Session 2325

Design and Implementation of an Aeronautical Design-Build-Fly Course

Peter W. Young[1], Olivier L. de Weck[2], and Charles P. Coleman[3]

Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge Massachusetts

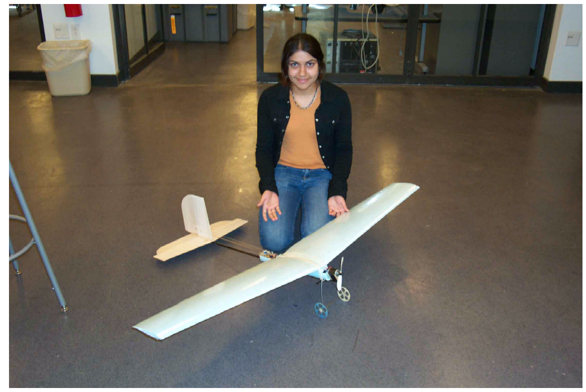
Introduction

Teaching aeronautical vehicle design is a significant challenge. We have found that teaching the design process in a pure, traditional lecture-style format is ineffective. Undergraduate students yearn for hands-on experiences that allow them to integrate theory and practice. At the undergraduate level, the complexity, expense, and time requirements of real world aeronautical systems seems to impose insurmountable barriers and detracts from learning the key principles. Furthermore, conveying key aspects of aerodynamic design and flight performance in a real flying context is challenging, to say the least.

This paper presents a potential remedy to these dilemmas in the form of a design-build-fly (DBF) course in aeronautics. Sophomore students at the Massachusetts Institute of Technology's Department of Aeronautics and Astronautics work in small teams to design, build, and fly small radio-controlled electric propulsion aircraft as part of their 2nd term (spring) semester in the Unified Engineering curriculum. An integral part of the Department's CDIO (conceive – design – implement -operate) educational strategy, the Unified Engineering DBF course is in its fifth year of development with continuous improvements incorporated each year.

This paper will provide an overview of the educational strategies employed, the learning objectives, and their connection to the Department's CDIO Syllabus. Fundamental assumptions and cognitive progression of teaching design-by-redesign will also be discussed.

[1] Senior Lecturer, Colonel USAF (ret.), Room 33-240, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge MA 02139, telephone: (617) 253-5340, e-mail: pwyoung@mit.edu – corresponding author
[2] Assistant Professor, Department of Aeronautics and Astronautics, Engineering Systems Division, Room 33-406, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge MA 02139, telephone: (617) 253-0255, e-mail: deweck@mit.edu
[3] Assistant Professor, Department of Aeronautics and Astronautics, Engineering Systems Division, Room 33-311, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge MA 02139, telephone: (617) 253-3640, e-mail: ccoleman@mit.edu



The stock Dragonfly model (left) constructed from the factory kit and the aircraft as redesigned (note wing modification) by an MIT student for competition.

DBF Project Inception

Unified Engineering is a required multi-disciplinary course for MIT Aero-Astro students enrolled in their second year. First developed and implemented in the mid-1970's [1,2], Unified Engineering is a two-semester course sequence, 24 credit hours per semester, that covers Materials and Structures, Dynamics, Signals & Systems, Fluid Dynamics, and Thermodynamics & Propulsion in a fast-paced curricular schedule that includes lectures, recitations, laboratories, and objective tests taught in an intensive 5 day/week schedule. Unified Engineering's purpose is to introduce sophomore students to the disciplines and methodologies of aerospace engineering at a basic level with a balanced exposure to analysis, empirical methods, and design. Several laboratory experiments are performed and a number of systems problems integrating the different disciplines are included over the course of the year.

Students graduating from Unified Engineering are expected to:

1. Formulate appropriate coupled multi-disciplinary models of engineering systems based on physical laws and principles and identify the underlying assumptions and limitations of those models.
2. Conduct experimental investigations, analyze experimental results, quantify experimental uncertainty and generate simple empirical models.
3. Use physics-based and empirical-experimental models of engineering systems to evaluate proposed designs, conduct trade studies, and generate new design solutions.
4. Understand the role of aerospace engineering in a wider social context including economics, policy, safety, the environment, and ethics among others.
5. Communicate engineering results in written reports using clear organization, proper grammar and diction, and effective use of graphs, engineering drawings, and sketches.

