Learning Aerospace Design and Manufacturing Processes to Demonstrate ABET Program Objectives

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Abstract

A new course was created in the fall of 2007 as part of a curriculum change seeking engineering accreditation from the Technology Accreditation Commission (TAC) of the Accreditation Board for Engineering and Technology (ABET) for Purdue University's Aviation Technology department. Titled, "Aircraft Advanced Process," AT408 is a course in which students are tasked with designing and manufacturing aircraft components. The class is structured as if the students are employees of a company, working for a simulated customer. In groups of three to five, the students are responsible for meeting the needs of the customer by successfully designing and manufacturing a satisfactory aircraft component by the end of the semester. The class is an excellent medium for learning team dynamics, engineering design processes, advanced manufacturing processes, and client-to-customer communication processes. The learning outcomes of AT408 have been tailored to fulfill the criteria established by the ABET committee as a component of the Aviation Technology department's new ABET curriculum.

Introduction

Aircraft Advanced Processes, AT408, was one of many new courses added to the Aviation Technology plan of study at Purdue University. The purpose of the class was to fulfill the ABET learning objectives to receive accreditation in the future, which will change the degree received from Aviation Technology to Aeronautical Engineering Technology. AT408 was part of the first curriculum revision that will be submitted for ABET review. The course was first offered in the fall semester of 2007 and is now required for graduation. The objective of this paper is to evaluate AT408's incorporation of the learning objectives established by ABET for engineering technology programs. The objective of AT408 was to incorporate quality standards established by the professional and technical societies in the field in which graduates will work [1]. Accreditation,

> a) provides a structured mechanism to assess, evaluate, and improve the quality of a program; b) helps the students and their parents choose quality college programs; c) enables employers to recruit graduates they know are well-prepared; d) is used by registration, licensure, and certification boards to screen applicants [2].

Accreditation also,

> assures the student that the institution operates on a sound financial basis, has an approved program of study, qualified instructors, adequate facilities and equipment, and approved recruitment and admissions policies [3].

The purpose of the change of the program was to enable the Aeronautical Engineering Technology program to produce graduates who are able to work in a team environment, have the skills and expertise to make critical decisions, and are able to effectively communicate with "pure" engineers. Students will have extensive hands-on experience, as well as basic theoretical knowledge in engineering. These skills will give graduates of the program an opportunity to fill entry-level positions at aerospace companies as design, project, and liaison engineers. Graduates will also be qualified to perform the duties of maintenance personnel or technical support. Specifically, the course was designed to provide students with the skills they will need for future growth into management positions within two to five years after graduation. Research has shown that engineering accredited programs consistently produce successful graduates [4].

The following are the specific criteria that a graduate of an approved ABET engineering program must demonstrate:

- a) An appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines
- b) An ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology
- c) An ability to conduct, analyze, and interpret experiments, and apply experimental results to improve processes
- d) An ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives
- e) An ability to function effectively on teams
- f) An ability to identify, analyze, and solve technical problems
- g) An ability to communicate effectively
- h) A recognition of the need for and an ability to engage in lifelong learning
- i) An ability to understand professional, ethical, and social responsibilities
- j) A respect for diversity and a knowledge of contemporary professional, societal, and global issues
- k) A commitment to quality, timeliness, and continuous improvement [5]

Students do not need to demonstrate all of the aforementioned criteria while completing AT408. ABET does not require that each course fulfill every requirement, rather that the entire curriculum works in conjunction to satisfy the requirements [1]. AT408 was evaluated on the following criteria: a, b, d, e, f, g, and k.

Requirements and Solutions

AT408 was structured like an independent business enterprise. The course syllabus was titled, "AT408, Inc. Trainee (student) Orientation Manual (syllabus)" [6]. During the initial lecture, the students were divided into teams, and a semester-long project was discussed. Each team was to report to an assigned customer who had a specific need. The authors of this paper will focus on one of the teams who designed and manufactured a mock-up of the turbine case cooling valves for the Pratt and Whitney PW4098 Turbofan Engine. This engine is used as a teaching aide in the Purdue University Aviation Technology Powerplants Laboratory. Each team had a different component to design and manufacture, but all shared the same customer. All of the products would eventually be mock-up parts for the same PW4098 engine.

