Using Design, Build, Fly Projects to Provide Life Lessons in Engineering

James Helbling, Department of Aeronautical Engineering
Embry-Riddle Aeronautical University, Prescott, AZ

This paper recounts the methods applied in a senior design course taught at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona. It will discuss the life lessons provided via design, build, fly (DBF) projects which allow students to experience competition and collaboration as part of the same year-long project.

The capstone sequence at ERAU consists of Preliminary and Detail Design courses in both the Aircraft and Spacecraft tracks. In the Aircraft track, students in the Preliminary course form design teams which are given a choice of projects defined by Request for Proposals (RFP's). Two teams select an RFP suitable for design of an aircraft which can be fabricated as a flight test article in the Detail Design course. These two teams then create independent designs to be further refined in Detail Design. The two competing teams then become 'design groups' as a part of a single team in Detail Design. Each group fabricates a scaled model for the purpose of collecting aerodynamic data via wind tunnel testing. This testing is completed within the first six weeks of the semester, allowing a faculty panel to select the design which has the highest likelihood of success as a flight test article based on the wind tunnel test results. The two design groups then combine their efforts toward the collaborative design and fabrication of a radio-controlled aircraft representative of the down-selected concept which is structurally tested and optionally flight tested later in the semester. The flight test is optional to allow course compatibility with design teams that choose to pursue non-DBF design options.

This paper begins by explaining the context that led to the incorporation of the DBF option in the Aircraft Detail Design course, followed by a description of the chronological sequence of events which guided this curricular change. Descriptions of the life lessons experienced by the students are then provided. These lessons are formed while students are working with their former competitors and, for one of the design groups, in the disappointment of leaving their design behind and working on the design and fabrication of their competitor's concept during the final two months of the semester. This paper will conclude with an evaluation of the success of the program and a discussion of how the DBF projects allow ERAU to better meet ABET design objectives, followed by suggestions as to how the program has and will be further improved based on lessons learned.

Context

ERAU/Prescott is a 4-year university in Northern Arizona with an enrollment of approximately 1,600 undergraduate students. The most popular engineering degree program is Aerospace Engineering (AE). Within the AE curriculum, there is a strong emphasis on laboratory and design work to prepare the students for senior capstone design courses.

Students majoring in AE must choose one of two design tracks: aircraft or spacecraft. The aircraft track culminates in a sequence of two (2) senior design courses: Aircraft Preliminary

Design and Aircraft Detail Design. Likewise, the spacecraft track also has two (2) senior design courses: Spacecraft Preliminary Design and Spacecraft Detail Design.

In each of the Preliminary Design courses, students work in teams to design a conceptual aircraft or spacecraft from the ground up. These craft may be designed in response to a set mission statement (e.g., in response to the yearly AIAA design competition) or according to the interests and objectives of the student teams and instructors. In the Detail Design courses, each team selects one (1) component or set of subsystems from their craft—a wing section, a tail section, a satellite tracking system—and creates scaled models that they then subject to various tests, such as wind tunnel, vibration, and static structural tests. These test results are then compared to computer-based simulations and are presented by each team at a formal briefing at the end of the semester. This formal briefing is open to the university and is scored by a panel consisting of faculty members and guests from industry.

In addition to the general requirements described above, students in the Aircraft Detail Design course have the option of pursuing a DBF design of a full aircraft model. The DBF teams still must focus on the structural design and test of a single aircraft component, but perform static structural testing to only 80% of design limit load rather than testing to failure (which is the requirement of non-DBF teams). Limiting the load applied during the test allows the component to be optionally used as a part of a flight test article later in the semester while still affording the team the opportunity to verify their ability to predict structural response via simulation. It should be noted that teams typically complete the incorporation of their structural test article into a flight test article, but this is not a requirement of the course for reason previously stated.

The chronology which led to the incorporation of the DBF option into the Aircraft Detail Design Course and the life lessons that resulted from this curricular change are discussed in the following paragraphs.

Chronology of the Aircraft Detail Design DBF Option

Prior to the curricular change, students in the Aircraft Detail Design course gathered data from wind tunnel testing that failed to correlate well with theoretical predictions. In addition, students generated structural analysis results using computer simulation (Finite Element Analysis) tools, but had no feel for whether or not the results made sense.

