Engineering Education:
PREPARATION FOR LIFE

PROCEEDINGS
1984 ANNUAL CONFERENCE
SALT LAKE CITY, UTAH
JUNE 24-28, 1984

EDITED BY:
LAWRENCE P. GRAYSON
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AMERICAN SOCIETY FOR ENGINEERING EDUCATION

VOLUME 1 -MONDAY, JUNE 25

1984

American Society for
Engineering Education

92nd Annual Conference

June 24-28, 1984

The Salt Palace
Salt Lake City, Utah

PROCEEDINGS

Volume I

Theme

"Engineering Education:
Preparation For Life"

Hosted By:
University of Utah
Brigham Young University
Utah State University
Weber State College

Edited By:
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Joseph M. Biedenbach
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Printed in United States of America

USING THE HP-41 PROGRAMMABLE CALCULATOR

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Orlando, Florida

This workshop is designed to acquaint engineering educators with the power and effectiveness of hand-held programmable Hewlett-Packard calculators, both in and out of the classroom. No previous experience is required.

The tutorial opens at "ground zero" with a thorough discussion of HP stack architecture and follows with engineering applications selected to teach one-by-one the fundamentals of interactive "Loop-type" techniques, indirect addressing for memory management, subroutine and flag use for efficiency and prompts and cues for easy-to-use program design. Tutorial examples will apply to all areas of engineering and all HP calculators, however the HP-41 is recommended for this workshop. Furthermore, algorithm formulations are ideally suited for maximum speed and efficiency on PC computers.

DR. RICHARD C. HARDEN, P.E.

Richard C. Harden was born in Miami, FL., Aug. 11, 1920. He received a BME degree in 1944, a BEE in 1956, an MSE and Ph.D. degrees in electrical engineering in 1957 and 1961 respectively, all from the University of Florida. In 1944/45 he was a U.S. Naval Reserve officer on active duty; 1945/50 a rocket and guided missile range engineer at the U.S. Naval Ordnance Test Station, CA; 1950/55 he served in the capacities of Chief Engineer at Cape Canaveral Launching Facility; Deputy Chief Optics - Mechanical Dept. of Technical System Laboratory, and Manager of the Optical Development Lab., RCA Missile Test Project, Patrick AFB, FL. He was a Professor of Electrical Engineering at the University of Missouri at Rolla 1961/67; 1967/72 he was Professor of Electrical Engineering and Resident Director of the University of Florida Graduate Engineering Education System (GENESYS) at Orlando, FL. Since 1972 he has been Professor of Engineering with the University of Central Florida (formerly FTU) and Director of UCF - South Orlando Campus. Member of Eta Kappa Nu, Phi Kappa Phi, Sigma Zi, Tau Beta Pi, IEEE, ASEE, SES, NSPE & FES. Received best paper John Curtis Award.

DR. FRED O. SIMONS, JR., P.E.

Fred O. Simons, Jr. was born in Heidelberg, Mississippi on July 7, 1937. He received his BSEE degree in August 1960 from Mississippi State University, and his MS and Ph.D. degrees in electrical engineering from the University of Florida in 1962 and 1965 respectively. From August 1960 thru June 1961 he was an instructor with the Department of Electrical Engineering at Mississippi State University. He later joined NASA at Huntsville, Alabama for three months. From 1965 to 1971 he was with the University of Florida's Graduate Engineering Education System (GENESYS), Orlando, Florida as an Associate Professor of Electrical Engineering. From September 1971 to September 1972 he was an Associate Professor of Electrical Engineering at the University of Florida's Eglin AFB Center. In 1972 he joined the University of Central Florida (formerly Florida Technological University) as an Associate Professor and in 1978, after a years leave of absence to direct a Navy Lab, returned to UCF as a full Professor. He is a member of Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, IEEE, SCS, FES and ASEE. Received best paper John Curtis Award.

PERSONAL COMPUTER SOFTWARE EXCHANGE-ENGINEERING TECHNOLOGY SESSION

Allen Katz
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For a number of years informal groups have existed inside the ASEE for the purpose of exchanging educationally related microcomputer software. This session organized by the Engineering Technology Division is designed to familiarize faculty with some of the various programs available from these groups and to provide a convenient means of software distribution.

The exchange is organized in the style of a poster session with "speakers" on hand to demonstrate and discuss their programs. Most common personal computers (Apple, TRS80, IBM, CPM, etc.) will be available for software duplication. Attendees are responsible for bring their own tape or diskettes to copy software.

The following programs developed by the author and some of his students are a sampling of the type of software which will be available at the exchange. These programs were written to run on CDL Extended Disk Basic. With the exception of sections of programs which SAVE and/or READ data files to/from disk, these programs should run under Micro Soft's MBASIC or other similar versions of the BASIC language with little or no modification.