Starting in September 1998, the Department initiated investigations into the development of a challenging aeronautical DBF project for the Spring 1999 term. A primary impetus was the increasing availability of lightweight and miniaturized digital proportional equipment and small electric propulsion units for radio-controlled miniature aircraft. This raised the possibility of flying small radio controlled aircraft inside an athletic facility, thus eliminating the need for suitable outdoor flying weather.

Concurrently, the Department was redesigning its undergraduate curriculum in-line with the Department's Conceive – Design – Implement - Operate educational strategy [3] in which fundamentals of engineering education are merged with teamwork, hands-on learning projects, design projects, and other key attributes more fully described in the Department's CDIO Syllabus [4]. It was now felt that the new aeronautical DBF project could achieve major portions of the Department's CDIO educational goals as well as Unified Engineering's specific 2nd year multi-disciplinary goals.

A variety of prototype aircraft configurations, electric propulsion systems, and radio control systems were evaluated during the Fall 1998 semester and verified that miniature, slow-flying electric propulsion aircraft could be safely operated inside a relatively small indoor flying space. The success of these first field trials led to the development of teaching objectives for the Spring 1999 semester for Unified Engineering, the sophomore engineering course for MIT students majoring in Aeronautics and Astronautics.

In previous years, Unified Engineering students had designed and built small free-flight hand launched gliders to test their understanding of aerodynamic design but it was now felt that the attributes of the radio-controlled models would be more suitable for quantitative analysis, performance prediction and verification, rigorous design engineering plus providing operational "pilot in the loop" aspects missing from the previous exercises. With 65 to 70 students enrolled in Unified Engineering each year, team size averaged 4 students with the faculty selecting team members based on students' previous modeling experience, class standings and gender.

Development history – the first two years (Spring 1999 and 2000 semesters)

The project was formally initiated in the Spring 1999 semester with the Unified Engineering students responsible for the design, construction, and flight of small aircraft designed to be operated inside MIT's Johnson Athletic Center, an indoor multi purpose athletic facility with an open space approximately 200 feet long, 80 feet wide, and a 25 foot usable ceiling height. The flying area, while somewhat constrained, has proven to be adequate for these aircraft which fly at relatively slow speeds on the order of 6 m/s. The pedagogy called for the students to develop aircraft designs to meet pre-stated flight objectives using basic aeronautical design and engineering principles. Wings were fabricated from blue Styrofoam using plywood airfoil templates and handheld, heated cutting wires. Fuselages were made using lightweight arrow shafts, balsa wood, and Styrofoam; tail surfaces were made from thin sheet balsa.

From the very start, the students accepted with great enthusiasm the challenge of designing the small aircraft. There were quite a variety of design approaches chosen within the constraints of the rules: pusher propeller as well as conventional "propeller first" designs, small and large wing areas, and innovative methods to package the digital camera payload (first year) and micro-sized television camera and transmitter (second year). The radio control equipment proved to be reliable and reasonably robust, and rechargeable battery packs for the aircraft allowed multiple flights simply by replacing discharged flight packs. Pre- and post-course assessments (insert data, tables) showed that the new DBF course had substantially improved students' enthusiasm and motivation for aeronautical engineering (reference).

For the first two years of the new DBF aircraft project, substantial progress was made towards achieving the goals described above. The challenge of designing and building "aircraft that really flew" was a great motivator and created a sense of excitement not previously experienced in previous years. The hands-on experience coupled with teamwork was felt to be a substantial improvement over prior years' efforts.

However there were some areas that, upon post-course reflection, could be improved. For the first two years of the DBF Design Competition, primary emphasis was placed on the design of the students' aircraft projects – the C (conceive) and D (design) elements of the Department's CDIO strategy. Due in large part to lack of prior experience in hands-on projects (a common syndrome among young engineering students in recent times), the aircraft were often rushed to completion and not satisfactorily constructed, aligned, or test flown.

Furthermore, the wing fabrication technique described above was an inefficient use of students' time. Plywood or metal templates had to be fabricated when there were changes to airfoil parameters (airfoil type, wingspan, or chord dimensions), and several hours were typically required to make these changes and produce new wing planforms. These time delays stifled the ability of the students to incorporate changes late in the design and construction cycle.

Lastly, the students were not required to have their aircraft flyable until the flight competition at the end of term. As a result, almost all the aircraft in the first two years of the DBF project were untested, and the pilots didn't have opportunities to conduct flight tests and to make necessary changes late in the cycle.

