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A Space Engineering Education Program for the Future*

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The next decade will bring a number of technological changes that will significantly impact engineering education programs, especially the field of aerospace engineering. Advances in technology will include improved ground and air transportation systems, new communications and information systems, new space missions, and full integration of computer technology into all engineering fields. Space technology has had a major influence on the lives and commerce of people around the world. Because of the increased attention to space engineering and its impact on the world, it is important that associated instructional programs be carefully considered. Two perspectives on space engineering are presented: (1) space engineering in traditional curricula, and (2) space engineering as a separate curriculum.

INTRODUCTION

THE FIELD of aerospace engineering includes both aeronautics and astronautics, and deals with almost every aspect of both manned and unmanned flights—from light planes to satellites to deep space probes. Since the Wright brother's original flight at Kitty Hawk, the field of aerospace has grown rapidly and expanded to travel through space. From the rapid advance of technology necessary for these achievements have come 'spin-offs' that benefit our everyday lives—from medical diagnostic techniques to minicomputers.

Universities have developed curricula to educate engineers to utilize economically the materials and forces of nature for the benefit of mankind. In the past, aeronautical engineering programs and aerospace engineering programs were developed to meet specific needs. Engineering education has responded to these needs over the years, changing as technology changes. It is interesting, then, to observe how aerospace engineering programs have evolved in the United States.

Engineering education in the United States began in 1802 with the basic rudiments of military engineering, with the first engineering degree granted in 1835. Since that time, the field of engineering has expanded to many institutions and a wide variety of engineering programs. In the early 1900s, aeronautical engineering programs were established to meet the needs of aviation. These programs initially represented areas of emphasis for students in mechanical engineering, but in many colleges the programs developed into separate departments or institutes for aeronautical engineering training.

With the advent of the space program in the United States came the creation of special engineering courses such as 'orbital mechanics' and 'rocket propulsion'. These courses usually originated from faculties of aeronautical engineering or mechanical engineering departments. As these eduational programs evolved, many departments extended their teaching and research to the areas of flight mechanics, rocket propulsion and astronautics. With increased emphasis on space activity, many aeronautical engineering departments became 'aerospace engineering' departments.

In view of the increased interest in deep space probes and space stations, and the number of countries interested in space activity, the time has come for universities to develop 'space engineering' programs that focus specifically on space engineering. Such programs should be designed to provide engineers with an understanding of the many phases of space operations and thus produce graduates who can play a key role in the high technology of the rapidly expanding use of space for the benefit of mankind.

ENGINEERING ENROLLMENT AND ACCREDITATION

In the United States, a strong interest in engineering education has led to a significant growth of the total engineering enrollment. At the same time, both undergraduate and graduate engineers who select aerospace engineering have also grown in numbers. Figure 1 illustrates the growth of the undergraduate enrollment for all engineering students in the United States and the enrollment of aerospace engineering undergradu-

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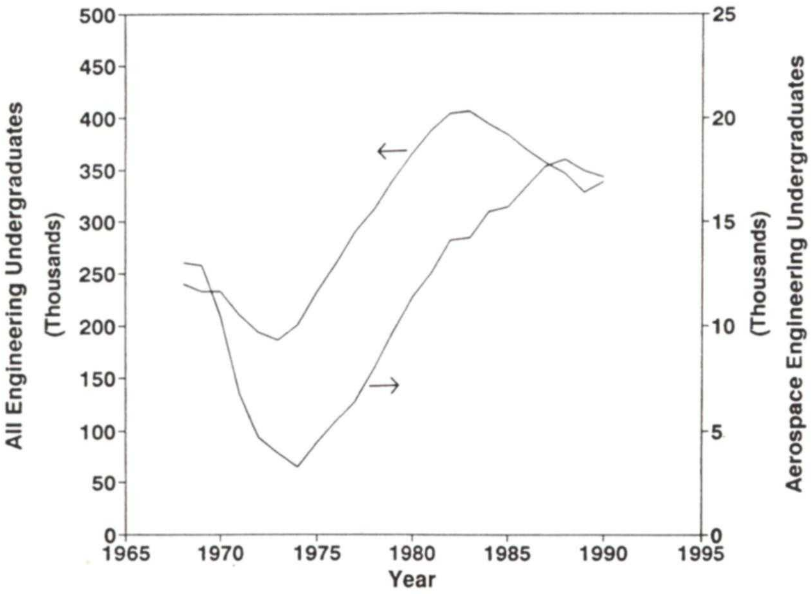

