate program in naval architecture and marine engineering has very recently been significantly revised, not as yet eliminating the existing specialization options but now focusing on just two "Areas of Excellence." These are first, Marine Hydrodynamics and Marine Environmental Engineering and, second, Concurrent Marine Design, and they are intended to categorize departmental and individual faculty research interests and activities as well. A minimum of 30 credit hours of courses must be completed to earn a master's degree and there are level and distribution requirements as well. The Master of Science degree, unlike the Master of Science in Engineering degree, requires a thesis and is now viewed as the more scientific choice preparing graduates for careers in research and development or for continuing study towards the doctoral degree. The Master of Engineering degree is at present in Concurrent Marine Design, or in an interdisciplinary program in manufacturing with specialization in naval architecture and marine engineering. The relatively new M.Eng. degrees are administered by the College of Engineering while all of the other degrees are granted by the Rackham School of Graduate Studies – an umbrella-like organization that among its other responsibilities attempts to insure some degree of uniform high quality among all graduate degree programs throughout the University whether they be in anthropology or zoology or any field in between. Students seeking admission to the M.Eng. degree programs must have a bachelor's degree in an engineering discipline plus relevant industrial experience, and initially it is intended primarily for those who plan to return to industrial careers. The two professional degrees of Naval Architect and Marine Engineer require an additional 30 credit hours of course work beyond the master's degree requirements and successful completion of a comprehensive examination, and both emphasize application of engineering science at the level of advanced engineering practice. The Doctor of Philosophy degree also requires additional course work beyond the master's degree requirements, plus pursuing an independent investigation in a special new area or concern of naval architecture and marine engineering so as to complete a dissertation that contributes original and significant knowledge and understanding to this discipline. Doctoral committees are created for each doctoral candidate after their successful completion of preliminary examinations and preparation of a prospectus describing their intended investigation, but the chairman of the committee is the student's chosen advisor and usually has assisted in preparing the prospectus. Most faculty members chair one or more committees and are members of others at any given time, and at Michigan seven faculty members are also assigned as the specialization option advisors, under a single overall graduate program advisor or chairman, for each of the still used eight specialization options: computer-aided marine design, marine engineering, marine production, marine structures, marine systems management, and offshore engineering, all within the concurrent marine design area; and marine hydrodynamics and marine environmental engineering in that area.

There is at Michigan, as at some of the other schools, the possibility of earning an interdepartmental but single master's degree in several disciplines simultaneously, and this requires at least 40 credit hours of graduate-level work. There is also the opportunity to pursue simultaneously two separate master's degrees, and this requires a minimum of 50 hours of graduate-level work. In addition, a joint M.S.E. in Naval Architecture and Marine Engineering / M.B.A. in Business Administration program has been available for some years and it requires 45 credit hours in business administration plus usually fewer than the 30 hours normally required for the M.S.E. degree depending on the business administration courses elected. Additional aspects of the graduate programs at Michigan, such as how faculty assignments or promotions are made, how graduate students are supported, more detailed descriptions of several key if not all individual courses, how frequently specialized graduate-level courses – usually with small numbers of students enrolled – are offered, the special arrangements with the U.S. Coast Guard and the normal procedures for the contingent of Coast Guard officers assigned there for study each year, and others, would need to be described to provide a more complete understanding of them (or of any of the programs at any of the other schools), but for the purposes of this study the more pertinent details on the structural specialization option and the structural courses will be covered in the next section of this report.

The University of New Orleans

The School of Naval Architecture and Marine Engineering at New Orleans graduate program is much less extensive and complicated, but is otherwise similar if limited. The single master's degree program leading to a Master of Science in Engineering in Naval Architecture and Marine Engineering, does have two options, one requiring 33 hours of graduate credit and the other requiring a thesis and 30 hours of graduate work including six hours of thesis research. As is done with the undergraduate courses, most of the graduate-level courses are also offered late in the day so part-time students can work toward an advanced degree. No areas of specialization are formally defined and there is no Doctor of Philosophy degree program specifically in naval architecture and marine engineering.

Memorial University of Newfoundland

At Memorial graduate students can earn a Master of Engineering and Applied Science degree in ocean engineering by completing a program that includes four courses and a thesis. It is offered within the School of Graduate Studies, but the courses are taught by and the thesis is directed by the Faculty of Engineering and Applied Science. The Doctor of Philosophy degree, actually in ocean engineering, is similarly awarded and directed. There are 34 courses available that are numbered 9000 and above (i.e., at the graduate level). There is also a special program entitled the VLSI (for Very Large Scale Integrated) Design Programme offered in conjunction with the Department of Computer Science and leading to a Master of Engineering degree.

The University of California - Berkeley

The graduate studies programs at Berkeley offered by the Department of Naval Architecture and Offshore Engineering can lead to any of an array of degrees: Master of Science in Engineering and Doctor of Philosophy in Engineering, Master of Science in Engineering Sciences and Doctor of Philosophy in Engineering Sciences, and Master of Engineering and Doctor of Engineering. The latter degree has been in place for a number of years and Berkeley is one of only a few schools that now awards it, but there is a strong trend at many of the better engineering colleges towards doing so as well. This is partly because the Master of Engineering – rather than the Master of Science in Engineering – programs have been well received by industry and because the so-called professional degrees are still not well understood outside academic circles. At Berkeley the Master of Science degrees require at least 20 units of primarily graduate work plus a thesis, or a minimum of 24 units and a comprehensive final examination. The Master of Engineering program is awarded for completion of a minimum of 40 units of which at least 20 must be for graduate courses and the total program must include 16 to 20 units oriented towards design and analysis. There are other distribution requirements much as for the graduate programs at the other schools being discussed, and while each student has considerable latitude in selecting the courses to include his total program has to be acceptable to his or her academic advisor, the department, and the college. With only a few departmental faculty members at present, and hence a limited number of graduate courses available from the department, it may well be that the current graduate students at Berkeley must complete a number of courses offered by other engineering departments. But Berkeley is a large and truly outstanding engineering college and this should not be a significant problem. The doctoral degree requirements are similar to those at Michigan – and MIT, Texas A&M, etc. – but four semesters of residence, a minimum of 33 units of formal courses, a program consisting of one major field and two minor fields, the usual qualification exams (often referred to as prelims), and a thesis that demonstrates the candidate has made a creative contribution to the knowledge of the chosen field of study or (for the Doctor of Engineering) to the solution of a significant engineering problem, are all mentioned specifically in their graduate publications. It is very interesting, however, that the Naval Architecture and Offshore Engineering Department alone at Berkeley still has a doctoral program language requirement. A combined engineering and business administration program, and several other interdisciplinary programs are available at Berkeley.

Virginia Polytechnic Institute and State University

At Virginia Tech the graduate programs in ocean engineering are administratively in the Graduate School and are much like those at the other universities, the same degrees – Master of Science with or without a thesis, Master of Engineering, and Ph.D. – but in ocean engineering are awarded and the same procedures, particularly for the Doctor of Philosophy degree, are followed. There are some 34 graduate courses offered by the Aerospace and Ocean Engineering Department, 30 credit hours including 15 hours of 5000-level or above courses are required in the two master's degree programs, a thesis counting for 6, and 27 hours of graduate level courses are required in the doctoral program.

Massachusetts Institute of Technology

At MIT graduate students in the Department of Ocean Engineering can currently earn Master of Science, Master of Engineering, and Doctor of Philosophy or Doctor of Science degrees, and the professional degrees of Ocean Engineer or Naval Engineer. The latter is associated with the Naval Construction and Engineering program for naval officers, known as XIII-A. The Ocean Systems Management program is known as XIII-B, and the Joint MIT-Woods Hole Oceanographic Institution program is designated XIII-W. There are a number of other special programs combining ocean engineering studies with, for example, technology and policy or with management of technology, but the program designated as XIII without a following letter does lead to either a Master of Science in Ocean Engineering or a Master of Science in Naval Architecture and Marine Engineering. There is a new program in Marine Environmental Systems leading to a Master of Engineering degree. The size of the Department of Ocean Engineering faculty at MIT and the breadth of their backgrounds and activities, along with the recognition that the current MIT catalog indicates they offer no less than 85 individual courses which carry graduate credit, insures that their graduate students can together with their individual academic advisors select some number of courses suitable for their own interests and career objectives while still meeting the appropriate degree requirements. At least 66 graduate subject units and a thesis are necessary for the Master of Science degree.

Texas A&M University

Graduate studies in ocean engineering at Texas A&M include programs leading to the degrees of Master of Engineering requiring a minimum of 36 credit hours, Master of Science in Ocean Engineering requiring a minimum of 36 credit hours plus a thesis, Doctor of Philosophy in Ocean Engineering requiring a minimum of 64 credit hours beyond the Master's degree and a thesis, and Doctor of Engineering which seemingly is awarded infrequently and requires industrial experience as well as a final comprehensive examination. There are 18 graduate-level ocean engineering courses, only two of which are concerned with structures even though ocean structures (along with coastal engineering and marine hydrodynamics) is considered one of the primary areas of interest. There are, however, suitable additional structures courses in mechanical and civil engineering so that comprehensive individual programs can be arranged; but ship structures specifically would not be the focus.

Florida Atlantic University

The close relationship between ocean and civil engineering at Florida Atlantic is apparent in that the Department of Ocean Engineering offers master's degrees in both disciplines, but a student interested in structures generally would probably attempt to satisfy the requirements for that major in the civil engineering program while one interested in marine structures would be enrolled in the ocean engineering program. The Master of Science in Engineering (Ocean Engineering), or (Civil Engineering) degree requires a minimum of 30 credit hours of which up to six must be for research related to a thesis, while the Master of Engineering (Ocean Engineering), or (Civil Engineering) requires 33 credit hours plus passage of an oral final comprehensive exam. The Doctor of Philosophy degree in Ocean Engineering program includes 30 hours of course work beyond the master's degree, the thesis and the research for it, and very much the same arrangement as at all of the other schools with a qualifying exam – called General Examination I at Florida Atlantic – before candidacy and a thesis defense – called General Examination II. The current graduate catalog lists 53 graduate-level courses given by the Department of Ocean Engineering and at least one-quarter of them are in the structural mechanics or materials and fracture mechanics areas, but as at Florida Tech the application focus is not on ships in any of them.

Florida Institute of Technology

At Florida Tech 30 credit hours, including a thesis, are required in the Master of Science in Ocean Engineering program, although there as elsewhere the thesis is valued at 6 credit hours and can be replaced by two additional courses if the student can produce the results of a similar effort performed previously at Tech or somewhere else. There are four subject areas, one of which is Materials and Structures (the others are Marine Vehicles and Ocean Systems, Coastal Processes and Engineering, and Fisheries Engineering) even though there are only two graduate-level structures courses in ocean engineering required. The Doctor of Philosophy degree program is similar to that at other schools, but 48 credit hours beyond the master's degree are required. While this seems onerous it is tempered by the allocation of 24 of these for the thesis work.

Technical University of Nova Scotia

The graduate program in Naval Architecture and Marine Engineering at Nova Scotia is administratively under the Faculty of Engineering – equivalent to a school or college in the U.S. – and the individual faculty members have their appointments in the Department of Mechanical Engineering. With a slightly different name than the M.S.E. degree awarded at most U.S. schools, the Master of Applied Science degree at TUNS is similar particularly in contrast to the TUNS Master of Engineering degree in the same sense as in the U.S. It requires completion of a minimum of six courses and a thesis, while the Master of Engineering requires completion of a minimum of ten courses but two of which can be for the required project. Because most students entering the program have not earned their undergraduate degrees in naval architecture or in ocean engineering (at least not at Canadian schools) some adjustments in the ten course requirement are made for those who did have their degrees in mechanical and civil engineering – reducing it to eight, for example – that probably would not occur with other engineering disciplines. The Doctor of Philosophy requirements and procedures are very similar to those at the U.S. schools as described above. Some 16 graduate-level courses covering the usual subjects in ocean engineering and naval architecture are listed in the mechanical engineering series in the current catalog (calendar) and together they deal with ship and platform concerns reasonably comprehensively and are concerned not at all with such topics as coastal processes and oceanographic instrumentation.

STRUCTURAL ANALYSIS AND DESIGN COURSES IN NAVAL ARCHITECTURE AND OCEAN ENGINEERING CURRICULA

This section of this report will include descriptions – for the most part from the same publications used earlier in describing the various undergraduate and graduate programs, but also in more detail by means of syllabuses and outlines or portions thereof exactly as provided by professors responsible for or actually teaching the courses – for those courses which deal with ship and offshore structural analysis and design in the programs at each of the schools considered in the foregoing section. Including all of the syllabuses in hand, and much of the ancillary information needed to explain some of the other details of the individual courses or to provide fully the context in which they are presented in the respective institutions' own publications, would needlessly make this section massive in size and far more cumbersome than deemed necessary to reach the conclusions sought. Enough material at both the undergraduate and the graduate level will be provided to suggest that while many of the schools may use more courses to cover essentially the same ground, or even consider worthy of graduate credit courses that cover topics that at another one are in those meant for undergraduates, or in elective courses, cataloging the distinctions among the programs is considered not as much needed as is the ability to judge what current program graduates generally should know and understand and how professionally capable they should be.

Individual Course Descriptions

Webb Institute

As indicated above, Webb is in the unique position of having only a single curriculum and can therefore integrate the courses in the curriculum to great advantage. The actual course descriptions of interest from their catalog will not be as useful here as the excerpt from a letter from Professor George Petrie shown in Figure 13. Note that rod and beam element stiffness matrices are introduced in the basic strength of materials course in the second year prior to the students taking any

Re: Info on ship structures content in Webb Naval Arch. Program

Attached are course outlines for several courses, wholly or partly devoted to aspects of ship structures. In addition, I offer the following commentary, on a course by course basis.

Freshman:

NA-1 Introduction to Naval Architecture (outline not included)

Basic nomenclature, including common structural elements. Students perform a weight/foot calculation for given midship section. Students construct small models of typical structural details, i.e. a hatch corner, double bottom, web frame, bulkhead, etc.

CAD/Graphics (outline not included)

As a final drafting/CAD exercise, students prepare a CAD drawing of a given midship section.

Sophomores:

Strength of Materials

Basic principles, as noted on course outline. Introduction to finite element analysis; basic principles of matrix stiffness analysis, derivation of rod and beam element stiffness matrices. Hand calculations of elementary structures (truss problem).

NA-2 Ship Statics

Primarily hydrostatics, trim and stability. Fundamentals of longitudinal strength addressed in lectures 45, 48, 51, 52 and 55, as noted on course outline.

Juniors:

NA-4 Ship Structures

Longitudinal strength, primary, secondary, tertiary stresses, shear flow calculations, plate bending, fatigue assessment and elastic buckling of plates and stiffened panels, as shown on course outline. Ship Structural Design by Hughes is used as a reference. Several finite element problems are worked, using ALGOR Program. FEM assignments include

1. Flat plate under uniform load w/ different mesh densities and boundary conditions (compare to plate theory)
2. Combined beam and plate (compare to beam theory)
3. Stiffened panel under uniform load.
4. Hull module analysis project (Coarse mesh 3-D model)

New to the course this year is a series of six lectures at the end of the term directed to composite materials and design methods.

NA-5 Ship Dynamics

Primarily maneuvering and seakeeping, as shown on course outline. Strip theory approach to computing ship motions and sea loads is introduced, along with probabilistic approach to estimating extreme values.

NA-6 Elements of Design and Production

Mainly a preliminary design course, revised this year to include design of GRP hulls typical of yacht-size semi-displacement craft. Design includes preliminary scantlings of shell and longitudinal stiffeners, using GRP laminates, and corresponding weight estimates.

Seniors:

NA-7 Ship Design I (course outline not included)

Project 1 Preliminary design of container ship
Project 2 Lines plan for same ship

NA-8 Ship Design II

Project 1 Revise design to conform to final set of lines
Project 2 Evaluate longitudinal strength requirements, using ABS Rules, Quasi-static bending moment and Design Sea Method (SMP87 wave induced loads).
Project 3 Develop scantlings for midship section, using ABS Rules. Evaluate typical transverse web frame using ALGOR finite element program.

FIGURE 13. EXCERPT FROM LETTER FROM PROFESSOR PETRIE DESCRIBING STRUCTURES CONTENT IN COURSES AT WEBB

course in ship structures, for example, and that a midship section is prepared in their first-year CAD/graphics course. (It should also be noted that while that first course in ship structures for example is in the figure referred to as NA-4, in the Webb catalog Roman numerals are used.) Syllabuses for NA IV, Ship Structures; NA VI, Elements of Ship Design and Production; NA VIII, Ship Design II; and for the strength of materials course are given in Figures 14 through 17. The ship design course is the second of two covering preliminary design, as it is in this course that the structural design is accomplished.

The University of Michigan

If the total Webb undergraduate program is indeed very nearly an ideal example, the Michigan undergraduate program is in the same sense the best representative of many of those at other schools, including those once available at Berkeley and MIT. The principal undergraduate courses in marine structures are NA 310, Marine Structures I, and NA 410, Marine Structures II. Not all undergraduate students elect the latter since it is not actually specifically required, but most do. It can also be taken for graduate credit, and all master's degree students must now elect the third course in the structures sequence, NA 510, Marine Structural Mechanics, and hence must be familiar with the material in NA 410. The catalog course descriptions along with their outlines are shown in Figures 18 through 20, respectively. Because the same textbook is used for both NA 310 and NA 410, pertinent portions of the Table of Contents of it are reproduced in Figure 21. What can not so easily be represented are the soft cover bound "course notes" that are absolutely essential in describing fully how the subject matter dealt with in each of these courses, but the tables of contents of the versions prepared by Professors Vorus and Karr now being used in NA 310 and in NA 510 are reproduced in Figures 22 and 23 and the agreement with the course outlines is obvious. Course notes, or "course packs" as they are now known on most campuses, often make liberal use of figures and data from textbooks and other references (and while the sources are always given this practice has many of the original publishers very much concerned and has led to a number of law suits) but blend these and the instructor's own material into a coherent package that reinforces and to some extent supplements the lectures. Several additional courses in structures beyond NA 510 are available for graduate students at Michigan, including particularly NA 518, Strength Reliability of Ship and Offshore Structures, and NA 574, Computer-Aided Hull Design and Production.

NA IV - SHIP STRUCTURES | PROF. PETRIE

FALL 1994

Lecture No.	Date	Topic	Reading
1.	M-8/22	Course Overview & Introduction	1-16
2.3.	T-8/23	General Approach to Analysis of Design	78-84
4.	Th-8/25	Sources of Loading	
5.	M-8/29	End Launching	
6.7.	T-8/30	Lab-Launching Project	
8.	Th-9/1	Load Transfer & Framing Systems	
9.	M-9/5	NO CLASS - LABOR DAY	
10.11.	T-9/6	Lab-Launching Project	
12.	Th-9/8	Candidate Structure Design Procedure	
13.	M-9/12	Plate Bending Theory	
14.15.	T-9/13	Lab-F.E.M. Intro; ALGOR plate modelling	
16.	Th-9/15	Shear Lag-Effective Width	
17.	M-9/19	Modelling of Combined Beam and Plate	
18.19.	T-9/20	Lab-ALGOR-beam flexure	
20.	Th-9/22	Hull Module; Structural Modelling	
21.	M-9/26	Hull Module; Loads & B.C.	
22.23.	T-9/27	Lab-ALGOR-stiffened panel	
24.	Th-9/29	Hull Girder Shear Flow	
25.	M-10/3	EXAM #1	
26.27.	T-10/4	Lab. - Project I - Hull Module	
28.	Th-10/6	Design Criteria	
29.	M-10/10	Failure Modes & Limit States	
30.31.	T-10/11	Lab. - Project I	
32.	Th-10/13	Fatigue Assessment	
33.	M-10/17	NO CLASS - FALL RECESS	
34.35.	T-10/18	Lab. - Project I	
36.	Th-10/20	Large Deflection Plate Bending Theory	
37.	M-10/24	Intro. to Elastic Buckling of Plates	
38.39.	T-10/25	Lab. - Project I	
40.	Th-10/27	Plate Buckling	
41.	M-10/31	Stiffened Panel Buckling	
42.43.	T-11/1	Lab. - Project I DUE	
44.	Th-11/3	Principal Member Analysis - Modelling	
45.	M-11/7	Principal " " - Loads & B.C.	
46.	T-11/8	(Monday Schedule) Intro. to Project II-P.M.A.	
47.	Th-11/10	GRP - Material Properties	
48.	M-11/14	GRP - Single Skin & Cored Construction	
49.50.	T-11/15	Lab. - Project II	
51.	Th-11/17	SNAME Meetings	
52.	M-11/28	GRP - Panel Design	
53.54.	T-11/29	Lab. - Project II	
55.	Th-12/1	GRP - Panel Design	
56.	M-12/5	GRP - Stiffener Design	
57.58.	T-12/6	Lab. - Project II	
59.	Th-12/8	GRP - Stiffener Design	

FIGURE 14. SYLLABUS FOR WEBB COURSE NA IV, SHIP STRUCTURES

PROF. TIKKA
PROF. PETRIE

NA VI - ELEMENTS OF DESIGN AND PRODUCTION

SPRING 1998
JUNIORS

Reference Texts: Munro - Smith - Elements of Ship Design
Taggart - Ship Design and Construction
SNAME - Principles of Naval Architecture

Lecture

No	Date	Subject	Reference
1	2/27	Introduction to ship design (Tikka)	Taggart - pp. 1-8
			Munro- Smith Chap. 1
2	3/1	Design requirements. Design spiral. Levels of design.	Taggart - pp. 1-13
		(Tikka)	Munro- Smith Chap. 1
3	3/3	Concept design (Tikka)	Taggart - pp. 13-24
			Munro- Smith Chap. 2
4	3/6	Preliminary, contract and detail design (Tikka)	Taggart - pp. 24-29
			Munro- Smith Chap. 2
5	3/8	Feasibility model (Tikka)	
6	3/10	Assignment of design project. Design of a composite vessel (Tikka)	
7	3/13	Proportions and hull form (Petrie)	
8	3/15	Preliminary weight and powering (Tikka)	
9	3/17	Engine and propeller selection (Tikka)	
Lab	3/20	1 hour lab	
10		Structural arrangement. Material properties and selection (Petrie)	
Lab	3/22	1 hour lab	
Lab	3/24	1 hour lab	
Lab	3/27	1 hour lab	
11		Design loads. Panel thicknesses (Petrie)	
Lab	3/29	1 hour lab	
Lab	3/31	1 hour lab	
Lab	4/3	1 hour lab - Design review	
12		Stiffener design. Revised weight estimate (Petrie)	
Lab	4/5	1 hour lab	
13	4/7	Intact and damage stability (Tikka)	
Lab	4/10	2 hour lab	
Lab	4/12	1 hour lab	

PROF. TIKKA
PROF. PETRIE

NA VI - ELEMENTS OF DESIGN AND PRODUCTION

SPRING 1998
JUNIORS

Lab	4/14	1 hour lab	
Recess			
Lab	4/24	2 hour lab	
14	4/26	Ship production - General considerations.	
		Producibility. (Tikka)	
15	4/28	Shipyard layout and material flow.	
Lab	5/1	2 hour lab - Design review	
16	5/3	Planning and scheduling	
17	5/5	Analysis of producibility: Different shipyard practices	
Lab	5/8	2 hour lab	
18	5/10	Case study #1 - US shipyard	
19	5/12	Case study #2 - European yard	
Lab	5/15	2 hour lab	
20	5/17	Case study #3 - Japanese yard	
No class	5/19	Juniors to ASNE	
Lab	5/22	2 hour lab - Design review	
21	5/24	Case study #4 - Marinex	
22	5/26	Comparison of case studies	
No class	5/29	Memorial day	
23	5/31	Weights, centers, volumes	Taggart - pp. 37-41
			Munro- Smith Chap. 3
			PNA Vol. I pp. 69-71
24	6/2	Weight classification and levels	
Lab	6/5	2 hour lab	
25	6/7	Weights - Statistical data	
26	6/9	Weight control and margin	Taggart - pp. 37-41
			Munro- Smith Chap. 3
			PNA Vol. I pp. 69-71
Lab	6/12	2 hour lab	
27	6/14	Design project due	

