Developing an Integrated Aerospace Engineering Curriculum

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Abstract

When the College of Engineering at the University of Oklahoma was given additional faculty positions to boost the major areas of Aerospace Engineering (AE), Electrical Engineering (EE), and Computer Science (CS), the three Schools started an ongoing discussion about the best multidisciplinary use for such faculty members. On recommendation of then Assistant Dean of Engineering at OU, Donna Shirley, who was the manager of the NASA Mars Exploration Program in the 90's, the School of Aerospace and Mechanical Engineering (AME) decided to update and modernize its AE course sequence, adding new thrust areas in EE and CS to its award winning and ABET accredited conventional AE program.

Over the last two years, AME has developed a challenging and exciting modern AE curriculum that incorporates the growing field of intelligent systems as a major aspect into the mix of courses and increases the space-engineering component while preserving a strong aeronautics program. Specifically, the digital aspects of AE technology were added: an embedded real time systems experience and an expanded controls sequence. The standard modern physics course was replaced by our own course in astrodynamics and space science, coupled with an elective follow-on course in space systems and mission design to enhance the space component of the program. The new course offerings are rounded out by a systems engineering course together with two capstone semester experiences.

It is expected that these changes will better prepare our students to compete in a job market that has moved to hiring students who understand the systems integration of differing technologies, all coming together to make up a complex aircraft or spacecraft, rather than students trained solely in the conventional aerospace disciplines.

Introduction

In 1999, the enrollment of the Aerospace Engineering program at the University of Oklahoma had declined to less than 100 students, compared to the Mechanical Engineering enrollment of over 500. In the same time frame, the University of Oklahoma College of Engineering (CoE) was going through the ABET 2000 accreditation process. Based on the industrial and government laboratory (JPL) experience of Donna Shirley and members of the AME Advisory Board, it was obvious that a modern Aerospace Engineering program had to teach more than the old basics of aerodynamics, structures, and propulsion, especially more material in the control of aerospace systems. Modern aerospace systems range from piloted aircraft and interplanetary spacecraft to unmanned autonomous vehicles to "smart" missiles, all of which depend heavily on computer control. In the design of such vehicles, decisions have to be made between conflicting aspects of performance, for example, having stability provided entirely by the structural and aerodynamic design or using computer systems to provide control for inherently unstable systems. Also, modern aerospace systems are becoming more and more autonomous. Cruise missiles can recognize terrain and landmarks and attack targets with ever increasing accuracy. Airliners such as the existing Boeing 777 and the planned Boeing 7X7 are optimized for fuel efficiency, noise reduction, passenger comfort, etc., but sacrifice stability in some operational regimes, relying on computer control instead. Even the ancient (1960's) computer systems in the space shuttle control the reentering shuttle when it passes through flight conditions which cannot be controlled by the pilot. In the late 1990's, the Deep Space I interplanetary mission encountered a comet and an asteroid which it autonomously detected and imaged while traveling at enormous velocity. The 1997 Mars rover, Sojourner Truth, had some rudimentary form of autonomous control when it traveled across the Martian surface. An additional rover mission, launched in 2003 and landed on Mars in early 2004, is presently demonstrating much higher levels of autonomous control.

To update the Aerospace Engineering course sequence by the addition of such intelligent systems technologies, we had to provide additional courses in software engineering, computer architecture, and controls, disciplines not normally covered by the average teaching capabilities of standard Aerospace Engineering faculty. In 1999, the Aerospace Engineering program had lost a number of faculty members to retirement. In addition to replacing them, the President of the University of Oklahoma agreed to let the College of Engineering hire between two and five additional faculty members to make the implementation of the new, intelligent systems-oriented curriculum possible. A multi-disciplinary faculty search committee was established which, over the next two years, succeeded in hiring two new faculty members, one in Aerospace and Mechanical Engineering and one in Electrical and Computer Engineering. A third colleague is about to be hired in Computer Science. By 'trading' teaching assignments between Schools, Aerospace Engineering students can now be taught by this Electrical Engineering faculty member under an AE course number, and can also be admitted into Computer Science classes. This paved the way for the development of an updated multidisciplinary 'Intelligent Systems in Aerospace Engineering (ISA)' curriculum by the author in collaboration with many faculty members from the Schools of Aerospace and Mechanical Engineering, Electrical and Computer Engineering, and Computer Science.