Fig. 1. Undergraduate engineering enrollment in the United States. (Source: AAES Engineering Manpower Commission.)

ate students. In spite of the general decrease in the total engineering undergraduates, it is interesting to note that there has been a steady increase in the number of undergraduates interested in aerospace engineering. The enrollment in graduate level M.Sc. and M.Eng. degree programs is shown in Fig. 2, along with the number of students enrolled at the Master's level in aerospace engineering. Clearly there is a general increase in the number of students seeking the M.Sc. degree in aerospace engineering, demonstrating significant interest in the field. At the doctorate level, enrollments for all engineering students seeking the Ph.D. degree, and those seeking such a degree in aerospace engineering are shown in Fig. 3. Again, it is interesting to note the continual increase of students seeking such an advanced degree. As a consequence, it would appear that the aerospace engineering curriculum is particularly attractive to students at both the undergraduate and graduate level, and suggests that an engineering curriculum that features space engineering would be equally attractive.

It should be noted that essentially all engineering education programs in the United States meet minimum levels of education through accreditation by the Accreditation Board for Engineering and

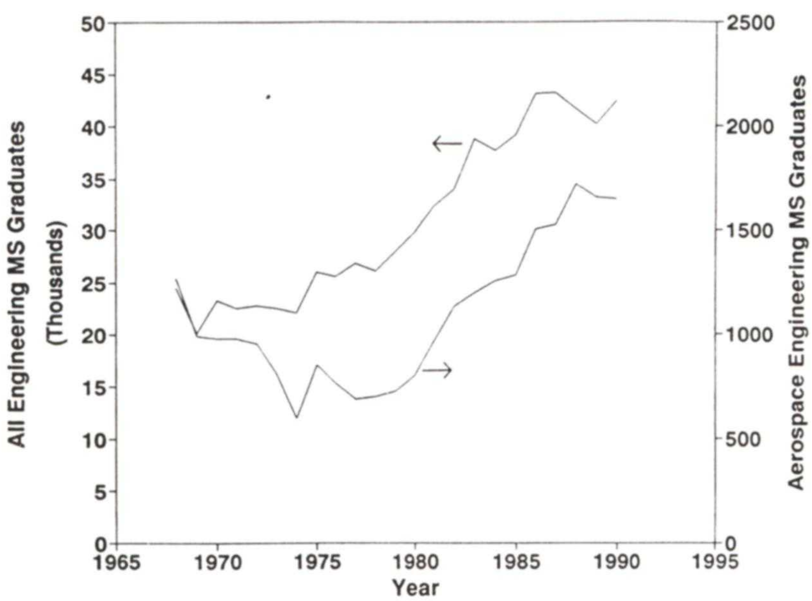

Fig. 2. Graduate engineering enrollment at the MSc. level in the United States. (Source: AAES Engineering Manpower Commission.)