FIGURE 15. SYLLABUS FOR WEBB COURSE NA VI, ELEMENTS OF DESIGN AND PRODUCTION

PROF. PETRIE
PROF. TIKKA

SPRING 1995
SENIORS

NA VIII - SHIP DESIGN II

Date		Class Hours	Topic
Tue	2/28	1	Project I Assignment - Introduction and Guidance (Petrie)
Wed	3/1	2	Intact and Damage Stability Review (Tikka)
Thu	3/2	1	Lab
Fri	3/3	2	Damage Stability - HECSALV & GHS Computer Programs (Tikka)
Tue	3/7	1	Lab
Wed	3/8	2	Damage Stability - Current and Future Rules (Tikka)
Thu	3/9	1	Lab
Fri	3/10	2	Lab
Tue	3/14	1	Lab
Wed	3/15	2	Lab
Thu	3/16	1	Lab
Fri	3/17	2	Interim Review
Tue	3/21	1	"Debriefing"
Wed	3/22	2	Lab
Thu	3/23	1	Lab
Fri	3/24	2	Lab
Tue	3/28	1	Lab
Wed	3/29	2	Lab
Thu	3/30	1	Lab
Fri	3/31	2	Project I Due 1600
Tue	4/4	1	Project II Assignment - Introduction and Guidance (Petrie)
Wed	4/5	2	Estimate of Longitudinal Weight Distribution (Tikka)
Thu	4/6	1	Longitudinal Strength Review (Petrie)
Fri	4/7	2	Lab
Tue	4/11	1	Wave Induced Bending Moment - Quasi Static and ABS Rules
Wed	4/12	2	Lab
Thu	4/13	1	Lab
Fri	4/14	2	Interim Review
			Recess
Tue	4/25	1	Wave Induced Bending Moment - Design Sea Method (Petrie)
Wed	4/26	2	Lab
Thu	4/27	1	Lab

PROF. PETRIE
PROF. TIKKA

SPRING 1995
SENIORS

NA VIII - SHIP DESIGN II

Fri	4/28	2	Lab
Tue	5/2	1	Candidate Structure Geometry (Tikka)
Wed	5/3	2	Lab
Thu	5/4	1	Lab
Fri	5/5	2	Project II Due 1600
Tue	5/9	1	Project III Assignment - Introduction and Guidance (Petrie)
Wed	5/10	2	Lab
Thu	5/11	1	Use of ABS Rules for Scantlings (Petrie)
Fri	5/12	2	Lab
Tue	5/16	1	Lab
Wed	5/17	2	Lab
Thu	5/18	1	Lab
Fri	5/19	2	Lab
Tue	5/23	1	Lab
Wed	5/24	2	Lab
Thu	5/25	1	Lab
Fri	5/26	2	Interim Review
Tue	5/30	1	2-D Finite Element Analysis (Petrie)
Wed	5/31	2	Lab
Thu	6/1	1	Lab
Fri	6/2	2	Lab
Tue	6/6	1	Lab
Wed	6/7	2	Lab
Thu	6/8	1	Lab
Fri	6/9	2	Lab
Tue	6/13	1	Lab
Wed	6/14	2	Project III Due

FIGURE 16. SYLLABUS FOR WEBB COURSE NA VIII, SHIP DESIGN II

PROF. G. L. PETRIE
STRENGTH OF MATERIALS (4 hours)

Sophomores
FALL 1994

Text: Mechanics of Materials, 4th. Ed., Higdon, Ohlsen, Stiles, Weese and Riley - John Wiley and Sons, 1985
The Finite Element Method, 2nd Ed., Rockey, Evans, Griffiths, and Nethercot

Les. No.	Date	Subject	Study Assign.	Prob. Assign.
1.	8/22	Concept of Stress	1-1 to 1-4	
2.	8/23	Stress at a Point	1-5, 1-6	
3.	8/25	Principal Stresses	1-7	
4.	8/25	Mohr's Circle for Stress	1-8	
5.	8/29	Concept of Strain, strain @ a Point	2-1 to 2-4	
6.	8/30	Plane Strain	2-5	
7.	9/1	Principal Strains-Material Properties	2-6, 3-1, 3-2	
8.	9/1	Hookes Law	3-3	
9.	9/6	Strain Energy, Working Stress	3-4, 3-5, 3-6	
10.	9/8	TEST NUMBER 1	Lessons 1 thru 9	
11.	9/8	Axial Load Applications	4-1 to 4-3	
12.	9/12	Statically Indeterminate Members	4-4	
13.	9/13	Pressure Vessels	4-5	
14.	9/15	Torsion	5-1 to 5-3	
15.	9/15	Statically Indeterminate Members	5-4, 5-9	
16.	9/19	Stresses on Oblique Planes	5-5	
17.	9/20	Inelastic Action	5-7, 5-8	
18.	9/22	Noncircular Sections	5-10, 5-11	
19.	9/22	Finite Element Analysis	Page 8-12	
20.	9/26	" " "	Page 12-19	
21.	9/27	Finite Element Analysis	Page 20-24	
22.	9/29	" " "	Page 24-28	
23.	9/29	" " "	Page 29-32	
24.	10/3	TEST NUMBER 2	Lesson 11 thru 23	
25.	10/4	Flexural Stresses and Strains	6-1 to 6-4	
26.	10/6	Flexural Stresses	6-5, Append. B-1 to B-4	
27.	10/6	" "	Append. B-5 to B-8	
28.	10/10	Shear and Moments in Beams	6-6, 6-7	
29.	10/11	Shear and Moment Diagrams	6-8	
30.	10/13	Shearing Stress by Equilibrium	6-9, 6-10	
31.	10/13	Shearing Stress Formula	6-10	
32.	10/18	Principal Stresses in Beams	6-11	
33.	10/19	Unsymmetrical Bending	6-12	
34.	10/20	Thin Walled Open Sections-Shear Center	6-15	
35.	10/20	" " " "	"	
36.	10/24	Composite Materials	6-16	
37.	10/25	TEST NUMBER 3	Lessons 25 thru 36	
38.	10/27	Flexural Deflections	7-1 to 7-4	
39.	10/27	Superposition	7-10	
40.	10/31	Statically Indeterminate Beams	8-1, 8-2	
41.	11/1	" " "	8-4	
42.	11/3	Combined Static Loading	9-1 to 9-4	
43.	11/3	" " "	9-5	
44.	11/7	Theories of Failure	9-6	
45.	11/8	Finite Element Analysis	Page 33-39	
46.	11/10	" " "	Page 40-43	
47.	11/10	" " "	Page 44-48	
48.	11/14	" " "	" "	
49.	11/15	" " "	Page 49-56	
50.	11/17	" " "	Page 70-76	
51.	11/17	TEST NUMBER 4	Lessons 38 thru 50	
52.	11/28	Column Theory	10-1 to 10-3	
53.	11/29	" "	10-4 to 10-6	
54.	12/1	" "	10-7, 10-8	
55.	12/1	Welded Connections	13-4	
56.	12/5	Stress Concentration & Fatigue	1-10,11-1 to 11-3	
57.	12/6	Fatigue	11-4	
58.	12/8	Limit Design Concepts	8-6	

References: 1 Meriam & Kraig, Engineering Mechanics Vol. 1 Statics 2nd Ed., Chapter 4

FIGURE 17. SYLLABUS FOR WEBB STRENGTH OF MATERIALS COURSE

310. Marine Structures I

Prerequisite: ME 211. I (4 credits)

Quasi-static analysis of ship hulls and offshore structures. Hull primary response. Introduction to probabilistic approach. Plated structures and ship structural components. Combined stresses and failure theories. Framing systems. Brittle fracture and fatigue failure modes, structural details. Midship section synthesis, classification society rules stress superposition. Material and fabrication considerations.

NA310 MARINE STRUCTURES I

Fall 1994

COURSE OUTLINE

		Notes	Text
I.	Introduction	1	1.1-1.5
	a. Still Water Loading	11	
	b. Wave Loading	23	
II.	Beam Stress Analysis	25	
	a. Composite Beam Bending	25	
	b. Midship Section Analysis	33	
	c. Beam Buckling	44	12.1-12.5
	d. Stress Superposition	69	
	e. More Thorough Evaluation of Stress	78	2.1-2.4
III.	Stiffened Plate and Framing Systems	95	
	a. Hull Transverse Strength	97	
	b. Static Stability and Determinacy	103	
	c. Bending and Buckling of Rectangular Plates	110	13.1-13.4
IV.	Energy Methods	111	5.1-5.5
	a. Work and Strain Energy	111	
	b. Virtual Work and Equilibrium Requirements	116	
V.	Finite Element Analysis	127	19.1-19.6
VI.	Failure Analysis	139	
	a. Ductile and Brittle Failure Criteria	139	4.1-4.6,15.1
	b. Fracture	139	15.1-15.4
	c. Fatigue	139	16.1-16.3
VI .	Structural Details	140	
	a. Stress Concentrations	140	14.1-14.3
	b. Weld Stress Analysis	140	
	c. Bolted Connections	144	

<u>INSTRUCTOR:</u>

Prof. Dale G. Karr
NAME 236B
764-3217

<u>COURSE MATERIALS:</u>

Course notes (by William S. Vorus & Dale G. Karr) available at Ulrich's
Text: *Advanced Mechanics of Materials*, by Boresi, Schmidt, and Sidebottom; fifth edition.

FIGURE 18. MICHIGAN CATALOG DESCRIPTIONS, AND COURSE OUTLINE FOR NA 310, MARINE STRUCTURES I

410. Marine Structures II

Prerequisites: NA 310, preceded or accompanied by NA 340. I, II (3 credits)

Equilibrium methods, energy methods and matrix methods are applied to problems in linear elastic beam theory. Solutions for classic beam problems include static bending, torsion, buckling, and vibration. Modeling and analysis techniques for ship and marine structural design are reviewed. Introduction to finite element analysis.

NA410 MARINE STRUCTURES II

Fall 1994

Course Outline

	Topic Description	Text
I.	Unsymmetrical Beam Bending and Extension	
	a. Equilibrium, Stresses, and Deflection	7.1-7.4
	b. Shear Centers	8.1-8.5
	c. Elastic Stability	12.1-12.5
II.	Energy Methods	
	a. Work and Energy	
	b. Principle of Minimum Total Potential Energy	5.1
	c. Castigliano's Theorems	5.2-5.4
	d. Reciprocal Theorem	
	e. Rayleigh-Ritz Method	
III.	Torsion	
	a. Circular and Noncircular Cross Sections	6.1-6.5
	b. Thin-Walled Closed Cross Sections	6.6
	c. Warping	6.7
	d. Lateral-Torsional Beam Buckling	
IV.	Elastic-Plastic Analysis	
	a. Ideal Plasticity	4.1-4.2
	b. Limit Analysis of Beams	6.9,7.5
	c. Thick-Walled Pressure Vessels	11.1-11.5
V.	Finite Element Analysis	
	a. Beams and Beam Systems	
	b. Plane- and Space-Frame Analysis	19.5

<u>INSTRUCTOR:</u>

Prof. Dale G. Karr
NAME 236B
764-3217

<u>TEXT:</u>

Advanced Mechanics of Materials, by Boresi, Schmidt, and Sidebottom; fifth edition.

FIGURE 19. MICHIGAN CATALOG DESCRIPTION, AND COURSE OUTLINE FOR NA 410, MARINE STRUCTURES II

510. Marine Structural Mechanics

Prerequisite: NA 310 or CEE 312 or ME 311 or Aero 314. II (4 credits)

Von Karman plate equations. Strip-beam and plate solutions with geometric and material non-linearities. Application to ship and platform analysis in damage condition. The flange tripping non-linearity. Elastic and plastic analysis of flat plates. Effects of aspect ratio. Ship main-deck buckling example.

NA510 MARINE STRUCTURAL MECHANICS

Winter 199[illegible]

Course Outline

Topic		Text Chapter
I.	Introduction	
	a. Geometric and Material Nonlinearities	
	b. Tripping of Plate Stiffeners -	
II.	Continuum Mechanics	
	a. Stress and Deviatoric Stress Tensors	1.1 - 1.6
	b. Deformation Tensors	1.7
	c. Strain Tensors	1.7 - 1.11
	d. Constitutive Equations	1.12 - 1.13
III.	Von Karman Plate Equations	8.5
	a. Nonlinear Strain-Displacement Relations	
	b. Kirchoff Approximations	
	c. Equilibrium and Compatibility Equations	
IV.	Calculus of Variations	2.1 - 2.12
	a. Principle of Virtual Work	3.1 - 3.2
	b. Principle of Minimum Total Potential Energy	3.3
	c. Linear Beam Theory	4.0 - 4.4
	i. Energy Functionals	
	ii. Euler-Lagrange Equations	
	iii. Natural and Kinematic Boundary Conditions	
V.	Applications	
	a. Strip Beam Analyses	8.3 - 8.4
	b. Snap-Through Problems	8.8
	c. Plane Elasticity	1.17 - 1.20
	d. The Timoshenko Beam	4.5
	e. Classical Plate Theory	6.1 - 6.7
VI.	Failure of Plates	
	a. Plate Buckling	8.13 - 8.15
	b. Post Buckling Strength	
	c. Effective Width and Breadth	
VII.	Introduction to Theory of Plasticity	
	a. Yield Conditions	
	b. Rigid, Perfectly Plastic Deformation	
	c. Upper and Lower Bound Theorems	
	d. Plastic Collapse of Structural Elements	

INSTRUCTOR:

Prof. Dale G. Karr
NAME 236B
764-3217

TEXTS:

Energy and Finite Element Methods in Structural Mechanics, by I. H. Shames and C. L. Dym.

NA510 Marine Structural Mechanics Course Notes, by D.G. Karr and W. S. Vorus.

FIGURE 20. MICHIGAN CATALOG DESCRIPTION, AND COURSE OUTLINE FOR NA 510, MARINE STRUCTURAL MECHANICS

CONTENTS

FIGURE 21. PORTIONS OF THE TABLE OF CONTENTS OF ADVANCED STRENGTH OF MATERIALS BY BORESI, SCHMIDT, AND SIDEBOTTOM, 5TH EDITION, PUBLISHED BY WILEY

NA 310 - MARINE STRUCTURES I

Table of Contents

FIGURE 22. "NA 310 COURSE NOTES" TABLE OF CONTENTS (COURTESY OF VORUS AND KARR)

TABLE OF CONTENTS

FIGURE 23. "NA 510 COURSE NOTES" TABLE OF CONTENTS (COURTESY OF DALE KARR)

There are of course several dozen also available among those offered by the Aerospace Engineering Department, in the Applied Mechanics program of the Mechanical Engineering Department, and by the Civil and Environmental Engineering Department, for example, and those students interested in structural analysis and design could in selecting among these courses specialize in any aspect of this broad field. The advantages of being a graduate student in a large and comprehensive engineering college are indeed apparent.

The University of New Orleans

The required undergraduate course in marine structural analysis and design at New Orleans is NAME 3120, Ship Hull Strength, but (as at Michigan) many also elect the second course, NA 4120, Ship Structural Design and Analysis. The descriptions of these two are given in Figures 24 and 25, in this instance in the ABET prescribed accreditation format. Note that neither course includes finite element analysis, but that it is offered in an elective course, NAME 4096, Finite Element Analysis in Ship Structures, for which the description is as shown in Figure 26. That same course number, NA 4096, named Special Topics in Naval Architecture in the catalog, is used for a course entitled Stability of Ship Structures, for which the description is as shown in Figure 27. There are other courses offered by the School of Naval Architecture and Marine Engineering that might be mentioned, some more concerned with load formulation than structural analysis or design, but one entitled Small Craft Design does include substantial structural material and is described in Figure 28. There are also Electrical, Civil and Environmental, and Mechanical Engineering Departments in the College of Engineering at New Orleans and hence graduate students can choose among an array of courses offered by those departments. A popular elective among the naval architecture undergraduate students, perhaps because they are drawn mostly from the Gulf region, is ENME 4756, Mechanics of Composite Materials. The description is given in Figure 29.

Memorial University of Newfoundland

Required undergraduate structure courses at Memorial are Engineering 6002, Ship Hull Strength, and Engineering 7002, Ship Structural Analysis and Design. Course information sheets, in the format for the Canadian Accreditation Board, for these are given in Figures 30 and 31. Among the suggested technical electives in the

COURSE DESCRIPTION

NAME 3120--Ship Hull Strength

Fall Semester 1991

1992 Catalog Data: NAME 3120: Longitudinal strength, simple beam theory, trochoidal wave and smith correction, weight, buoyancy, load shearing force and bending moment curves; midship section modulus; composite hull girder; transverse strength, strain energy and moment distribution methods; torsional strength; torsion of thin walled, open sections, torque distribution; torsional loads, the use of classification society rules in midship section design.

Textbook: William S. Vorus, NA310 Ship Strength I: Informal Notes, U. of Michigan NAME, 1986.

Reference: Ship Design and Construction, and Ship Structural Design, SNAME.

Coordinator: J.M. Falzarano, Assistant Professor of NAME

Goals: This course is designed to give juniors in naval architecture and marine engineering an understanding of the overall ship structural design process including loads, basic analysis techniques. Also included are special topics related to fabrication and production.

Prerequisites by topic:

1. Ship hydrostatics, weight and buoyancy
2. Strength of Materials

Topics:

1. Introduction to ships and offshore Structures (3 classes)
2. Loads on ships and offshore structures (2 classes)
3. Longitudinal Strength (4 classes)
4. Transverse Strength (2 classes)
5. Plated Structures (4 classes)
6. Stress concentration and Fatigue (2 classes)
7. Joints in ships and offshore structures (2 classes)
8. Fabrication and Welding (2 classes)
9. Midship Section Design (4 classes)
7. Tests (2 classes)

Computer usage:

1. Each student must write and run a FORTRAN 77 program to determine the section modulus of a ship midship section

2. The computer program written for the above is then used in designing a midship section that meets ABS requirements.

ABET category content as estimated by faculty member who prepared this course description:

Engineering science: 1.5 credits or 50%
Engineering design: 1.5 credits or 50%

Prepared by: Dr. J.M. Falzarano Date: March 28, 1994

FIGURE 24. COURSE DESCRIPTION FOR NEW ORLEANS NAME 3120, SHIP HULL STRENGTH

COURSE DESCRIPTION

NAME 4120--Ship Structural Design and Analysis

Spring Semester 1994

1992 Catalog Data: NAME 4120 Review of Longitudinal Strength; principal stress distributions and stress trajectories; local strength analysis; panels under lateral load; columns and stanchions under uniform edge compression loading and panels under shear and combination loading; rational ship structural design synthesis based upon stress loading hierarchy; primary, secondary, tertiary stress as a criteria of ship strength including grillage aspects.

Textbook: Robert E. Sandstrom, NA410 Ship Strength II Lecture Notes, U of Michigan.,1982.

Reference: Principles of Naval Architecture, SNAME.

Coordinator: J.M. Falzarano, Assistant Professor of N.A.M.E.

Goals: This course is designed to give seniors in naval architecture and marine engineering a more advanced understanding of beams, beam/columns and plates to integrate them into overall ship structural design.

Prerequisites by topic:

1. Elementary ship structural design
2. Elementary Vibrations
3. Ordinary DEQ's, Fourier series, introductory PDE's

Topics:

1. Overview of ship structural design and analysis (2 classes)
2. Derivation of general asymmetric beam equations (4 classes)
3. Application of beam equation to static stress and asymmetric bending (6 classes)
4. Shear Stress, shear center, shear in asymmetric and closed sections (4 classes)
5. Ship Hull and Beam Vibration (6 classes)
6. Buckling of Beam Columns (2 classes)
7. Energy Methods (2 classes)
8. Plates/frames (2 classes)
7. Tests (2 classes)

Computer usage:

1. Each student must solve for roots of a transcendental characteristic equation and plot the corresponding mode shapes.

ABET category content as estimated by faculty member who prepared this course description:

Engineering science: 2 credits or 67%
Engineering design: 1 credits or 33%

Prepared by: Dr. J.M. Falzarano Date: March 28, 1994

FIGURE 25. COURSE DESCRIPTION FOR NEW ORLEANS NAME 4120, SHIP STRUCTURAL DESIGN AND ANALYSIS

COURSE DESCRIPTION

NAME 4096--Finite Element Analysis in Ship Structures

Fall Semester 1992

1992 Catalog Data: NAME 4096 Special Topics in Naval Architecture

Textbook: William Weaver, Finite Elements for Structural Analysis, Prentice Hall, 1984.

Reference: K. Gallager, Finite Element Analysis Fundamentals, Prentice Hall, 1975

Coordinator: J.M. Falzarano, Assistant Professor of N.A.M.E.

Goals: This course is designed to give seniors in naval architecture and marine engineering an introductory understanding of the use of finite elements for ship structural design and analysis.

Prerequisites by topic:

1. Basic Ship structural design
2. Strength of materials
3. Basic vibrations

Topics:

1. Introduction to Finite Elements (6 classes)
2. Plane Stress and Strain (6 classes)
3. Isoparametric Formulation (4 classes)
4. Flexure of Plates (4 classes)
5. General and Axisymetric Shells (4 classes)
6. Vibration Analysis (4 classes)
7. Instability Analysis (2 classes)
8. Tests (2 classes)

Computer usage:

1. Three homework assignments, students are required to run a general purpose finite element program to analyze various aspects of finite element analysis including a cantilever beam and a plate with a hole in it.

ABET category content as estimated by faculty member who prepared this course description:

Engineering science: 2 credits or 67%
Engineering design: 1 credits or 33%

Prepared by: Dr. J.M. Falzarano Date: March 28, 1994

FIGURE 26. COURSE DESCRIPTION FOR NEW ORLEANS NAME 4096, FINITE ELEMENT ANALYSIS IN SHIP STRUCTURES

COURSE DESCRIPTION

NAME 4096 - Stability of Ship Structures

Spring Semester 1994

Proposed Catalog Data:
NAME 4096 Stability of Ship Structures. 3 Credits.
Stability problems of ship and off-shore structures; stability of columns and frames, beam-columns; plastic buckling; buckling of plates and thin shell-type structures.

Textbook: Theory of Elastic Stability, S. P. Timoshenko and J. M. Gere, McGraw-Hill, New York, 1981.

Reference: Structure Stability, W. F. Chen and E. M. Lui, Elsevier, 1987.

Coordinator:

Goal: This course is designed to give students the knowledge of stability problems of ship and offshore structures.

Prerequisites by Topics:
Theory of stresses and strains
Differential equations
Theory of bending of beams
Knowledge of ship/off-shore structures

Topics:
Beam-columns (8 classes)
Elastic buckling of bars and frames (6 classes)
Inelastic buckling columns (3 classes)
Buckling of elastic plates (7 classes)
Fundamentals of buckling of shells (3 classes)
Tests (3 classes)

Estimated ABET Category Content:
Engineering Science: 3 credits or 100%

Prepared by: Dr. B. Inozu Date: March 24, 1994

FIGURE 27. COURSE DESCRIPTION FOR NEW ORLEANS NAME 4096, STABILITY OF SHIP STRUCTURES

COURSE DESCRIPTION

NAME 4151 - Small Craft Design

Spring Semester 1994

1994 Catalog Data:NAME 4151: Small Craft Design. Credits 3. Case study of a 60-ft. motor boat design, planing theory, trim, lift and drag in planing, use of standard series, hydrofoil vessel performance calculations, seakeeping, hull structure, hull materials, powering using supercavitating propellers or pump-jet. **Prerequisite:** Credit or registration in NAME 3120.