TCAP - Trenton Circuit Analysis Program, a general purpose circuit analysis program written in Basic which performs DC and AC circuit analysis on an N node circuit. This program is similar to classical Fortran ECAP. Possible elements include resistors, capacitors, inductors, voltage sources, current sources, transistors (NPN and PNP) and Operational amplifiers. Both frequency and component value can be varied. Output can be displayed in both tabular and graphical form.

SAT - Satellite system design program. This program calculates communications system characteristics for an active satellite network. Both up-link and down-link parameters are considered.

IND-CALC - Inductor design and analysis program. This program allows the analysis or synthesis of inductors composed of strap, straight wire or wire wound in a cylindrical coil.

UPLOT - Universal plotting program written to work with any terminal and printer. This program will graph two sets of data points and automatically handle all scaling. It also provides for editing and storing of data files on disk.

FILTER - Filter design program. Allows the synthesis of LP, HP and BP filters of Butterworth or Chebishev type - up to 10 sections. Specify pass band frequency limits, stop band frequency limits, required attenuation and terminal impedance. The program calculates the number of sections necessary for a given filter type and the required component values. The program allows the choice of 11 different prototype configurations (only 7 are implemented in the current version). This feature facilitates the realization of a filter with practical component values. The program also allows individual parameters to be varied (as terminal impedance) until satisfactory component values are achieved.

AMPCALC - S parameter circuit design program which calculates from a set of S parameters: input and output impedance, voltage gain, available gain and transducer gain (both unilateral and actual gain), unilateral constant gain circles, stability constant, optimum source and load impedances for unconditionally stable amplifiers, stability circles, and constant noise figure circles (when gamma opt. data is available). The program also permits the source and load impedances to be varied in an interactive manner which allows the optimum transducer gain to be determined for a conditionally stable amplifier and S parameter files to be saved and read from disk.

L-MATCH - L matching network design program. Specify L network configuration, unloaded Q, complex source and load impedances and this program gives the elements required for a match, loaded Q and network loss in dB.

Q-MATCH - This program is an extension of L-MATCH to common 3 and 4 element matching networks (i.e. PI, Tee, PI-L). The program allows the loaded Q to independently be specified and provides the element values necessary for both match and required Q. The impedance of the source is limited to 50 ohms real. The load may be any complex impedance.

S-MATCH - Single stub matching program. The position from the load and length of a shorted shunt stub is calculated for a specified complex load and line Z0. Stub and line characteristic impedance are assumed to be the same.

MS - Microstrip design program. Allows analysis and synthesis of both coupled and single microstrip transmission lines. The program also calculates wavelength on the basis of effective permittivity at a specified frequency.

COMB - Microstrip comb line filter design program. Calculates the dimensions of band pass microstrip comb line filters. Normalized low pass prototype element values for the desired filter type are required.

FILT-ELE - Low pass prototype filter element program. This program is usually used in conjunction with COMB to determine equivalent LPF elements. Data require is identical to that of FILTER except normalized prototype element values are provided.

YZHT-S - Two port conversion program. This program converts either Y, Z, H or T (ABCD) two port parameters to their equivalent S parameters.

S-YZHT - S parameter conversion program. Reverse of YZHT-S program. Converts S to either Y, Z, H or T parameters.

SPUR - Spur analysis program. Calculates N x M products of a local oscillator multiplier chain. Considers both clean and dirty L.O. cases. Allows any number of simultaneous critical bands to be specified. Allows range of N x M products to tailored to specific system needs.

T-PI - Tee and PI network two port parameter program. The Z parameters of a generalized T or the Y parameters of a PI network are calculated. Resultant two port parameters may be saved as a disk file.

T-NET - Tee network S parameter program. Calculates the S parameters of a generalized Tee network.

MAT - Two port arithmetic program. Adds or multiplies 2 two port matrixs. Reads and saves two port files.

NF-CALC - Noise figure calculation program. Calculates amplifier NF from Y factor, gain and 2nd stage NF data.

WAVE-G - Rectangular Waveguide design program. Calculates cut-off frequencies for different modes, characteristic impedance and wavelength in the guide for a specified operating frequency.

TEMP-2P and TEMP-3P - Thermistor temperature compensation programs for a 2 and 3 point curve fit respectively.

FOURIER - Fourier series program. Calculates and plots the Fourier spectrum of a waveform. A square wave is specified in the program. The program most be modified for other shape waveforms.

FFT - Fast Fourier transform program similar to Fourier but uses Fast Fourier algorithm.

DC-BIAS - Bias calculation program. Performs analysis or synthesis of common bipolar transistor bias circuits.

