Integrating Graduate and Undergraduate Education Through Student Design Competitions

Daniel P. Schrage, Professor
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0150

ABSTRACT

The Georgia Tech graduate program in Aerospace Systems Design was initiated in 1984 with two rotorcraft design courses as part of the Georgia Tech (U.S. Army Research Office sponsored) rotorcraft center of excellence. The American Helicopter Society (AHS)/industry student design competition has been used as a focus for the rotorcraft design courses from the outset. In 1992 a fixed wing aircraft set of graduate design courses, focusing on the integration of design and manufacturing for the High Speed Civil Transport (HSCT), was also introduced through a grant under the NASA USRA Advanced Design Program (ADP). The Aerospace Systems Design Laboratory (ASDL) was also formed in 1992 to support the graduate design research effort in Concurrent Engineering(CE) and Integrated Product/Process Design/Development (IPPD). In 1995 a space launched vehicle set of graduate design courses was also introduced. While the graduate program in aerospace systems design has been quite successful the need to offer highly motivated undergraduate students a chance to enter national competitions and provide a seamless transition with the graduate program was needed. This has been accomplished over the past few years by having highly motivated undergraduates take both the capstone senior design courses, as well as enter national student design competitions and participate as teams, using the CE/IPPD methodology developed in the graduate program. This approach has proven to be highly successful and has provided an excellent recruiting program for the graduate design program as well as provide a smooth transition. It also has been used to help satisfy the ABET 2000 intent of outcome measurement. With the conversion from a quarter system to a semester system in 1999 we plan to provide an even tighter linkage between our graduate and undergraduate design programs. This paper will summarize our efforts.

INTRODUCTION

Engineering education today is built primarily around engineering science courses with a focus on disciplinary analysis. Product synthesis is usually taught in an undergraduate senior capstone design course. System synthesis (product plus process synthesis) is seldom taught due to the difficulties of integration of design and manufacturing and the coupling of synthesis with economic analysis. Multidisciplinary analysis across engineering science courses is also quite rare. For example, a student is not expected to use thermodynamics and fluid mechanics in a course in mechanics of materials. Problems that are worked in these courses are selected to illustrate and reinforce the principles of the disciplinary analysis courses. If the student constructed the appropriate model, he/she could usually solve the problem. Most of the input data and properties are given for these courses, and there usually are a correct answer to the problems. However, real-world engineering problems rarely are that neat and circumscribed. The real problem in engineering design that is expected to be solved may not be readily apparent - necessitating the need for problem definition as well as problem analysis. The engineering designer needs to draw on many technical disciplines (solid mechanics, fluid mechanics, electromagnetic theory, etc.) for the solution and usually on non-engineering disciplines as well (economics, finance, law, etc.). The input data may be fragmentary at best, and the scope of the project may be so huge that no individual can follow it all. If that is not difficult enough, usually the design must proceed under severe constraints of time and/or money. There may be major societal constraints imposed by environmental or energy regulations. Finally, in the typical design you rarely have a way of knowing the correct answer. Hopefully, your design works, but is it the best, most efficient design that could have been achieved under the conditions? Only time will tell. Thus it can be seen that engineering (design) extends well beyond the boundaries of science.(Ref. 1)

Much of engineering today is about "designing a system". By a system is meant the entire combination of hardware, software, information, and people necessary to accomplish some specified mission. A large system usually is divided into subsystems, which in turn are made up of components. There is no single universally acclaimed sequence of steps that leads to a workable engineering design. The design process is usually viewed as a sequential process consisting of many design operations. Examples of the operations might be 1) exploring the alternative systems that could satisfy the specified need, 2) formulating a mathematical model of the best system concept, 3) specifying specific parts to construct a component of a subsystem, and 4) selecting a material from which to manufacture a part. Each operation requires information, some of it general technical and business information that is expected of the trained professional and some of it very specific information that is needed to produce successful outcome. Acquisition of information is a vital and often very difficult step in the design process, but fortunately it is a step that usually becomes easier with time. Once armed with the necessary information, the design engineer (or design team) carries out the design operation by using the appropriate technical knowledge and computational and/or experimental tools. At this stage it may be necessary to construct a mathematical model and conduct a simulation of the component's performance on a digital computer. Or it may be necessary to construct a full-size (or scaled) prototype model and test it in a wind tunnel, in flight, or in a hardware-in-the-loop simulation. The final result of the chain of design modules is a new working object or a collection of objects that is a new system. However, many design projects do not have as an objective the creation of new hardware or systems. Instead, the objective may be the development of new information that can be used elsewhere in the organization. It should be realized that few system designs are carried through to completion; they are stopped because it has become clear that the objectives of the project are not technically and/or economically feasible. However, they create new information, which, if stored in retrievable form, has future value.(Ref. 1)