Texts: Robert Latorre, NAME 4151, Small Craft Design, Informal Note Set, Vols. I and II.

References:

1. Creative Naval Architecture, G. N. Hatch, Thomas Reed Publications, Ltd., London, 1971.

2. Mechanics of Marine Vehicles, B. R. Clayton, R. E. D. BishopGulf Publishing, 1983.

3. Principles of Naval Architecture, John P. Comstock, editor, The Society of Naval Architects and Marine Engineers, 1967.

Coordinator: Dr. Robert Latorre, Associate Professor, NA&ME

Goals: The objective of this course is to present the design methodology for high speed small craft such as planing hulls and hydrofoils in contrast to the conventional ship off-shore structure. This course is designed to give juniors in Naval Architecture and Marine Engineering an introduction to the small craft design spiral through a case study (Ref. 1) and then treat in detail the design calculations required for propulsion and hull strength.

Prerequisites by Topic:

1. Ship and off-shore structures, weight distribution, dynamic loads and combined stresses.
2. Structural consideration of floating, fixed pile, submersible and jack-up platforms.
3. Strength of plated structures and stiffeners. 4. Failure modes.
5. Design of bottom, side and deck plating; welding and other fabrication technologies.

Topics:

1. Introduction. (1 class)
2. Design example 60 ft. high speed vessel. (9 classes)
3. Planing hull hydrodynamics and EHP estimates. (6 classes
4. Hydrofoil/catamaran design. (3 classes)
5. Seakeeping design. (3 classes)
6. Structural loads on hull. (1 class)
7. Structural design with aluminum - FRP. (2 classes)
8. Supercavitating propellers/pump jet. (1 class)
9. Tests. (2 classes)

Computer Usage:

1. Homework Assignments.

   a) Development of high speed craft powering data base using Lotus 1-2-3 on PCs.

   b) Estimation of high speed craft resistance using polynomial expressions.

2. Project. Design of Modularized high speed planning vessel

Computer Aided Engineering using class materials.

Examples: i) Hull scantling review software
ii) Performance estimate of hydrofoil vessel

ABET Category Content:

Engineering Design: 3 credits or 100%.

Prepared by: Robert Latorre **Date:** April 20, 1994

FIGURE 28. COURSE DESCRIPTION FOR NEW ORLEANS NAME 4151, SMALL CRAFT DESIGN

ENME 4756-Mechanics of Composite Materials
Fall Semester 1993

1992/94 Catalog Data: ENME 4756 Mechanics of Composite Materials Cr. 3
Prerequisites: Civil Engineering 4353 or consent of department. Analysis of stress, strain, and strength of fiber reinforced composite laminates. Topics include laminated plate theory, stress analysis of orthotropic plates, damage mechanisms, fatigue, impact, and environmental effects.

Textbook: Agarwal, B. D., and Broutman, L. J., Analysis and Performance of Fiber Composites, Second Edition, J. Wiley & Sons, Inc.

Reference: Jones, R. M., Mechanics of Composite Materials, Scripta Book Co., 1975.

Coordinator: Paul D. Herrington, Assistant Professor

Goals: The goal of this course is to provide students a fundamental understanding of the mechanics of composite materials and their behavior under typical service conditions. A design project including a written and oral presentation is required.

Prerequisites by Topics:
1. Advanced Strength of Materials
2. Engineering Analysis

Topics:
1. Introduction (1 class)
2. Materials and processing (3 classes)
3. Behavior of uni-directional composites (4 classes)
4. Analysis of orthotropic lamina (8 classes)
5. Analysis of laminated composites (6 classes)
6. Damage mechanisms and failure criteria (3 classes)
7. Impact and fatigue (2 classes)
8. Environmental degradation (1 class)
9. Nondestructive evaluation (1 class)

Computer Usage:
Students are required to use the VAX-cluster and/or microcomputer for solving homework problems and for the analysis of design project alternatives.

ABET category content as estimated by faculty member who prepared this course description:

Engineering Science: 2 credits or 66.7%
Engineering Design: 1 credit or 33.3%

Prepared by: Paul Herrington Date: September 24, 1993

FIGURE 29. COURSE DESCRIPTION FOR NEW ORLEANS ENME 4756, MECHANICS OF COMPOSITE MATERIALS

COURSE INFORMATION SHEET

COURSE NUMBER & TITLE: Engineering 6002 - Ship Hull Strength
CALENDAR REFERENCE: Page 297 of the 1991/1992 Undergraduate University Calendar.

CEAB COURSE TYPE: Program Compulsory
TOTAL NUMBER OF LECTURE SECTIONS: One
MINIMUM/MAXIMUM NUMBER OF STUDENTS PER SECTION: 5/15
TOTAL NUMBER OF LABORATORY/TUTORIAL SECTIONS: One
MINIMUM/MAXIMUM NUMBER OF STUDENTS PER LABORATORY/TUTORIAL SECTION: 5/15
MAJOR TOPICS:

1. Longitudinal Strength of Ships (9 lectures).
2. Transverse Strength (12 lectures).
3. Torsion (3 lectures).
4. Matrix Displacement Method (6 lectures).
5. Finite Element Methods (6 lectures).

PRESCRIBED TEXT(S):

1. Strength of Ships, by J.R. Paulling, Chapter 4, in Principles of Naval Architecture, Vol. I E.V. Lewis, Editor. , SNAME, (1988).
2. Introductory Structural Analysis, by Wang and Salmon, Prentice Hall, (1984).

INSTRUCTIONAL HOURS PER WEEK: 3 lectures and 2 lab./tutorial hours per week.

COMPUTER EXPERIENCE: Students are required to design a spread sheet for a ship's midship section calculation.

LABORATORY EXPERIENCE: students are required to submit a midship section design project.

PROFESSOR-IN-CHARGE: M. R. Haddara, Ph.D., M.S., P.Eng., C.Eng., Professor (Naval Architectural Engineering).
TEACHING ASSISTANTS (NUMBER/HOURS): 1/52

CEAB CURRICULUM CATEGORY CONTENT:
TOTAL NUMBER OF LOAD UNITS = 4
Engineering Science = 2.4 units
Engineering Design = 1.6 units

AVERAGE GRADE/FAILURE RATE: 69%/0%

FIGURE 30. COURSE INFORMATION SHEET FOR MEMORIAL E6002, SHIP HULL STRENGTH

COURSE INFORMATION SHEET

COURSE NUMBER & TITLE: Engr.7002 Ship Structural Analysis and Design
CALENDAR REFERENCE: Page 299 of the 1991-92 Undergraduate University Calendar (listed as 8002)
CEAB COURSE TYPE: Compulsory
TOTAL NUMBER OF LECTURE SECTIONS: 1
MINIMUM/MAXIMUM NUMBER OF STUDENTS PER SECTION: 5/13
TOTAL NUMBER OF LABORATORY/TUTORIAL SECTIONS: 1
MINIMUM/MAXIMUM NUMBER OF STUDENTS PER LABORATORY/TUTORIAL SECTION: 5/13
MAJOR TOPICS:

1. Ship structural safety: rational design; rule-based design; partial safety factors; safety index; probability of failure (5 lectures)
2. Long uniformly loaded thin plates: elastic, elasto-plastic and plastic design; various edge constraints (8 lectures)
3. Finite aspect ratio plates: elastic, elasto-plastic and plastic design; various edge constraints (4 lectures)
4. Buckling and ultimate strength of columns (3 lectures)
5. Buckling of (long) plates including concepts of effective and reduced effective width (6 lectures)
6. Grillage design: effective breadth; plastic design of beams; combined loads and failure; magnification factor; interaction equations to estimate failure (6 lectures)
7. Buckling of wide plates; welding distortions and their effect on incremental collapse (4 lectures)

PRESCRIBED TEXT(S): No texts are prescribed due to expense; the following is a reference for the course:
Hughes, O.F., 1983, Ship structural design, Wiley-Interscience. Republished by The Society of Naval Architects and Marine Engineers, New York.

INSTRUCTIONAL HOURS PER WEEK: 3 lecture hours per week (1 term); occasional tutorial and discussion sessions averaging out to 1 hour every two weeks.
COMPUTER EXPERIENCE: nil
LABORATORY EXPERIENCE: nil

PROFESSOR-IN-CHARGE: Neil Bose, Ph.D., P.Eng., Assoc. Prof. (Naval Architectural Engineering)
TEACHING ASSISTANTS (NUMBER HOURS): 1/50
CEAB CURRICULUM CATEGORY CONTENT:
TOTAL NUMBER OF LOAD UNITS = 3.25
Engineering Science = 1.5
Engineering Design = 1.75
AVERAGE GRADE/FAILURE RATE: 72.4/0 (1988-91)

FIGURE 31. COURSE INFORMATION SHEET FOR MEMORIAL E7002, SHIP STRUCTURAL ANALYSIS AND DESIGN

senior year are 7933, Stress Analysis, and 8058, Submersible Design. The brief course descriptions, from the calendar, and those for 4312 and 5312, the two course sequence in the basic Mechanics of Solids that are prerequisites for the ship structures courses, are reproduced in Figure 32. Other structural analysis and design courses are available in the programs in civil and mechanical engineering also offered by the Faculty of Engineering and Applied Science.

The University of California - Berkeley

The single undergraduate structures course in the current undergraduate program at Berkeley is NA 154, Ship Structures, and the description of it in the ABET format is shown in Figure 33. More interesting perhaps are the several outlines in hand for that same course in recent years, particularly the differences in actual content as well as the different ways in which several of the same topics can be described by two different but knowledgeable professors (and Professors Mansour and Paulling are indeed very well qualified to be so designated). Also, because these outlines collectively include just about every topic with which it would be highly desirable every bachelor's degree naval architect and/or ocean (or "offshore," since Berkeley is the subject) engineer had presented to him, they are reproduced in Figures 34 through 36. Viewed in that sense, they also clearly demonstrate that a single required course in marine structural analysis and design in any undergraduate program in naval architecture or offshore engineering is indeed inadequate. With the situation at Berkeley currently in transition it is probably not entirely established what material should be in what course at present, but there are two graduate courses, 240A and 240B, being given at present by the department. A tentative outline for 240A, Theory of Ship Structures, is shown in Figure 37, primarily to illustrate how rational and current course content at that level can be in that the probabilistic approach to loading and a reliability based determination of response are both included. Other departments and programs at Berkeley in all of the established engineering disciplines offer a great number of additional courses in structural analysis and design and related subjects, and graduate students in the Naval Architecture and Offshore Engineering Department can specialize further by selecting from among them much as do those at Michigan and the other universities.

6002. Ship Hull Strength. Longitudinal strength, still water and wave bending moment, shear and bending moment curves, Smith Correction, section modulus calculation, torsion and racking forces. Bulkhead and girder scantlings, portal frame analysis by moment distribution and energy method. Finite element analysis. Use of Classification Society rules for design of midship section.

7002. Ship Structural Analysis and Design. Review of longitudinal strength. Principal stress distributions and stress trajectories. Local strength analysis. Panels under lateral load. Columns and stanchions. Panels in buckling under uniform edge compression loading and panels under shear and combination loading. Rational midship section design synthesis based on stress and loading hierarchy. Primary, secondary and tertiary stresses as criteria of strength in ship structural design, including grillage aspects.

7933. Stress Analysis. Introduction. Stress and strain in three dimensions. Principal stresses and strains and maximum shear in three dimensions. Two dimensional elasticity. Airy's Stress Function. Problems involving Cartesian co-ordinates and polar co-ordinates. Stress concentrations. Bending and shear in beams with asymmetrical cross sections. Principal moments of inertia. Curved beams under pure bending. Axisymmetrically loaded members. Thick-walled pressure vessels. Rotating discs and shafts. Torsion of non-circular sections. Shear flow in thin-walled multi-ply connected sections. Beams on elastic foundations.

8058. Submersibles Design. Formulation of mission statement, understanding various design constraints and reviewing the historical developments of submersibles design. Study of the hydrostatics principles of floatation, stability and control of submersibles. Performing resistance and propulsion calculations. Study of manoeuvering and control equations. Survey of different materials and their selection criteria. Design of pressure hulls. Structural design of submersibles. Study of various support systems. Relevant laboratory exercises.

4312. Mechanics of Solids I. Axial force, shear and bending moment. Stress-strain relations. Torsion. Bending and shearing stress in beams. Thin cylinders. Compound stresses. Transformation of stress.
Relevant laboratory exercises.

5312. Mechanics of Solids II. Deflection of beams by integration applied to statically determinate and indeterminate beams, method of superposition for deflections. Moment-area method for determinate/indeterminate uniform/varying (discrete) beams. Energy methods: unit load method and Castigliano's theorem, application to trusses, determinate beams/frames and, depending on discipline, multi-span beams. Stability of columns for centric/eccentric loads. Failure theories for ductile/brittle materials: maximum normal/shear stress and distortion energy criteria. Additional topics depending on discipline will be chosen from: Limit state analysis of continuous beams and frames, Impact Loading. Review of variation of transverse shear stress throughout a section. Triaxial stresses and extension of combined stress theory (Mohr's Circle) to complicated loadings. Laboratory experiments on deflection, energy method, buckling and limit state behaviour or combined stresses.

FIGURE 32. SELECTED MEMORIAL CALENDAR COURSE DESCRIPTIONS

NA 154
Fall Semester 1988

1988-89 Catalog Data:	NA 154: Ship Structures. Credit 3. Introduction to the specialized features of ship structures and their design. Structural loads, hull girder and hull components analysis, laterally loaded grillages and cross-stiffened plates, plate buckling, modes of possible failure to be designed against, use of theory and classification society rules in combination in the design process. Prerequisites: NA 151, CE 130.
Textbook:	J.P. Comstock Editor, Principles of Naval Architecture, SNAME, 1967.
	R. Taggart, Editor, Ship Design and Construction, SNAME, 1980.
Coordinator:	Alaa E. Mansour, Professor of Naval Architecture & Offshore Engineering
Goals:	To introduce the student who has already completed a course in elementary strength of materials to the specialized aspects of ship structural analysis and design.

Prerequisites by Topic:

1. 2-D elasticity.
2. Elementary theory of bending of beams.
3. Elementary column buckling theory.
4. Theory of torsion of simple closed tubes.

Topics:

1. Structural loads experienced by ships and other marine structures. (6classes)
2. Box girder theory with emphasis on shear and torsional effects. (7 classes)
3. Hull-deckhouse interaction. (6 classes)
4. Elastic theory of stiffened plates. (7 classes)
5. Plate buckling theory and the used of design charts for predicting the buckling strength of structural components. (5 classes)
6. Modes of ship failure and appropriate design considerations. (7 classes)
7. The structural design process as a synthesis of rules, codes and rational procedures. (7 classes).

Computer Usage:

1. Homework assignment on designing stiffened panel of a ship bottom structure.

Laboratory Projects (including major items of equipment and instrumentation used):

1. None

ABET category content as estimated by faculty member who prepared this course description:

Engineering Science:	2 credits or 66%
Engineering Design:	1 credits or 33%

Prepared by: A. Mansour   Date: 5/2/1988

FIGURE 33. COURSE DESCRIPTION FOR BERKELEY NA 154, SHIP STRUCTURES

OUTLINE

NA 154 — Ship Structures — A. E. Mansour

1. Characteristics of ship structure
   (a) Strength versus stiffness
   (b) Primary, secondary and tertiary behavior
   (c) Typical midship sections
2. Loads applied to ship structure
   (a) Static loads--standard longitudinal strength calculations
   (b) Dynamic loads--low and high frequency loads
3. Box girder analysis
   (a) Two dimensional stress analysis
   (b) Stress distribution around a section
   (c) Shear and girth stresses
   (d) Design considerations
   (e) Ultimate strength and failure modes
4. Shear lag and effective breadth
   (a) Basic concept
   (b) Application and design charts
5. Deckhouses and superstructures
   (a) Two-beam analysis
   (b) Experimental results
6. Bending of plates
   (a) Isotropic plates
   (b) Orthotropic and stiffened plates
7. Buckling of plates
   (a) Isotropic
   (b) Orthotropic
8. Ultimate strength of beams, plates and box girders

FIGURE 34. ANOTHER COURSE DESCRIPTION FOR BERKELEY NA 154, SHIP STRUCTURES

NA154	Ship Structures	Fall 1989
Instructor:	J. R. Paulling	

Course Outline and Schedule (Subject to change at whim of instructor)

Reading Reference: PNA = Principles of Naval Architecture, Vol. 1, Lewis (Ed.)
Pub. SNAME, N.Y., 1988.

Week	Topic	Reading Reference
1	Introduction - The big picture. Ship structural static loads.	Ch. 3, Sect. 1 2.1, 2.1
2	Dynamic wave loads - deterministic, Probabilistic.	2.3-2.5 2.6-2.8
3	Long term extreme loads. Other components of dynamic loading	2.9-2.10 2.11
4	Box girder analysis Section modulus computation	3.1-3.2 3.3
5	Shear and transverse stress distribution	3.4-3.5
6	Shear lag and effective breadth	3.6
7	Torsion and related effects	3.7
8	Secondary structural response	3.8, 3.9
9	Plate bending MIDTERM EXAM	3.10, 3.11
10	Transverse strength considerations Deckhouses and superstructures	3.12 3.13
11	Modes of structural failure, limit states Failure theories	4.1-4.3
12	Structural instability and buckling	4.5-4.7
13	Ultimate strength Fatigue	4.9 4.11
14	Introduction to reliability	Sect. 5
15	Catch up. Loose ends. Review.	

FIGURE 35. ANOTHER COURSE DESCRIPTION FOR BERKELEY NA 154, SHIP STRUCTURES

Topical Outline

NA 154 - Ship Structures

1. Nature of ship structures and basic concepts of ship structural design.

   a. Arrangement of structural components.

   b. Function of structural components.

   c. Comparison of ship structures to other structures.

   d. Subdivision of response (primary, secondary, tertiary).

2. Ship structural loads (demand)

   a. List of loads (static, quasi-static, dynamic)

   b. Standard static load computation and use in classification society rules.

3. Plane stress analysis

   a. Derivation of equations of equilibrium.

   b. Stress concentration.

4. Analysis of hull girder and hull module components

   a. Elementary box beam analysis in bending.

   b. Torsion of thin-walled slender beams with closed sections.

   c. Shear effects in thin-walled slender beams.

5. Laterally loaded grillages and cross-stiffened panels: description of phenomena, derivation of equations of equilibrium, use of design charts.

6. Buckling and ultimate strength of columns and plates.

7. Further aspects of structural failure (capability).

   a. Tensile/compressive fracture and failure theories

   b. Fatigue

   c. Brittle fracture

   d. Welded connections

8. Uncertainty of design process (demand vs. capability).

9. Classification society rules.

FIGURE 36. ANOTHER COURSE DESCRIPTION FOR BERKELEY NA 154, SHIP STRUCTURES

240A - THEORY OF SHIP STRUCTURES
Alaa Mansour

TENTATIVE OUTLINE

I. Representation of the Sea Surface
   1. Probability distributions associated with a random process.
   2. Stationary and ergodic processes.
   3. Autocorrelation function and spectral density of a stationary random process.
   4. Typical sea data and sea spectra.

II. Dynamic loads and response of a ship hull considered as a rigid body.
   1. Input - output relations
   2. Transfer functions /response amplitude operators.
   3. Ship response spectra in long-and short-crested seas.

III. Long-term Prediction of Wave Loads - Extreme Value and Order Statistics
   1. Long-term distributions.
   2. Extreme wave loads - order statistics.
   3. Extreme total wave and stillwater loads.

IV. Fully Probabilistic Reliability Analysis (Level III)
   1. Variability in hull strength.
   2. Reliability concepts.
   3. Probability of failure using deterministic or normally distributed stillwater loads.
   4. Modes of failure in hogging and sagging conditions - bounds on the total probability of failure.

V. Failure Analysis Procedures - Design Considerations
   1. Long-term procedure.
   2. Short-term procedure.
   3. Application of failure analysis to a Mariner and a tanker.
   4. The level of safety-optimization criteria.
   5. Determination of a hull section modulus for a prescribed level of safety.

VI. Semi-Probabilistic Reliability Analysis (Level II)
   1. The mean value first order second moment method.
   2. The Hasofer/Lind reliability index.
   3. Inclusion of distribution information.
   4. Partial safety factors (Level I).
   5. Example application and comparisons.

VII. Dynamic Loads and Response of a Ship Hull Considered as a Flexible Body
   1. High-frequency steady springing loads and response.
   2. High-frequency transient-slamming loads and response.
   3. Combining the high-and low-frequency loads.

VIII. Ship Hull Ultimate Strength
   1. Failure as a result of yielding and plastic flow (the plastic collapse, shakedown and initial yield moments).
   2. Failure as a result of instability and buckling (modes of stiffened plate buckling failure).

FIGURE 37. COURSE DESCRIPTION FOR BERKELEY NA 240A, THEORY OF SHIP STRUCTURES

United States Coast Guard Academy

The contents of the 1442 course entitled Principles of Ship Design and 1444, entitled Ship Design and System Integration, at the Coast Guard Academy include many topics beyond those involving structural analysis and design. But Figure 38 includès the actual two assignments involving structures from among 21 listed, along with the catalog description of the first course, and Figure 39 includes similar items from the second. The handout material for these courses is very detailed but very organized and extensive. Students at the Coast Guard Academy possibly do not have available to them the same level and technologically advanced treatments of marine structural analysis and design as do those at many of the other schools, but those graduating are certainly familiar with the fundamentals of the subject since it is dealt with soundly and well.

United States Naval Academy

While there are several required courses dealing with several aspects of structural analysis and design in the naval architecture and in the ocean engineering programs at the Naval Academy, and more elective courses available, EN 358, Ship Structures, and EN 441, Ocean Engineering Structures, are, respectively, the principal ones. The respective capstone design sequence courses include the usual structures content, but students in both programs are also required to take EN 380, Naval Materials Science and Engineering, and evidently learn about fatigue and fracture there in addition to the more scientific topics which are all that are included in many of the basic materials science courses elsewhere. Syllabuses for EN 358 and EN 441 are included in Figures 40 and 41, along with the reference list for 358 and the ABET description for 441. These last two items would seem to indicate some difference in the levels of the treatments in the courses, but this could be in error and is only suggested because the 358 reference list includes some quite old – but classic – entries despite listing the very valuable Hughes book as well.

Virginia Polytechnic Institute and State University

The required undergraduate structures courses at Virginia Tech reflect the arrangement that places the ocean engineering program and the aerospace engineering in the same department, and that it is an ocean engineering program

Principles of Ship Design **1442**

The art and science of ship design. Hull strength and structural design requirements by first principles and ABS rules; the design process; application of estimation and iteration procedures with emphasis on preliminary hull dimensions and weight estimates; comparative analysis of vessel and payload with figures of merit; hull vibrations; preliminary development of general arrangements. CAD intensive course terminates with a team-prepared preliminary hull and arrangements design to be completed in Ship Design/System Integration (1444).

