AC 2007-2071: INTEGRATING GENERAL AVIATION AIRCRAFT IN THE AEROSPACE CURRICULUM

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Integrating General Aviation Aircraft In the Aerospace Curriculum

Abstract

The Aerospace Engineering Department at Cal Poly State University, San Luis Obispo, is in the later phase of a dynamic experiment to revitalize its “hands on” approach to undergraduate engineering education and bring it better in line with evolving accreditation standards. Part of this plan is to introduce commercially available aircraft manufacturing and fabrication “kits” into its laboratory curriculum. This has been largely accomplished, and the challenges of the initial phases of this task were presented in a previous publication. This paper presents how the lessons learned and resulting innovative learning experiences are being integrated throughout the aerospace curriculum with a critical eye towards meeting accreditation standards. These innovative experiences include modifying course syllabi across many technical areas, focusing on the individual learning styles that generate interest and enthusiasm in students, overcoming the inertial of established grading processes that do not recognize or reward exceptional teamwork, and linking with funded projects and related proposals supporting work up to the graduate level.

The way that Cal Poly has been meeting the above challenges has been unique and rewarding, yet still contains risk relative to accreditation. These risks are discussed relative to the next accreditation visit where the department hopes to win approval for its innovative approach to curriculum development.

The Educational Challenge

About some topics perhaps too much has been written, an over-consumption that discourages even honest effort to contribute further. Education, especially technical education, is one such topic. Open a literary magazine and there is the latest *forum* on education; newspapers both local and nationwide[1] carry the latest surveys, court decisions, and politics regarding our schools; major news magazines rank colleges[2] annually; editorials tell us where we have gone wrong with our children and what to do about it; and everywhere there are educational statistics, graduate earnings comparisons, cost and savings plans for each state in the union; numbers and charts everywhere, and all of them reminders of Benjamin Disraeli's lament on the progression of data masquerading as truth— "*lies, damned lies, and statistics.*”

Similarly, ideas abound on how to improve technical education[3] by changing America’s culture of teaching. Engineering accreditation teams struggle with how to promote and evaluate the laboratory experience[4] so that more can share in the benefits of “hands on” activity. One of the primary goals of engineering practice has always been to link theory with practice, and true-life stories of engineering practice are both interesting and profound.[5, 6] Providing the student with his or her own true-life experience while at the academy increases both the motivation to master a subject and the developing passion for creative activity.

Moreover, educators from all fields bemoan the fact that many, if not most, of our students do not develop a passion for learning or the habit for independent, innovative thought that is at the heart of all professional education.[7,8] Despite the significant promotion of team activities in engineering colleges, some still view the engineering profession as a place where solitary work is done in isolated cubicles: a work primarily consisting of reading reports and accessing computer programs in preparation for technical meetings. This view, unfortunately, matches and is reinforced by much of their academic experience in the classroom. The link between theory and practice may be spoken, but it is seldom experienced, for many of our students. It is well known that all education[9] is deficient that does not present a proper balance between experience and reflection, and this type of imbalance is especially unfortunate when it occurs in technical fields.

As shrinking budgets put increasing pressure on undergraduate laboratory education, and as a greater percentage of students enter the curriculum without practical experience in mechanics or a familiarity with tools and tooling, there is a strong need to expose aerospace engineering students to these realities of the aviation workplace, a workplace that traditionally has been highly motivational. The Aerospace Engineering Department at Cal Poly is trying to expose students to these hands-on skills of the aviation workplace and thus provide motivating experiences, at reasonable cost, by developing special lab courses to construct modern general aviation aircraft (or to construct parts of these aircraft) using “kits” normally offered to the public by commercial vendors.

There is surprisingly little information in the technical literature on this subject except for trade publication articles and web site narratives. Isolated projects involving “kit” aircraft, such as the “roadable aircraft,” have been described[10, 11] , and NASA funds a program called “AGATE” to revitalize general aviation[12], but there are no specific guideposts for actually implementing “kit” aircraft into existing aerospace engineering curricula. In a humble spirit, the purpose of this document is to provide a few of these guideposts.