Curriculum Development

The old AE curriculum and the new ISA curriculum are shown in Figure 1 for comparison. The latter was designed to satisfy five requirements:

REQUIREMENTS FOR THE BACHELOR OF SCIENCE IN AEROSPACE ENGINEERING

Old AE Degree Requirements: 123 Total Credit Hours

Yr	FIRST SEMESTER	Hr	SECOND SEMESTER	Hr
1	ENGL 1113, Prin. of English Composition	3	ENGL 1213, Prin. of English Composition	3
	MATH 1823, Calculus & Analytic Geometry I	3	MATH 2423, Calculus & Analytic Geometry II	3
	CHEM 1315, General Chemistry	5	PHYS 2514, General Physics for Eng. & Science	4
	HIST 1483, U.S. 1492-1865, or	3	ENGR 1001, Engineering Computing	1
	1493, U.S. 1865-Present		AME 2103, Interactive Eng. Design Graphics	3
	ENGR 1112, Intro. to Engineering	2	P SC 1113, American Federal Government	3
2	MATH 2433, Calculus & Analytic Geometry III	3	MATH 2443, Calculus & Analytic Geometry IV	3
	PHYS 2524, General Physics for Eng. & Science	4	MATH 3113, Engineering Mathematics	3
	ENGR 2113, Rigid Body Mechanics	3	ECE 2613, Electrical Science	3
	ENGR 2213, Thermodynamics	3	AME 2533, Dynamics	3
	ENGR 2313, Structures & Properties of Materials	3	Approved Elective: Social Science	3
	AME 2222, Intro. to Aerospace Engineering	3		
3	MATH 4163, Partial Differential Equations	3	AME 3333, Flight Mechanics	3
	ENGR 3723, Numerical Methods	3	AME 3523, Aerospace Structural Analysis	3
	AME 3143, Solid Mechanics	3	AME 3803, Compressible Fluid Flow	3
	AME 3112, Solid Mechanics Lab	2	AME/ENGR Approved Technical Elective	3
	AME 3253, Aerodynamics	3	Approved Elective: Western Civ. & Cult.	3
	AME 3272, Wind Tunnel Lab	2		
4	PHYS 3223, Modern Physics	3	AME 4373, Aerospace Vehicle Design II	3
	AME 4273, Aerospace Vehicle Design I	3	AME 4593, Space Science and Systems	3
	AME 4243, Aerospace Propulsion Systems	3	AME Approved Experimental Elective	2
	AME 4513, Flight Controls	3	Approved Elective: Artistic Forms	3
			Approved Elective: Non–Western Civ. & Cult.	3

New ISA Degree Requirements: 128 Total Credit Hours

1	ENGL 1113, Prin. of English Composition	3	ENGL 1213, Prin. of English Composition	3
	MATH 1823, Calculus & Analytic Geometry I	3	MATH 2423, Calculus & Analytic Geometry II	3
	CHEM 1315, General Chemistry	5	PHYS 2514, General Physics for Eng./Science	4
	HIST 1483, U.S. 1492-1865, or	3	*CS 1313, Programming for Non-Majors (AE)*	3
	1493, U.S. 1865-Present		P SC 1113, American Federal Government	3
	Approved Elective: Artistic Forms,	3		
	ENGR 1410, Freshman Orientation I	0	*ENGR 1420, Freshman Orientation II*	0
2	MATH 2433, Calculus & Analytic Geometry III	3	MATH 2443, Calculus & Analytic Geometry IV	3
	PHYS 2524, General Physics for Eng./Science	4	*MATH 3113, Ordinary Diff. Equations (AE)*	3
	AME 2113, Rigid Body Mechanics	3	*MATH 3990, Laboratory*	1
	AME 2223, Intro. to Aerospace Engineering	3	*AME 2623, Circuits and Sensors*	3
	AME 2213, Thermodynamics	3	AME 2533, Dynamics	3
			AME 2303, Mat., Design, Manuf. Processes	3
3	AME 3143, Solid Mechanics	3	AME 3333, Flight Mechanics	3
	AME 3112, Solid Mechanics Lab	2	AME 3523, Aerospace Structural Analysis	3
	AME 3253, Aerodynamics	3	*AME 3623, Embedded Real Time Systems*	3
	AME 3272, Wind Tunnel Lab	2	*§ AME Approved Experimental Elective*	2
	AME 4383, Control Systems	3	AME 3103, Interactive Eng. Design Graphics	3
	ENGR 2003, Engineering Practice I	3	*ENGL 3513, Technical Writing*	3
4	*AME 4273, Aerospace Systems Design I*	3	*AME 4373, Aerospace Systems Design II*	3
	AME 4493, Space Sciences/Astrodynamics	3	# AME/ENGR Approved Technical Elective	3
	AME 4243, Aerospace Propulsion Systems	3	* Approved Elective: Social Science	3
	AME 4513, Flight Controls	3	* Approved Elective: Western Civ. & Cult.	3
	# AME/ENGR Approved Technical Elective	3	Approved Elective: Non–Western Civ. & Cult.	3

**Students must take either COMM 3153 as Western Civ. & Cult. Elective or ANTH 4623 as Non-Western Cult. Elective.*
§ Students to take AME 4802 "Robotics Laboratory" or AME 4812 "Dynamics/Controls Laboratory" as Exp. Elective.
 # Students to take AME 4263 "Systems Engineering" and/or AME 4593 "Space Systems/Mission Design" as Tech. Elect.