Credit Hours:	4.0
Format:	Class Project
Prerequisite:	1342
Corequisite:	1453
Restrictions:	1/c Cadets and NAME Majors only

PROJECTED OFFERING: FALL

19. Longitudinal Strength Analysis (8) - Based upon your Second Weight/COG Estimate, Loading Condition Calculations and appropriate routines from MaxSurf/Hydromax, the Design Team shall:

   a. Evaluate Still Water, Hogging and Sagging Longitudinal Strength of your vessel in each of the 4 loading conditions. The maximum bending moment and shear force shall be highlighted for each condition.

   b. Using the maximum bending moment and shear force values from part a), determine the material used in the construction of your hull and calculate the maximum permissible bending and shear stress.

   c. Calculate the required midship section modulus for your vessel.

   d. Provide plots of the weight, buoyancy, load, shear and bending moment curves for each of the analyzed cases, identifying the locations of the maximum shear and bending moment values.

20. Midship Section Design (5) - Based upon the results of the Longitudinal Strength Analysis of your vessel and appropriate structural design criteria, the Design Team shall:

   a. Design, draw and label the midship section for your vessel. Insure that all major structural members are included and dimensions are provided.

   b. Determine the plate thickness for all decks, shell and bottom plating.

   c. Determine the size and location for all major structural members in accordance with applicable ABS rules, USN/USCG specifications, and CFR requirements.

   d. Determine the required thickness and stiffener sizing for typical bulkheads - collision, deep tank and standard watertight.

   e. Determine the Moment of Inertia and location of the Neutral Axis for your midship section. Provide actual bending moment and shear stress calculations for this section and compare said actual values to the maximum permissible values from part b) of the Longitudinal Strength Analysis.

FIGURE 38. CATALOG DESCRIPTION AND SELECTED ASSIGNMENTS, USCG ACADEMY COURSE 1442, PRINCIPLES OF SHIP DESIGN

Ship Design/System Integration **1444**

The Capstone design course for Naval Architecture & Marine Engineering Majors. Completion of project begun in Principles of Ship Design (1442). Hull model resistance testing, electric plant and auxiliary system design, CPM/PERT planning, HVAC, engineering economics, and trade-off studies in design, construction and life cycle costing applied to preliminary ship design developed in course 1442. Emphasis on integration of hull and machinery systems.

Credit Hours:	4.0
Format:	Class/Project
Prerequisite:	1442 and 1453
Restrictions:	NAME Majors only
PROJECTED OFFERING:	SPRING

Guidance for Midship Section Design   Responsible Person:

I. General Procedure :

1. Using the maximum bending moment information from the longitudinal strength section and the required section modulus, design a midship section for your vessel.

2. Compute the required section modulus for your vessel as defined by the ABS Rules for Steel Vessels and compare it to your section as per part 1. Comment on the differences and state reasons for which section modulus you may use.

II. Specific Design Procedure :

1. Draw the ship's midship section.

2. Label and identify the major structural members.

3. Justify the selection of major structural members, frame spacing, etc.

4. Calculate the moment of inertia and the location of the neutral axis of your midship section.

5. Based on the midship section and the bending moment diagram from longitudinal strength, estimate the required section modulus for the forward and aft quarter points.

6. Estimate the weight, VCG, LCG of the midship and quarter points based on plating, scantlings and sectional area. Compare these values to your weight estimates.

III. Deliverables :

1. Provide a scaled midship section drawing (1/4" = 1' scale).

2. Scantlings table (midship only).

3. Provide a summary sheet for section weight, VCG and LCG.

4. Provide all supporting calculations and checks of allowable stress.

5. Provide an analysis of the reasonableness of your design.

6. Demonstrate the use of optimization techniques in the design of this section.

IV. Schedule : NLT April 10

V. Weighting Factor : 3

Guidance for Longitudinal Strength   Responsible Person :

I. General Procedure :

1. Re-evaluate the placement of known weights/tankage aboard your vessel taking into account arrangement, trim and powering problems encountered in PSD.

2. Run the longitudinal strength portion of the Hydromax program.

II. Specific Design Procedure :

1. None

III. Deliverables :

1. Obtain numerical output for your lightship, burnout, minimum operating and full load conditions.

2. Plot the shear and moment diagrams for all cases.

3. Calculate the maximum required section modulus for each case.

4. Provide an analysis of the reasonableness of your output and comment on future ramifications on material choice and midship design.

IV. Schedule : NLT April 10

V. Weighting Factor : 3

Guidance for Bulkhead Design   Responsible Person :

I. General Procedure :

1. Read ABS Rules for Steel Vessels and DDS-1100-4 Structural Design of Flat Plating and Stiffeners Subject to Water Pressure.

2. Using these references, design a standard bulkhead to ABS requirements for the deepest part of the ship.

3. Estimate its weight per foot of beam and using that estimate, calculate the weight for all bulkheads and their VCG and LCG in the transverse plane.

II. Specific Design Procedure :

1. Review PNA and Basic Ship Theory (BST) on bulkheads. Review BST on grillage and Statics & Strengths on loading, shear, bending moments and stress.

2. Determine loading on bulkhead, end conditions and maximum allowable stress.

3. Determine bulkhead thickness, stiffener sizing and spacing.

III. Deliverables :

1. Provide a scaled drawing of typical "midship", tank, and collision bulkhead.

2. Provide a typical scantling table.

3. Provide a table for transverse bulkheads, weights, VCG's, and LCG's.

4. Design history documentation.

IV. Schedule : NLT April 10

V. Weighting Factor : 2

FIGURE 39. CATALOG DESCRIPTION AND SELECTED ASSIGNMENTS, USCG ACADEMY COURSE 1444, SHIP DESIGN/SYSTEM INTEGRATION

SHIP STRUCTURES
EN-358
SPRING SEMESTER 1995

Lesson	Date	Topics	Assigned Reading
1	11 Jan.	Introduction	SDM 2-1 to 2-9
2	13 Jan.	Components of a Ship's Structure	Handout SD&C
•••	16 Jan	**Martin Luther King's Holiday**	
3	17 Jan.	Loads on a Ship's Structure	SDM 4-1 to 4-23
4	18 Jan.	Hull Girder Response	3.1, 3.2
5	20 Jan.	Hull Girder Response (cont.)	3.2
6	23 Jan.	Hull Girder Fatigue	3.6
Lab #1	24 Jan.	*Weight Curve Development*	3.2
7	25 Jan.	Hull Girder Fatigue (cont.)	3.6
8	27 Jan.	Section Modulus	3.6
9	30 Jan.	Composite Beam Approach	3.6
Lab #2	31 Jan.	*Quasi-Static Balance Using SHCP*	
10	1 Feb.	Hull Girder Shear Stress	3.7
11	3 Feb.	Hull Girder Shear Stress (cont.)	3.7
12	6 Feb.	Shear Effects on Beam Theory	3.8
Lab #3	7 Feb.	*Shear Effects Lab*	
13	8 Feb.	Hull-Superstructure Interaction	3.9
	10 Feb.	**Exam #1**	5.1
14	13 Feb.	Stiffness Matrix of a Bar	5.1
15	14 Feb.	Structure Stiffness Matrix	
16	15 Feb.	Pin-Jointed Frames	5.2
17	17 Feb.	Pin-Jointed Frames (cont.)	5.2
•••	20 Feb.	**President's Day Holiday**	
Lab #4	21 Feb.	*Truss Analysis Using GIFTS*	
18	22 Feb.	Flexure-Only Beam Element	5.3
19	24 Feb.	Ordinary Beam Element	5.3
20	27 Feb.	General Beam Element	5.5
Lab #5	28 Feb.	*Frame Analysis Lab*	
21	1 Mar.	General Beam Element (cont.)	5.5
22	3 Mar.	Transverse Structure Design Considerations	
•••	6-10 Mar.	**Spring Break**	
23	13 Mar.	Transverse Structure Design Considerations	
Lab #6	14 Mar.	*Midship Section Design*	
24	15 Mar.	Plate Bending - Small Deflections	9.1
25	17 Mar.	Plate Bending	9.1
26	20 Mar.	Large Deflection Plate Theory	9.2
Lab #7	21 Mar.	*Plate Bending Laboratory*	
27	22 Mar.	Plates Loaded Beyond the Elastic Limit	9.3
28	24 Mar.	Design for Allowable Permanent Set	9.4
29	27 Mar.	Column Buckling	11.1
Lab # 8	28 Mar.	*Midship Section Design*	
30	29 Mar.	Column Buckling	11.1 - 11.2
31	31 Mar.	Effect of Lateral Load	11.3
32	3 April	Elastic Plate Buckling - Uniaxial Compression	12.1
Lab # 9	4 April	*Midship Section Design*	
	5 April	**Exam #2**	
33	7 April	Elastic Plate Buckling (cont.)	12.2
34	10 April	Biaxial Compression, Shear	12.3 - 12.4
Lab # 10	11 April	*Midship Section Design*	
35	12 April	Plates Under Combined Loads	12.5
36	14 April	Ultimate Strength of Plates	12.6
37	17 April	Elastic Buckling of Stiffened Panels	13.1
Lab #11	18 April	*Plate Buckling Lab*	
38	19 April	Elastic Buckling of Stiffened Panels (cont.)	13.1 - 13.2
39	21 April	Local Buckling of Stiffeners	13.1
40	24 April	Buckling of a Cross-Stiffened Panel	13.5
Lab #12	25 April	*Midship Section Design*	
41	26 April	Buckling of a Cross-Stiffened Panel (cont.)	13.5
42	28 April	Submarine Structural Design Considerations	
43	1 May	Review for Final Exam	

Texts:

Ship Structural Design: A Rationally-Based, Computer-Aided, Optimization Approach, Owen F. Hughs, Society of Naval Architects and Marine Engineers, New York, 1988.

"Structural Design Manual for Naval Surface Ships," NAVSEA 0900-LP-097-4010, Naval Sea Systems Command, 1976.

"GIFTS Primer Manual", CASA/GIFTS Inc., Tucson, Az. 1986.

References:

1) *Principles of Naval Architecture: Volume I - Stability and Strength*, E.V. Lewis (Editor), SNAME, New York, NY., 1988 (Chapter 4).
2) *Ship Design and Construction*, R. Taggart (Editor), SNAME, New York, NY, 1980.
3) *Ship Structural Design Concepts*, J.H. Evans (Editor), Ship Structure Committee (SSC), Washington, DC, 1974.
4) *Ship Structural Design Concepts: Second Cycle*, J.H. Evans (Editor), Cornell Maritime Press, Centerville, MD, 1983.
5) *Strength of Ships' Structures*, W. Muckle, Edw. Arnold, Ltd., London, 1967 (Out of Print)
6) "On the Structural Design of a Midships Section," M. St.Dennis, DTMB Report C555, Oct. 1954.
7) "Manual of the Properties of Combined Beam and Plate: Part I - Tees and Angles," U.S. Department of Commerce, Washington, DC.
8) *Basic Ship Theory: Volume I*, K.J. Rawson and E.C. Tupper, Longman Inc., New York, (Third Edition), 1983. (Chapters 6 and 7).

FIGURE 40. SYLLABUS FOR US NAVAL ACADEMY COURSE EN 358, SHIP STRUCTURES

EN 441 OCEAN ENGINEERING STRUCTURES 1995

Week	Topic	Reading Assignment
1-9	Introduction Matrix Algebra	pp 3-25 Appendix
1-16	Matrix Algebra	--
1-23	Structural Analysis	pp 27-36
1-30	" " Quiz 1	pp 36-51
2-6	Structural Analysis	pp 51-67
2-13	" " Quiz 2	pp 67-80
2-20	Environmental Loads	pp 89-98
2-27	" "	pp 98-102
3-6	Spring Break	
3-14	Environmental Loads	pp 122-133
3-20	" " Quiz 3	pp 133-145
3-27	Static Methods	Class Notes
4-3	" "	
4-10	" " Quiz 4	
4-17	Foundations	Class Notes
4-24	"	
5-1	Review	
5-4 to 5-12	Examination Period	

EN441 - OCEAN ENGINEERING STRUCTURES

1993 Catalogue Data: EN441: OCEAN ENGINEERING STRUCTURES (3-0-3). Structural design considerations for fixed ocean structures. Design techniques including matrix methods and finite element analysis are introduced. Boundary conditions, wave effects, foundations, loading, and materials considerations are studied. Prerequisite: EN217.

Textbook: now out of print, but appearing in print soon OFFSHORE STRUCTURAL ENGINEERING (Prentice Hall) (by T. H. Dawson)

Course Coordinator: T. H. Dawson, Professor

Goals: This course is designed to give ocean engineering majors a working knowledge of matrix structural; analysis, environmental loadings and foundation considerations as they relate to analysis and design of offshore structures.

Prerequisites by Topics: 1. Strength of Materials

Topics:	Classes
1. Matrix structural analysis	15
2. Wind and wave loadings	9
3. Analysis of offshore structure	15
4. Foundation considerations	6
5. Tests	3

Computer Usage:

1. Matrix operations and matrix computer solution of linear equations by matrix inversion.
2. Spreadsheet programming of scalar equations associated with wave forces, joint loads, etc.
3. Matrix computer analysis of structures.

Laboratory Projects:

1. Term Project: Detailed analysis of an offshore structure for deflections and stresses.

Estimate Content:

Engineering Science: 1 credit 33%

Engineering Design: 2 credits 67%

FIGURE 41. COURSE DESCRIPTION AND SYLLABUS FOR US NAVAL ACADEMY COURSE EN 441, OCEAN ENGINEERING STRUCTURES

rather than one in naval architecture. The first one after the basic mechanics of deformable bodies, AOE 3024, is in fact named Thin Walled Structures and is included in both curricula. Information on this course, including the syllabus, is reproduced in Figure 42. The content is somewhat advanced for a first course actually dealing with structures rather than fundamental material, but it is obviously tailored to prepare students for the differing following structures courses in each of the programs. In ocean engineering this is AOE 3224, Ocean Structures. The description of this course, in the same format, is given in Figure 43 and examination will demonstrate that ships as well as ocean structures such as offshore platforms are involved. Professor Hughes evidently incorporates the limit state analysis concept – buckling, fracture, and plastic collapse, for example – in this course much as he did in the text "Ship Structural Design: A Rationally-Based Computer-Aided Optimization Approach." (Terming this work a textbook rather than a reference is justified by comparing it with say the chapters concerned with ship structures in the various other Society of Naval Architects and Marine Engineers books and several other references mentioned elsewhere in this section. It does indeed remain the single best text currently available dealing with marine structural analysis and design.) Somewhat abbreviated syllabuses for many of the succeeding structures courses offered by this single department – AOE 4034, Computational Structural Analysis, AOE 4054, Stability of Structures, AOE 4184, Design and Optimization of Composite Structures, AOE 4984, Computer-Based Design of Thin-Wall Structures, and AOE 5024, Vehicle Structures – are given in Figures 44 through 48 to illustrate the advantages in combining the structural offerings needed in two mechanics-based engineering disciplines so as efficiently to provide viable undergraduate and graduate programs in both.

Massachusetts Institute of Technology

The situation at MIT is apparently in transition as this is written, but those undergraduates in the ocean engineering program presumably take or recently took a course 13.014, Marine Structures and Materials, and the syllabus for this course as taught in 1994 is given in Figure 49. The combining of classical somewhat advanced strength of materials topics with the properties and basic science considerations of materials – as determined by someone as eminently qualified as Professor Masubuchi – results in a presentation in which matters like fracture and plastic deformation must be better explained and hence better understood by the

November 15, 1985

AEROSPACE AND OCEAN ENGINEERING 3024

STRUCTURES I

(ADP TITLE: STRUCTURES I)

I. CATALOG DESCRIPTION:

3024 STRUCTURES I

Review of mechanics of materials. Stresses in stiffened shell beams. Deformation analysis by energy methods. Multicell beams. Introduction to the matrix stiffness method includ ing truss and beam elements. Pre: ESM 2004 (3H, 3C), I

II. COURSE STATUS:

a. Revised Course
b. Combination of present AOE 3251, 3252 and 3253 coverage
c. Effective March 1987
d. Not for Graduate Credit

III. PREREQUISITES & COREQUISITES:

ESM 2004 Mechanics of Deformable Bodies lays the foundations for the material in this course.

IV. JUSTIFICATION:

This is the basic structures course for aerospace and ocean engineers. It is focused on the thin-walled beams that dominate the construction of aerospace and ocean vehicles. This course is a combination of material from the current (quarter) courses 3251, 52, 53.

V. EDUCATIONAL OBJECTIVES:

The two major objectives are to make the student gain the physical understanding of the effect of loads on generic aero & ocean structures and to acquaint them with simple computational techniques needed for rough estimates of stresses and displacements.

VI. INSTRUCTOR:

R. Haftka, 4860

VII. TEXTS AND SPECIAL TEACHING AIDS:

Peery and Azar, AIRCRAFT STRUCTURES, McGraw-Hill, 1982.

VIII. SYLLABUS:

	Percent of Course
1. Review of mechanics of materials	5%
2. Stresses in stiffened-shell beams	35%
Skin-stringer approximation	
Open sections: stresses and shear center	
Single-cell closed sections: stresses	
Unsymmetrical sections	
3. Deformation analysis by energy methods	20%
Strain energy method	
Work-energy method	
Unit load method	
Single-cell closed sections: Twist and elastic axis	
Maxwell's theorem of reciprocal displacements	
4. Multi-cell beams	15%
Stresses and deformations	
Torsional stiffness and elastic axis	
5. Introduction to the matrix stiffness method	25%
Review of linear algebra and matrix arithmetic	
Definitions: descrete displacements, actions, and degrees of freedom; flexibility and stiffness matrices	
Element stiffness matrices for truss and beam elements	
Structure stiffness matrix by superposition	
Solution for displacements and reactions	
Computer applications	
	100%

FIGURE 42. COURSE DESCRIPTION OF VIRGINIA TECH AOE 3024, STRUCTURES I

October 24, 1995

AEROSPACE AND OCEAN ENGINEERING 3224

OCEAN STRUCTURES

(ADP TITLE OCEAN STRUCTURES)

I. CATALOG DESCRIPTION:

3224 OCEAN STRUCTURES

Overview of surface ship, submarine and offshore structural systems, materials and loadings. Application of beam and plate bending and buckling theories. Frame and finite element structural analysis. Pre. 3024 (3H, 3C) II

II. COURSE STATUS:

a. Revised Course
b. No major change; revision of course syllabus
c. Effective Jan 1996
d. Not for graduate credit

III. PREREQUISITES & COREQUISITES:

The required backgrounds in mechanics of deformable bodies and matrix structural analysis are provided by AOE 3024.

IV. JUSTIFICATION:

The increasing power and availability of desktop computers, and advances in limit state analysis (buckling, fracture, plastic collapse, etc.) of large thin wall structures are transforming the structural design process for ships and ocean structures. The revisions incorporate these new methods of structural design.

V. EDUCATIONAL OBJECTIVES:

Having successfully completed this course, the student will be able to: (1) identify the various limit states that pertain to each of the different types of ocean structures; (2) use the appropriate computational algorithm for each of these limit states; (3) perform structural analysis using the finite element method; (4) design ocean structures that can withstand the harsh load environment and perform their intended functions.

VI. INSTRUCTOR:

Owen Hughes, 1-5747

VII. TEXTS AND SPECIAL TEACHING AIDS:

Text:

Hughes, Owen, SHIP STRUCTURAL DESIGN: A RATIONALLY-BASED, COMPUTER-AIDED OPTIMIZATION APPROACH. Society of Naval Architects and Marine Engineers, Jersey, City, NJ. 1988. 564 pages.

VIII. SYLLABUS

	Percent of Course
Overview of Rationally-Based, Computer-Aided Structural Analysis and Design of Thin-Walled Structures.	15
Principal Loading and Structural Response of Ocean Structures.	20
Basic Aspects of Finite Element Analysis.	25
Plate Bending.	10
Buckling of Columns and Beam Columns.	10
Buckling and Ultimate Strength of Plating.	20

FIGURE 43. COURSE DESCRIPTION OF VIRGINIA TECH AOE 3224, OCEAN STRUCTURES

November 25, 1985

AEROSPACE AND OCEAN ENGINEERING 4034

COMPUTATIONAL STRUCTURAL ANALYSIS

(ADP TITLE: COMP. STRUCT. ANALYS.)

I. CATALOG DESCRIPTION:

4034 COMPUTATIONAL STRUCTURAL ANALYSIS

Static and vibratory response of framed structures. The matrix eigenvalue problem for buckling and free vibrations. Static response of laminated composite plates by the finite element method. Pre: 3124 or 3224. (3H,3C) II.

II. COURSE STATUS:

a. Revised course
b. Expansion of the present AOE 4250
c. Effective March 1987
d. Graduate credit not requested

III. PREREQUISITES & COREQUISITES:

Introduction to matrix stiffness method and linear vibrations of multi-degree-of-freedom systems. AOE 3124 and AOE 3224 cover these topics.

IV. JUSTIFICATION:

This course is designed to continue from AOE 3124 or AOE 3224, and presents more advanced computerized analysis of structural statics, stability, and vibrations. This course is an expansion of the material now covered in AOE 4250. Prerequisites make this a senior level course

V. EDUCATIONAL OBJECTIVES:

The objectives are to provide the understanding of, and methods to implement the computer solution to, the static and vibratory response of skeletal and continuous structures found in vehicles.

VI. INSTRUCTOR:

E. R. Johnson, 6699

VII. TEXTS AND SPECIAL TEACHING AIDS:

VIII. SYLLABUS:

	Percent of Course
1. Continued matrix structural analysis by the stiffness method for trusses, frames, and grids	20%
Distributed loads, temperature variations, structural modifications, symmetrical structures	
Matrix algebra and linear simultaneous equations: bandedness, sparseness, triangularization	
2. The matrix Eigenvalue Problem	20%
Buckling of columns and simple frames (geometric stiffness)	
Free vibrations of multi-degree-of-freedom structures	
Matrix iteration	
3. Introduction to numerical Analysis of laminated Composite Plates	60%
Kirchhoff plate theory; strain-displacement equations, equilibrium equations, boundary conditions, vertual work	
Classical lamination theory: shear-extension coupling, extension-bending coupling	
Finite element method for static response of mid-plane symmetric laminates: the plane stress or in-plane problem; the bending problem	
	100%

FIGURE 44. COURSE DESCRIPTION OF VIRGINIA TECH AOE 4034, COMPUTATIONAL STRUCTURAL ANALYSIS

November 25, 1985

AEROSPACE AND OCEAN ENGINEERING 4054

STABILITY OF STRUCTURES

(ADP TITLE: STAB. OF STRUCTURES)

I. CATALOG DESCRIPTION:

4054 STABILITY OF STRUCTURES

Introduction to the methods of static structural stability anlysis and their applications. Buckling of columns and frames. Energy method and approximate solutions. Elastic and inelastic behavior. Torsional and lateral buckling. Use of stability as a structural design criterion. Pre: 3024 or CE 3111 or ESM 3080. (3H,3C) I,II.

II. COURSE STATUS:

a. Revised course
b. Expansion of AOE 4600
c. Effective March 1987
d. Graduate credit requested

III. PREREQUISITES & COREQUISITES:

Basic methods of structural analysis covered in 3024 or CE 3111 or ESM 3080.

IV. JUSTIFICATION:

This course is an elective for AOE, CE and ESM seniors and graduate students. The course includes both theoretical concepts of stability and applications to structural engineering practice. To understand the mathematical theory requires a minimum of senior level maturity in structural analysis. This is an expansion of the material covered in AOE 4600. The course is cross listed with CE and ESM 4054.

V. EDUCATIONAL OBJECTIVES:

The aim is to give students an understanding of the importance of stability as a governing design criterion and to provide the basis for understanding the buckling criteria in design codes.

VI. INSTRUCTOR:

E. R. Johnson, 6699

VII. TEXTS AND SPECIAL TEACHING AIDS:

Simitses, G. M., ELASTIC STABILITY OF STRUCTURES, Prentice Hall, 1976.