As a result, while there were substantial promising aspects to the DBF program in its first two years, the overall results were not entirely satisfactory. While the students were very enthusiastic about the aircraft project, only a small percentage of their aircraft could be flown successfully inside the facility confines. The primary causes for unsuccessful flights were untested aircraft coupled with a lack of flying experience. Clearly, there was room for improvement in the DBF Design Competition.

Developmental Changes, next two years (Spring 2001 and 2002 semesters)

To address the problems described above, several key developmental changes were incorporated into the DBF program starting with the AY 2001 program. Unified Engineering's faculty and staff felt that drastic steps needed to be taken to improve the students' skills in assembling and operating their aircraft (the (I and O elements in CDIO). Starting in December 2000 in preparation for the Spring 2001 term, the students were given access to computerized flight simulation training using the same radio control transmitters as are used for actual flying. Experience has shown that only a few hours are needed for students to gain basic familiarity with the transmitter controls and to gain a good sense for the flight behavior, especially in response to control inputs, that they will experience with the actual aircraft. More importantly, they can develop their flying skills without damaging any actual aircraft, exactly as is the case with full-scale flight simulators.

After the student pilots had acquired basic flying skills with the flight simulators, they were given use of pre-built aircraft for more advanced flight training use. These training sessions were conducted outdoors in calm weather or indoors inside the Johnson Field House. A significant aid to student training was the use of electronic connector cords that connect the transmitters of both a student and an instructor pilot. With these devices, the instructor can quickly gain control of the flying aircraft from the student pilot merely by actuating a spring-loaded switch to transfer control to the instructor's transmitter.

The problem of more efficiently fabricating foam wing panels was solved when the Department purchased a custom-built CNC foam cutter that a commercial vendor was relinquishing; this unit provides template-free wing fabrication with access to more than 450 airfoils stored in computer memory. Fabrication of cores is highly automated and high fidelity wing cores with numerous design refinements incorporated on demand can be achieved in less than four minutes per panel. Unified Engineering Teaching Assistants are trained in the operation of the CNC machinery and provide supervision of the Unified students who are ultimately responsible for fabricating wing panels for their aircraft.

Finally, to provide students with added opportunities to develop hands-on construction and assembly experience, in the Spring term's first week the student teams are given opportunities for *early success* – they are provided commercial kits for a radio controlled aircraft in the same size range and using the same electric propulsion and radio controls they will use later in the term. The kit chosen, the Dragonfly "slow flyer" produced by Diversity Model Aircraft (www.FlyDMA.com, phone <(858) 693-8188>, has been found to be an excellent vehicle for this type of educational experience. The students are required to assemble this airplane using the kit's instructions, then evaluate flight performance in flight trials in the Johnson Athletic Center. These flights accomplish key objectives of providing flight labs data required for several Unified problem sets keyed on quantitative performance estimation. This is the starting point for the redesign efforts where the students are encouraged to first focus on the "low hanging fruit", i.e. those design changes that have a high sensitivity to the competition's success criteria. Design by redesign is a common mode of operation in industry and our experience has found that this doesn't stifle creativity, but allows the students to have a learning experience with higher complexity, performance, and reliability than with the alternative of starting the scratch. Equally important, the *early success* approach gives the students increased confidence and experience working in teams in addition to developing their construction, assembly, and flight operations skills.

With the changes made as described above, the AY 2001 and 2002 DBF efforts were substantially improved in all the major phases. The design competition rules were revamped to emphasize excellence in aerodynamic design more so than in the past. For Spring 2001, the students were required to complete pylon laps both with and without a payload weight of their choice. For

Spring 2002, the flight rules were changed to have the students' planes fly for maximum duration with a relatively small motor battery pack (350 mah) and carrying a single chicken egg for payload. For this year's effort, the students will, as in the prior year, design their aircraft for maximum endurance but will be provided opportunities to carry up to four chicken eggs, with flight scoring adjusted to incentivize carrying heavier payloads. A comparison of the major performance goals, year by year, is summarized in the following table:

	Primary performance goals	**Significant project changes**
Spring 1999	Digital camera - aerial reconnaissance	Major upgrade from previous DBF projects
Spring 2000	Wireless TV camera - aerial reconnaissance	Aircraft required to be stowed in a small container pre-flight
Spring 2001	Payload and speed goals	First use of flight simulators, radio trainer boxes, commercial kits ("early success"), CNC foam cutter
Spring 2002	Maximum endurance with fixed payload (single egg), limited battery pack size	Emphasis on efficient flight at slow speeds
Spring 2003	Maximum endurance, payload complement (1-4 eggs) determined by student teams	

The developmental changes described above contributed to a significantly improved quality of the project: in the past two years, there have been a higher percentage of successfully completed flights by the teams and more student pilots successfully flew their team aircraft. The technical performance of the superior teams was quite outstanding, and clearly showed that superior system performance was a combination of teamwork, design, engineering, assembly, and pilot skills.