REFCOEF - The reflection coefficient corresponding to a given complex impedance is calculated. This program also calculates the inverse relationship.

IMD5 - This program calculates all intermodulation products up to fifth order generated by a nonlinear transfer function represented as a power series. Both the frequency and level of intermodulation products are displayed in order of ascending frequency. The program requires the level and frequency of the two sinusoidal signals to be applied to the input of the nonlinearity and the coefficients of the power series representing the nonlinearity.

Z-INVT - Impedance inversion program. This program calculates the parallel equivalent of circuit of a given complex impedance.

SMITH - Smith Chart program. This program calculates the input impedance of a transmission line terminated in an arbitrary load impedance.

C-AMP2 - Class C amplifier design program. Simplistic program to design class C transistor amplifier. (Based on equations in RCA Power Devices handbook.)

TRANSLIN - Transmission line simulation program. This program displays the voltage standing wave pattern along a transmission in a graphical form.

Other authors will present programs from the fields of mechanical and civil engineering as well as additional electronics applications and programs for grading and record keeping. (Contact the author for further information on user groups and software exchange.)

CALL FOR SOFTWARE

The Engineering Technology division will be sponsoring a special Personal Computer (PC) Software Exchange session at the ASEE Annual Conference in Salt Lake City, Utah. The exchange will be organized in the style of a poster session with "speakers" on hand to demonstrate and discuss their programs. Most common PC's will be available for software duplication. (Plans call for Apple, TRS80, IBM, CPM and Commodore machines to be present. Attendees will be responsible for bringing their own tape or diskettes to copy software.

Engineering technology related software of all forms and types are sought for this exchange.

Faculty interested in sharing their software should send a short description (less than one page) to Dr. Allen Katz, Electronics Engineering Technology Department, Trenton State College, Trenton NJ 08625, (609-771-2487).

Presenters are expected to bring a copy of their software along with a description and explanation of its application. (A nearby copier will be provided for copying documentation.) Each speaker will be required to sign a release form, agreeing that software and documentation are shared freely. Presenters are also encouraged to write-up a detailed description of their software for inclusion in the conference proceedings.

CONTRIBUTION FORM FOR ASEE/ETD SOFTWARE EXCHANGE

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DESCRIPTION OF WHAT IT DOES:

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ALLEN KATZ

Dr. Allen Katz is chairperson of the Electronics Engineering Technology Department at Trenton State College and is currently president of Electrical/Electronics Engineering Technology Department Heads Association. He is an active consultant in the RF/Microwave area and was involved with the design of the first direct broadcast satellite for RCA Astro Electronics. He is a director of the Amateur Computer Group of New Jersey and coordinator of the Trenton Computer Festival. He received his doctorate from New Jersey Institute of Technology in 1970. Before assuming his present position he was with ITT laboratories and RKO General. He is also an active radio amateur and received the American Radio Relay Leagues' Technical Merit Award in 1976 for his work with Earth-Moon-Earth Propagation.

Undergraduate Space Education at the United States Air Force Academy

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INTRODUCTION

The United States Air Force Academy has a relatively long history of offering space education at the undergraduate level, both in the core curriculum and in the elective majors' program. In this paper, I'll briefly discuss the core program and then present, in some detail, the three space-related disciplinary academic majors' programs leading to a bachelor of science degree: astronautical engineering, space sciences, and space physics.

Before we start, I need to make an important point. The first mission of the Academy is to graduate the best possible officers for a career in the United States Air Force. We feel it's much more important to graduate a good officer with no academic major, than to graduate a top engineer who will be a poor officer. So, although we concentrate a great deal of effort on creating a top-notch academic program, we do so without compromising the military and athletic programs that are equally important to the Academy mission.

THE CORE PROGRAM

Each cadet at the Academy must complete 114 semester hours of core studies as follows:

Basic Sciences	34.5 hours
Engineering	24
Social Sciences	25.5
Humanities	27
Flight Core	3

Included in this core program is a three-semester-hour course in the principles of astronautics. In addition to the balanced core program, every cadet has the opportunity to select one of 19 disciplinary majors consisting of eleven additional three-semester-hour courses focused in a specific disciplinary area. A cadet selecting one of these disciplinary majors will then graduate with a total of 147 semester hours and a Bachelor of Science degree in that major.

THE ASTRONAUTICAL ENGINEERING MAJOR

Our astronautical engineering major was first offered to graduates of the class of 1965. To my knowledge, this major is unique because it's the only accredited pure astronautical engineering major offered at the undergraduate level in the country. To date, we've graduated approximately 700 astro majors. The program has tripled its enrollment over the last few years -- we now have about 80 majors in each graduating class. The major has changed over the years from a requirement of about 18 additional courses beyond the core to the current eleven.