In the Fall 2003 semester, an instructor change in the Aircraft Detail Design course led to a major curriculum alteration that emphasized component design and the addition of structural testing of scaled models of aircraft components. The new curriculum required student teams to build both wind tunnel and structural models of an aircraft component (e.g., a wing section, tail section, pylon) to allow students an opportunity to verify both aerodynamic and structural analysis methods.

Therefore, beginning in the Fall 2003 semester, students were required to select a single component from the aircraft they developed in the Preliminary Design course and concentrate on the design of that component alone. They were first required to fabricate and test a wind tunnel model of the selected component, with the intent of determining coefficient data that would allow verification of the aerodynamic coefficients derived during the preliminary design process.

The students then used the coefficient data to verify loads predictions for the component being designed. Concurrently, students designed a scaled structural model of their chosen component to sustain critical design loads (verified by the wind tunnel results). Since the structural model was scaled, an emphasis was placed on verification of analytical method versus design of the full-scale component. Students were required to simulate their structural model as it was actually built and constrained using a Finite Element Model, and then verify their ability to predict structural response by comparing strain and deflection measurements obtained from the actual model to those predicted by the computer simulation.

In Spring 2006, the course took a different path when the DBF option was introduced. This option was initiated to allow the development of a vehicle capable of being launched using a mag-lev rail system designed and fabricated as a part of a NASA grant program. Brainstorming led to the idea of having two (2) design teams create competing designs as a part of the Preliminary Design course. Since it was assumed that taking on the additional tasking that would be required to design and build a full aircraft flight test article would require additional manpower than that of a typical Detail Design team, it was decided to have the two teams combine into one ‘super team’ in the Detail Design course. Since wind tunnel testing was already an important component of the detail design process, it became immediately apparent that wind tunnel testing was the most logical means for deciding which of the two competing designs would have the most promise as a flight test article. This down select process would need to be completed during the first five to six weeks of the semester to allow the combined team sufficient time to complete the design, build, and flight test of the selected concept. It should be noted that it was necessary to continue to require structural testing of a selected component (typically a wing) as a course goal for the DBF team to maintain similar course outcomes to those Detail Design teams which choose to pursue non-DBF designs. This structural test requirement made the flight portion of the design purely optional, with the potential of ‘bonus’ grade points being part of the incentive provided to students to complete the flight test.

This DBF option is now engrained into the Preliminary Design course where two (2) design teams are provided identical RFP’s in the form of a design competition which culminates in the Detail Design course as a wind tunnel ‘fly-off’. The two Preliminary Design teams combine to form a single team of 12-16 students in Detail Design. The two former teams become ‘design groups’ which continue to develop their designs through the fabrication of full aircraft wind tunnel models making use of rapid prototyping wherever possible.[1] The models are then tested using identical procedures and the results are submitted to a faculty panel which then selects the design which appears to have the most promise as a flight test article. Teams which choose this DBF option still have the requirement to perform structural tests to verify a finite element simulation; however unlike the non-DBF teams in the Detail Design class they do not test to failure. The DBF teams instead perform a ‘proof’ test to 80% of the predicted limit load so that their component can be used for their flight test article. The DBF team is then allowed to pursue the design and fabrication of a flight capable vehicle.

It is important to note that every component included in the flight test article must be verified analytically and documented via a ‘pre-released’ drawing package prior to component fabrication. A radio controlled (RC) flight control system is then incorporated into the design to allow for a remotely piloted flight test operation. The team is required to prepare a formal flight test plan including a ‘go/no-go’ list similar to what would be used for a UAV flight test in industry.

This DBF competition is unique in that it involves competing designs being devised by teams within the same course at the same school. Typically, DBF competitions pit aircraft designs fabricated by teams representing an entire campus or university against those from other schools. A well known example of this is the annual American Institute of Aeronautics and Astronautics (AIAA) DBF completion which is held every Spring. While these competitions provide students with an opportunity to gain valuable experience working within design teams, they do not allow students the opportunity to learn the life lessons inherent in the ERAU capstone model.