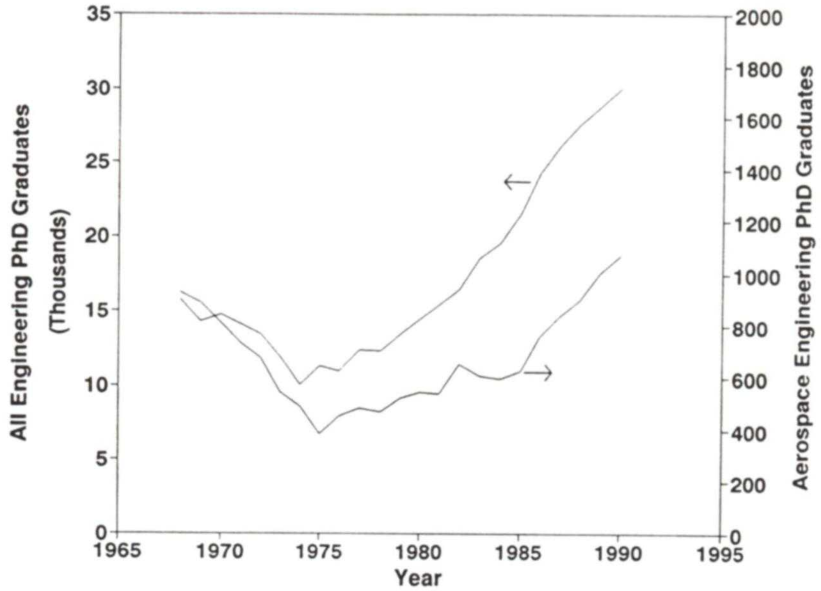

Fig. 3. Graduate engineering enrollment at the Ph.D. level in the United States. (Source: AAES Engineering Manpower Commission.)

Technology (ABET). Authorization for the accreditation of engineering degree programs in colleges and universities has been granted to ABET by the Council on Postsecondary Accreditation of the US Department of Education.

The general accreditation criteria used in the evaluation of all engineering education programs are intended to ensure an adequate foundation in science, the humanities and social sciences, engineering sciences and engineering design methods, as well as preparation for an engineering specialization. The course work must also include at least one full year of mathematics and basic sciences, one year of engineering sciences, one-half year of engineering design and one-half year of humanities and social sciences. In addition, the overall curriculum must provide an integrated educational experience, including laboratory experience, directed towards problem-solving in the engineering specialization area. This educational program also includes computer-based experience as well as the development of competency in written and oral communications.

The Accreditation Board for Engineering and Technology reviews and inspects undergraduate engineering education programs to ensure that the programs meet critical standards with respect to faculty, curricular objectives and content, student body, administration, institutional facilities, and institutional commitment. Each year, a list of accredited programs is published in the ABET Annual Report. Table 1 lists the accredited programs in the area of aerospace engineering and similarly named programs. It should be noted that an institution must elect whether or not it wishes to have its programs seek accreditation at the Bachelor's (basic) or Master's (advanced) level. It may have programs at both levels, but may not have accredited programs at both levels.

AEROSPACE ENGINEERING CURRICULUM

In order to set the stage for the establishment of a space engineering curricula, it is useful to trace the evolution of aerospace engineering by reviewing the early curricular requirements for a typical aeronautical engineering programs. The requirements for such a program are lised in Table 2 for a four-year baccalaureate degree in aeronautical engineering, in the early 1940 [1]. Note the number of basic courses, and the rather traditional third- and fourth-year courses.

As the aeronautical engineering field matured, and the focus on space became more pronounced, many aeronautical engineering programs changed technical electives, and restructured the course requirements. A typical aerospace engineering curricula for the 1980s is shown in Table 3 [1]. There have been significant changes in the required courses, and the focus of the technical electives has changed dramatically. Aerospace engineering education programs have clearly changed to meet the ever-changing needs of technology.