Even the most complex system can be broken down into a sequence of design objectives. Each objective requires an evaluation, and it is common for the decision-making phase to involve repeated trials or iterations. The need to go back and try again should not be considered a personal failure or weakness. Design is a creative process, and all new creations of the mind are the result of trial and error. In fact, if it were possible to work a design straight through without iteration, the design would indeed be very routine. The iterative nature of design provides an opportunity to improve the design on the basis of the preceding outcome. That, in turn, leads to the search for the best possible technical outcome. That, in turn, leads to the search for the best possible technical condition, e.g., maximum performance at minimum weight (or cost). Many techniques for optimizing a design have be developed, and although they are intellectual pleasing and technically interesting, they often have limited application in a complex design situation. In the usual situation the actual design parameters chosen by the engineer are a compromise among several alternatives. There may be too many variables to include all of them in the optimization, or non-technical considerations like available time or legal constraints may have to be considered, so that trade-offs must be made. The parameters chosen for the design are then close to but not at optimum values. They are often referred to as optimal values, the best that can be achieved within the total constraints of the system.(Ref. 1)

In a 1990 report, *Scholarship Reconsidered (Ref.2)*, Ernest Boyer, then president of the Carnegie Foundation for the Advancement of Teaching, proposed that universities broaden their view of professional scholarship to include four overlapping areas -- the scholarship of discovering knowledge (conducting research), the scholarship of integrating knowledge, the scholarship of applying knowledge, and the scholarship of teaching. He states that American higher education is imaginative and creative enough to support and reward not only those scholars uniquely gifted in research but also those who excel in the integration and application of knowledge, as well as those especially adept in the scholarship of teaching. Such a mosaic of talent, if acknowledged, would bring renewed vitality to higher learning and the nation. The scholarships of integrating knowledge and applying it, along with the scholarship of teaching, are required for university engineering design programs, especially for complex systems. The Georgia Tech graduate program in aerospace systems design, will be used to illustrate the scholarship of integrating knowledge along with the participation in student design competitions to illustrate the scholarship of application.

GEORGIA TECH GRADUATE PROGRAM IN AEROSPACE SYSTEMS DESIGN

The Georgia Tech Baseline Practice-Oriented M.S. Degree program in Aerospace Systems Design is illustrated in Figure 1. Five courses are included and described as follows:

• AE 8113 - *Introduction to Concurrent Engineering*

This graduate course was first introduced in 1992 and consists of introducing the students to the generic Concurrent Engineering (CE)/Integrated Product/Process Design/Development (IPPD) methodology developed by the author that can been used for education and research. The generic CE/IPPD methodology is illustrated in Figure 2 and consists of four key elements: Systems Engineering methods/tools, Quality Engineering methods/tools, Top Down Design Decision Support process, and a Computer Integrated Environment. Below the umbrella are illustrated the specific sub-elements and the information flow (via arrows) between methods/tools and the decision support steps. The first three steps of the decision support process (Establish the Need, Define the Problem, and Establish Value Objectives) are accomplished by teams of students on a variety of complex systems where the need is usually established by national student design competition request for proposals (RFPs). Principal tools used in this course are the Seven Management and Planning Tools and Quality Function Deployment (QFD) from Quality Engineering (Ref.3) and N2 diagrams for functional decomposition from Systems Engineering (Ref. 4). The goal for this initial course is to familiarize the students with the generic CE/IPPD methodology and to define the problem for the complex system (a critical, but often overlooked step) that will be synthesized in follow-on design courses.