The major in astronautical engineering is the broad application of science and engineering to aerospace operations. Special emphasis is placed on astrodynamics, aerospace systems design, and control systems. Thus, the cadet is prepared for Air Force duty with specialization in research, design, development, and analysis of space technology. The major is structured as follows:

Basic Engineering Techniques

A required three-course sequence consisting of the following courses:

Applied Differential Equations

Aerospace Engineering Techniques (Dynamics, FORTRAN, and numerical methods)

Linear Systems Analysis and Design

General Astronautical Engineering

A required four-course sequence consisting of the following courses:

Principles of Astronautics (core requirement)

Space Vehicle Systems (sensors, support systems, propulsion, and navigation, guidance and control)

Astrodynamics

Linear Control Systems Analysis

Applications

A three-course sequence specializing in one of the following seven categories:

Astrodynamics
- Classical Mechanics I
- Classical Mechanics II
- Advanced Astrodynamics

Navigation, Guidance and Control
- Applications of Aerospace Guidance and Control
- Inertial Navigation
- Modern Control Theory and Design

Propulsion
- Propulsion I
- Propulsion II
- Option

Structures
- Dynamics
- Aircraft Structural Analysis
- Vibrations

Flight Mechanics
- Flight Mechanics I
- Flight Mechanics II
- Inertial Navigation

Communication
- Signal and System Analysis
- Communications Systems
- Digital and Data Communications

General (any three-course combination taken from the courses offered in any of the above six categories)

Many of the courses offered in the applications sequence are administered by other departments (mechanical engineering, electrical engineering, aeronautics, and physics).

Design

A two-course sequence consisting of the following courses:

Aerospace Vehicle Systems Design

Space Mission Design or Digital Control Theory and Design

Throughout this major, we place primary emphasis on real-world applications and design. Cadets have extensive lab facilities available including a complete guidance and control lab, several computer systems, and design equipment. Cadets also build and fly small experiments aboard the Space Shuttle each year.

THE SPACE SCIENCES MAJOR

We added the space sciences major to the curriculum in the 1983 fall semester. Although it was intended to be offered first to the Class of 1986, three cadets will graduate with this major in 1985. The major is designed to develop Air Force officers with an understanding of contemporary problems and issues peculiar to space. Courses in astronautics, physics, electrical engineering, computer science, mathematics and other disciplines provide the breadth of education the space field requires. This interdisciplinary program appeals to students who wish to prepare themselves for a future in space-related careers.

Required Courses

The following eight courses are required for all students in this major:

Principles of Astronautics (core requirement)

Introduction to Space Sciences

Space Vehicle Systems

Structured FORTRAN for the Scientist/Engr

Astrodynamics

Instrumentation Systems

Mathematical Modeling

Space Mission Design

Social Sciences Option

The cadet must choose one of the following social sciences courses:

Systems Acquisition and Management

Human Factors Engineering

Macroeconomic Theory

International Law

Public Administration

Analytical Methods Option

The cadet must choose one of the following analytical methods courses:

Aerospace Engineering Techniques

Applied Differential Equations

Computational Matrix Algebra

Cartography

Geographic Application of Imagery Analysis

Astronomical Techniques

Introduction to Management Science

Space Sciences Option

The cadet must take one upper-level course (course number 300 or 400) in the basic sciences or engineering sciences.

Open Option

The cadet must take one additional upper-division course (course number 200 or higher) offered by any academic department.

Although this is a brand-new major and we don't have firm enrollment projections, we anticipate that 20 to 30 cadets will graduate each year with this degree. This major is not as academically challenging as the astronautical engineering major and hopefully will attract cadets with a strong interest in space who would have a difficult time with the more demanding engineering major.

THE SPACE PHYSICS MAJOR

The major in physics concentrates on basic principles and on mathematics. It provides an excellent academic background for a wide range of technical assignments with the Air Force, particularly in the field of research and development. The major is divided into three areas of emphasis: pure physics, engineering physics, and space physics. I'll address the space physics area here.

Required Physics Courses

Each cadet must complete the following nine physics courses:

General Physics I (core requirement)

General Physics II (core requirement)

Applied Differential Equations

Classical Mechanics I

Classical Mechanics II

Introduction to Modern Physics I (Special Relativity - core substitute)

Introduction to Modern Physics II (Quantum Mechanics)

Laboratory Techniques

Electromagnetic Theory I

The Space Physics Track

Each cadet must take the following two courses:

Introduction to Space Science

Plasma Physics

The cadet then selects one of the following two courses:

Solar-Planetary Interactions

Astrophysics

Additionally, the cadet selects one course from the following options:

Solar-Planetary Interactions

Upper Atmospheric Physics

Astronomical Techniques

Astrophysics

Astrodynamics

Finally, each cadet must take one optional advanced math course.