Course Objectives

It has been important from the outset that a laboratory course involving aircraft construction be more than one that merely turning students into “kit builders,” though that may certainly be one of the outcomes. The official course objectives of Aero 572, “Aircraft Manufacturing and Fabrication,” were specifically developed with this in mind. The course is offered two quarters of every academic year, and the specific objectives as taken from the study guide are listed and discussed below.[13]

> The course objectives are to provide a hands-on demonstration and practice of the techniques used in aircraft manufacturing and fabrication. They may include, but are not limited to, hands-on practice in working with aircraft materials and systems, seminar topics, field trips to aircraft designers, and reading aircraft plans and publications necessary for piloted flight. The primary purpose of the course is to compliment the capstone aircraft design sequence and give selected students significant exposure to aircraft fabrication techniques. By its nature this requires a team orientation, exposure to most if not all engineering disciplines as

they relate to flight, and a systems view of planning, task scheduling, documentation, and testing.

Students completing this course will be able to: (1) explain fundamental manufacturing and fabrication techniques used for aircraft made of metal or of composites; (2) implement the types of fabrication processes used by industry and by small aircraft builders; (3) document their own progress using established procedures; (4) demonstrate expertise in reading aircraft plans and construction diagrams, especially as the systems of the aircraft come together; (5) analyze how modifications and errors impact fabrication time and cost; (6) integrate aircraft construction with FAA certification, safety, systems testing, and (if appropriate) flight simulation." These objectives conform to what is often called Bloom's taxonomy of learning (see Appendix).[14]

Course History

This laboratory course is unique in that it was *student initiated and funded* at Cal Poly starting in 2003. In many ways a "perfect storm" of funding, available expertise, and student interest developed at that time allowing a unique opportunity quest. A few individuals in the aerospace program asked the department chair to consider offering an aircraft manufacturing and fabrication class that would give students much needed hands-on experience in working with the structural components, fabrication techniques, control surfaces, and avionics on small aircraft, specifically an RV-7 "kit" aircraft offered by Van's Aircraft in Oregon.

Since the drawings, structural components, controls, and flight systems of the RV-7 are "state-of-the-art" in many respects, and since the concepts (structures, control, propulsion) relative to educational value apply to much larger and more expensive aircraft, the department decided to offer this largely student-initiated and funded course in the 2003-04 academic year and received prompt approval from appropriate university committees. It is important to emphasize that without student interest, involvement, and funding this course would have been very difficult to start through the normal university process. The course is thus a credit to the initiative, creativity, and technical talent of our student population. Since its inception it has received wide support from the Industrial Advisory Board of the Aerospace Engineering Department (IAB) and from local chapters of the Experimental Aircraft Association, Inc. (EAA).

For the initial course offerings students met in a rented hangar at a nearby airport after some rudimentary classwork.There they were divided into teams and worked on the aircraft (as called for in the plans). Initially, work was documented on large dry-erase boards by the team leader. Based on the experiences and problems of this approach over time, the currently-used laboratory study guide and project management were greatly revised from those that existed in the initial course offerings. Students now are exposed to a much more structured environment, receive extensive preparation in the class room, and must earn the right to work on the aircraft at a campus lab location.

Each course offering now consist of three relatively well-defined major parts. In the first part basic skill sets are demonstrated, then expected from the students, including familiarity with appropriate tools, shop safety procedures, and expertise in reading plans. In the second part of the course student teams actually build duplicate wing sections from plans accompanying a "training kit." The training kit is supplied by Van's Aircraft (located in Oregon) and is designed specifically to provide the hands-on skills that students need to work on an actual aircraft. Students who do poorly on the second project must redo that project and take a written in-class final exam. Otherwise, students who perform acceptably on this second project are allowed to propose a final team task or set of tasks that involve working on the actual aircraft. This is done in lieu of a written final exam and results in either an "A" or an "F" grade for the final project. The department technician, a licensed aircraft mechanic, must approve the final work before it is signed off and documented.