Although the DBF option is considered an excellent learning experience, not all students wish to pursue the somewhat simpler designs required for the successful completion of the DBF project. Students who are interested in high speed jet aircraft design, for instance, can choose to complete the preliminary design of an advanced fighter aircraft, knowing that they will turn their attention to wind tunnel testing of their design and the structural test of a single aircraft component in detail design. These students also get excellent design experience, which is the ultimate desired outcome of the course. The university is also limited to pursuing only one DBF option per semester due to the additional costs incurred for full aircraft fabrication, which requires one or two design teams to pursue non-DBF options due to cost constraints.

The following section provides an illustrated chronology of a recent DBF design project.

Illustrated Chronology of the DBF Design Process

The following figures provide an illustrated chronology of the DBF designs which competed during the Spring 2009 semester. Figure 1, below, shows the CAD renderings of each design, as completed during the preliminary design phase.

Figure 1 – CAD Renderings

The Spring 2009 competition involved reconnaissance UAV designs, with 12 foot wingspans for the flight test articles, as depicted in Figure 1.

Each design group fabricated scaled wind tunnel test models for data collection and flow visualization, as shown in Figures 2 and 3, below.

Figure 2 – Wind Tunnel Models

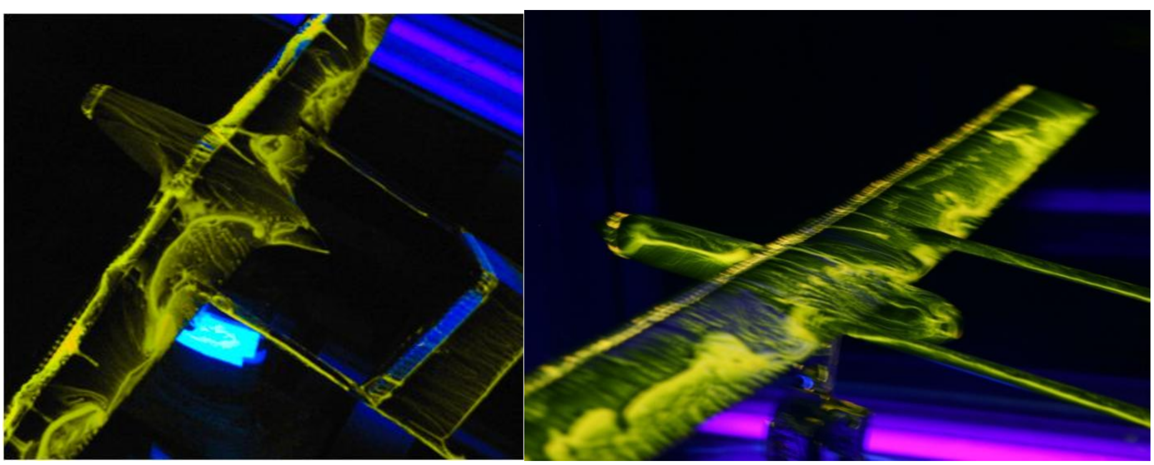

Figure 3 – Flow Visualization

These figures show the scaled models being tested in the ERAU, Prescott low-speed wind tunnel. The resulats obtained from wind tunnel testing were used to down-select to the concept on the right which was then structurally tested and flight tested.

Figure 4, below, shows the structural test of the selected concept.

Figure 4 – Structural Proof Test

The figure shows sandbags being applied to the underside of the wing surface to simulate lift on the inverted test article. Only 80% of the design limit load is applied to preclude structural failure which would prevent the use of the wing structure for the flight test article. Strain and displacement measurements are recorded for ten (10) load steps, with the results compared to a finite element simulation. This simulation attempts to model the lift distribution and mechanical contraints as they are applied to the test article.

The last step in the process is flght test. Figure 5, below, shows the flight test article on the runway prior to the aircraft's first taxi test..

Figure 5 – Flight Test Article

Figure 5 also shows the team and both instructors enjoying this proud moment. It should be noted that half of those present represented the design group which spent four acedemic months designing the concept which was not selected.