Figure 1. Comparison of Old AE Curriculum and New ISA Curriculum

1. *An accreditable aeronautics core program had to stay in place*, since we have acquired an excellent reputation in aerospace (mostly aeronautical) design, based on many AIAA Design Competition awards earned over the years.

2. *Our space offerings were to be increased* since student interviews and surveys had indicated a distinct shift in the interest of incoming students toward this area.

3. Most importantly, *an intelligent systems emphasis was to be included in* the course sequence to make our graduates more diverse and marketable.

4. A new emphasis in the College of Engineering required that *some aspects of communication and professional practice* be added as well.

5. Finally, the former *Engineering core courses were to be returned to the Schools* at this time.

All of this was to be accomplished while keeping the graduation requirement at or below 128 hours, up from a previous low of 123 hours.

Requirement #1: Preserve Accreditable Aeronautics Core Program

To satisfy the first requirement, we wanted to preserve our existing strength by keeping a full Aeronautical Engineering base curriculum in place: *AME 2222 Introduction to Aerospace Engineering, AME 2533 Dynamics, AME 3253 Aerodynamics, AME 3272 Wind Tunnel Lab, AME 3333 Flight Mechanics, AME 3523 Aerospace Structural Analysis,* and *AME 4243 Aerospace Propulsion Systems*, dropping only *AME 3803 Compressible Flow*, but distributing its course content to the aerodynamics and propulsion courses.

Requirement #2: Increase Space Content

The second requirement was served by increasing the space content: We first added a third hour to *AME 2223 Introduction to Aerospace Engineering*, dealing with an introduction to space. Based on student comments and exit interviews, we dropped the 'Modern Physics' course and replaced it with *AME 4493 Space Sciences and Astrodynamics*, taught by a new AME faculty member with a physics degree. Our previous 'Space Science and Systems' course was restructured as a technical elective, *AME 4593 Space Systems and Mission Design,* to incorporate mission planning and space navigation.

Requirement #3: Incorporate Intelligent Systems Emphasis

The intelligent systems component of the curriculum required the addition of new material together with some restructuring of existing courses. In order to allow for the later programming of autonomous systems, a three-hour C programming course in the School of Computer Science (*CS 1313 Programming for Non-Majors*) was chosen to replace the generic one-hour CoE programming offer. The standard CoE Sophomore electrical science course was replaced by a new version, *AME 2623 Circuits and Sensors*, which introduces the students to sensors and digital systems while providing some lab aspects. The follow-up to this course is *AME 3623 Embedded Real Time Systems*, where the students are introduced to robotics and intelligent systems applications in aerospace engineering. A faculty member who was essential in the development of the Mars rover, Sojourner Truth, teaches this course. Every intelligent systems program requires extensive controls offerings. Here, we expanded the former stability and controls course, which consisted mostly of a general controls sequence with some stability and flight controls toward the end, to a two-course sequence: a general introduction of controls presented in *AME 4383 Controls Systems* and a full-fledged *AME 4513 Flight Controls* course. All of the subjects taught in this sequence are reinforced experimentally by a choice of labs, *AME 4802 Robotics Lab* or *AME 4812 Dynamics and Controls Lab.*

Requirement #4: Add New CoE Professional Core Courses

At the same time, the College of Engineering mandated changes to its core curriculum. These require the inclusion of the following courses or at least course materials into every engineering curriculum: two zero-hour freshman engineering seminar courses to replace the present two-hour 'Introduction to Engineering' course; a three-hour professional communications course, replacing the two hours just gained plus adding one, generally served by the 'Technical Writing' course offered in the English Department; and two three-hour 'Engineering Practice I and II' offerings. In order to keep our curriculum to the desirable 128 hours, only 'Engineering Practice I' was added while the 'Engineering Practice II' material will be covered in the capstone design courses, which will include projects proposed and sponsored by industry.

Requirement #5: Return Old Engineering Core Courses to Schools

In a long standing agreement between the various CoE Schools, certain engineering core courses had been taught by faculty members from given Schools for all CoE students that required the material. Since more and more Schools left this agreement to substitute their own specialized courses, the core courses will now revert back to the respective Schools. This means that AME will teach their own courses *AME 2113 Rigid Body Mechanics, AME 2213 Thermodynamics*, and a redesigned *AME 2303 Materials, Design, and Manufacturing Processes* to AE students.