The space physics major, like the astronautical engineering major, is both challenging and academically difficult. We will graduate our first space physics majors in 1985 and anticipate that we will continue to graduate approximately 10 to 20 each year. It attracts the student interested in the science, rather than in the engineering, side of space.

CONCLUSION

In a few short pages, I've tried to provide you with an overview of space education at the Air Force Academy. From the course titles, you should be able to determine the approximate course content. If you need more information, refer to the Academy Catalogue or feel free to write the specific department at the Air Force Academy.

We feel we offer a broad range of space-related majors tailored to current national needs. We anticipate that we will continue to provide academic leadership in meeting the future space needs of both the Air Force and the nation.

COLONEL ROBERT B. GIFFEN

Colonel Robert B. Giffen, U.S. Air Force, is a distinguished graduate of the United States Air Force Academy and was graduated summa cum laude from the University of Heidelberg, where he earned a PhD in Astrodynamics as an Olmsted Scholar. Colonel Giffen is a senior pilot and a graduate of the United States Navy Test Pilot School, with five years of test pilot experience and more than 200 combat missions as a special operations and combat rescue pilot in Southeast Asia. His most recent assignments include Senior Research Fellow with the National Defense University and concurrently a student at the National War College, Deputy Head for Astronautics at the USAF Academy. He has published articles in the journal "Astronomy and Astrophysics" International Astronautical Union, the Air University Airpower Symposium, the USAF Academy Military Space Doctrine Symposium and the Fletcher School of Law and Diplomacy. Colonel Giffen is currently serving as Professor and Head, Department of Astronautics, USAF Academy, Colorado.

Some Ideas for an Undergraduate Curriculum in Astronautics

Robert F. Brodsky
Director, Technology Planning
TRW Space & Technology Group
Redondo Beach, California

INTRODUCTION

The purpose of this paper is three-fold:

1. To make it clear that a course of study in astronautics is a unique specialty, which, although sharing the concept of "flight," bears no closer relationship to aerospace engineering than does, for example, mechanical engineering

2. To describe the undergraduate and graduate astronautics courses needed to supplement the core engineering courses

3. To begin the initial campaign either to revise the AIAA accreditation Program Criteria (guidelines) which cover aerospace engineering so that they unambiguously include astronautics, or to insist on the establishment of a separate set of guidelines unique to astronautics. (Requiring that astronautical engineers learn advanced aerodynamics is as inappropriate as insisting that aeronautical engineers learn orbital mechanics.)

The basic premise of these three points is that it has been and will continue to be possible for a substantial number of aerospace-trained engineers to live their whole professional lives without ever coming in contact with an airplane. If such contact does occur, a well-trained astronautical engineer should be able to learn "in the back alley," just as I learned to transform myself successfully from an aeronautical into an astronautical engineer.

Author's Qualifications

To lend a greater air of authenticity to this paper, I think it worthwhile to digress sufficiently to convince the reader that I am capable of writing authoritatively on the subject. I am a former full-time educator (Professor and Head of the Aerospace Engineering Department at Iowa State University), and have made my living in the spacecraft field since 1959. In 1973, I introduced a new course, Space Systems Design, at Iowa State and, in the following year, a course in Remote Sensing Instrumentation; both were pioneering astronautics courses. I serve on the AIAA Educational Activities Committee, and am an AIAA accreditation visitor and coauthor of the AIAA accreditation guidelines. Moreover, I have been thinking about this problem since I served as accreditation visitor to the AFIT Masters of Astronautical Engineering Degree program, sans suitable guidelines. My present thoughts jelled this winter when I aired them in a short talk entitled "Where Is the 'Space' in Aerospace?" at an educational panel session at the AIAA Aerosciences meeting in January.

BACKGROUND

Before describing the key courses that might characterize undergraduate and graduate degree programs in astronautical engineering, I will describe my view of the present educational attitude vis-a-vis astronautics.

Truth in Advertising

In the '60s, when progress overtook traditional education, most aeronautical engineering departments changed their names and degrees to "Aerospace" or "Aeronautics and Astronautics" Engineering by the simple expedient of adding an elective (usually) course in orbital mechanics taught from early texts easily understood by professors skilled in dynamics. Later, the capstone design courses included a "Space" option as literature became available, and propulsion courses added a bit of rocket propulsion theory. Alas, this situation remains static today. To my knowledge,* the only undergraduate aerospace schools (besides the Air Force Academy, which grants a BS degree in astronautics from their Department of Astronautics) which conform to truth-in-advertising ethics (by offering at least one true space course in addition to orbital mechanics) are MIT, Michigan, Purdue, Colorado**, Illinois, and Howard. Note, however, that this is still a far cry from the course content that will be proposed later. At the graduate level, in addition to the Air Force Institute of Technology, education in space is

*See Report on the Request for Information on Aerospace-Type Programs, prepared for the Academic Affairs Committee of the American Institute of Aeronautics and Astronautics by Professor Eric Jumper, Air Force Institute of Technology (24 departments surveyed).