Course Content

Although the main topic for the course is listed in the catalog, the actual contents depend on the status of aircraft construction. All these courses, regardless of topic title listed in the catalog, cover the same basic information through the mid-term exam. This includes familiarity with aircraft materials and construction techniques, exposure and practice to tools, especially those unique to working on aircraft, lab safety procedures, and demonstrated expertise in reading plans and construction diagrams. To avoid proposing a new course for every phase of aircraft construction, and yet to satisfy the university schedulers, each quarter the Aero 572 lab course cycles through one of the topics in the subtitle list below:

1. Cockpit Systems Integration
2. Primary Structural Components
3. Lift and Control Surfaces and Linkages
4. Engine Systems Integration
5. Flight Qualities: Performance
6. Handling Qualities and Testing
7. Avionics Systems Integration
8. Inspections and Certification
9. Human Factors Integration
10. Maintenance, Repair, and Modifications

The three projects in the course are described as follows:

Project 1: This project provides the students with a familiarity with tools and basic metalworking fabrication. Students demonstrate fabricating and connecting small metal parts, reading plans, and documenting their work. Student teams receive their own tools and tool box for this project and become proficient in riveting (see Figure 1).

Figure 1 Students Demo Flush Riveting with a Bucking Bar in Project #1

Project 2: The student is expected to demonstrate skills in the second project. It consists of the construction of a stiffened wing section from plans and associated documentation that are provided in a "training kit" by Van's aircraft. The instructions for this project are as follows:

Project #2 Student Instructions [15]
METAL WING SECTION FABRICATION AND CONSTRUCTON

A. Protection (Eyes and Ears), Partners (No Working Alone), Phone (available).
B. Read and Initial that you have read the material to the left of the instructions.
C. Preview the photos available on the class web site for this project.
D. Date the web log when each sub-task is completed (also at the left of the instruction).
E. Take the completed project to the instructor with your documentation log for grade.

The goal of Project #2 is to enable the student to competently work on an aircraft fabrication task and to document it thoroughly. It is imperative that the student integrate all that has been learned in Project #1 and that work not be hurried. The plans are more difficult to read in this project and demand insight and planning. There is important detail in every label, view, and dimension on the plans. Figure 2 shows students receiving a grade for Project #2.

Figure 2 Grades Are Assigned for Project #2

Project 3: Students who do not demonstrate acceptable skills with tools in Project 2 are required to complete a written in-class final exam. Students showing acceptable skill in aircraft fabrication are invited to present a proposed project and, if approved, will be allowed to work on an actual RV-7 project. The grade for these students will be "A" or "F" for the final project (a licensed aircraft mechanic will be the evaluator). Figure 3 shows work on the actual empennage of the RV-7 aircraft.

In order to communicate and coordinate student work with minimum confusion, a web-based construction log was developed. Before the web log each group's work was documented in a notebook , or written on whiteboards, then verbally communicated between group members or exchanged via e-mail. This created multiple mediums and required many hours to regroup into a single source and translate the document notes and pictures into a format acceptable to the Federal Aviation Administration (FAA), the final arbiter of the acceptability of the work.

A senior aerospace engineering student developed the website from ground-up. He facilitated this compiling effort in a web-based form as his senior project. With the website the RV-7 current status can be accessed from any internet connection, and each group that possesses a password can review the work of others and submit their own logbook entry without having to meet or coordinate messages, eliminating the multiple sources of information.

A sample log entry follows below:

Aircraft Section: *Wing (Section 7)* ***Date***: *12/20/05*
Workers: *Robert Rivera, Joon Kim*
Work Done: *The Right Leading edge was attached to the right main wing. Not completed. 14 Rivets used, 9 AN470AD4-5 and 5 AN470AD4-7. The interior spars are difficult to rivet because of low visibility and accessibility, so the interior spars are not yet attached. One rivet hole on out most spar not used because the hole is slightly oblong from drilling out rivets, looking into options for this hole and interior spar attachment.*
Parts Used: *Right Main Wing Assembly, Right Leading Edge Assembly*

Figure 3 Student Works on the Empennage of the RV-7 Aircraft in Project #3

Integrating the Lab Course Material into the Curriculum

It has been a challenging task to integrate the resulting laboratory course materials into the existing aerospace curriculum on an ongoing basis. The first step was to obtain special status for this course so that a student can take different subtopics for credit under the same course number and title, as described in the "course content" section above. The next step was to allow special credit at either undergraduate or graduate level for specialized, experienced students who will help in the training of newcomers and assist on final projects. At Cal Poly a two-course sequence called the "senior project" is required that must be defined and accomplished by the student. These projects are ideally suited to the ongoing development of the aircraft. Projects at Cal Poly in this area have included installing stress sensors in the wing, designing a low-drag cover for the engine, and designing flight test instrumentation for eliminating propeller drag during glides. Since this ongoing project creates a steady stream of students with varying degrees of experience to tap for assistance, it automatically provides trained and motivated teaching lab assistants.