VIII. SYLLABUS:

	Percent of Course
1. Introduction Using Rigid Bar and Spring Models of Real Structures Concepts and definitions of stability Equilibrium, energy, and kinetic methods of analysis Forms of instability bifurcation, limit point Imperfection sensitivity	20%
2. Flexural Buckling of Columns Equilibrium approach; perfect and imperfect columns, Southwell Plot Kinetic approach, load-frequency curves Energy approach and approximate methods; Rayleigh-Ritz, Galerkin, finite difference Elastic support conditions and elastic foundation; critical spring stiffness Inelastic behavior; column design curve	30%
3. Buckling of Plane Frames Application of beam-column theory Sway buckling	20%
4. Torsional-Flexural Buckling and Lateral Buckling of Thin-Walled Open-Section Columns	20%
5. Nonconservative Loads Beck's Column	10%
	100%

FIGURE 45. COURSE DESCRIPTION OF VIRGINIA TECH AOE 4054, STABILITY OF STRUCTURES

AEROSPACE AND OCEAN ENGINEERING 4184

DESIGN AND OPTIMIZATION OF COMPOSITE MATERIALS AND STRUCTURES

(ADP TITLE: DES/OPT OF COMP MATLS)

I. CATALOG DESCRIPTION:

4184
ESM 4184
DESIGN AND OPTIMIZATION OF COMPOSITE MATERIALS AND STRUCTURES

Design aspects of laminate constitutive relations, coupling and decoupling of in-plane and out-of-plane elastic response. Tailoring of laminated composite materials to meet design requirements on stiffness and strength through the use of graphical and numerical optimization techniques. Introduction to integer programming: branch-and-bound method and genetic algorithms. Stacking sequence design of laminated composite beams and plates via integer programming.

Pre: 3024, CE 3404, or ESM 3084. (3H, 3C) each. II.

II. COURSE STATUS:

a. New Course.

b. N/A.

c. Effective date is Spring Semester, 1993.

d. Graduate credit is not requested.

III. PREREQUISITES & COREQUISITES:

Knowledge of the fundamentals of mechanics of deformable materials, and structural mechanics is prerequisite. Knowledge of mechanics of composite materials is highly recommended but not required.

IV. JUSTIFICATION:

Laminated composite materials are replacing conventional materials in many structural design applications. An increased number of material variables that can be used to meet design requirements makes optimization an ideal tool for design. The discrete nature of ply thickness and fiber orientation angles that are used for practical design situations further requires the use of integer programming methods. The design of composite materials is, therefore, primarily a stacking sequence optimization problem which requires very special optimization tools.

V. EDUCATIONAL OBJECTIVES:

At the successful completion of this course, the students will be able to design stacking sequence of laminated composites optimally by making use of unique elastic properties of the material that couple in-plane and out-of-plane deformation modes in a complex manner. Students will be able to use novel computer based programming techniques for the stacking sequence design, and demonstrate the approach by designing beam and plate structures for in-plane and out-of-plane stiffness and strength requirements.

VI. INSTRUCTOR:

Zafer Gurdal, ESM Professor, 1-5905 and Raphael T. Haftka, AOE Professor, 1-4860.

VII. TEXTS AND SPECIAL TEACHING AIDS:

Required Class notes by Z. Gurdal, R. T. Haftka, and P. Hajela (To be Published). Optional reference textbooks include:

Jones, R. M. MECHANICS OF COMPOSITE MATERIALS. New York, Hemisphere Publishing Co., 1975. 350.

Tsai, Stephen W. COMPOSITE DESIGN. Dayton, Ohio: Think Composites, 1990. 380.

Vinson, J. R., and R. L. Sierakovski. THE BEHAVIOR OF STRUCTURES COMPOSED OF COMPOSITE MATERIALS. Boston: Martinus Nijhoff Publishers, 1987. xi, 323.

	Percent of Course
1. Introduction to design and optimization	2.5%
2. Laminate constitutive behavior	12.0%
a. Mechanical loading (3.5%)	
b. Hygrothermal loading (3.5%)	
c. Coupling response, decoupling (2.5%)	
d. Design variable definitions (2.5%)	
3. Composite failure theories	5.0%
a. Lamina failure (2.5%)	
b. Laminate failure (2.5%)	
4. Laminate in-plane stiffness and strength design	26.0%
a. Ranking, carpet plots (5%)	
b. Graphical optimization (7%)	
c. Graphical stacking sequence design (3.5%)	
d. Sandwich laminate design (3.5%)	
e. Design for temperature and moisture loading (7%)	
5. Stacking sequence design via integer programming	17.5%
a. Branch-and-bound algorithm (7%)	
b. Genetic search algorithm (7%)	
c. Stocking sequence design as an integer problem (3.5%)	
6. Stacking sequence design for bending stiffness and strength	26.0%
b. Beam design for buckling (7%)	
c. Plate design for buckling (graphical) (2%)	
d. Plate design for buckling (computational) (10%)	
7. Expert systems and artifical intelligence in composite design	11.0%
a. Expert systems for composite design (5.5%)	
b. Neural networks for composite design (5.5%)	
	100%

FIGURE 46. COURSE DESCRIPTION OF VIRGINIA TECH AOE 4184, DESIGN AND OPTIMIZATION OF COMPOSITE MATERIALS

AEROSPACE AND OCEAN ENGINEERING

Proposal for a New Course

AOE 4984

Computer-based Design of Thin-Wall Structures

ADP Title: COMP. STRUCT. DESIGN

I. CATALOG DESCRIPTION:

4984 Computer-based Design of Thin-Wall Structures

Method for creating computer-based structural models for combined finite element analysis, limit state analysis and optimization (for use in the analysis/design projects). Buckling of plates, stiffened panels and cylinders. Eigenvalue methods for buckling and vibration. Incremental plastic collapse; other progressive collapse. Ultimate strength of large structural modules. Approximately six computer-based limit analysis/design projects, of increasing scope and realism, are assigned throughout the course.

Pre: 3124 or 3224. (3H, 3C). II.

II. COURSE STATUS:

New course; to commence Spring 1996; 1 semester. Graduate credit is requested.

III. PREREQUISITES:

Some of the material in the AOE 3124 and AOE 3224 is essential for this course: basic structural analysis, the fundamentals of the finite element method, and the simpler types of structural failure.

IV. JUSTIFICATION

The increasing power and availability of desktop computers, and advances in the limit state analysis (buckling, fracture, plastic collapse, etc.) of large thin-wall structures are transforming the structural design process for structures. Increasingly the various limit states are analyzed explicitly (rather than implicitly, by codes) and are used to formulate the constraints for a mathematical optimization process which produces an optimum structure, according to the designer's specified measure of merit.

This subject introduces the student to this new method of structural design, giving him/her:

(1) an understanding of the various types of structural failure and other limit states that can occur in large complex thin-wall structures

(2) a knowledge of the computer-based algorithms that are needed to perform limit state analysis

(3) hands-on experience, through a series (approximately six) of increasingly comprehensive and realistic computer-based limit state analysis and optimum structural design projects.

This course builds on the junior level courses AOE 3124 Aerospace Structures and AOE 3224 Ocean Structures, which give simply an overview and some of the fundamentals (e.g. the basics of finite element analysis, and the simpler types of limit states). This course covers the more complex types of limit states and mechanisms of failure for structures of differing geometry and loading: aircraft, ships, and other thin-wall structures. Besides the theory, it also presents the computational algorithms that are required for these limit state analyses.

The computer-based projects give the student a firsthand knowledge of how the theory and the algorithms are actually used in modern computer-aided optimum structural design and/or limit state analysis. This practical experience greatly assists the understanding and appreciation of the subject material, the same as do laboratory experiments in the natural sciences. It also gives the student some experience in the design of structures, which at present is not included in the curriculum.

Graduate credit is requested because this is a relatively new development in structural design. It is more thorough and it involves more theory (or "engineering science" or "first principles approach") than the traditional senior structural design course. Many aerospace and/or ocean engineering departments do not yet teach this new, more comprehensive approach, and therefore many incoming graduate students will not be familiar with it.

V. EDUCATIONAL OBJECTIVES:

Having successfully completed this course, the student will: (1) have a good knowledge of the various limit states that pertain to each of the different types of th. wall structures; (2) be familiar with the computational algorithms for dealing with these limit states; (3) understand how the various limit states are integrated into a "rationally-based" optimum design method, by constituting some of the "constraints" the optimization; (4) have obtained first hand experience at using these algorithms f. limit state analysis and at using a modern computer-aided optimum structural design method.

VI. INSTRUCTOR:

Professor Owen Hughes, 5747

VII. TEXTS AND SPECIAL TEACHING AIDS:

Text

Hughes, Owen. SHIP STRUCTURAL DESIGN: A RATIONALLY-BASED, COMPUTER-AIDED OPTIMIZATION APPROACH. SNAME, Jersey City, New Jersey, 1988. - 564 pages.

Manual for the computer-aided design projects:

USER'S MANUAL FOR MAESTRO. Proteus Engineering, Stevensville, MD, 198: 220 pages.

Special Teaching Aids:

None

VIII. SYLLABUS

	Topic	Percent of Course
1.	Modeling Methods for Computer-Aided Structural Design	15
2.	Buckling (elastic and inelastic) of Plates	15
3.	Buckling (elastic and inelastic) of Stiffened Panels	20
4.	Buckling (elastic and inelastic) of Stiffened Cylinders	15
5.	Buckling and Vibration by Eigenvalue Methods	15
6.	Failure of Large Structural Modules Due to Bending and Shear	5
7.	Methodology of Computer-Based Structural Design	15

FIGURE 47. COURSE DESCRIPTION OF VIRGINIA TECH A0E 4984, COMPUTER-BASED DESIGN OF THIN-WALL STRUCTURES

March 19, 1986

AEROSPACE AND OCEAN ENGINEERING 5024

VEHICLE STRUCTURES

(ADP TITLE: VEHICLE STRUCTURES)

I. CATALOG DESCRIPTION:

5024

VEHICLE STRUCTURES

Exact and approximate methods for analysis and design of aerospace and marine structures. Stresses, Strains, Constitutive Equations, Boundary Value Problems, and Two Dimensional Elasticity. Torsion. Variational Methods, Virtual Work and Energy Principles, Structural Mechanics Theorems, Traditional Approximate Methods and Laminated Plates. (3H,3C)

II. COURSE STATUS:

a. Modified Course
b. Revision of AOE 5221, 2,3 sequence into single course
c. Effective Fall 1988

III. PREREQUISITES & COREQUISITES:

IV. JUSTIFICATION:

An accurate stress analysis of various aerospace and ocean structures is a prerequisite to their optimum design. In practice, various exact and approximate analysis techniques are used to perform such an analysis. There is a need to teach our graduate students a course that provides an indepth knowledge of concepts in advanced Structural Analysis techniques and also helps them in the understanding of various concepts of Structural Mechanics.

V. EDUCATIONAL OBJECTIVES:

The educational objectives of this course will be to impart a comprehensive knowledge of various concepts of Structural Mechanics as employed in the analysis and design of aerospace and marine structures. This knowledge will also prepare the students to take other, more specialized, courses in Structures.

VI. INSTRUCTOR:

R. K. Kapania - 4881, R. T. Haftka - 4860

VII. TEXTS AND SPECIAL TEACHING AIDS:

Reddy, J. N., "ENERGY AND VARIATIONAL METHODS IN APPLIED MECHANICS," John Wiley, NY 1984. Also class notes.

VIII. SYLLABUS:

	Percent of Course
PART A (THEORY OF ELASTICITY)	
1. Introduction, Stress and Strain Stress and Strain at a point, Stress Tensors and Cauchy's Formula, Lagrangian and Eulerian Variables, Rotation Tensor, Transformation of Stress and Strain Tensors, Principal Stresses, Principal Planes, Principal Axes of Strain, Compatibility Equations.	15%
2. Constitutive Equations and Other Considerations Generalized Hooke's Law, Anisotropic Materials, Tensor of Elastic Constants, Strain Energy Density Function Elastic Symmetry, Transformation of Elastic Modulii, Relation among Elastic Constants, Boundary Value Problems for Linear Elasticity, Saint Venant's Principle, Uniqueness of Solution	15%
3. Torsion Torsion of Circular and Noncircular Sections, Thin Walled Sections, Single and Multicell Tubes, Warping Function, Divergence of aircraft wings, Axial constraint for thin walled sections under torsion	20%
PART B (APPROXIMATE METHODS)	
1. Virtual Work and Energy Principles Work and Energy, Strain and Complementary Energy, Principles of Virtual Displacements, Unit Dummy Displacement Method, Principles of Total Potential Energy, Virtual Forces and Complementary Potential Energy, Unit Dummy Load Method. Castigliano's First and Second Theorems, Maxwell-Betti Reciprocal Theorem. Traditional Approximate (e.g. Ritz, Galeskin, least square and collocation) methods. Approximate Methods to Analyze Aircraft Wings under Aerodynamic Loads	20%
2. Analysis of Thin Laminated Plates Equations of Motion for Isotropic and Thin Laminated Plates, Kirchoff's Theory, Exact and Approximate Solutions of Bending of Plates, Thermal Stresses, Analysis of Delta Wings and Control Surfaces	15%
3. Analysis of Thin Laminated Shells Equations of motion for cylindrical and spherical shells, Axisymmetric, Asymmetric and Edge loads, Shallow-Shell Theory, Inextensional Shell Theory, and Membrane Shell Theory. Analysis of Rings (Bulkheads). Analysis of Aerospace Vehicles	15%
	100%

FIGURE 48. COURSE DESCRIPTION OF VIRGINIA TECH AOE 5074, VEHICLE STRUCTURES

Course Syllabus, Fall 1994

1.	9/7	Introduction		
2.	9/9	Atomic structures of materials		
3.	9/12	Axial force, shear, & bending moment	5.1-5.10	
4.	9/14	Alloy systems		PS#1 Out
5.	9/16	Bending stresses	6.1-6.5	
6.	9/19	*No Class*		
7.	9/21	Basic metallurgy of steel		PS#1 Due, PS#2 Out
8.	9/23	Composite beams	6.8	
9.	9/26	Shear stresses	7.1-7.8	
10.	9/28	Basic metallurgy of steel		PS#2 Due, PS#3 Out
11.	9/30	Box girder analysis		
12.	10/3	Deflections	10.1-10.7	
13.	10/5	Stresses & strains	1.1-1.9, 2.1-2.9	PS#3 Due, PS#4 Out
14.	10/7	Isotropic & anisotropic materials	3.1-3.2, 3.4-3.8	
	10/10	*Columbus Day (No Class)*		
15.	10/12	Thin-walled shells	3.9-3.10	PS#4 Due
16.	10/14	Thick-walled shells	3.11-3.13	
17.	10/17	Composite shells		
18.	10/19	Quiz 1		PS#5 Out
19.	10/21	Yield	8.15-8.18	
20.	10/24	Fracture Criterion	8.19-8.20	
21.	10/26	Mechanisms of increasing strengths of alloys		PS#5 Due, PS#6 Out
22.	10/28	Inelastic bending	6.10, 10.12	
23.	10/31	Fundamentals of mechanical properties of metals		
24.	11/2	Atomic mechanisms of plastic deformation and fracture		PS#6 Due, PS#7 Out
25.	11/4	Atomic mechanisms of plastic deformation and fracture		
26.	11/7	Plastic limit analysis	13.5-13.9	
27.	11/9	Joining and cutting technologies		PS#7 Due, PS#8 Out
	11/11	*Veterans Day (No Class)*		
28.	11/14	Structural instability	11.1-11.5	
29.	11/16	Joining and cutting technologies		PS#8 Due
30.	11/18	Column buckling	11.7-11.10, 12.14	
31.	11/21	Quiz 2		
32.	11/23	Brittle fracture		PS#9 Out, Term Project
	11/25	*Thanksgiving Holiday (No Class)*		
33.	11/28	Elastic strain energy	[illegible]	
34.	11/30	Brittle fracture		PS#9 Due, PS#10 Out
35.	12/2	Examples using energy method	[illegible]	
36.	12/5	Virtual work	[illegible]	
37.	12/7	Fatigue fracture		PS#10 Due
38.	12/9	Castigliano's theorem	[illegible]	
39.	12/12	Deckhouse and superstructures		Term Project Due
40.	12/14	Project Presentations		

FIGURE 49. SYLLABUS FOR MIT COURSE 13.04, MARINE STRUCTURES AND MATERIALS

undergraduate students enrolled. At the master's degree level, and specifically in the Naval Construction and Engineering program for naval officers well known as Course XIII-A, Professor Alan Brown has provided the two course flow charts reproduced in Figure 50. Figure 51 gives a description of 13.410, for some reason entitled there and on the flow chart Introduction to Naval Architecture even though it is obviously a basic solid mechanics course. The 13.111, Structural Mechanics, course taught by Professor Wierzbicki is described in Figure 52 and examination of the topics listed establish it is largely concerned with plates and shells and would seemingly be very challenging if preceded only by 13.410. The insertion of 13.10J, Introduction to Structural Mechanics, should help and so it is described in Figure 53. The brief but current catalog descriptions of these and several other structures courses are reproduced in Figure 54, but that and other publications do not provide a coherent or representative listing the individual courses that must be completed satisfactorily to earn any of the various graduate degrees awarded. With the availability at MIT of very many other structural analysis and design courses offered by departments other than Ocean Engineering, however, graduates should be able to complete programs in this field fully consistent with the image this institution enjoys.

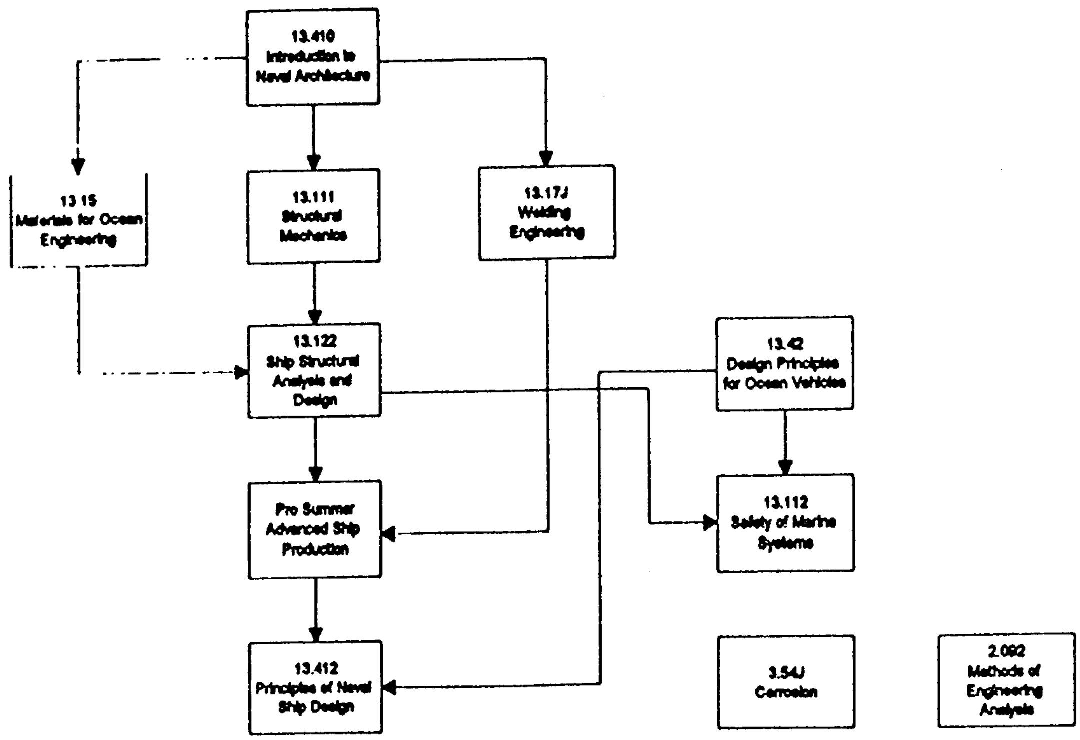
Texas A&M University

The first undergraduate structures course in the ocean engineering curriculum at Texas A&M is OCEN 345, Theory of Structures, and the syllabus for it is as given in Figure 55. The topics included in OCEN 301, Dynamics of Offshore Structures, are given in Figure 56, and those in OCEN 686, Offshore and Coastal Structure, are listed in Figure 57. These make clear that the undergraduate and graduate programs at Texas A&M are wholly devoted to offshore and coastal structures and not at all concerned explicitly with ships.

Florida Atlantic University

While the two undergraduate courses of interest at Florida Atlantic are in fact technical electives, they are included among four in the structures option that requires three of the four courses listed be completed. One of the others is entitled Design of Marine Concrete Structures, but EOC 4414, Design of marine Steel Structures, and EOC 4410C, named Ocean Structures in the curriculum list but evidently Structural Analysis I at present, do include ocean engineering applications.

CURRENT AREA CONCENTRATION IN SHIP STRUCTURES AND STRUCTURAL FABRICATION
Figure 1



PROPOSED AREA CONCENTRATION IN SHIP STRUCTURES AND STRUCTURAL FABRICATION
Figure 2

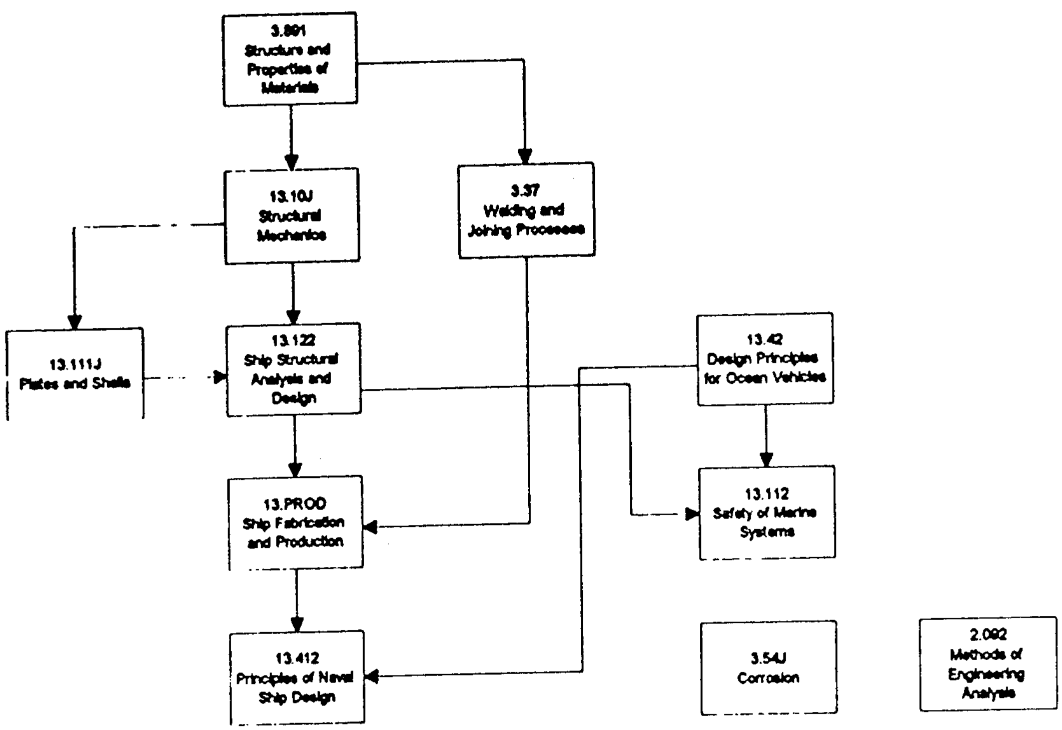


FIGURE 50. ARRANGEMENT OF STRUCTURAL COURSES FOR MIT III-A, NAVAL CONSTRUCTION AND ENGINEERING PROGRAM (COURTESY OF ALAN BROWN)

13.410 Introduction to Naval Architecture
(Mechanics of Solids)

Text: An Introduction to the Mechanics of Solids. S. H. Crandall. N. C. Dahl & T. J. Lardner. McGraw-Hill. 1978.