Through their experience in FAA approved Part 147 classes, the students learned to work in teams and to follow instructions. Most Aviation Technology labs require students to work together in small groups to make better use of limited resources of engines and available aircraft. For example, an engine overhaul might be performed by three students working on one engine. However, some tasks specifically require multiple people to perform a task per maintenance manual procedures or physical limitations. The skills developed in those cooperative environments were used throughout the design and manufacturing processes in AT408. In addition to learning the basic principles and concepts of design, students physically performed all the stages of the process [7]. The goal was to allow students to become active participants in their own learning [8]. When applying for summer internships, many students received positive feedback from potential employers during interviews once human relation personnel and managers learned about this addition to the coursework.

The course material was taught by incorporating different methods of learning, including the following: “independent readings, lecture meeting twice a week, laboratory meeting once a week, all to accomplish a team project” [6]. The Trainee Orientation Manual covered the specifics of the attendance policy, laboratory safety policy, and established the grading rubric. “Company objectives” were explained and included project planning, organization, communication, managing technical information, communication of technical ideas, understanding financial impact, problem solving and system thinking, and team dynamics. Three formal presentations were required to keep the customer, the professor, and the other students in the class abreast of each team’s progress. The presentations were in the form of a conceptual design review, a detailed design review, and a final presentation. Each presentation included written documentation, an oral presentation delivered during scheduled lecture time, and all findings submitted in an electronic format to support and explain the design and manufacturing processes.

The final goal of the instructor is to have real-life projects from aerospace and aviation-related companies. Upon completion of these projects, students would provide a design of non-structural components, testing equipment, tooling, and many other services. Students could also be responsible for initial research on new products or services, as well as gathering information from multiple sources for related use [8].

Demonstration of ABET Learning Objectives

The students in AT408 were required to demonstrate “a) an appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines” [5]. Many of the skills were used during the design process of the turbine case cooling valves (TCCV), with emphasis placed on learning how to apply design principles [9]. With no previous engineering drawings of the component at the students’ disposal, the geometry involved in designing such an assembly was complex. Extensive dimensional analysis was required to successfully model and eventually manufacture the component. The students were required to come up with project planning, provide cost analysis, and produce three dimensional, computer generated models. Materials engineering methods were studied in deciding how to make each part. Students considered multiple materials, including aluminum, carbon-fiber composites, and acrylics. Consideration was also given as to how the selected materials would respond to the manufacturing processes, which would be performed in the Advanced Materials laboratory. Students applied problem solving skills from initial concept through final assembly.

Students' successful navigation of problems encountered during AT408 demonstrated "b) an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology" [5]. AT408 students had already completed the Materials and Manufacturing Processes in Aviation (AT308) course, which is a prerequisite to AT408. In AT308, the students learned about manipulating the properties of materials and became familiar with different machining processes, including the use of a mill and a lathe. In AT308, the students were grouped in teams and given work orders and work instructions to develop their understanding of the logic behind procedures [10]. At the conclusion of the semester, thirteen projects were finished. Most of the projects involved machining, but others required the students to calculate the strength of riveted joints and to use a tensile tester. The new course required the students to apply these previously learned skills and material.

The students are required to demonstrate "d) an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives" [5]. Before starting a project in the first offering of the course, each team went through initial research on how the assigned system works on the PW4098 turbine engine. The knowledge gained during this research enabled the students to produce a successful design. As previously mentioned, the students were not limited to particular materials or manufacturing processes. Some teams chose to use clay and composite material; other teams used more traditional materials like sheet metal, aluminum alloy bars, and rods. One team even produced an aluminum casting and used ZCorp's 3D printer to manufacture a mold. Each team could design the part any way they wanted; however, the students needed to justify the selection of materials. The students were required to do a cost analysis to prove that the material(s) selected was the best for the design. The teams were required to develop three unique designs for the component. To help determine which concept was the best, the teams used a Decision (Pugh) Matrix, which is one of tools used in Six Sigma methodology. The first step is to establish a datum concept and set of weighted criteria. The second stage is to compare two concepts according to selected criteria (see Figure 1.) The concept with the largest score is the best [11].