We would be remiss if we didn't mention the role that the DBF competition plays in introducing the Unified Engineering students to teamwork. Student teams are encouraged to develop mission statements and team goals, to run meetings with set agendas, articulate and document roles and responsibilities that best use the students' strengths and backgrounds, and understand the inter-dependent roles that the students must fulfill to achieve success in a project of significant complexity.

Some interesting reflective comments from the students gathered from Spring 2002's post-course critiques are:

"When we started the project, our main goals were to complete the main parts of the project the best we could in the time allowed. Winning the competition was certainly not a main goal. The finished product performed way beyond what we expected and we could not have been more pleased."

" I believe as a team we worked extremely well together. We were tolerant of each other, always trying to maintain constructive criticism and to respect each other's opinions in every situation. We learned to depend on each other very much and several times, had to pull each other "out of the hole."

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Conclusions

Unified Engineering's Design-Build-Fly design competition has evolved into a highly satisfactory teaching and learning experience over the past four years. Incremental improvements have developed and reinforced pedagogical implementation of "early success" as well as "design by redesign". Challenges for the future include a strengthening of the design experience's linkages to the other engineering disciplines taught during the sophomore year.

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Biographical Information

PETER W. YOUNG, Col, USAF (ret.) is a Senior Lecturer and Director of CDIO Initiatives in the Department of Aeronautics and Astronautics at MIT. He served 29 years in the USAF and NRO in a variety of missile and space Program Office assignments. Col Young was Program Manager for the DoD Space Test Program (1995-1996) and the Space Based Infra-Red (Low) Program, 1996-1997.

OLIVIER L. DE WECK is an Assistant Professor with a dual appointment between the Department of Aeronautics and Astronautics and the Engineering Systems Division at MIT. His research and teaching interests are in Integrated Modeling and Simulation, Multidisciplinary Design Optimization, and System Architecture of aerospace vehicles.

CHARLES P. COLEMAN is the Boeing Assistant Professor for Aeronautics and Astronautics at MIT. He has taught the Systems part of Unified Engineering in the 2000, 2001, and 2003 academic years. Prof. Coleman conducts research in the areas of Service and Sustainment Engineering

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Appendix A

Unified Engineering's Official 2002 Aerial Competition

Objectives, Scoring Method, and Constraints

1) Objective. To design-build-fly an electric radio controlled aircraft to do the following:

a. Fly two laps around the Johnson track area, 30 points maximum. Lap scoring starts upon takeoff from the ground and ends upon landing after two complete laps. The scoring algorithm is:

up to 1:20 - 30 points
1:20 to 1:40 – 25
1:40 to 2:00 – 20
2:00 to 2:20 - 15
2:20 to 2:40 - 10
2:40 to 3:00 - 5
3:00 and greater - 0 points.

Two pylons will be set up at opposite ends of the Johnson flying area. The planes must pass beyond and circle around the pylons; if they "cut" a pylon, they must go back and circle the pylon.

b. Land and load a cargo of a single chicken's egg to be supplied by the contest management. The time required to prepare the airplane for flight will be logged and this "pit time" deducted from the flight score. Pit time ends at wheels up.

c. Duration flight: the airplane must takeoff from the ground and flight scoring is the time, in seconds, that the plane is in the air. The aircraft does not have to fly around the pylons. Timing stops when the plane comes to rest.

d. The penalty for a cracked or broken egg is a ZERO scoring flight.

e. Typical scoring:

- 1:45 for two laps: + 20 points.

- 15 seconds "pit time" -15

- Duration flight, 3:00 +180

Total Score: 185 points

2) Constraints:

a. Contest management will supply the pre-charged battery pack to be used for official flights: an 8 cell 350 mah Nickel-Cadmium battery pack.

b. No limitations on wing area or wing span.

c. Standard 4 channel HiTec radios and servos must be used.

d. If desired, fliers can choose from a selection of gearbox ratios (3:1. 2.5:1, 1.2:1) and propellers to be supplied.

e. Wings must be fabricated from blue foam plastic. The Department's computerized foam cutter can be used, if desired.