Course Schedule

1. Introduction & Fundamentals of Mechanics (Chapter 1)
2. Equilibrium of Rigid Bodies and Free-Body Diagrams (Chapter 1)
3. Deformable Bodies (Chapter 2)
4. Statically Determinate & Indeterminate Structures (Chapter 2)
5. Stress & Strain (Chapters 4 & 5)
6. Mohr's Circle (Chapter 4)
7. Equations of Elasticity (Chapter 5)
8. Initial Yield (Chapter 5)
9. Fracture & Fatigue (Chapter 5)
10. Pressure Vessels (Chapter 5 & Class Notes)
    - Thin-walled cylindrical & spherical shells
    - Thick-walled cylinders & spheres
11. Elementary Beam Theory
    - Bending moment and shear diagrams (Chapter 3)
    - Bending stresses and shear flow (Chapter 7)
    - Composite beams (Chapter 7)
    - Deflection (Chapter 8)
    - Torsion (Chapter 6)
    - Beam buckling (Chapter 9)
    - Yielding and plastic beam analysis (Class Notes)
      - Inelastic bending and ultimate strength (Class Notes)
      - Plastic buckling (Class Notes)

FIGURE 51. SCHEDULE FOR MIT COURSE 13.410, INTRODUCTION TO NAVAL ARCHITECTURE

13.111 STRUCTURAL MECHANICS

Fall 1995

in Room 1-242

COURSE INFORMATION

INSTRUCTOR	Tomasz Wierzbicki Professor of Applied Mechanics Room 5-218, Ext. 3-2104 Office Hours: Monday & Wednesday 1:00 - 2:00 Friday 11:00 - 12:00
TEACHING ASSISTANT	Djamil Boulahbal Room 5-014A, Ext. 3-4966 Office Hours: Monday, Wednesday 1:00 - 2:30 and by arrangement
GRADING POLICY	3 Quizzes (25% each) 75% 10 Problem Sets 25%
HOMEWORK	Assigned each Wednesday. To be returned the following Wednesday There will be a penalty for unexcused late homework. Excuses should be directed to the T.A. or the faculty ahead of time.
REFERENCE BOOK	A. C. Ugural, ***Stresses in Plates and Shells***, McGraw Hill

SUPPLEMENTARY READING

1. Irving H. Shames and Clive L. Dym, ***Energy and Finite Element Methods in Structural Mechanics***, McGraw Hill
2. Timoshenko and Woinowsky-Krieger, ***Theory of Plates and Shells***, McGraw Hill

COURSE OUTLINE

1. Concept of Strain
   - One-Dimensional Case
   - Initial and Current Coordinates
   - Elements of Tensor Analysis *
   - Derivation of Strain Tensors
   - Strain-Displacement Relations for Moderately Large Deflections of Plates
2. Concept of Stress
   - One-Dimensional Case
   - Work Equivalence
   - Three-Dimensional Case
3. Theory of Linear Elasticity
   - Stress-Strain Relations
   - Elastic Strain Energy and Complementary Energy
   - 1-D Case and 3-D Case
4. Variational Principles of Elasticity
   - Principal of Stationarity of Total Potential Energy
   - Principal of Minimum Potential Energy
   - Castigliano's Theorems
   - Approximation Methods
   - Ritz Method, Galerkin Method and their Equivalence
5. Application of Variational Methods for Derivation of Equilibrium Equations
   - Three-Dimensional Body
   - Equilibrium of Plates
   - Equilibrium of Shells, General Case
   - Rotationally Symmetric Shells
6. Moderately Large Deflection of Plates
   - Variational Approach
   - Equilibrium
   - Boundary Conditions
   - Examples
7. Elastic Stability of Structures
   - General Concept
   - Adjacent Equilibrium Versus Energy Method
   - Linear Stability Equations of Plates
   - Buckling Solutions for Rectangular Plates
   - Buckling of Stiffened Plates
   - Ultimate Strength of Plates
   - Elastic-Plastic Buckling
8. Buckling of Cylindrical Shells
   - General Equations
   - Applications, Uniform External Pressure
   - Axial Loading
   - Combined Loading
   - Torsional Buckling
   - Imperfections and Comparison with Experiments
9. Bending of Shells
   - Thin Shell Approximation
   - Shallow Shell Approximation
   - Membrane Shells
   - Applications, Cylinders, Cones and Spheres
10. Transverse Shear Effects in Beams, Plates and Shells, Basic Concepts in Sandwich Structures

FIGURE 52. COURSE INFORMATION AND OUTLINE FOR MIT COURSE 13.111, STRUCTURAL MECHANICS

13.10J
INTRODUCTION TO STRUCTURAL MECHANICS

Fall 1992

COURSE OUTLINE

1. The concept of stress

-- Stress tensor
-- Cauchy formula
-- Principal stresses
-- Stress deviator
-- Plane stress
-- Mohr circle
-- Rotation of coordinate system
-- Polar and cylindrical coordinates

2. The concept of strain

-- Strain measures
-- Strain and spin tensors
-- Physical interpretation
-- Plain strain
-- Uniaxial strain

3. Elastic constitutive equations

-- Lame constants
-- Young's modulus and Poisson's ratio
-- Isotropy and homogeneity
-- Simple states: hydrostatic loading
-- Uniaxial stress and pure shear
-- Hook's law for plain stress

4. The concept of equilibrium

-- Equilibrium of a 3-dimensional body
-- Generalized stresses
-- Equilibrium of a beam
-- Effects of large rotations
-- Equilibrium of a mooring line (cable)
-- Equilibrium via the principles of virtual work

. Elementary theory of beams

-- Love - Kirchhoff hypothesis
-- Integrated constitutive equation
-- Classical bending equations
-- Boundary conditions
-- Example solutions
-- Effects of large displacements

6. Energy methods in elasticity

-- Bending and membrane energies
-- Total potential energy
-- Equilibrium via variational formulations
-- Boundary conditions
-- Ritz and other approximate methods
-- Examples

7. Stability of equilibrium - buckling

-- Discrete column - illustration of basic concepts
-- Trefftz condition for stability
-- Column buckling as an eigenvalue problem
-- Euler formula
-- Plastic buckling
-- Design of columns - buckling curve

8. Elementary plasticity

-- Yield condition as a failure criterion
-- Behavior beyond initial yielding
-- Plastic flow and strain - hardening
-- Necking and fracture
-- Plastic bending - the concept of a plastic hinge
-- Limit analysis
-- Crushing of circular and prismatic tubes

FIGURE 53. OUTLINE FOR MIT COURSE 13.10J, INTRODUCTION TO STRUCTURAL MECHANICS

13.014 Marine Structures and Materials

Prereq.: 2.001, 18.03
U (1)
3-0-9

Fundamentals of solid mechanics and materials science needed for design and fabrication of marine structures. Topics related to solid mechanics include advanced beam theory, beam buckling, plastic beam response, and structural failure. Topics related to materials science include atomic structures of materials, phase diagrams, mechanical properties, cutting and joining techniques.
K. Masubuchi

13.10J Introduction to Structural Mechanics

(Same subject as 1.573J)
Prereq.: 2.01 or 2.001, 18.03
G (1)
4-0-8 H-LEVEL Grad Credit

Fundamental concepts of structural mechanics with applications to marine and civil structures. Governing equations of continuum mechanics. Analysis of beams, columns, and shafts. Exact and approximate methods for analysis of statically indeterminate structures, energy methods, principle of virtual work. Elastic buckling of columns. Examples from trusses, buildings, ships, and cables.
N. M. Patrikalakis, J. Connor

13.110 Introductory Structural Analysis

(Subject meets with 13.111)
Prereq.: 13.014
G (1)
3-0-1

Concepts of deformation and equilibrium of one-dimensional structures (bars, beams, strings, and cables). Bending and shear. Principle of virtual work and energy methods in elasticity. Approximate methods, Rayleign-Ritz and Galerkin. Effect of geometry changes. Buckling of discrete and continuous columns. Interpretations and experimental verification. Taught in the first five weeks of the term. Meets with subject 13.111.
T. Wierzbicki

13.111 Structural Mechanics

(Subject meets with 13.110)
Prereq.: Permission of instructor
G (1)
3-0-9 H-LEVEL Grad Credit

Concept of deformation and equilibrium in continuum mechanics and plate and shell structures. Derivation of elastic stress-strain relations for plate and shell elements. Bending and buckling of rectangular plates. Nonlinear geometric effects. Post-buckling and ultimate strength of typical stiffened panels used in naval architecture. General theory of elastic shells and axisymmetric shells. Buckling and crushing strength of cylindrical shells. Meets with subject 13.110.
T. Wierzbicki

13.112 Safety of Marine Systems (New)

Prereq.: 13.014 or 13.410, 13.111, *13.42, 13.121*
G (2)
3-1-8 H-LEVEL Grad Credit

Marine safety regulation with historical perspective. Ship grounding and collision including damage case studies, methods for protection, and residual strength of damaged ships. Extreme wave loads, slamming, and ice damage. Statistical analysis of ship intact stability, subdivision, and damaged stability. Decision-making methods necessary to consider engineering, maintenance, and operational alternatives affecting environmental impact of tanker oil spills. Capstone for Marine Safety concentration, Program in Marine Environmental Systems.
A. J. Brown, T. Wierzbicki

13.122 Ship Structural Analysis and Design

Prereq.: *13.111*, 13.14 or 13.410
G (2)
3-2-7 H-LEVEL Grad Credit

Ship longitudinal strength and hull primary stresses. Ship structural design concepts. Effect of superstructures and dissimilar materials on primary strength. Transverse shear stresses and thermal stresses in the hull girder. Torsional strength of ships. Design limit states including plate bending, column and panel buckling, panel ultimate strength, and plastic analysis. Matrix stiffness, grillage, and finite element analysis. Computer projects on the structural design of a midship module.
A. J. Brown

13.15 Materials for Ocean Engineering

Prereq.: —
G (2)
3-0-6

Properties of metals used for the construction of ships and ocean engineering structures. Microstructures, processing, heat treatment, service behavior, and failures with special emphasis on corrosion resistance of ferrous and nonferrous metals.
K. Masubuchi

13.16J Fracture of Structural Materials

(Same subject as 3.90J, 1.591J)
Prereq.: 2.30 or 3.11 or 13.15
G (1)
3-0-6 H-LEVEL Grad Credit

See description under subject 3.90J.
K. Masubuchi, F. J. McGarry

13.17J Welding Engineering

(Same subject as 3.36J)
Prereq.: 13.15
G (2)
3-0-6 H-LEVEL Grad Credit

Detailed study of processing variables involved in joining materials by welding, brazing, and adhesive bonding. Synthesis of elementary physical phenomena such as transient heat flow, phase transformations, and dimensional changes into the complex overall reactions associated with joining. Testing, inspection, and properties of finished joints. Laboratory demonstrations of arc and other welding processes.
K. Masubuchi

13.410 Introduction to Naval Architecture (Revised Content and Units)

Prereq.: —
G (S)
3-0-9

Introduction to principles of naval architecture, ship geometry, hydrostatics, calculation and drawing of displacement and other curves, intact and damaged stability, hull structure strength calculations, and ship resistance. Projects include computer-aided ship design and analysis tools.
A. Brown

FIGURE 54. CATALOG DESCRIPTIONS OF SELECTED MIT STRUCTURES COURSES

Class	Date	Topic	Read
1	1/18	Introduction	Chap. 1
2	1/20	Basic Concepts	2.1-2.9
3	1/23	Work and Energy	2.10-2.14
4	1/25	Virtual Methods	2.15-2.17
5	1/27	Examples	
6	1/30	Stiffness and Flexibility	2.18-2.19
7	2/1	Reactions	Chap. 3
8	2/3	Examples	
9	2/6	Visual Analysis	Notes by Prof. Roschke
10	2/8	Beams and Frames	5.1-5.5
11	2/10	Shear and Moment Diagrams	5.6-5.9
12	2/13	Examples	5.10-5.11
13	2/15	Influence Lines (IL)	6.1-6.3
14	2/17	Mueller-Breslau's Principle	6.4
15	2/20	Use of IL	6.5-6.6
(Evening Examination 2/21: 7:00-8:30 p.m.)			
16	2/22	Examples	
17	2/24	Deflections of Structures	7.1-7.3
18	2/27	Virtual Work Method	7.4-7.6
19	3/1	Deflection of Beams	8.1-8.3
20	3/3	Examples	
21	3/6	Energy Methods	8.10
22	3/8	Examples	
23	3/10	Static Indeterminacy	9.1-9.4
(Spring Break)			
24	3/20	Alternative Analysis	9.5-9.7
25	3/22	Statically Indeterminate Structures	9.8-9.9
26	3/24	Compatibility Methods	10.1-10.4
27	3/27	Support Settlements and Elastic Supports	10.5-10.6
28	3/29	Examples	
29	3/31	Statically Indeterminate Trusses	10.10-10.11
30	4/3	Examples	
31	4/5	Slope-deflection Equations	11.1-11.4
32	4/7	Frame Problems	11.5
33	4/10	Examples	11.6
(Evening Examination 4/11/95: 7:00-8:30 p.m.)			
34	4/12	Equilibrium Method for Truss Analysis	11.9
(Holiday on 4/14)			
35	4/17	Equilibrium Equations by Energy Methods	11.10
36	4/19	Examples	
37	4/21	Moment Distribution Method	12.1-12.4
38	4/24	Examples	12.5
39	4/26	Matrix Methods of Analysis	13.1-13.3
40	4/28	Member Stiffness and Flexibility Matrices	13.4-13.7
41	5/1	Transformations and Examples	13.8-13.9
42	5/3	Review	

Final Examination: Friday, 5 May 1995: 10:00 a.m.-Noon

FIGURE 55. SYLLABUS FOR TEXAS A&M COURSE CVEN 345, THEORY OF STRUCTURES

OCEN 301. DYNAMICS OF OFFSHORE STRUCTURES
FALL 1994, MWF 3:00 - 3:50
Instructor: Dr. M. H. Kim (Rm. WERC 236B, Tel. 847-8710)
Prerequisite: OCEN 300, CVEN 345, and Computer Programming Skill

TOPICS

PART I. Review of Vibration Analysis

1. Introduction
2. Free vibration of single-degree-of-freedom linear systems
3. Forced vibration of single-degree-of-freedom linear systems
4. Two-degree-of-freedom systems

- Examination I

5. Multi-degree-of-freedom systems (introduction)
6. Continuous systems (introduction)

PART II. Application to Offshore Structures

7. Various offshore structures
8. Design consideration
9. Dimensional analysis
10. Environmental loads (wind, wave, and current loads)
11. Review of regular and irregular wave theory

- Examination II

12. Wave loads on offshore structures (Morison equation)
13. Dynamic system modeling
14. Responses of offshore structures
15. Design wave loads and statistical design method
16. Elementary mooring analyses

- Final Examination

FIGURE 56. TOPICS LIST FOR TEXAS A&M COURSE OCEN 301, DYNAMICS OF OFFSHORE STRUCTURES

CVEN 686 Offshore and Coastal Structure
Course Outline -- Spring 1991

Instructor: Dr. J.M. Niedzwecki
Department of Civil Engineering
Office: CE\TTI 705 C
Telephone: 845-1993
Office hours: As posted or call for an appointment.
Lecture: MWF 9--9:50 CVLB 114

Topics

1. Offshore and Coastal Structures
   Design Considerations and Procedures
2. Waves and Structures
   Environmental Forces
   Wave Force Equations
3. Physical Model Testing
4. Design Wave Approach
5. Dynamic Analysis and Simulation Methods
6. Estimates of Wave Characteristics & Structural Response
7. Diffraction Analysis --- (Dr. J. Roesset, time TBA)

   Mid-semester Examination (Wednesday March 6, 1991)

8. Offshore Structures
   Jack-up Rigs
   Fixed Jacket Structures
9. Pile Driving Analysis --- (Dr. L. Lowery, week of March 18, 1991)
10. Gravity Platforms
11. Wave Impact Loading on Platform Decks --- (Dr. R. Mercier, April 3, 1991)
12. Mooring Analysis --- (Dr. H. Jones, week of April 7, 1991)
13. Compliant Platforms
14. Coastal Structures
    Seawalls, Bulkheads, Revetments, Piers and Wharfs
    Groins, Breakwaters and Jetties
15. Pipelines & Outfalls

    Final Examination (Monday May 6, 1991, 8-10am)

FIGURE 57. TOPICS LIST FOR TEXAS A&M COURSE CVEN 686, OFFSHORE AND COASTAL STRUCTURE

They are described, in the ABET format, in Figures 58 and 59. Brief catalog descriptions of a number of pertinent available graduate courses are reproduced in Figure 60.

Florida Institute of Technology

At Florida Tech undergraduate students in the ocean engineering program complete a basic deformable solids course, MAE 3082, and the first structures course is CVE 3015, Structural Analysis and Design. This course is described in the ABET format in Figure 61, and can be seen to be typical of most first civil engineering structures courses. The single ocean engineering structures course offered is OCE 4574, Structural Mechanics of Marine Vehicles, and this is described also in the ABET format in Figure 59. This is a required course in both the Marine Vehicles and Ocean Systems and the Materials and Structures options in the graduate program.

Technical University of Nova Scotia

As indicated in the previous section, the program at Nova Scotia is only at the graduate level and of some 16 individual courses available for naval architecture and marine engineering students five deal with ship and platform structural analysis and/or design. ME 6700, and ME 6705, Dynamics of Offshore Structures I and II, focus more on jacket-type and even gravity-based structures; but ME 6820, Ship Structure Analysis and Design, is ship oriented. ME 6870 and ME 6875, Theory of Ship Structure Analysis I, and II, together include a more rational approach using a probabilistic approach to loading, some treatments of reliability concepts and plastic analysis, and, interestingly, consider springing along with slamming in dealing with hydroelasticity. The catalog (calendar) descriptions of these five courses are reproduced in Figure 63. With a wide range of graduate-level structures courses also available in civil engineering, in applied mathematics, and among the other courses offered in mechanical engineering the situation at Nova Scotia demonstrates that the absence of an undergraduate program in naval architecture or ocean engineering at an institution with strong programs in other engineering disciplines – but in civil and mechanical engineering particularly – can offer a viable and worthy program at the graduate level.

BOC 4414 - DESIGN OF MARINE STEEL STRUCTURES
Spring Semester 1995

1994-95 Catalog Data:	BOC 4414: Design of Marine Steel Structures, 3 credits. Prerequisites: BOC 3150 (Strength of Materials) and BOC 4410C - Structural Analysis I. Underlying theory and design of structural steel members and their incorporation into beam, truss and frame structures. Case study of an Ocean Engineering application based upon current American Institute of Steel Construction specification and design manual.
Textbook:	McCormac, Jack C., "Structural Steel Design: LRFD Method", Harper and Row, 1989.
Instructor:	Hector Vergara, Visiting Professor of Ocean Engineering.
Goals:	This course is intended to: (1) introduce seniors to the design of simple structural steel members and their incorporation into beam, truss and frame structures; (2) emphasize an understanding of the theory underlying the design code requirements; (3) clarify lessons learned by recourse to a case study of a carefully selected, small, 3D frame structure in an ocean engineering application.
Prerequisites by Topics:	1. Strength of materials. 2. Structural analysis.
Topics:	1. Principles of steel design. 2. Tension members. 3. Axially-loaded columns. 4. Beams. 5. Beam-columns. 6. Connections. 7. Case study of ocean engineering structure.

Homework, Tests and Projects:

1. Homework problems involving aspects of design covered in class are assigned on a weekly basis and graded (20%).
2. Two one-hour tests are given during the term (30%), plus a two-hour final exam at the end of the term (30%).
3. The design project assigned requires the student to synthesize the concepts learned into the design of a marine steel structure (20%).

Estimated ABET Category Content: Engineering Science: 1 1/2 credits or 50%
Engineering Design: 1 1/2 credits or 50%

Prepared by: ______________________________ Date: ____________

FIGURE 58. COURSE DESCRIPTION FOR FLORIDA ATLANTIC EOC 4414, DESIGN OF MARINE STEEL STRUCTURES

EOC 4410C - STRUCTURAL ANALYSIS I
Fall Semester 1995

1994-95 Catalog Data:	EOC 4410C: Structural Analysis I, 3 credits. Prerequisite: EOC 3350 - Strength of Materials. Classical methods of analysis of beams, trusses, frames, cables and arches for ocean and civil structure applications. Approximate methods, moment area, virtual work, consistent deformations (force method).
Textbook:	Hibbeler, Russell C., "Structural Analysis", 3rd Ed., Prentice-Hall Publishing Company, 1995.
Coordinator:	Warner Lansing, Visiting Professor of Ocean Engineering.
Goals:	This course is designed to give seniors in ocean engineering the ability to perform internal force and deformation analyses of beam, truss and frame structures by classical methods. Throughout the course, classroom discussions, homework, laboratories and tests all relate to practical ocean structure design goals as much as possible.
Prerequisites by Topics:	1. Tension, compression and shear. 2. Axially loaded members. 3. Torsion. 4. Shear force and bending moment. 5. Stresses in beams. 6. Analysis of stress and strain. 7. Deflection of beams. 8. Columns.
Topics:	1. Equilibrium, determinacy, stability and superposition. 2. Truss equilibrium. 3. Beam equilibrium. 4. Beam moment diagrams by superposition. 5. Frame equilibrium. 6. Cable and arch equilibrium. 7. Approximate analysis of redundant structures. 8. Beam deflections by moment area. 9. Displacements by virtual work. 10. Force method of redundant structure analysis - applications to truss, beam and frame structures. 11. Three moment equation.

Laboratory Projects (each consisting of two hours of lab work plus a report):

1. Testing of simplified model of dock facility gantry crane and comparison with predictions of existing matrix displacement method (MDM) analysis.

2. Engineering work station MDM analysis of Pratt truss for offshore crude oil handling facility. Study of analysis results.

3. Same as Lab 2 except structure is multi-span beam.

Estimated ABET Category Content: Engineering Science: 1.5 credits
Engineering Design: 1.5 credits

Prepared by: ______________________________ Date: ____________

FIGURE 59. COURSE DESCRIPTION FOR FLORIDA ATLANTIC EOC 4410C, STRUCTURAL ANALYSIS

EOC 6152 Adv. Mechanics of Materials in Ocean Applications 3 credits
Prerequisite: EOC 3150
Thin and thick walled cylinders under external hydrostatic ocean pressure. Beams on elastic foundations. Energy methods, handling hooks and curved beams. Contact stresses. Buckling problems. Inelastic behavior of beams. Theories of failure.

EOC 6153 Theory of Plates 3 credits
Prerequisite: EOC 3150
Plate elements in ocean structures. Analysis and design of plate structures. Includes linear theory, large deflection theory and the effects of shear deformation.

EOC 6154 Theory of Elasticity 3 credits
Prerequisite: EOC 3150
Classical formulation of the mathematical expressions for state of stress and strain in a three dimensional medium. Constitutive relations for linearly elastic materials. Solid bodies as boundary value problem. Plane stress and plane strain. Deep submergence effect on yield surface.

EOC 6155 Finite Element Methods 3 credits
Prerequisite: EOC 3150
Finite element approach to the solution of elasticity problems. Emphasis on displacement method, using direct stiffness approach for generation of overall stiffness matrix of a structure. Energy method for elemental stiffness matrices.