**Just embarking on a "Space Sciences" elective option towards their BS degree in Aerospace Engineering Sciences.

available to some extent at Stanford, USC, Texas/Austin*, Howard, and Iowa. (I apologize to those schools who believe they should be added to this sparse list, many of whom participated in the Getaway special program.) My suggestion, therefore, is for each aero department to examine the question of whether they are truly meeting their advertised claims — or revert back to "Aeronautical Engineering."

Jobs in Astronautical Engineering

It is my contention that if a survey of students in aerospace engineering programs were taken, about half would express an interest in employment in the space industry. I imagine that considerable similar student interest exists in mechanical and electrical engineering fields. A major premise of this paper is that space-oriented industry and government organizations can, do, and will continue to support a significant number of engineers, and thus deserve to be better served by academia. The leading three or four spacecraft primes listed below are each billion-dollar-a-year enterprises — and growing. Chief competitors in this category, in rough order of sales, are the space part of Lockheed Space and Missiles, the Space and Communications Group of Hughes Aircraft, the spacecraft part of RCA, the Space and Technology Group of TRW, the spacecraft (as opposed to the Shuttle) part of Rockwell, followed by the spacecraft parts of Ford Aerospace, General Electric, Fairchild, Ball Brothers, and Martin/Denver. Government labs and support organizations heavily involved in spacecraft and space instrumentation are the NASA Goddard and Ames centers, a sizable part of the Jet Propulsion Lab, parts of Aerospace Corporation, MITRE, Applied Physics Lab, and Naval Research Lab. Moreover, a burgeoning commercial business of companies involved in the communications field is emerging.

Additionally, many large programs conducted by the major aerospace primes are devoted to space transportation. Chief among these companies are Rockwell, McDonnell-Douglas, Martin/Denver, General Dynamics, and Boeing. These efforts are supported by NASA Centers in Houston, Huntsville, and Cleveland, as well as Air Force Labs at Wright Field and Edwards Air Force Base, and the Vandenberg and Kennedy launch facilities. Moreover, private enterprise in the commercial expendable launch vehicle and upper stage vehicle is emerging.

Finally, it seems obvious that our next big initiative in space will be the establishment of space stations. Here again, the major prime industry companies who will be involved are Boeing, Rockwell, McDonnell-Douglas, TRW, Grumman, General Dynamics, Martin, and Lockheed, as well as many other subsystem specialist companies. NASA organizations at the Johnson, Marshall, Lewis, Langley and Goddard centers will join headquarters personnel in running the program. Finally, if one notes the military budget in space, it may be seen that it already outstrips the entire NASA budget. Many new civilian jobs are being developed as a result of this increased budget, both in support of DoD organizations and in industry.

One may ask why the space industry has not voiced a concern to academia about the apparent lack of relevant training of university graduates in space technology. My feeling is that industry is resigned to the fact that the academic world is not presently capable of either knowing what the proper training is, or how it can be supplied. Thus, the space industry is willing to perform "on-the-job" training, building on the excellent basic background that most graduates have assimilated. I firmly believe that this industry will be more than willing to support university research in astronautics as soon as capable faculty seek such support.

The Trouble in Academia

Although astronautical engineering logically could be adopted by mechanical engineering (structures, heat transfer, controls), electrical engineering (power, communications, controls), or aerospace engineering (structures, aerodynamics, controls, orbital mechanics), it appears almost by default to have become the neglected offspring of the aerospace departments. It gives the faculties of most aerospace engineering departments great comfort to believe that since their curriculum teaches the "basics," their proffered education already "covers" the field of astronautics. This is not surprising since profiles of the faculties of the 50-odd departments giving some kind of an aerospace degree show that only a handful have worked in the space industry for any signifcant time, and that few consult with this industry. Moreover, most are well-established in research devoted to aeronautics and thus have little incentive to take an interest in space technology. It is easy for them to rationalize their arguments, since they don't know what an astronautical engineer needs to know.

The AIAA Accreditation Program Criteria

To illustrate this trouble, one need simply examine the only specific guidelines (AIAA Accreditation Guide) which now accredit (at the basic level) the two available astronautical engineering programs (i.e., the Air Force Academy BS and Air Force Institute of Technology MS Degrees):

> "Engineering Sciences. Topics in aerodynamics, aerospace materials and structures, propulsion, and flight mechanics shall be included. Programs emphasizing space flight (astronautics) shall also include topics in orbital mechanics, space environment, attitude determination and control, and avionics/telecommunications."