Additional Changes

Student surveys together with faculty input led to an interesting change in the mathematics sequence. The previous curriculum contained two three-hour math courses, 'Ordinary Differential Equations' and 'Partial Differential Equations', and a three-hour 'Numerical Methods in Engineering' course. Negotiations with the Math Department resulted in a combination of these three courses into a single three-hour math course, *MATH 3113 Ordinary Differential Equations (AE Section),* and a one-hour computer lab, *MATH 3990 Lab.* Since much of the partial differential equation material is already being presented and reinforced in such courses as 'Aerodynamics', 'Flight Mechanics', and 'Control Systems', this reduction in PDE content hours seemed reasonable. Also, the math lab allows us to have our students taught in computer applications of differential equations using MATLAB, which they will encounter again in the controls sequence.

Two technical electives remain in the Senior year to allow for some specialization; however, to reinforce the space and ISA emphases, it is recommended that the students take *AME 4593 Space Systems and Mission Design* and *AME 4623 Systems Engineering*, a course, which we expect to be taught in collaboration with industry. Specifically, Lockheed Martin in Fort Worth has agreed to provide lecturers to enhance the content.

The 'Interactive Engineering Design Graphics' (introductory CADD) course was moved from the second semester in the Freshman year to the second semester in the Junior year since this material is mostly required in the subsequent senior design courses. This move is expected to resolve previous issues with material retention.

Finally, the two capstone design courses, *AME 4273 Aerospace Systems Design I* and *AME 4373 Aerospace Systems Design II,* are served by the systems engineering background the students now bring to complex multidisciplinary aerospace design. Also, intelligent systems themes can be incorporated into the projects sponsored by industry or proposed by AIAA.

Overall, we managed to keep the total number of hours to the desired 128.

Assessment

The new curriculum will be assessed on a regular basis according to ABET 2000 requirements, including but not restricted to: studies of retention from Freshman to Sophomore year, graduation rates, intermediate and exit interviews, student and employer surveys, and constant interaction with the AME Board of Advisors.

Implementation Issues

As stated earlier, the addition of three cross-disciplinary faculty members in Electrical and Computer Engineering (ECE), Aerospace Engineering (AE), and Computer Science (CS), respectively, has made it possible to keep the new curriculum offerings cost effective and efficient. Special care was taken to hire professionals who had the necessary expertise to supplement the course offerings in the ISA curriculum, i.e., who had some previous exposure to aeronautics or astronautics.

The new AE faculty member with a background in physics, astronomy, space mission design, and reusable launch vehicles teaches the new and modified space offerings as well as 'Flight Mechanics'. The recent ECE faculty hire teaches and performs research in his own School, but is obligated to teach two courses in the new curriculum, the 'Circuits and Sensors' course and the basic 'Control Systems' course. The new CS faculty member will also teach two courses in AE, the basic C programming course and the 'Embedded Real Time Systems' course.

The two 'Freshmen Orientation' courses and the 'Engineering Practice I' course will be taught for the entire College of Engineering by regular and adjunct faculty specifically selected for the purpose, but not from the standard units. Other new requirements such as the communications courses, the anthropology course, and the 'Ordinary Differential Equations (AE)' math course with lab sequence are taught in their respective departments and do not add FTE load to AME.

Since the AE courses in previous years had low enrollment numbers, the newly experienced increase in students only serves to bring the student /faculty ratio closer to that of the ME program.

Returning the core courses to the Schools does not bring much change to AME, since we already taught the largest number of these courses in the past. Also, the CoE encourages Schools to trade courses for similar future arrangements.

Conclusions

We took a fully ABET accredited, award wining Aerospace Engineering curriculum, added an emphasis on space and on intelligent systems, integrated professional development material, and made the program multidisciplinary by incorporating courses taught by instructors in the Electrical and Computer Engineering and the Computer Science Schools. These changes were made to provide our students with a competitive edge in a job market that has moved away from hiring students trained in traditional aerospace disciplines to students that have an understanding of the systems integration of differing technologies, all coming together in the design and development of a complex aircraft or spacecraft.

It is hoped that these efficient innovations will make the program more competitive nationwide and more exciting for the students. The revised curriculum, which was partially implemented in the Fall of 2003 and will be finalized by the Fall of 2004, has already shown results in terms of our AE enrollment. *Between the Fall of 2001 and 2002, Freshmen enrollment in Aerospace Engineering more than tripled and has held about steady at the new levels.*

Biographical Material

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Dr. Striz serves as Professor and L.A. Comp Chair in the School of Aerospace and Mechanical Engineering at OU. He is also the Associate Director for Research at OU for the Oklahoma NASA Space Grant Consortium and the Associate Director of the Center for Engineering Optimization in the College of Engineering. His interests are in computational mechanics, aeroelasticity, structural optimization, MDO, and, recently, curriculum development.