EOC 6188 Fluid Structure Interaction 3 credits
Prerequisite: EOC 6180
Dynamic interaction between fluid and solid systems. Hydroelasticity, hydrostatic divergence, galloping vibrations and stall flutter, vibrations of a pipe containing a fluid flow, and turbulent flow over compliant surfaces.

EOC 6205 Composite Materials 3 credits
Prerequisite: Permission of Instructor.
This course covers the use of composite materials in engineering applications. The course covers the following topics: non-isotropic mechanical behavior; micromechanical behavior of lamina and fibers; bending, buckling, and vibration of composite materials; matrix and reinforcement materials for composites; manufacturing techniques for composite materials.

EOC 6417 Advanced Marine Structural Dynamics 3 credits
Prerequisites: EOC 6152, EOC 6425
Basic features of dynamic loading and response, physical properties of dynamic analysis, environmental loading, flow induced vibrations, calculation of the dynamic response of typical structures, effects of structural vibrations, use of models to predict dynamic loads and the response of structures.

EOC 6425 Ocean Structural Dynamics 3 credits
Prerequisites: EOC 3114
Methods of analysis for elastic ocean frames subject to time dependent loading; vibration theory applied to structural systems; modes of vibration, energy methods, and damping.

EOC 6431 Offshore Structures
Prerequisites: EOC 6152
Basic structural systems, environmental loading, fixed and gravity type platforms, semi-submersibles, floating and compliant platforms, external pressure shell structures including oil storage tanks, pipelines, wet and dry subsea completion systems, buoy engineering, concepts for frontier areas, dynamic response.

FIGURE 60. CATALOG DESCRIPTIONS OF SELECTED FLORIDA ATLANTIC GRADUATE STRUCTURES COURSES

CVE 3015 STRUCTURAL ANALYSIS AND DESIGN

1994-95 Catalog Data:	CVE 3015 Structural Analysis and Design. Credit 3. The study of the force-displacement relationships for simple structures; introduction to the analysis and design of structural elements for axial, torsional, shear, and bending loads in steel and concrete. Includes the classical methods of virtual work, consistent deformations and moment distribution for analyzing structures. Prerequisite: MAE 3082
Textbook:	Schodek, Structures, Prentice Hall, 1992
References:	Beer & Johnson, Mechanics of Materials, 2nd edition, McGraw Hill
Coordinator:	Mr. J. W. Schwalbe, P.E., Associate Professor of Civil Engineering
Goals:	To teach the various methods of analyzing a structure and to introduce the student to the design of structural elements in steel and concrete.

Pre requisites by topic:

1. Static equilibrium
2. Free body diagrams
3. Stress-Strain concepts
4. Mechanical behavior of materials

Topics:
1. Structural systems, loads and codes; the design process. (2 classes)
2. Stability and determinacy. (2 classes)
3. Virtual work. (6 classes)
4. Statically indeterminate structures,
   - Consistent deformations. (6 classes)
   - Moment distribution. (5 classes)
5. Design of steel beams. (4 classes)
6. Design of reinforced concrete beams. (4 classes)
7. Design of steel columns. (4 classes)
8. Design of reinforced concrete columns. (4 classes)
9. Design of connections. (5 classes)
10. Exams. (2 classes)

Computer Usage: None

Laboratory Project: Not applicable

Estimated ABET Category Content:

Engineering Science: 2 credits or 67%
Engineering Design: 1 credit or 33%

Prepared by J. W. Schwalbe John W. Schwalbe Date: 5-25-94

FIGURE 61. COURSE DESCRIPTION FOR FLORIDA TECH CVE 3015, STRUCTURAL ANALYSIS AND DESIGN

Florida Institute of Technology
Marine and Environmental Science Division
Ocean Engineering Program

OCE 4574 STRUCTURAL MECHANICS OF MARINE VEHICLES — Fall Semester
Instructor: Andrew Zborowski, Ph. D. — Room E-112
Text: "Basic Ship Theory", Vol. 1, Rawson & Tupper
References: "Ship Design and Construction", Publ. SNAME, ABS Rules for Building and Classing, on Library Reserve

Week	Topic
1,2	Introduction. Description of Ship Hull Structure. Structural Design Based on ABS Rules.
3	Hull Girder. Loads on Hull Structure. Calculation of Shear Forces and Bending Moment.
4,5	Standard calculation. Stress Level and Calculation of Sectional Modulus. Criteria of Failure.
6,7	Bending Moment in Waves. Strip Method. Prediction of Bending Moment in Irregular Waves. Risk and Reliability.
8,9	Local Strength. Structural design and Analysis. Buckling. Stiffened Platings. Midterm Exam.
10,11	Panels of Plating.
12,13	Vibration of Ship Structure. Application of Simple Beam Theory and Other Concepts.
14, 15	Impact on Hull Structure at High Speed and due to Waves. Slamming and its Prediction.

Grading:		
	Home Work	15%
	Midterm Exam	40%
	Final Exam	45%

OCE 4574 STRUCTURAL MECHANICS OF MARINE VEHICLES

SYLLABUS

1. Review of marine vehicles structural problems.
   Components of ship structure.

2. Review of basic concepts of structural mechanics.

3. Marine vehicles overall strength.
   -Longitudinal bending moment. Calculation of bending moment fo a simple body floating in calm water.
   -Bending moment of an actual vessel in waves. Standard calculation.
   -Calculation of section modulus and determination of bendinç stresses.
   -Extension to standard calculation. Influence curve.
   -Application of classification societies' rules for ship structural design.
   -Criteria of failure and permissible stresses.

4. Probabilistic model for bending moment prediction in realis irregular waves. Strip theory and calculation of Response Amplitude Operator. Wave spectrum and spectral method for prediction of the bending moment in random seas.

5. Basic concepts of reliability and risk analysis.

6. Local strength of marine vehicles.
   -Stiffened plating.
   -Panels of plating.
   -Rudder and appendages.

7. Ship vibration.

8. Hydrodynamic impact.
   -Example of impact load prediction of high speed craft.

FIGURE 62. COURSE DESCRIPTION FOR FLORIDA TECH OCE 4574, STRUCTURAL MECHANICS OF MARINE VEHICLES

ME6700 Dynamics of Offshore Structures I

This course deals with methods of analysis of structures in the ocean including deterministic wave loading and the subsequent response of jacket-type structures.

The types of wave loading considered are linear waves, higher order waves and waves based upon the stream function. Matrix stiffness analysis is used in the computer analysis of structures. The static responses of structures to wave loads are determined and the deflected shapes and stress levels determined. Dynamic response using normal mode methods are carried out under the action of wave spectra and spectral fatigue analysis is presented.

ME6705 Dynamics of Offshore Structures II

The course deals with random loading and the response of both jacket and gravity based structures. The statistical representation of the sea is developed and the diffraction-radiation analysis of large structures is presented. The finite element method for analysis is outlined. Various numerical methods used in the analysis of offshore structures are considered. Both time-domain and frequency-domain analysis is carried out.
Prerequisite: ME6700.

ME6820 Ship Structure Analysis and Design

Types of loading and environmental conditions affecting a ship are considered. Topics include: stresses on a ship and the design of members to carry loads; riveted and welded connections; girders, compression members, and frames. Plates in compression and under fluid loading are examined. These concepts are applied to bulkheads and decks and extended to the design of shells. Longitudinal strength calculations are also considered.

ME6870 Theory of Ship Structure Analysis I

This course provides students with theoretical methods of structural analysis for ships and ocean structures in various marine environments. It contains: probabilistic descriptions of ocean wave loads acting on ships and ocean structures; the input-output relations; responses in long and short crested seas; extreme value statistics of wave loads; variability on hull-strength modes of failure; reliability concepts and design considerations.

ME6875 Theory of Ship Structural Analysis II

This course provides students with advanced theoretical methods of structural analysis for ships and ocean structures in various marine environments. It deals with hull-structure responses to environmental induced loads; hydroelastic analysis of hull flexibility, slamming and springing; isotropic and orthotropic plate theories; plastic analysis of structures; finite element methods and their applications to ships and ocean structures.
Prerequisite: ME6870.

FIGURE 63. CATALOG DESCRIPTIONS OF SELECTED NOVA SCOTIA STRUCTURES COURSES

MARINE STRUCTURAL EDUCATION IN RELATION TO PRACTICES AND EXPECTATIONS IN INDUSTRY

In order to determine marine structural analysis and design practices and capabilities in the marine industry at present, so as to be able then to consider the implications this may have in evaluating the level and type of educational programs required, a questionnaire was composed and sent to some fifty organizations. Among them were both representative large and small design firms, several large and small shipyards, a few ship operators, and several regulatory and government agencies including the Coast Guard, the American Bureau of Shipping and the Naval Sea Systems Command. The design firms and the shipyards were geographically well distributed among the various regions of the United States and Canada. Several design firms and builders specializing in small craft – including even ocean racing sailboats, yachts, casino boats, tugs, catamaran ferries, etc. – were included, as were some that are engaged primarily with offshore platforms and other offshore systems of various types. Most of the very large design firms and shipyards but only a very few of the smaller ones have in recent years evidently been concerned with work for the U.S. Navy exclusively, and still seemed to be when they were contacted.

To solicit frank answers the recipients were assured that their responses would not be published, or even circulated among those sponsoring and monitoring this project or in due course reviewing this report. The intent was not to document in great detail the educational backgrounds and experience of those currently responsible for structural analysis and design at these organizations, or, for example, to determine and then state exactly what computer software and hardware they currently employ, but to seek adequate information to reach on a sound basis some general conclusions appropriate to this study. Not all organizations contacted replied and several did not give answers to one or more of the eight questions, but thirty-eight did and many of them wrote lengthy accompanying letters expanding on their answers well beyond what was expected. One letter from a major shipyard, however, stated that they considered company confidential most of the subjects dealt with in this questionnaire, and did not believe their answers would be helpful, and therefore did not return it. This single negative response could be construed as indicating that they consider their engineering personnel and procedures in the area of marine structural analysis and design as entirely satisfactory if not exemplary, and if so that too was helpful information.

The Questionnaire

Copies of the transmittal letter, the actual questionnaire, and the Ship Structure Committee project prospective that were included in the mailing are shown in Figures 64, 65, and 66. While it was anticipated that all of the replies would be received in several weeks, a few were in fact not returned until several months later. This was due in part to those individuals to whom they were sent – mostly personal acquaintances or those known to be engaged in or responsible for the structures work at their organization – having left their organizations for employment elsewhere or possibly, of course, their having recently retired or been separated because of downsizing.

The Responses

Questions 1 and 2

The answers to the first two questions made it abundantly clear that, as expected, marine structural analysis and design today is being conducted as often by civil and to a lesser extent mechanical engineers as by the naval architecture graduates of the undergraduate programs described earlier. Several of the civil engineers had earned master's degrees in naval architecture, but more in civil engineering or applied mechanics. A surprising number of those engaged in structural work, perhaps one-quarter, were educated – often in naval architecture, however – overseas, most notably in the United Kingdom. Unexpectedly, perhaps another quarter or more of all those so employed have not received any formal higher education. It would be misleading to describe them all as just very experienced draftsmen who have learned what they need to know on the job, but it is quite normal for them to call themselves – and often their employers at most of the smaller firms also to call them – "designers." Those who were educated in naval architecture in the United States and Canada were most often graduates of Webb or Michigan, certainly because these two programs have enrolled and graduated with bachelor's degrees the

RAYMOND A. YAGLE
Consulting Naval Architect
Room 210, NA and ME Building
North Campus
Ann Arbor, Michigan 48109
Telephone: (313) 764-9138

May 8, 1995

[This "form letter" is most often being addressed to the appropriate individuals for their response, but in some instances to responsible acquaintances or just an organization in anticipation that it will be forwarded to the proper person.]

Dear Sir:

I have for the last two months been engaged in carrying out many of the requirements seeking a determination of the current status of marine structures education as listed in the enclosed copy of the prospectus for an active Ship Structures Committee project, and am writing to you to request your assistance now in addressing the several tasks that deal with present practice and capability within the marine industry. The enclosed questionnaire I have prepared may not be entirely adequate for your or any other single organization, but I will greatly appreciate your taking a few moments to jot down -- in pencil if you wish, since the returns are only intended to help me discern the range in the level of competence being applied in current work and the scope and nature of the problems being encountered and will not be quoted or identified to anyone else -- whatever responses you deem appropriate. I certainly will in due course contact by telephone a number of those whose answers warrant greater attention, and may even wish to conduct personal interviews in some instances. This project -- as the prospectus makes clear -- is aimed at improving engineering education in this specific area and will ultimately I believe be of some direct benefit to your organization and our entire industry; thus frank and even candid answers, when justified, are essential.

A stamped and self-addressed envelope is enclosed for use in returning the completed questionnaire, and while an immediate reply is not in any sense mandatory I have phrased the questions so that answering them should not require more than an hour or so to enable you to do so promptly.

Gratefully,

Raymond A. Yagle

FIGURE 64. COPY OF INDUSTRY QUESTIONNAIRE TRANSMITTAL LETTER

QUESTIONNAIRE

(Please answer in the space below each question, but if this is not adequate use the back of the sheet to continue. If any answer is more easily handled by attaching a page or two of printed material please do so. But if actual documents are believed necessary or the weight added is at all substantial, please mail separately.)

1. Please identify (even though it is apt to be yourself) the individual within your organization most responsible for dealing with ship and/or boat and/or platform structural engineering activities technically, not necessarily administratively nor the person with the most sophisticated ability or longest experience.

   Briefly, what is his or her technical background: undergraduate degree school, graduation year and discipline; similar graduate degree information, if any; pertinent experience prior to current employment?

2. How many other engineers within your organization spend a major portion of their effort resolving marine structural problems or originating marine structural specifications (the actual assembly configuration of the various structural elements and their scantlings) as part of the overall design process?

   If only several, please identify them and provide similar information on their backgrounds. If a large number, please respond for several typical individuals.

3. Does most of your work entail new ship and/or boat and/or platform structural design, or structural alterations to accomplish conversions, or modifications to alleviate problems encountered in operation, or all three? Are your "customers" commercial or military, or both? Please describe several examples, briefly.

   Does your organization regularly respond to RFP's from the several government agencies that support marine structural research and development projects, and if so, please give several recent examples.

4. In an attempt to create a hierarchy or scale indicative of the level of complexity of the structural design work normally carried out by or that your organization can undertake, and on the assumption that you are probably familiar with the books published by the Society of Naval Architects and Marine Engineers, would you find the level of the material represented by the treatment in say Chapter 4, Strength of Ships, in the 1967 (Comstock) edition of Principles of Naval Architecture representative, that same but more "modern" chapter in the 1988 (Lewis) edition more so, or the even more rational and obviously more comprehensive coverage in the Owen Hughes book Ship Structural Design (now published by SNAME) the best match?

   Do you routinely evaluate the reliability of the structure you design and utilize probabilistic methods to describe loads and establish structural performance?

5. To what degree are material considerations a major factor in the structural design efforts of your organization? That is, do they routinely involve composites (including "exotic" ones) only, and/or aluminum, or only selective application of high-strength steel? Do you believe you can or could, properly carry out structural design for any reasonably suitable material with your present personnel? Please comment, briefly.

   Are you confident your work currently demonstrates sufficient understanding of fabrication procedures and the concurrent problems that may be encountered in construction, or has this never been a concern? Please explain, briefly.

6. To what extent are your undertakings governed primarily by classification society "rules" and those of other regulatory agencies (presumably ABS and the U.S. Coast Guard for most of you), and do you sometimes feel this may unduly constrain your developing and then advocating unusual or even innovative structural arrangements? Or, do you more often take comfort in the fact that their guidance precludes the risk of your making a major mistake or even being required to design structure using your own understanding of the fundamentals of structural mechanics and procedures based wholly upon them — generally termed "designing from first principles"? Please comment, briefly, and cite an example or two to illustrate your answer if possible.

7. Do you believe your group is fully competent technically to handle properly the activities in which you are regularly engaged or do you occasionally encounter situations that engender some sense of inadequacy? Are you in such circumstances able to hire a consultant — an individual "specialist" or a consulting engineering firm specializing in that aspect that is of concern? If so, how frequently do you do so? Please give an example or two, if possible, explaining that perhaps your organization does not regularly need to determine say ultimate strength or vibratory response or estimate fatigue failure, etc., and how you therefore proceeded.

   Does your organization encourage participation in continuing education — "short courses" usually offered during the summer or regular but limited enrollment at nearby institutions for courses in the late afternoon or evening?

8. Please respond to previous question but with regard to your in-house computer capability (rather than your personnel), stating what software you use routinely and what equipment you use it on, whether you on occasion engage outside computer firms, etc., but again limiting your answer to structural analyses and design.

9. If you have any additional comments — or concerns not covered, or suggestions as to the manner in which this project should proceed, or whatever — that you believe will be helpful, please note them here.

FIGURE 65. COPY OF INDUSTRY QUESTIONNAIRE

Evaluation of Marine Structures Education in North America

Objective Provide the knowledge needed for the SSC to wisely and effectively take steps to improve the structural engineering departments in North American colleges and universities in support of ship structural design.

Benefit The project will result in improved training in ship structural design and construction and hence improved ship structural designs and international competitiveness of the U.S. shipbuilding industry.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. maritime industry in shipbuilding, maintenance, and repair.

SSC Strategy Sponsoring university research in areas such as design tools development, producibility, production processes, reliability design, and damage-tolerant structures

Background In many instances, ship structural designers have either undergraduate or graduate degrees, or both, in civil engineering. Therefore, all applicable aspects of structural engineering are included in this discussion of ship structural design. The SSC has officially recognized in its strategic plan that healthy, capable schools teaching modern methods of ship structural design and construction are essential to sustaining and improving the international competitiveness of the U.S. ship design and construction industry. At the same time, the SSC has recognized that the extent and quality of ship structural engineering education has apparently declined in recent years and has indicated a desire to take steps to improve the situation. Reasons for the decline noted above seem to include the general decline of engineering as a career choice of talented high school students. In addition, the decline of commercial shipbuilding in the U.S. has had two effects—a decline in the number of students attracted to ship structural design as a career choice and a decline in the pool of faculty candidates with relevant ship structural design experience. Furthermore, the reduction in government and industry support for university research in ship structure research and development has decreased the number of faculty members who specialize in this area. The SSC must be armed with facts concerning the current status of and trends in ship structural design and construction education before it can make proper decisions on how to improve the situation.

Recommendations Perform the following tasks:

- Perform a study to assess the current status of applicable ship structural design and construction training in North America and trends in the condition of that training. Address both undergraduate and graduate programs at public and private institutions. Utilize external resources such as Accreditation Board for Engineering and Technology and the Education Committee of the Society of Naval Architects and Marine Engineers as well as direct contact with the institutions themselves.
- Develop a set of questions that can be asked of each institution to gain a comprehensive understanding of the situation. Examples of topics about which questions might be asked are:
  1. the annual number of graduates who have majored in ship structural design and recent trends;
  2. the annual number of students attending ship structural design courses and recent trends;
  3. courses offered in ship structural design and ship construction;
  4. the content of the ship structural design and ship construction courses offered;
  5. the balance between theoretical and practical design courses;
  6. design projects required (length, scope, individual versus team efforts,etc.);
  7. practical work experience required;
  8. lab work required;
  9. industry experience of faculty in ship structural design;
  10. faculty experience in ship structural design research and development;
  11. industry experience of faculty in ship construction;
  12. emphasis given in curriculum to ship production and producibility of structural designs;
  13. emphasis given to economic aspects and cost-effectiveness trade-offs in ship structural design; and
  14. emphasis given to the relationship between ship structural design and total ship system design.
- Wisit the major North American Naval Architecture and Marine Engineerng universities so that faculty may be interviewed, facilities to support lab work can be examiined, and curriculum to support structures education can be reviewed.
- Perform an analysis of the survey results to develop a comprehensive picture of the current status of ship structural design and construction education in North America.

In addition to assessing the current status of status of structures education, an assessment should be made of the current ship structures employment opportunities available upon graduation. This will require interviewing several of the major employers including design firms, shipyards, class societies, and regulatory and government agencies. Through the interview an assessment should be made to determine:

1. What is the typical education background of those currently involved in ship structural engineering.
2. What are typical projects they become involved iwith dealing with ship structural engineering.
3. What type of structural engineering background do they require for those working on their engineering projects.

- As a result of the above findings, identify major deficiencies and problem areas.
- Develop a set of recommendations for SSC actions that would help to correct the major problems identified.

FIGURE 66. COPY OF SSC PROJECT PROSPECTUS THAT ACCOMPANIED INDUSTRY QUESTIONNAIRE

largest number of students in recent years. Several in this particular group, when interviewed in person or by telephone, were less than enthusiastic about their normal work activities and said they were disappointed they were not more challenged and were not recognized as more important to their organizations than they seemed to be. Others deemed themselves as part of a larger "team," and had input to other aspects beyond those involving the structural concerns of the projects on which they worked. All of these views had to be judged with regard to the type and the size of the organization at which they were employed.

Questions 3 and 4

The next two questions were intended to clarify this somewhat expected previous response, but since an effort was made initially to include in the mailing organizations of many types both large and small, the answers were equally varied. Almost all of the design firms and most shipyards felt capable of, and were active in, completing new designs (albeit within the size range of vessels with which they had experience) and hence would be able to generate the plans and/or handle the construction of conversions as well as new construction. Resolving structural problems in existing vessels was seemingly the one type of task that those from both the large and the small shipyards and design offices, and the regulatory and government agencies and operators as well, all felt they could accomplish. Some of those interviewed later obviously did not really understand, or at least had no experience to suggest to them, that some conversion structural problems could demand greater sophistication and capabilities than they anticipated would be needed and that perhaps their confidence was not wholly justified. This was not the case for those organizations that are dedicated to doing research and development work in the marine structures area, and hence are aware that all too often seemingly mundane marine structural problems can require the attention of even those with doctoral degrees using procedures and techniques not available to nor in routine use by practicing engineers.

The great majority of answers to the fourth question, that used the two versions of the strength chapter in the Principles of Naval Architecture editions and the textbook Ship Structural Design – all published by The Society of Naval Architects and Marine Engineers – as a rough scale by which to characterize the complexity and the level of work they felt capable of handling and/or in which they were normally engaged, did not select the latter. Some in fact responded that they did not know of the book, a very telling reply indeed since it was not always made by the smaller organizations. The responses to the second part of that question generated the same discouraging impression: most smaller design firms and even larger ones, and both large and small shipyards, do not concern themselves with evaluating, for example, the reliability of their structural designs and, even more significantly since they may not know how to evaluate reliability, they also do not utilize probabilistic methods to describe design loads. Loading would seem to be (if most of the responses are to be taken unequivocally) a matter for the regulatory agencies or most often just common sense, by which their replies suggest they mean experience gained with structures of whatever type and "routine" static loads and no unsatisfactory eventual performance of which they are aware. Whatever their approach, they tend to believe they are being very conservative and hence safe to such a large degree that no improvement in their methods on that basis is routinely required.

Question 5

The first part of the fifth question regarding materials universally elicited the answers that might be expected. Firms dealing with only fiberglass at present were not at all confident they could work with steel or aluminum. Larger firms normally engaged in designing or building with steel indicated they could and quite often did have projects involving high-strength steel, including those dedicated to offshore platforms rather than ships. The design firms for the most part believed they could handle any analyses or designing required whether it was aluminum or steel – or evidently any other material for which the engineering properties were known – and more than a few seemed to imply that they wanted it understood they could as well, if called upon, properly resolve any normal structural problems whether the application was marine or otherwise. The answers to the second part of this fifth question indicate the smaller design firms and most yards do include consideration of fabrication procedures in dealing with whatever structural analysis and/or design activities in which they may become engaged. This would appear to be especially true in regard to structural details. Larger design firms evidently do not always worry about fabrication considerations in the conceptual phases of their design activities, but are apt to be more familiar with what might be termed good design practices in regard to structural details and to be better equipped to analyze those they may anticipate will be troublesome.