Criteria	Weight (1-5)	Concepts					
		Bolt/ Rivet Parts Together		Machine Part from One Solid Piece		Mate Parts with Industrial Adhesive	
		Rating (-3 to +3)	Score	Rating (-3 to +3)	Score	Rating (-3 to +3)	Score
Aesthetic Appeal	5	Datum		-1	-5	3	15
Manufacturability	3			-3	-9	3	9
Structural Integrity	4			1	4	-1	-4
Functionality	3			-3	-9	1	3
Maintainability	2			1	2	-1	-2
Cost (Estimated)	3			-3	-9	-1	-3
Part Life (Time)	2			1	2	-2	-4
Safety	1			1	1	0	0
Total =		0		-23		14	

Score = Weight * Rating

Figure 1: Decision (Pugh) Matrix

The structure and project requirements for AT408 served to fulfill each of the following ABET objectives: “e) an ability to function effectively on teams” and “g) an ability to communicate effectively” [5]. Each team operated completely autonomously, with minimal direction from the instructor, and met independently outside of class to work on the project. Each team created a time action plan, unique to their group, which established their deadlines for the major milestone events of the semester. The completion date was well defined; a project had to be finished by the last week of a semester, giving the teams 15 weeks to accomplish the task.

The first milestone of AT408 was the conceptual design review (CDR). The CDR was an oral presentation in which each group discussed progress on their component and their plan for the semester with the other groups in the class, the customer, and the professor. The CDR for the turbine case cooling valves system included the following: identification of the customer and specific design requirements for the project; identification and statement of the problem to be solved; a brief explanation of the assigned system; a breakdown of the TCCV assembly; three unique design concepts; a decision matrix that quantitatively compared the concepts versus the customer’s design requirements; a cost analysis of the projected completed, manufactured cost of each concept; the design concept pursued and justification of the decision; a time action plan in the form of a Gantt chart; and, a concluding question and answer session. The CDR was a 20-minute oral presentation to which each of the three team members contributed equally.

The second milestone of AT408 was the detailed design review (DDR). This group presentation was similar to the CDR in format and duration. The content of the DDR differed from the CDR in that the detailed presentation showed the completed final draft of the TCCV design. The presentation included the following: a brief review of the chosen concept and the CDR presentation; a cost analysis of the materials required for the design; the specific vendors to order materials from; a detailed labor-hour breakdown of the estimated manufacturing time; tooling requirements for manufacturing; final CAD drawings of our component using CATIA V5R16; an assembly summary explaining the subparts of the system and how they would be assembled; and a concluding question and answer session. The DDR was a presentation in which the team discussed the completely dimensioned computer models and drawings and an explanation of the process by which the team would manufacture the TCCV assembly.

The third milestone of AT408 was the final presentation. This presentation not only demonstrated the final component but discussed the actual approaches and manufacturing methods used during the manufacturing process. The manufacturing process for the TCCV assembly involved a combination of aluminum sheet and acrylic fabrication. The students were able to complete the fabrication using the tooling and equipment available to them in the designated Advanced Aircraft Processes laboratory. Equipment used during the manufacturing process included: horizontal engine lathe, vertical milling machine, vertical band-saw, vertical drill press, metal break, pneumatic hand drill, pneumatic rivet gun, bucking bar, arbor press, round file, flat file, sandpaper, micrometer, caliper, optical comparator, and epoxy syringe. Aircraft Material Processes, the prerequisite course mentioned earlier, taught the skills and techniques required to safely operate the aforementioned equipment.