• AE 4353 - *Design for Life Cycle Cost*

This undergraduate senior elective course (also available for graduate students) was first introduced in 1990 with the objective of introducing engineering students to the importance and uncertainties of estimating life cycle cost (LCC) early in the design process for complex systems, such as aerospace. LCC estimating models are introduced along with robust design methods. During the first few years Taguchi methods for robust design through parameter design optimization were used. In later years as robust design simulation (RDS) methods and tools were developed in the ASDL a more complete

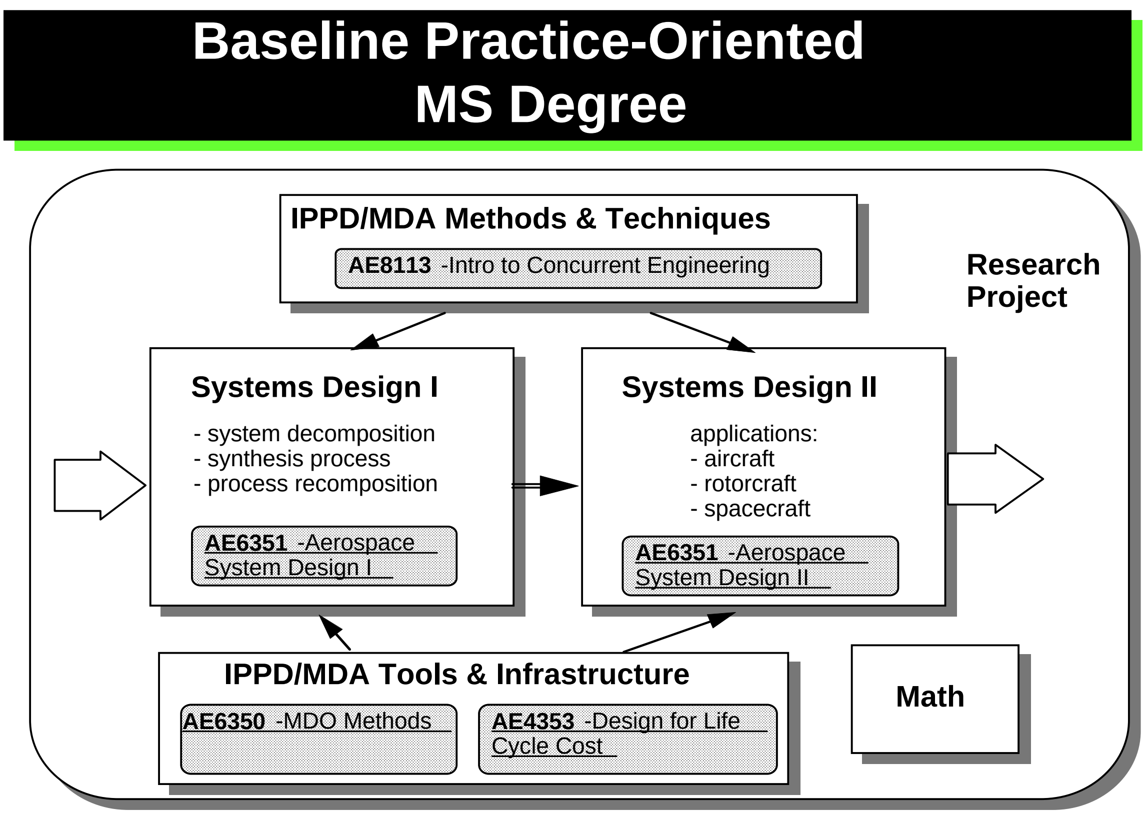

Figure 1. Georgia Tech Baseline Practice-Oriented MS Degree in Aerospace Systems Design