The operative word is "also." The statement says that after a student has taken the courses which cover the topics to qualify as an aeronautical

*Will shortly offer their Aero students an undergraduate option of Atmospheric Flight or Space Flight; each with a 7-hour core. For Space Flight, they will offer a 3-hour course in Altitude Control; a 1-hour laboratory; and a 3-hour course in Spacecraft/Mission Design. These courses replace Compressible Fluids, Compressible Fluid Laboratory, and Aircraft Design.

engineer, then additional topics can be taken in the astronautics field as electives. This is second-class citizenship at its most brazen, pronounced by persons of goodwill protecting the good and pure name of the "Aerospace Engineering" degree. But an astronautical engineer really doesn't need to take required courses in airplane flight mechanics, gas turbine engines, and advanced aerodynamics. It is clear that the guidelines must be changed to permit this new field of endeavor to stand on its own feet; moreover, such guidelines must be written by space practitioners, and not by the uninformed. Admitted, the author was a part of the group that achieved the quoted change to the old criteria. The adopted wording was the best compromise that could be attained against the old guard philistines.

CURRICULUM

The gist of this paper is the revelation of what courses (falling in the "Engineering Sciences" category for accreditation) constitute a basic professional astronautical engineering curriculum at the undergraduate level. I will present this information in two parts, first describing the new course material I think is necessary, and then reviewing the existing Air Force Academy (AFA) and Air Force Institute of Technology (AFIT) programs. A curriculum in astronautical engineering would obviously include the same core courses in math, physics, chemistry, science, and humanities as any other engineering program.

The new courses needed to provide a broad background in astronautics are described below. Note that not every course topic would necessarily constitute a semester's (or quarter's) worth of work. Some topics could be incorporated into ongoing courses, while others might be combined to make a separate course.

- Orbital Mechanics I. Traditional course in two-body and restricted three-body mechanics.
- Orbital Mechanics II. Launch vehicle performance requirements, mission ΔV requirements, launch window considerations, and orbital perturbations. Special emphasis on geosynchronous, sun-sychronous, and Molniya-type orbits, and mission design and optimization. A course somewhat akin to Atmospheric Flight Performance.
- Spacecraft Dynamics and Control. Momentum conservation, spinning spacecraft dynamics (including dual spin and gyrostats), fuel sloshing, damping, nutation control, zero momentum, momentum-biased systems, control by CMGs, magnetics, gravity gradient, etc.
- Spacecraft Instrumentation. Attitude determination systems; scientific instruments; principles of visual, infrared, and microwave radiometry; radar sensing and imaging systems; lasers and fiber optics applications; optics, CCD, and SAWS techniques; solar, stellar, and horizon sensors. (Overlap with Physics Department.)
- Spacecraft Power. Solar cells, fuel cells, batteries, and power distribution and control systems (theory and design). Nuclear power systems, solar array systems, and conversion of power via microwaves. (Overlap with Electrical Engineering and Physics Departments.)
- Telecommunications. A series of courses, starting with an undergraduate introduction, covering antenna theory, link losses, modulation, noise, bit error rates, Shannon's law, etc. (Overlap with Electrical Engineering Department.) The book on the telecommunications cited in Table 1 permits this subject to be successfully taught to an engineer with any disciplinary background.
- Avionics. Gyros, navigation, inertial systems, guidance systems, and displays. (Overlap with Electrical Engineering Department.)
- Space System Design. Broad-brush course covering all major subsystems, stressing design trade-off and state-of-the-art figures of merit. This could be the capstone design course. (This is the course which I developed at Iowa State University, and now teach at the graduate level at USC.)
- Spacecraft Propulsion. Low-thrust monopropellant and bipropellant engines: pump versus pressure-fed systems; tankage design and propellant management systems; electrothermal, resisto-jet, and electric propulsion; nuclear rocket propulsion; solid motor design; and thrust vector control.
- Space Environment. Description of the near-earth environment and its effect on spacecraft design. Survivability, hardness considerations, testing, charge buildup, Space Shuttle environment, and magnetic cleanliness.
- Radiation Heat Transfer and Temperature Control. Coatings, form factors, machine programs, active and passive control systems, heat pipes, cryogenics, and insulation. (Overlap with Mechanical Engineering.)
- Manned Space Flight. Physiology, life support, man's capabilities, living in space, testing systems, EVA, and mechanical and propulsive support systems (overlap, in part, with Bio Med Engineering).
- Data Handling/Processing. High-volume, high-speed data systems; data compression; artificial intelligence; system architecture, ground versus space operation. (Overlap with Computer Science Department.)
- Structure and Mechanisms. Finite elements applied to spacecraft/Shuttle/cradle combinations; new materials for space applications, special mechanisms, zero-gravity simulations.