The DBF option has been pursued on five occasions since the Spring 2006 semester, with varying levels of success. What has been constant, however, is the exposure that students receive to life lessons in terms of collaboration with a former competitor and the feeling of loss that one design group is forced to experience when one of the concepts is 'left behind'. The following section addresses these experiences and their impact on student learning.

Life Lessons Resulting from the DBF Option

The DBF option documented in the preceding section was aimed at enhancing student preparation for their professional lives. This preparation is a critical student outcome of engineering capstone courses and can be established in a number of effective ways:

- By having students work within multi-disciplinary design teams.[2]
- By providing instruction geared toward oral and written communication skills.[3,4]
- By focusing on the ethical foundation of the engineering profession.[4]
- By teaching social awareness through interaction with real-life customers.[5]

While the ERAU aircraft capstone sequence incorporates the first three of these attributes, it is unique in that it provides the additional components of induced collaboration with a team of students which may have been previously seen as adversarial, and the introduction of the potential for loss in terms of a project down-select. These components allow students to experience what many engineers in industry have experienced as a result of company mergers or being on the losing end of a design competition. Although these life lessons result in team conflicts and anger over having to leave a substantial investment in time and energy behind, the feedback received from students regarding this course methodology has been overwhelmingly positive (as further discussed in the following section).

The preparation for this process begins while students are still enrolled in the Aircraft Preliminary Design course. The Detail Design instructor delivers two guest lectures to the Preliminary Design students to inform them of the process that will occur as they transition to the Detail Design course. These lectures lay the groundwork for the two independent teams combining into a single entity with the end goal of designing and manufacturing a flight test article representative of the more promising of the two designs. The students understand that it is to their benefit to put in an optimal effort in the wind tunnel testing portion of the Detail Design course in order to achieve the most representative results possible. The teams also know that one of their designs will not be moving forward to the production phase, and that it behooves them to become more knowledgeable of their competitor's design should that design be chosen over their own.

The first class period of Detail Design is dedicated to providing teams with Statement of Work documents which clearly provide the two previous competing teams with tasking which will require the two design groups to work together as a single team toward a common goal. The two teams sit down together and formulate a schedule and a distribution of tasks such that each team member is given the opportunity to work in their areas of interest. The instructor encourages at least one design group member to volunteer to work on the opposite group's wind tunnel model construction to gain a better understanding of the intricacies of the design and encourage team collaboration.

The team continues to work as two design groups for the first five weeks of the semester until wind tunnel testing is complete. However, weekly team meetings including both design groups are required, and the team is encouraged to refer to themselves as a single unit, rather than 'us' and 'them'. After the wind tunnel test results are evaluated by a faculty panel, one of the two designs is chosen leading to another life lesson, that of loss.

The emotions that students display immediately after the down-select typically include anger and resentment (along with joy for the design group responsible for the selected design). These emotions have been voiced during student-instructor meetings and in the course evaluations compiled at the end of the semester. This loss represents a major academic set-back in the minds of many of the students, and thus the 'healing' time varies depending on each student's maturity. It must be remembered that the students have devoted hundreds of hours outside of the classroom over four months of their academic lives to their designs by the time the down-select occurs, so naturally the pain of loss can be quite intense. However, this feeling typically subsides as both design groups focus on the task of designing, fabricating, and testing an aircraft structure and control system within a two-month window. The excitement of designing an actual aircraft with the potential of flight test often lessens the pain of loss even if the aircraft represents the design of their previous competitor. The course instructors also devote considerable time to address any continued resentment through conflict-resolution planning and individual student meetings.

Evaluation of Success

Although a quantitative assessment of the success of the capstone curriculum change is difficult at this time due to sparse data, a qualitative appraisal is possible based upon student course evaluations, senior exit interviews, and feedback received from alumni.