SPACE ENGINEERING CURRICULA

Two approaches to space engineering education may logically be considered. First, space engineering education may be integrated into the traditional aeronautical or aerospace engineering curricula. Alternatively, a separate new space engineering

Table 1. US accredited programs leading to degrees in aerospace and similarly named engineering programs[a]

Aeronautical and astronautical engineering
Illinois at Urbana–Champaign, University of
Ohio State University
Purdue University, West Lafayette

Aeronautical engineering
Rensselaer Polytechnic Institute
California Polytechnic State University, San Luis Obispo
United States Air Force Academy
Wichita State University

Aeronautical science and engineering
California, Davis; University of

Aeronautics and Astronautics
Massachusetts Institute of Technology
Washington, University of

Aerospace engineering
Alabama, University of
Arizona State University
Arizona, University of
Auburn University
Boston University
California State Polytechnic University, Pomona
California, Los Angeles; University of
Central Florida, University of
Cincinnati, University of
Embry-Riddle Aeronautical University, Daytona Beach Campus
Embry-Riddle Aeronautical University, Prescott, Arizona Campus
Florida, University of
Georgia Institute of Technology
Illinois Institute of Technology
Iowa State University
Kansas, University of
Maryland, University of
Michigan, University of
Michigan, University of; Ann Arbor
Mississippi State University
Missouri–Rolla, University of
New York at Buffalo, State University
North Carolina State University at Raleigh
Northrop University
Notre Dame, University of
Oklahoma, University of
Parks College of St Louis University
Pennsylvania State University
Polytechnic University
Princeton University
San Diego State University
Southern California, University of
Syracuse University
Tennessee at Knoxville, University of
Texas A&M University
Texas at Arlington, University of
Texas at Austin, University of
Tri-State University
United States Naval Academy
Virginia Polytechnic Institute and State University
Virginia, University of
West Virginia University

Aerospace engineering and mechanics
Minnesota, University of

Aerospace engineering sciences
Colorado at Boulder, University of

Aerospace option in mechanical engineering
Oklahoma State University

Astronautical engineering
United States Air Force Academy

[a] Taken from [3].

curricula could be developed. Each approach will be described in more detail.

Space engineering in traditional curricula

The objective of this type of program would be to provide an integrated educational experience directed toward development of the ability to apply pertinent knowledge to the identification and solution of physical problems in aerospace engineering with an emphasis on space operations. There have been a number of proposals on ways that present aerospace engineering curricula might be changed to include space engineering subject material.

The content of the program would be such that first-year introductory courses to aerospace engineering would be modified to serve as introductory courses to space or astronautical engineering. The time devoted to courses in aerodynamics, flight mechanics, propulsion and aircraft design would be reduced in order that courses on the fundamental operational activities of space might be included in the program. The educational resources of a comprehensive university would be necessary for the development of new courses concerned directly with space operations. Supporting course work in the fields of automation, manufacturing, telecommunications, safety, biotechnology, medicine, power, structures, navigation, meteorology, remote sensing, earth resources study, management and economics would also be necessary.

Special attention should be given to the development of new laboratories in order that competence to conduct experimental work in space engineering can be developed in the student. For example, such laboratories might permit telecommunications experimentation with satellites, computational simulation of orbit paths, simulation of space environments, or other aspects of the institutional commitment to space operations and studies.

Space engineering as a separate curriculum

The objective of such a curriculum would be to provide an integrated educational experience directed toward development of the ability to apply pertinent knowledge to the identification and solution of practical problems in space opera-

Table 2. 1940's curriculum: aeronautical engineering[a]

First year	
Chemistry–inorganic	Chemistry–inorganic
Engineering Drawing	Engineering drawing
English rhetoric	English composition
Algebra	Descriptive geometry
Trigonometry	Mathematical analysis
Engineering problems	Engineering problems
Second year	
Surveying	Aeronautics
English literature	Report writing
American government	Calculus
Calculus	Foundry
Welding	Engineering mechanics
Third year	
Aeronautics	Aerodynamic theory
Mechanics of materials	Airplane structures
Materials lab	Electrical machinery
Machine shop	Thermodynamics
Engineering mechanics	Machine design
Kinematics	
Fourth year	
Aerodynamics lab	Airplane design
Airplane design	Air transportation
Airplane construction	Aircraft engine testing
Advanced airplane structures	Seminar
Internal combustion engines	Economics
Elective	Public speaking
	Elective

Typical electives: aircraft propeller design; airplane detail design; flight test engineering

[a] From [1].

tions. Brodsky [2] has suggested the content for such a program with the title of 'astronautical engineering'.