Another area of studied faculty ignorance is in the matter of proper laboratory support of space-oriented coursework. Here again, the wind tunnel and its normal accoutrements is not the darling of the astronautical engineer. Rather, vacuum chambers, air bearings, inertial platforms, zero 'g' simulators are the devices and instrumentation that must be covered. In a physics lab sense, the art of testing detectors, e.g., I.R., and making radiation heat transfer tests, and determining the modulation transfer function of optical systems should be covered. In short, the lab support program must be rethought and, alas, new types of equipments must be acquired. Most of the above courses can be taught at an undergraduate level or at a senior/first-year-grad-student level. Graduate-level courses in remote sensing, telecommunications, data handling/processing, dynamics, and instrumentation are envisaged as continuations of the described courses at the next level of difficulty.

I have made no attempt to outline a strawman curriculum towards a degree. Individual faculties, properly advised, will have to do this, utilizing the strengths they have available to them. Obviously, because of the availability of local experts, urban university course selection might differ significantly from that of nonurban schools. Also, students could be offered options in "Aeronautics" and "Astronautics" if the accreditation guidelines were liberalized.

Two discouraging facts emerge: (1) there is a paucity — indeed, in some cases, a dearth — of textbooks to support most of these courses; (2) because of their multidisciplinary nature, there are a very limited number of regular faculty capable of teaching them. As suggested above, the latter problem can be solved initially (i.e., until regular faculty become available) in urban areas by utilizing adjunct professors from industry, and in the boonies by multidepartmental efforts and joint courses. The text problem will also correct itself with time, as more astronautics programs emerge. In the meantime, Table 1 offers a start on the textbook problem.

Now, let us see what the Air Force has done to protect their space interests. I believe that the Air Force found it necessary to develop undergraduate (AFA) and graduate (AFIT) degree programs in astronautics because they could find no other universities to train their officers. This situation still exists. Indeed, recognizing that the country will shortly embark on wider enterprises in space, the AFA is now offering, starting with the class of '85, a new major in "Space Sciences." The catalog listing will read:

> "The major in Space Sciences is designed to develop Air Force officers with an understanding of contemporary problems and issues peculiar to space. Courses in astronautics, physics, electrical engineering, computer science, mathematics, and other disciplines provide the breadth of education required for this growing field. This interdisciplinary program will appeal to students who wish to prepare themselves for a future in space-related careers."

Table 1. A Selection of Astronautics Texts

SUBJECT	TEXT
DYNAMICS, RENDEZVOUS	MODERN SPACECRAFT DYNAMICS AND CONTROL, MARSHALL H. KAPLAN, JOHN WILEY AND SONS
CONTROLS, ATTITUDE INSTRUMENTATION	SPACECRAFT ATTITUDE DETERMINATION AND CONTROL, J. WERTZ, EDITOR, REIDEL BOOKS
REMOTE SENSING	MANUAL OF REMOTE SENSING, AMERICAN SOCIETY OF PHOTOGRAMMETRY
TELECOMMUNICATIONS	COMMUNICATIONS SATELLITE SYSTEMS, J. MARTIN, PRENTICE-HALL, INC., 1978
SPACE ENVIRONMENT	PROF. L. SENTMAN NOTES (UNIVERSITY OF ILLINOIS) OR SPACE PHYSICS, ROSEN AND LE GALLEY, WILEY
SYSTEM DESIGN	SCIENTIFIC SATELLITES, NASA SP-133, CORLISS OR R. BRODSKY, IOWA STATE AND USC NOTES

Table 2 presents a comparison of the AFA's curricula in Aeronautics and Astronautics, listing the Engineering Science courses peculiar to each degree. A description of the astro courses is given in Appendix A. Table 3 lists the course selection for the new Space Sciences major.

The AFIT Master's degree in astronautical engineering consists of a required core program (Table 4), plus two specialty sequences of three courses each, chosen from the following eight specialty groups:

- Spacecraft Stability and Control
- Estimation Theory (Stochastic Controls I, II, and III)
- Propulsion
- Reentry Aerodynamics
- Heat Transfer
- Structural Analyses
- Vibrations
- Advanced Astrodynamics (i.e., Analytical Mechanics, Orbital Mechanics, and Orbit Determination).

AFIT also has added a three-course astronautics studies elective (Structures, Propulsion, Orbital Mechanics) to its Bachelor's program in aeronautical engineering. These courses are taken in addition to the normal aeronautics courses.