The percentage of positive student comments relative to the processes utilized as a part of the DBF option has been overwhelmingly positive since the DBF curriculum change was introduced in Spring 2006. Overall, students greatly appreciate the opportunity to apply real-world based design methods and verify their results through wind tunnel and structural testing, followed by the true test of their designs: flight test. Seniors have also voiced their overwhelming approval of the learning environment present in the Aircraft Detail Design course in senior exit interviews documented since the curriculum change. These responses indicate a continued satisfaction with the course requirements, even though they have become much more demanding with the inclusion of the DBF option, as evidenced by the increased number of hours invested per team per semester. The interview results indicate that, in general, students understand that the uncomfortable situations introduced through forced collaboration and loss are worthwhile in terms of their educational value. A typical student comment which follows this theme is: "The detail design course requires the DBF team to be physically and emotionally challenged, yet provides a complete capstone experience. This course proved to me that life is not always an enjoyable ride and I applaud the instructors for preparing us so well to go into industry."

Ideally, alumni surveys would be evaluated to determine whether the change in curriculum had enhanced ERAU graduates' abilities to immediately apply what they have learned and better prepared them for similar experiences in industry. However, because the curricular change has only recently been implemented, the surveys provided to recent ERAU graduates do not include questions which would allow evaluation specific to the changes resulting from the DBF option. Nevertheless, multiple alumni have sent email messages fully endorsing the DBF option and suggesting that it has left them better prepared for the transition to the demands of industry.

Enhancement of ABET Outcomes

The ERAU AE capstone sequences allow students to meet the majority of the ABET required outcomes (identified as (a) through (k) as defined by ABET Criterion 3), specifically:

- (b) an ability to design and conduct experiments, as well as to analyze and interpret data;
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- (d) an ability to function on multi-disciplinary teams;
- (e) an ability to identify, formulate, and solve engineering problems;
- (f) an understanding of professional and ethical responsibility;
- (g) an ability to communicate effectively;
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; and
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The DBF option specifically addresses the social constraints identified by outcome c) by forcing students to overcome potential barriers in terms of collaboration and competition. It also could potentially address outcome h) in terms of a broad education in a societal context in that it places students in situations that will allow them to better interact with fellow engineers and face societal issues more confidently due to the life lessons learned in the class.

Application of Acquired Knowledge and Program Enhancement

Over the five semesters that the DBF option has been offered, several improvements have been identified which have and will be applied to future DBF projects. The first is the necessity of acquiring verifiable data upon which to base the design down-select. In the past, questionable data achieved from the wind tunnel testing has been used to justify the elimination of one of the two design options, using the need for a timely selection as the basis for this decision. However, due to the tremendous effort put forward by the design groups prior to the down-select, hasty decision-making has resulted in high levels of resentment toward faculty and the students comprising the winning team. Therefore, additional investment has been made in acquiring wind tunnel equipment which has a proven level of accuracy necessary to provide reliable results upon which the down-select decision can be made.

A second improvement is in regards to limiting the scope of the project to allow students to complete a flight test article that has a reasonable chance for success. RFP's have been offered to students as a part of the DBF option which were too advanced to allow students to complete the design and fabrication of a flight test article in the allotted time frame. Therefore, RFP's are now being limited to more reasonable requirements to provide students with a higher probability of success, thereby limiting the frustration caused by incomplete projects.

Finally, follow-up alumni surveys are being planned to acquire quantitative data specific to the DBF option which will be used to assess the success of this curricular modification. These surveys will also be used to identify additional tools that could be incorporated into future DBF programs to better prepare AE graduates for professional challenges.

References

[1] Helbling, Jim, and Lance Traub. "Impact of Rapid Prototyping Facilities on Engineering Student Outcomes" , Proceedings of the 2008 American Society for Engineering Education Annual Conference and Exposition, Pittsburgh, PA: ASEE, 2008.

[2] King, Paul H., "Capstone Design and ABET Program Outcomes in the U. S.", European Society for Engineering Education, TN 37235-163.

[3] Helbling, Jim, David Lanning, Ron Madler, Angela Beck, and Patric McElwain. "Integrating Communications into Team-Taught Senior Design Courses", Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition, Washington DC: ASEE, 2005.

[4] Catalano, George D.. "Senior capstone design and ethics: A bridge to the professional world.", Science and Engineering Ethics, Springer, Netherlands, 2007

[5] Horenstein, Mark, "Teaching Social Awareness through the Senior Capstone Design Experience", University of Pittsburgh publication, 2002