As mentioned previously, the AT408 class was randomly divided into teams of three or four students, each assigned a different engineering problem given in the form of a customer need (see Figure 2). In each team, the students' individual talents and backgrounds emerged as team member roles, and the instructor took the role of a facilitator [12]. The team this article is focusing on had a student with an extensive computer graphics background, a student with communication experience, and a student with industry fabrication experience working together to design and manufacture the part. The students were able to benefit from a broad skill set during each phase of the course, which demonstrated the ability to function on a multi-disciplinary team. Throughout the semester, each team member was in contact with other team members via email, telephone, and meetings outside of lecture and laboratory. The students developed successful working relationships through the use of various forms of communication [13]. The feedback each team received from the instructor, customer, and other teams was an important component of learning and demonstrating effective communication.

Figure 2: Typical Team in Action

Successful completion of the project demonstrated, “f) an ability to identify, analyze, and solve technical problems” [5]. The students were assigned a customer at the beginning of the semester. Through multiple meetings with the customer, a general need was indentified and system requirements were established. It then became the responsibility of the team to identify the specific needs of the customer, formulate various methods and approaches to solve the problem, and implement the best possible solution.

The last ABET objective demonstrated by AT408 was, “(k) a commitment to quality, timeliness, and continuous improvement” [5]. The TCCV project was designed and modeled using industry standard CAD modeling software. The platform used to create all of the drawings and models was CATIA V5R16. It was important to become familiar with CAD and design software because even 10 years ago in industry, “the amount of CAD being performed in comparison to manual procedures was between 76 and 100 percent CAD systems…” [14]. CATIA is a proven tool used to increase quality without adding cost, which was the case when Boeing Company used CATIA to design the Boeing 777 aircraft. One of Boeing’s goals in the 777 program was to reduce part interference, fit-up, and rework by 50 percent by using three-dimensional software [15].

The design process used in AT408 was identical to methodologies used in the aviation industry today. Six Sigma methodology, covered during the lecture portion of the course, uses tools for designing or improving manufactured products and services [16, 17]. Discussions included the DMAIC and DMEDI approaches to process improvement and process design scenarios. The DMEDI method was the framework used for the design and manufacturing process. Through the use of modern design engineering software and design engineering processes, AT408 demonstrated an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The TCCV project incorporated another aspect of continuous improvement. After the best concept was initially selected using the Pugh Matrix, the students came up with a better idea for the assembly. Then, they decided to return to the initial stage to ascertain whether the use of clear acrylic would be a better for the project than aluminum alloy. This different material added a new dimension to the project; the mock-up part would allow future students to see the inside of the assembly, greatly increasing the value of the project as a visual teaching aid. As the Pugh matrix showed, it was a concept that was superior to the previous ideas.

Conclusion

AT408 was created as part of a curriculum change in the Aviation Technology department at Purdue University. The shift is from an emphasis on applied aircraft maintenance to a focus on the engineering process as it applies to aviation from design to manufacturing and maintenance. This course exposes students to design and manufacturing processes. Students in this class worked together in teams to solve complex engineering problems. The teams updated each other and the instructor through a conceptual design review, a detailed design review, and a final presentation. The class was structured as if the students were employees of a company. Project requirements were set by a simulated customer, and students were required to deliver a satisfactory mock-up component for the PW4096 turbine engine at the conclusion of the course. AT408 was one of many new courses added to the Aviation Technology curriculum in pursuit of ABET accreditation.

ABET accreditation is an important step in the continuous improvement of the Purdue University Aviation Technology department programs. The new plan of study required by ABET is pushing current students to perform at a higher level than the previous plan. AT408 successfully meets seven of the 11 ABET-defined learning objectives for an engineering curriculum. Helping students to demonstrate proficiency in the all desired areas required by ABET results in more competent and capable bachelor degree graduates. The class is an excellent medium for learning team dynamics, engineering design processes, advanced manufacturing processes, and client-to-customer communication processes. The learning outcomes of AT408 have been tailored to fulfill the criteria established by the ABET committee as a component of the Aviation Technology department's new ABET curriculum.

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Biography

BRENT VLASMAN received his B.S. in Aviation Technology at Purdue University in 2008. He was a member of the first class to complete the revised Aeronautical Engineering Technology curriculum, seeking to achieve ABET accreditation. He is currently a graduate student at Purdue University seeking an M.S. in the College of Technology.

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