Questions 6 and 7

The next two questions were perhaps the key ones included in the questionnaire in that they were meant to permit some truly significant conclusions to be drawn relevant to the major motivation for this project being undertaken. Almost all of the answers suggest that those individuals and organizations engaged in marine structural analysis and design seldom question the need for and are comfortable working with codes or rules or perhaps less specific but still mandatory guidelines, whether formulated and/or promulgated by classification or professional engineering societies or by the U.S. Navy or by other regulatory agencies. A few responses did agree that the existence of these on occasion prevent or severely constrain creating unusual perhaps innovative structural arrangements, as suggested in the question itself, but were more passive and unconcerned about this than had been expected. The tone of the responses in all cases to both questions would suggest that most marine structural analysis and design has been and is now done in this manner, and they anticipate it probably always will be. When, or if, the individual or the group responsible may sense they face a structural problem beyond their competence to resolve, they do indeed or believe they would go to a consultant or a consulting engineering firm, or possibly just find the time to delve more deeply into and further study the appropriate literature so as to eliminate the need for that option. The inclusion of examples, such as determining ultimate strength or estimating fatigue failure, in the statement of the questions was meant to suggest that those responding should also acknowledge in estimating their competence that some problems or some aspects of a problem that may be important may not on occasion immediately be apparent to them if they seldom if ever had needed to consider them before. Few presumably wanted, in writing, to underestimate their abilities, however, and hence it is not clear just how honest or forthcoming their answers were and how indicative they collectively are in gauging the confidence those responding have in their technical abilities.

The answers to the second part of the seventh question were encouraging in that they demonstrated the appreciation by those answering of the possible value of the various types of continuing education. Several stated that their participation was much more prevalent in years past than currently, but left the impression this was probably due more to economic concerns at present than lack of interest or recognition of need.

Question 8

The eighth question produced a wide range of answers, some listing all of their in-house structural programs and several all but the actual model numbers of the computers on which they run. Several of the more modest design firms have a great deal more capability that might be expected – or, perhaps, even necessary – and some relatively substantial shipbuilding organizations could be deemed somewhat deficient by current standards if their answers were in fact complete. NASTRAN is still in use at many locations for finite element analyses, as current and comprehensive a program as MAESTRO was available to those at more organizations than was expected, and ABACUS, GIFTS, SAFEHULL, PLATE, PipeNet, STEERBEAR and perhaps a dozen more programs with recognizable names used in ship structural analysis and design, and in shipbuilding, were mentioned in the replies received. Most organizations depended on 486 PC's for routine work, but one of the large shipyards dedicated to work for the U.S. Navy and one of the consulting engineering firms said they had workstations with access to Crays. Only one boatbuilder (but, perhaps, to some extent, another as well) of all those responding answered in such a way that would indicate their organization's computer usage was really very limited; most seemed to take some pride in how extensive their program libraries have become. The term optimization remains misused or overused, however, the pitfalls of modeling procedures are seemingly not apparent to some, and uncertainty if not absolute ignorance about how to treat marine loads rationally is still prevalent.

Question 9

There was a final, ninth, question seeking any additional comments those responding wished to make and requesting any suggestions, concerning matters, topics, or procedures that might have, or should have, been included to make the questionnaire better, or in any way to aid in fulfilling the needs of the study as defined in the project statement. The responses were lengthy in several instances, and helpful. That project statement did, of course, require that contact with the marine industry be made, and the questionnaire and the responses, collectively with respect to some items and less often individually in regard to others, have been adequate to suggest and to justify some of the conclusions given in the next section of the report.

CONCLUSIONS AND RECOMMENDATIONS

The information provided in two of the foregoing sections of this report is mostly descriptive: what academic programs of interest exist and what are they like in general, and how, in particular, do they present material concerning marine structural analysis and design to students. The immediately preceding section summarizing the responses to the industry questionnaire does not mention that there seems to be in industry any widespread dissatisfaction, with the manner in which the various schools have handled that presentation nor with the results they have achieved, because it was not evident that there was any at all. What is possibly more disturbing is there seems to be, instead, widespread but certainly not total indifference with regard to how the schools actually operate, how well educated with respect to marine structural analysis and design the graduates at all degree levels from those schools with programs in naval architecture and/or ocean engineering are, and even how they and their organization might better accomplish the structural analysis and/or design tasks they encounter and must complete.

Of the dozen schools with undergraduate programs that were included in the earlier section, the first four would seem to be graduating at present an adequate number of bachelor's-level naval architects to meet the current needs of the marine industry. This could not have been stated just several years ago since their normal collective enrollment, and therefore total number of graduates in the last year or two, were much reduced because students were not being attracted to this particular discipline at least in the U.S. due to the view generally held (but by many younger people especially) that the marine industry was nearing collapse as the U.S. Navy had to cut back ship procurement programs. But during the intervening period Webb has been able to admit and to graduate more students than ever before – approximately 24 and 18, respectively – and Michigan at present is again graduating 23 or 24 students this year and anticipates some further increase in each of the next several years. While the Memorial bachelor graduates generally remain in Canada after receiving their degrees, the total number of students at New Orleans would suggest that more than the usual 10 or so might graduate if it were not that most of the students work full-time and are only part-time students and concurrent work opportunities for them seem to be available at present in the Gulf region. The few students now receiving their undergraduate education in naval architecture each year from Berkeley, and the uncertainty about whether the number will increase, and much the same situation at MIT with regard to their remaining undergraduate program in ocean engineering, render concern for what their undergraduate students are taught or learn regarding marine structural analysis and design seem almost moot. Much the same conclusion not to include them among the four can be reached regarding the Coast Guard and Naval Academies even though they annually award several dozen degrees, since their graduates are not available to enter industry at once. But Virginia Tech now awards 15 or so bachelor's degrees in ocean engineering, and, as indicated earlier, their program has much of the same content and is more like the traditional programs in naval architecture than are those at the three remaining schools with programs also specifically called ocean engineering. These other schools with ocean engineering undergraduate programs are certainly providing additional graduates to the marine industry, but most continue to seek careers as coastal engineers or in some other branch of ocean engineering rather than in structural analysis and design even though they are often just as well qualified to contribute in that particular area as civil or mechanical engineering graduates.

Table 2 lists the number of degrees, at all levels, granted by the various institutions in 1993 and 1994, for reference. Some of the values are not necessarily exact since they were all obtained from several sources and these did not always agree. Even if approximate, however, they are adequate for the purpose of this report.

TABLE 2. NUMBER OF DEGREES AWARDED IN PROGRAMS OF INTEREST AT INSTITUTIONS INCLUDED IN THIS STUDY

INSTITUTION	B[1], '93	B, '94	M[2], E[3], '93	M, E, '94	D[4], '93	D, '94
Webb	16	18	-	-	-	-
Michigan	18	13	21	25	8	5
New Orleans	17	9	0	0	-	-
Memorial	6	4	9	7	2	1
Berkeley	4	5	6	7	2	3
Coast Guard Academy	23	24	-	-	-	-
Naval Academy	22,33	15,20	-	-	-	-
Virginia Tech	17	15	*[5]	2	*	*
MIT	1	5	41	55	11	13
Texas A&M	21	21	12	17	3	3
Florida Atlantic	16	22	8	14	4	2
Florida Tech	22	30	7	7	0	1
Nova Scotia	-	-	2	4	0	2

Sources: American Society for Engineering Education Directories (see BIBLIOGRAPHY) and personal communication.

[1]B=Bachelor degree, whether B.S.E., B.Sc., B.S., naval archtitecture or ocean engineering
[2]M=Master's degree, whether M.S.E., M.Eng., M.S., M.A.Sc., naval architecture or ocean engineering
[3]E=Professional degree: Naval Engineer, Naval Architect, Ocean Engineer
[4]D=Doctorate, whether D.Eng., D.Sc., Ph.D., naval architecture or ocean engineering
[5]Separate degrees in Ocean Engineering, rather than in Aerospace and Ocean Engineering, at the master's level began in 1993, and at the doctoral level no distinction is made.

Thus only the five undergraduate programs of most importance to this study – Webb, Michigan, New Orleans, Memorial, and Virginia Tech – could and perhaps should be judged as to how well they handle marine structural analysis and design, how viable is the content of their individual structures courses and complete the total coverage, how qualified the various professors involved may be technically, and maybe with regard to other pertinent factors. But none would in fact be found untenable, even though all may be wanting in one or several aspects. Discussions with professors and even those with administrative responsibility at these institutions make clear they are very much aware in what areas they may fall short, but are either attempting to remedy that circumstance or have other problems on which they place a higher priority. The differences among these five undergraduate programs with respect to how thoroughly they cover the fundamental knowledge graduates should know to be able properly to keep pace with the technological advances that are occurring in engineering today – in materials, in fabrication techniques, and even in analysis and design procedures – are not really very great, probably because it has long been accepted that universities are not "trade schools" and the basics must be taught first and well. The degrees to which these programs prepare their graduates for practice, how extensively they communicate how the basic material can be applied to real – and for the concerns of this project, marine – structural problems, does vary. Whether at several schools a second strength course taken after a basic one introducing the fundamentals of strength of materials is properly named, and is indeed concerned specifically with marine structures or just advanced strength of materials generally, can depend on the individual professor's inclination which in turn may well depend on his own particular background and experience. The course syllabuses reproduced in the foregoing do not illustrate any situations where what might be called the balance between fundamental theory and practical application – teaching useful problem resolving approaches and procedures with appropriate marine structures examples – is too far from equilibrium, even when some of the professors may have been educated as civil engineers and the applications may also occasionally involve structural problems not specifically marine.

What has obviously been of tremendous benefit to those teaching and to the undergraduate students learning about marine structures at several of the schools, however, has been the increasing attention being given in their programs to ship production and to fabrication practices in particular. It is now possible to recognize that many undergraduate and even graduate students were formerly not able to fully envision realistically what constituted structure in ships or platforms or even boats, and did not concern themselves at all with how the structure was assembled, especially in the classroom. Only Webb had a formal practical work period requirement until relatively recently, but summer intern programs have become popular at several additional schools to their great benefit. That these arrangements be emulated at the others is well worth recommending. It would also be of real value if several of the undergraduate programs could include greater treatment of fracture and fatigue, more on material behavior, and so on for many other topics. But any curriculum additions can only be accomplished by replacing and thus deleting other topics, or the unacceptable alternative of increasing the number of credit hours and hence terms required.

The trends in graduate engineering education – generally, but certainly at the master's degree level – towards greater concern for and emphasis on preparing graduates for practice, rather than seemingly sometimes only for even further education after a master's degree, bodes well for today's students. But practice must be interpreted broadly; it is too educationally demanding on the one hand to permit any but the very brightest graduate students to specialize in a worthy and meaningful specific area of engineering, and be certain they have dealt with all it entails technically no matter how narrow it may appear, and on the other hand simultaneously within the same number of credit hours to prepare them to some extent also to manage and to carry out the necessary economic planning, to consider marketability, and to anticipate operational problems and management concerns with regard to complex engineering systems as currently envisioned in the so-called "concurrent design" concept.

That doctoral programs, and theses, even in engineering may remain as esoteric as ever is not deemed a major concern at present. Basic knowledge and understanding must be advanced, and the entire marine industry with all its engineering activities and demands seemingly functions at all well only by being able frequently to utilize and adapt to current problems the advances that have more often been produced for other elements of industry by research and/or development efforts in disciplines other than naval architecture and/or ocean engineering. Thus the recognition that no more than five or six doctoral degrees in naval architectural aspects of structural analysis and design are being awarded annually in North America is, while unfortunate, again, an indication this area is not considered as attractive nor as well funded as others by potential candidates seeking doctoral degrees in engineering.

But the schools included in this study are, again, collectively seemingly graduating an adequate number of master's degree-level and even doctoral degree-level naval architects to meet the current needs of the marine industry. Michigan and Memorial, and probably New Orleans and Virginia Tech but certainly now including Berkeley and MIT, continue to maintain more or less traditional graduate programs, whether they be designated in naval architecture and marine engineering and/or ocean engineering, capable of educating more students than at present if a surge in enrollment because of a perceived industry need were to occur. And the healthy graduate programs at the other three ocean engineering schools endure. But more graduate students in all of the programs of particular interest at all of these institutions are specializing to the extent possible in hydrodynamics than are those in structures and production and power systems (marine engineering) and operational or environmental concerns (whatever the options may be called) combined, that is probably an indication not only that greater research funding and hence graduate student research is and has been predominantly in that field but that even adequate support in any of the others – but most particularly in structures – could alter that situation.

What recommendation or recommendations should be advanced to counter the perceived sort of malaise and uninterested mind-set that seemingly currently pervades marine structural analysis and design in general is not clear, but it is certain the fault is not primarily or even partially in the undergraduate or the graduate educational programs discussed even though it is manifested there as well as in practice. All of those teaching at all of the institutions discussed are dedicated and extremely capable people, productive and enthused about what they do even if several of the younger professors may possibly on occasion be less enthusiastic than desirable about teaching undergraduates and most are perhaps too focused on their research and/or consulting work. The subject content in the various programs is not, and the topics in the individual courses are not – and should not be – uniform, but reflect the emphasis and the rationale reasonable minds believe appropriate within the constraints they face. If indeed the problem is really most apparent in practice, in industry, it may be because the industry itself does not consider marine structural analysis and design of great enough importance nor amenable to much improvement. This cannot be due solely to overregulation even though that might be one factor, despite the fact that the regulators – the classification societies such as ABS, in particular – have often developed and promoted the approaches that have made more rational many of the techniques available for use today. That commercial firms have come to depend upon them, or the Department of the Navy, to do so does relieve them of the obligation, and does help explain why many recent and current naval architectural graduates are not as attracted to these activities within their organizations and less then thrilled when assigned to them.

It may also seem trite to suggest that another cause is that there are no "exotic new frontiers" in ship structures, at least to the degree there seems to be in some other engineering fields. But in structures generally, including such land-based structures as civic buildings and venues, bridges, and even shoreline structures, improvement and advances of many types are taking place even though they are being brought about by a relatively small number of people and organizations. It is just not being made apparent to individuals or to organizations in the marine industry that innovation and creative reconfigurations and other possibly more exciting developments such as, for example, "smart" materials and structures that adjust and adapt in response to their own sensors are indeed desirable and even needed in ships and platforms. Analyses that justified lengthening the frame spacing in a ship by an inch or two by modifying the arrangement of other structural members or using better material, and thereby reducing the hull steel weight overall by as much as one or two percent, just is in comparison not that satisfying an accomplishment and probably would not be rewarded anyway. How those who practice in what must be termed a conservative marine industry can be encouraged to propose possibly dramatic improvements in the area of structures – as some have in such other areas as propellers or hull form or even tank coatings – when the prevailing impression is that structure is governed by rules and codes in the name of safety, and deviation from these and the resulting redundancy and overdesign that often result will impose on those suggesting some variation a needless burden, is the real problem. Various awards to practicing naval architects and/or ocean engineers, for creativity and productive change, particularly if successful, offered by appropriate government agencies such as those that constitute the Ship Structure Committee or that interagency organization itself, might help. The recognition must be extensively publicized in each case, however, and the awards themselves should be as rich as possible. The Society of Naval Architects and Marine Engineers and the American Society of Naval Engineers should be encouraged to participate and could possibly manage the entire process.

It is foolish to suggest money, financial support for research, financial aid for education, does not matter; but it is questionable whether the availability immediately of a substantial additional amount of money will quickly improve marine structure analysis and design education and capability in industry significantly. What might help in the coming years, however, are dedicated government tax policies intended to encourage investors, unwilling to take the entire risk themselves, to carry through on entrepreneurial ventures that do incorporate or, preferably, even require innovative structural arrangements, or imaginative new material usage, or other such features. To encourage the government to do so would require an educational or lobbying campaign perhaps, but the prospectus for that is beyond the scope permitted here. However, it is not unreasonable nor inappropriate to recommend that an intense campaign be mounted at once by the individuals that constitute the Ship Structure Committee to convince their organizations to double and then double again their financial support, emphasizing that despite its shamefully modest funding this committee is at present the only continuous source of funds for research and development undertakings specifically in marine structural analysis and design, that these undertakings are not often as theoretical or sophisticated as to elicit the attention and support of the National Science Foundation or the Office of Naval Research on any regular basis but normally produce results of immediate value to the marine industry, and are in fact suggested by representatives from the marine industry and the cognizant government agencies and thus address current problems or concerns of real interest to them. At the very least the SCC reports should be given much greater distribution, thereby establishing how valuable they are and engendering wider appreciation for and application of the information they contain.

Another recommendation or two also with respect to the Ship Structure Committee program, since improving education in marine structural analysis and design is indeed among its specific goals, are suggested particularly by the information concerning the various schools and their programs presented in the preceding sections of the report. If, for example, the intent is to insure that more students become attracted to and hence interested in pursuing their studies concentrating in marine structural analysis and design, their single graduate scholarship and appointing a single student as a Ship Structure Subcommittee member are at best superficial attractions and probably not really all that effective. More graduate student support could be achieved if every project they consider awarding to a professor, whether through his institution or to him personally, required that the proposal being reviewed listed by name and program level if possible the students that would participate and the renumeration they would receive, and that this be a major consideration in evaluating the proposal. And, again, if additional input is desired, instead of students or even faculty members bring appointed as liaison members of the SSSC, since at present only those professors from the U.S. Coast Guard, Naval, and Merchant Marine Academies (none of which have graduate research programs dealing with structural analysis and design) are, more extensive liaison instead be sought and established with the National Shipbuilding Research Program, the Advanced Research Projects Agency's Maritech Program, and possibly even with the American Institute of Marine Underwriters, the Shipbuilders Council of America and/or the splinter group of its former members, or both, and other such organizations even though these may not be formally affiliated with or an integral part of the government. Strengthening ties with such existing liaison organizations as the Welding Research Council, and especially ONR is also essential if synergism of the level now achieved by the long established arrangement with the Committee on Marine Structures of the National Research Council is to be duplicated or even partially achieved with them.

While much of the foregoing is unfortunately capable only of portraying the status of marine structural analysis and design education, and practice, as somewhat stagnant, this is misleading with respect to that aspect of the subject that can most easily be characterized as loads and/or loading. The very best structural analyses are only meaningful if they describe the response to realistic loading, and structural design decisions certainly must be based on loads rationally derived and formulated. The progress in recent years in this area may be due more to the efforts of those who think of themselves as hydrodynamicists and their increased concern with motions than to structural engineers, but the value of and the acceptance of their contributions has enhanced marine structural analysis and design enormously. Nor is this the only positive development. The advent of ever more capable computer programs for both structural analysis and design, and the widespread availability of and dependence on computers capable of running them, has made it possible to carry out more extensive and more sophisticated analyses and to evaluate more design alternatives with greater confidence than ever before. These, and equivalent progress in better understanding material behavior, improving fabrication procedures, and other such advances should be more than adequate to invigorate, perhaps gradually but surely inevitably, marine structural analysis and design. They seemingly are capable of sustaining the educational efforts and attention that these subjects are receiving currently and may in time amplify and extend them, but they will do so only if the marine industry recognizes their own need that they do so and encourages them accordingly.

BIBLIOGRAPHY

1. ASEE's 1994-95 DIRECTORY OF ENGINEERING GRADUATE STUDIES AND RESEARCH, Published by The American Society of Engineering Education.
2. 1993 DIRECTORY OF ENGINEERING AND ENGINEERING TECHNOLOGY UNDERGRADUATE PROGRAMS, Published by the American Society of Engineering Education.
3. ENGINEERING AND TECHNOLOGY DEGREES 1994, Published by the Engineering Work Force Commission of the American Association of Engineering Societies, Inc.
4. CATALOG, WEBB INSTITUTE, 1995-96.
5. The University of Michigan, BULLETIN, COLLEGE OF ENGINEERING 1995-96.
6. The University of New Orleans, COLLEGE OF ENGINEERING INFORMATION BULLETIN 1994-1995.
7. CALENDAR 1994-95, Faculty of Engineering and Applied Science, Memorial University of Newfoundland.
8. The University of California, Berkeley, ANNOUNCEMENT OF THE COLLEGE OF ENGINEERING 1995-96.
9. 1994-1995 CATALOGUE OF COURSES, United States Coast Guard Academy.
10. United States Naval Academy, CATALOG 1993-1994.
11. Virginia Polytechnic Institute and State University, UNDERGRADUATE COURSE CATALOG AND ACADEMIC POLICIES 1994-1995.
12. Massachusetts Institute of Technology, BULLETIN 1993-94 (Courses and Degree Programs Issue).
13. Texas A&M University, OCEAN ENGINEERING AT TEXAS A&M UNIVERSITY, Undated Booklet.

14. Florida Atlantic University, UNDERGRADUATE CATALOG 1994-1995.

15. Florida Institute of Technology, UNIVERSITY CATALOG 1993-'94.

16. 1994/95 ACADEMIC CALENDAR, Technical University of Nova Scotia.

Project Technical Committee Members

PTC List for Publication

The following persons were members of the committee that represented the Ship Structure Committee to the Contractor as resident subject matter experts. As such they performed technical review of the initial proposals to select the contractor, advised the contractor in cognizant matters pertaining to the contract of which the agencies were aware, and performed technical review of the work in progress and edited the final report.

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SSC-390 Corrosion Control of Inter-hull Structures M. Kikuta, M. Shimko, D Ciscom 1996

SSC-389 Inspection of Marine Structures L. Demsetz, R. Cario, R. Schulte-Strathaus, B. Bea 1996

SSC-388 Ship Structural Integrity Information System-Phase II M. Dry, R. Schulte-Strathaus, B. Bea 1996

SSC-387 Guideline for Evaluation of Finite Elements and Results R. I. Basu, K. J. Kirkhope, J. Srinivasan 1996

SSC-386 Ship's Maintenance Project R. Bea, E. Cramer, R. Schulte-Strauthaus, R. Mayoss, K. Gallion, K. Ma, R. Holzman, L. Demsetz 1995

SSC-385 Hydrodynamic Impact on Displacement Ship Hulls – An Assessment of the State of the Art J. Daidola, V. Mishkevich 1995

SSC-384 Post-Yield Strength of Icebreaking Ship Structural Members C. DesRochers, J. Crocker, R. Kumar, D. Brennan, B. Dick, S. Lantos 1995

SSC-383 Optimum Weld-Metal Strength for High Strength Steel Structures R. Dexter and M. Ferrell 1995

SSC-382 Reexamination of Design Criteria for Stiffened Plate Panels by D. Ghose and N. Nappi 1995

SSC-381 Residual Strength of Damaged Marine Structures by C. Wiernicki, D. Ghose, N. Nappi 1995

SSC-380 Ship Structural Integrity Information System by R. Schulte-Strathaus, B. Bea 1995

SSC-379 Improved Ship Hull Structural Details Relative to Fatigue by K. Stambaugh, F. Lawrence and S. Dimitriakis 1994

SSC-378 The Role of Human Error in Design, Construction and Reliability of Marine Structures by R. Bea 1994

SSC-377 Hull Structural Concepts For Improved Producibility by J. Daidola, J. Parente, and W. Robinson 1994

SSC-376 Ice Load Impact Study on the NSF R/V Nathanial B. Palmer by J. St. John and P. Minnick 1995

SSC-375 Uncertainty in Strength Models for Marine Structures by O. Hughes, E. Nikolaidis, B. Ayyub, G. White, P. Hess 1994

SSC-374 Effect of High Strength Steels on Strength Considerations of Design and Construction Details of Ships by R. Heyburn and D. Riker 1994