The aircraft fabrication tasks should be related to other course work in aerospace, especially in the structures, propulsion, and stability and control areas. Avionics, mechanical systems, and materials engineering are fundamental parts of building a modern general aviation aircraft. The following discussion briefly describes experiments that have been developed for related courses in the aerospace engineering curriculum. While there is no "one method" of approach, the original intent was to compliment the materials taught in classroom with real "hands-on" applications from building an aircraft. This was done for four specific areas: structures, fatigue, aerodynamics, and "stability and control."

Rivet Strength Test. For a kit airplane constructed out of aluminum, the quality of the riveting plays a decisive role in determining the overall quality of the finished plane. There are limited ways to properly install a rivet, and there are many ways to commit errors, all of which detract from the airplane's quality and some of which can lead to serious flaws. Flush riveting, which is common on the exterior skin of RV kit planes, is an even more demanding skill to learn than non-flush riveting.

Most aircraft built today are stressed-skin designed[16]. In this process, the aircraft thin skins resist loading to prevent structural failure and are constructed from thin aluminum sheets riveted together to form the entire airframe. The correlation between building gliders in the introductory course, Aero 121, and building a kit airplane in Aero 572 highlights the many challenges involved as the scale of construction moves towards more complex and larger airplanes.

The rivet stress experiment will be accomplished with the Instron machine in the Aerospace Structures Laboratory, a machine that analyzes theoretical stresses relative to actual measured stresses. Students will explore various rivet defects using two common rivet types and study the structural impact on the overall strength of the material of the joined pieces. The calculated stresses are compared with the physical testing at which the joint lapse will fail, and the types of failures that occur are observed. This illustrates the excessive load conditions under which a rivet will fail, and clearly demonstrates the importance of quality riveting.

Fatigue and Crack Propagation. Modern aircraft structures are adequately designed to withstand severe gusts or maneuver loads. However, aircraft are subjected to many fluctuating loads over their life as well. Over a period of time, the overall strength of the material or structural components will deteriorate; failure may then occur below designed ultimate stress levels. The Cal Poly aerospace engineering curriculum currently offers a course in fracture mechanics, which includes a special topic on fatigue and associated theories. At the current time, however, no fatigue testing of actual aircraft structures is accomplished in our curriculum, and this experiment is intended to fill that need.

There are five main types of fatigue that can cause structural degradation: cyclic fatigue, corrosion fatigue, fretting fatigue, thermal fatigue, and acoustic fatigue.[17, 18] A simple cyclic fatigue test is proposed using the "shake table" available in the aerospace structures laboratory. In this test, the wing-section built by students and described in "Project 2" above can be tested for cyclic fatigue. This lab experiment remains in the planning stage at this time.

Low-Speed Aerodynamics Experiment. Many homebuilt experimental aircraft flying today have limited published technical data. This lack of information provides an excellent learning opportunity for students to apply engineering theory to actual aircraft data. At Cal Poly, for example, a computational program called "PanAir" is available whose results can be combined with wind tunnel testing to extract useful aerodynamic properties of the aircraft. The PanAir software[17] can be used to analytically calculate aerodynamic properties of the aircraft wing, fuselage, and control surfaces of the airplane.

By comparing the theoretical approximations made by "PanAir" to the data from a wind tunnel, an accurate model of the aerodynamics properties of the aircraft under construction can be obtained. To achieve a realistic dynamic test condition, a match must be made for compressibility, power effects, viscosity, and for the determination of stability derivatives. For a 2-D airfoil wind tunnel experiment, both the lift coefficient and the Reynolds number will be determined. This experiment is also under development at this time.

Stability and Control. The RV-7 aircraft has no published stability derivatives[19-20] that can be used for a qualitative flight evaluation and for prediction of flying qualities. Of course the fundamental equations for both longitudinal and latitude motion can be found in most controls textbooks. The stability and control analysis depends on the aircraft geometry, aerodynamic properties, controllability, handling characteristics, and dynamic flight conditions.