The content of a separate curricula should be formulated such that ABET accreditation criteria are satisfied. One year of a combination of mathematics (beyond trigonometry and including differential and integral calculus and differential equations) and basic sciences (chemistry, physics, astrophysics, astronomy, life sciences and earth sciences) should be included along with one year of engineering sciences (mechanics, thermodynamics, electronic circuits, materials science, transport phenomena, computer science, etc.). Also the program should include one-half year of engineering design (placed in the final year of the program). One-half year of humanities and social sciences (e.g. philosophy, religion, history, literature, fine arts, sociology, psychology, political science, anthropology and economics) and one year of an appropriate combination of areas with space applications (automation, human factors, manufacturing, telecommunications, safety, biotechnology, medicine, power, structures, navigation, meteorology, earth resources, management and economics) should complete the formal course work. A possible space engineering curriculum is shown in Table 4 [1].

Laboratory experiences that serve to combine elements of theory and practice must be an integral component of the program. For example, projects

Table 3. 1980's curriculum: aerospace engineering[a]

First year	
History	History
Chemistry–bonding	Chemistry–organic
Chemistry lab	Chemistry lab
Composition & rhetoric	Engineering analysis
Engineering analysis	Engineering math
Engineering graphics	Physics
Engineering math	Elective
Second year	
Computer science	Numerical methods
Engineering math	Materials
Engineering mechanics	Differential equations
Electricity & optics	Government
Aerospace introduction	Engineering mechanics
Third year	
Aerodynamics	High speed aero
Aerospace lab	Aerospace lab
Aerospace structures	Materials–strength
Aerospace dynamics	Materials–composition
Applied mathematics	Propulsion
Thermodynamics	Vehicle dynamics
Fourth year	
Vehicle design	Vehicle design
Propulsion	Seminar
Government	Economics
Humanities	Electrical circuits
Elective	Humanities
Elective	Elective

Typical electives: chemical rocket propulsion; aeroelasticity; numerical simulation

[a] From [1].

Table 4. 1990's curriculum: space engineering[a]

First year	
Mathematics	Mathematics
Chemistry	Chemistry
Physics	Physics
Humanities	Humanities
Computer science	Engineering analysis
Numerical methods	Materials
Second year	
Mathematics	Mathematics
Astrophysics	Biology
Engineering mechanics	Engineering mechanics
Thermodynamics	Electronics
Computer graphics	Transport phenomena
Political science	Philosophy
Third year	
Materials science	Materials science
Gas dynamics	Propulsion
Automation/controls	Telecommunications
Social science	Orbital mechanics
Laboratory	Laboratory
Fourth year	
Vehicle design	Vehicle design
Communication design	Life support design
Space seminar	Space seminar
Space power	Astronomy
Elective	Elective
Humanities	Humanities

Typical electives: remote sensing of earth resources; space safety; weightless manufacturing

[a] From [1].

related to space application might include the design of experiments for a weightless environment. Appropriate computer-based experience must be included in the program in order that the students may demonstrate knowledge of the use of digital computation techniques to specify space engineering problems. Oral and written communication skills must be demonstrated through the student work in the space engineering courses.

CONCLUSIONS

Universities provide an environment for intellectual change and should respond to the new directions in which civilization is heading. Space activities are no longer negligible when compared to land, sea and air activities. The fundamental problems of humanity such as famine, communications, pestilence and disease must be approached from a concept that is more than earthbound. Space aspects must be considered in our future research and teaching. Now is the time to initiate carefully planned 'space engineering' programs in order to train efficiently a new breed of engineer for the challenges of the future. This paper has offered two approaches to the development of space engineering programs. Both approaches are viable, and therefore the space engineering community should decide which approach best meets the needs of the future. Graduates of space engineering programs are essential for the research and development of space-related technology.

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