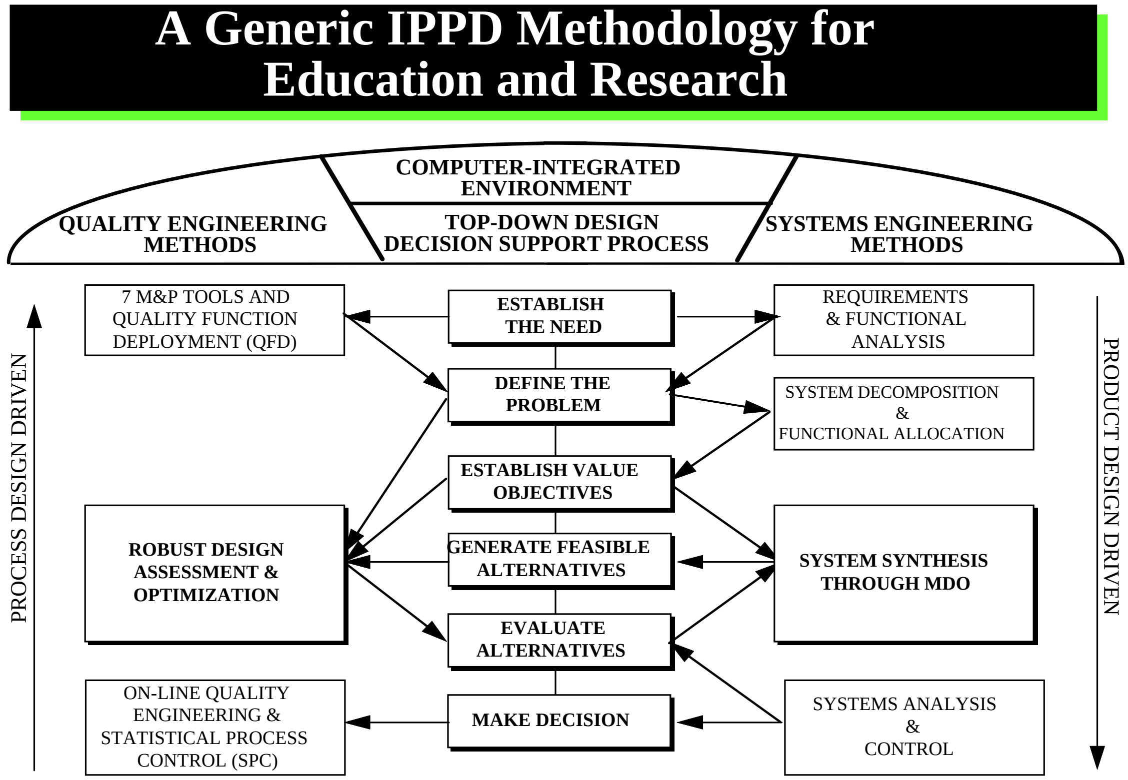

Figure 2. Georgia Tech ASDL Generic CE/IPPD Methodology

set of methods/tools have been introduced into the course. These methods include design of experiment (DOE), response surface methods (RSMs), Pareto Analysis, and Monte Carlo simulation. They provide the students the background to address the Quality Engineering Methods sub-element: *Robust Design Assessment & Optimization* illustrated in Figure 2. Once again the students are broken down into teams to calculate the LCC and its robustness for a number of complex systems.

• AE 6350 - *Multidisciplinary Design Optimization (MDO) Methods*

In recent years there has been considerable research activity related to MDO, principally related to multiple objective numerical optimization methods rather than DOE methods. In 1994 Georgia Tech was awarded a three year NASA program to develop new approaches to MDO and this course was introduced to familiarize students with some of the new MDO methods, such as Sobieski's global sensitivity equation (GSE) approach. This course also provides the students the MDO background to address the Systems Engineering Methods sub-element: *System Synthesis through MDO* illustrated in Figure 2.

• AE 6351 - *Aerospace Systems Design I*

This course along with the follow-on course was developed in 1984 and first taught for rotorcraft design in 1984, as part of the Army sponsored rotorcraft center of excellence (RCOE) program. In 1992 a set of fixed wing design courses were introduced based on the NASA USRA ADP grant: *Integration of Design and*

Manufacturing for the HSCT and in 1995-96 a set of space launched vehicle design courses were also introduced. During this first course system design synthesis is accomplished by a student design team based principally on a product design and decomposition(Systems Engineering) approach. The objective of this course is to teach students how to conduct conceptual design which makes the greatest demands on the designer's creativity. The concept(s) selected provide the Top-Down Design Decision Support Process step: *Generate Feasible Alternatives* illustrated in Figure 2. A baseline preliminary design configuration and the identification of technology options for subsystems/disciplines for the follow-on course are also an outcome of this course. It also initiates the system design optimization iteration illustrated in Figure 2 by the arrows coming out and going into the Systems Engineering Methods sub-element: *System Synthesis through MDO*.