Aircraft DATCOM[21] uses both theory and empirical data to calculate stability derivatives for a given aircraft configuration. The program itself operates similar to "PanAir," in that it requires a formatted input case with dynamic flight conditions and aircraft geometric data for the estimation of stability and control characteristics. Inputs to the program come from basic aircraft geometry and the flight dynamic condition, and the DATCOM program will then estimate the stability derivatives.

Another analysis program available to students at Cal Poly is a special software package called CIFER (Comprehensive Identification from Frequency Responses). This program was developed at the NASA Ames Research Center, and many graduate students from the aerospace engineering program have been funded to develop its user-interface.[22] Flight data is used by this program to develop transfer function models of the aircraft. This type of experiment requires a flyable aircraft, and thus it will be the last one to be implemented for the RV-7 aircraft. However, the modeling process can be simulated by generating "test" data with stability derivatives identified from the previously described experiments.

Conclusion

The on-going "hands on" educational experience continues at Cal Poly with the development of laboratory course Aero 572, and knowledge is passed onto a new generation of students. The revitalization of our curriculum continues to face difficult challenges and risk associated with implementing an aircraft project into the existing aerospace engineering curriculum. The practical experience and the unique applications gained from working with homebuilt aircraft brings a much needed "hands on" systems approach to engineering practice for the students. The many associated theoretical areas in aerospace engineering that the homebuilt aircraft can be linked to, such as aerospace structures, aerodynamics, and stability and control analysis, provide vital links between class exercises and real-life applications in an ongoing endeavor to effectively balance reflection and experience in the students' education. The laboratory exercises in this course, and their offshoots in other technical courses, meet the evolving ABET challenge for the aerospace engineering curriculum.

Comments from students who have taken this course:

"Since this was a unique challenge that we took, a lot of invaluable lessons have been learned throughout the course of trial and error and then adjusted for future considerations. It should be emphasized that the lessons and skills learned from working on this project far exceeds my expectation as it has taught me great deal about kit building, exposed me to many different approaches to solve a unique problem that has stumped many students and taught me the engineering practices performed on this particular aircraft as practiced in bigger industries."

"In a classroom environment, the instructor would discuss certain topics and try to explain to students what certain features of aircraft and their functions were using drawings and pictures. However, the hands-on approach to this kit airplane gave many of the students the chance to see the inner structures of how aircraft are built, how the loads are carried to main structures, why certain features were designed the way they are. All these would not likely have been discussed in a classroom environment nor had the impact."

"Working on an actual kit aircraft exposed us to the many different types of structures that are used to build an aircraft. We were able to identify different parts of the aircraft and understand the interaction between different types of control surfaces and how it affects the flight of an aircraft. We continue to learn new ways to solve problems trying different methods that puzzle us with all types of real-world problems faced by real engineers."

"As a student, I have greatly benefited from working on a kit airplane as part of the lab courses. Over the years, I have managed and worked on interesting projects from autonomous helicopter to building a re-usable rocket booster, but I was extremely excited and when I heard about the aircraft construction course being offered at Cal Poly, I took the course and I have not regretted it."

Appendix

Taxonomy of Educational Objectives: Cognitive Domain*

1. **Knowledge**—repeating information verbatim. [*Examples*: *list* the first ten alkanes; *state* the steps in the procedure for calibrating a gas chromatograph.]

2. **Comprehension—**demonstrating understanding of terms, concepts, and principles. [Examples: *explain* in your own words the concept of vapor pressure; *interpret* the output from a strip chart recorder or potentiometer.]

3. **Application—**applying concepts and principles to solve problems. [Examples: *calculate* the probability that two sample means will differ by more than 5%; *solve* the compressibility factor equation of state for P, T, or V from given values of the other two.]

4. **Analysis**—breaking things down into their elements, formulating theoretical explanations or mathematical or logical models for observed phenomena. [Examples: *interpret* discrepancies between a predicted experimental response and the measured response; *model* the dynamic performance of a laboratory stirred-tank reactor.]

5. **Synthesis—**creating something, combining elements in novel ways**.** [Examples: *formulate* a model-based control algorithm for the process studied in last week's lab experiment; *make up* a homework problem involving material covered in class this week; *design* a concrete canoe or solar-powered car.]

6. **Evaluation**—judging the value of material, choosing from among alternatives and justifying the choice using specified criteria. [Examples: *select* from among available options for measuring an experimental system response and justify your selection; *critique* a lab report.]

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