• AE 6352 - *Aerospace Systems Design II*

This course completes the five course sequence illustrated in Figure 1 and addresses system design optimization based on the IPPD and recomposition approach illustrated in Figure 2. The baseline system(s) identified from the previous system synthesis course is now optimized through evaluation of alternatives, using robust design assessment and optimization. This completes the system synthesis iteration and a final design decision is made. The outcome for national student design competitions, such as the AHS/industry RFP for the rotorcraft courses, is a submitted proposal. Over the past 14 years a Georgia Tech team has won first place in 11 years. For the fixed wing design courses an external advisory board (EAB), consisting of knowledgeable representatives from government and industry who are involved or are familiar with the NASA/industry high speed research (HSR)/HSCT effort, is convened annually to review the student team's design. The space launch vehicle design course sequence is also using an EAB, as well as having a student entry in national student design competitions, such as the X-Prize competition.

UNDERGRADUATE DESIGN COMPETITIONS

As the IPPD methodology and graduate design program has matured there has been increased interest from undergraduate students and from ASDL faculty to include their participation. Two undergraduate senior design capstone courses are required as a graduation requirement for all graduating seniors and are taught by a very knowledgeable instructor with considerable industry design experience. These courses, however, are not currently taught or oriented toward national student design competitions. However, over the past few years a number of highly motivated student teams have entered the American Institute of Aeronautics and Astronautics (AIAA) undergraduate competitions. They were given a crash course in the IPPD and RDS methods being applied in the graduate aerospace systems design program. These highly motivated students (they also take the required two capstone design courses) have been quite successful. Georgia Tech undergraduate teams or individuals have entered the following AIAA aircraft or engine design competitions over the past three years with the indicated results:

• 1994/1995 Team Engine Design Competition: *Propulsion System for a High Speed Civil Transport* - - First Place

• 1995/1996 Individual Aircraft Design Competition: Supersonic Business Jet - - Second Place

• 1996/1997 Team Engine Design Competition: *Propulsion System for a Multirole Multi-service Weapon System* - - First Place

INTERNATIONAL AERIAL ROBOTICS COMPETITION

Another competition that a number of Georgia Tech undergraduate and graduate students have participated in over the past six years has been the International Aerial Robotics Competition, sponsored by the Association of Unmanned Vehicles Society (AUVS). This competition was initiated in 1991 and requires both design, development, and building of a vertical takeoff and landing (VTOL) autonomous unmanned aerial vehicle (UAV). In 1993 using the IPPD methodology illustrated in Figure 2 was used to win the competition and the Georgia Tech Aerial Robotics (GTAR) team was the first team to demonstrate significant autonomous flight, including takeoff and landing. From 1992 to 1995 the GTAR teams were partially support from the NSF Southeastern Universities and Colleges Coalition for Engineering Education (SUCCEED) as a practice-oriented multidisciplinary project. A spin-off project from this successful effort was the U.S. Army sponsored Autonomous Scout Rotorcraft Testbed (ASRT) which led to an additional advancement in autonomous VTOL UAV technology and continuing research and education at Georgia Tech.

CONCLUSIONS

It can be seen that modern design methods based on CE/IPPD methodologies can be incorporated in universities and student design competitions used as outcome measures. The graduate design program has been firmly established and is being used to integrate undergraduate students through participation in national student design competitions. The use of student design competitions is an excellent way of helping to satisfy the ABET 2000 intent of outcome measurement. It also is an excellent way for engineering programs to demonstrate that their graduates have an ability to function on multi-disciplinary teams.

REFERENCES

1. Dieter, G.E., Engineering Design - A Materials and Processing Approach, McGraw-Hill, Inc., 1991.
2. Boyer, E.L., Scholarship Reconsidered - Priorities of the Professoriate, The Carnegie Foundation for the Advancement of Teaching, 1990.
3. Kusiak, A., Concurrent Engineering - Automation, Tools, and Techniques, John Wiley & Sons, Inc. 1993.
4. Systems Engineering Management Guide, Defense Systems Management College, January, 1991.