Group Design Projects

Abstract

In the junior-level fluid mechanics course in mechanical engineering at Bradley University, three different semester-long group design projects have recently been used. The first project is a rocket design project, in which student teams have to design and build a small model rocket that must travel a specified horizontal distance. While this project has many desirable attributes, it is not truly an open-ended design project, in that all successful rockets will have basically the same design. To improve upon this, a new design project was developed in which teams build foam gliders, with the highest score going to the team whose glider travels the furthest. No constraints are placed on the design of the glider, other than it must be made from a standard piece of foam that all teams receive. A third project is being implemented this semester in which each team will have to build a scale model wind turbine that will be tested in a wind tunnel. Grading will be based on the amount of power generated by each turbine. A comparison of the three projects with the advantages of each will be presented, along with a list of the required hardware to perform each project, and a description of the relationship of the projects to ABET learning outcomes.

Introduction

In the mechanical engineering system dynamics laboratory at Bradley University, a model rocket design project was developed[1] as a mini-project to teach students about the design project prior to their capstone design project. In this project teams of 3-4 students each had to design and build a small model rocket, with the goal of the rocket landing in a target area on a baseball field on its very first launch. This project drew on many areas of the students coursework, including:

- Using a load cell to measure the thrust force of a model rocket engine
- Using numerical integration and/or curve fitting to analyze the thrust data
- Using a wind tunnel to determine the aerodynamic characteristics of the model rocket
- Using numerical methods to solve the 2nd order equation governing the trajectory of the rocket

In addition to requiring the use of technical skills from several courses, the rocket project also gave the students the opportunity to practice some of the soft skills of engineering, including:

- Teamwork
- Written communication skills
- Financial management

Part of the score for the project was assigned based on the efficiency of each team in using the resources available to them, as measured in the amount of “Bradley Bucks” they spent to complete the project. Note that it is easy to create money for these projects by downloading the template for Monopoly Money from Hasbro[2] and Photoshopping in the faces of professors in your department. Printing on brightly colored paper works well to discourage counterfeiting.

While the rocket project was quite successful and well-liked by the students, it has the limitation of that the best rockets end up all looking the same, as the primary design variables available to the student are the size of the fins and the amount of weight in the nose cone. The two main reasons why new projects were developed after the model rocket project were that it was not truly an open-ended project – that is to say, all successful rockets looked the same, and that by the third semester it was obvious that some groups were copying from a previous semester's MATLAB trajectory prediction code rather than writing their own code.

Three design projects have been used:

- Model rocket design project (3 semesters)
- Foam glider design project (1 semester)
- Model wind turbine design project (1 semester)

The motivations for using group design projects will be discussed in the literature review in the next section, and more details on the design projects will be given in the following section. For what it is worth, the author's course evaluation scores have improved since adding a group design project to the junior-level fluid mechanics courses.

Literature Review

While there is some disagreement in the technical literature on team and group work in education about how teams should be constituted and the proper role of group work in classes, the literature does seem to be unanimous that teamwork assignments do improve student learning, and of course an ability to work on multidisciplinary teams is one of ABET's required learning outcomes.

For those interested in the literature on teamwork in engineering education, some recommended references are: Seat and Lord[3], Haag[4], Felder and Brent[5], and Smith[6]. Smith defines "Problem-based learning" as the process of working toward the understanding or resolution of a problem, in contrast to subject-based learning. Problem-based learning is suitable for engineering because it helps students develop skills and confidence for dealing with problems they have never encountered before. Team exercises should be designed that will require contributions from everyone and that could not likely be done by own of the team members on their own. Smith also remarks:

> "More is known about the efficacy of cooperative learning than about lecturing, the fifty-minute class period, the use of instructional technology, or almost any other aspect of education. Cooperation among students typically results in (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and (c) greater psychological health, social competence, and self-esteem."

Organization of Teams

As much as possible students are grouped into teams of 4 people each, with the teams selected by the instructor. Students are assigned in groups after filling out a survey. The survey asks for:

- Hometown
- Favorite Sports Team
- Other interests

These factors, along with demographic information, are used to group the students. GPA can also be used. For these semester-long projects are employed, the same teams are used for the group project and the homework to help build a sense of community. Normally all students in a given team receive the same project grade. The instructor makes it clear that he reserves the right to lower a student's homework grade if he does not participate in the group project. In the last semester using the glider design project, students were given the opportunity to evaluate their group mates. The results are below.

Students were also asked to rate the quality of the contributions of their teammates based on the following scale.

1. Minimal/Non-contributor - Contributions were minimal and could easily have been done by another member of team. Would not have noticed if he was not part of the team.

2. Marginal - Below average. Less than expected amount of effort, but still managed to contribute something useful to the group effort.

3. Acceptable - Did what was asked of him. Made significant contributions to the project. I would have no problem working with this person again in the future.

4. Exceptional - The person went above and beyond the call of duty to make the project a success. May also have taken a leadership role.

The overall class average was 3.46/4.0, and as can be seen in the table below, most students rated their teammates very highly. Only 3 out of the 32 students in the course had their contributions rated as below acceptable.

Table 1: Peer evaluations – rating scale

Bin	*Frequency*
1.0 - 1.5	1
1.5 - 2.5	2
2.5 - 3.5	10
3.5 - 4.0	19

Design Projects

While the rocket project is a worthwhile project that covers many different skills (data acquisition and analysis, numerical methods, modeling, teamwork, and design), it is not truly an open-ended design project, as all successful rockets will have basically the same design (weight in nose, large fins in back). To create a more open-ended design project, the glider project was implemented in which students build a foam glider, with the only constraints being in the amount of foam provided. The first run of the project was a success, as each team developed separate designs, and as seen in the survey results, the students enjoyed the project while learning engineering skills. While the use of "Bradley Bucks" was essential in the relatively simple Rocket project to keep students from using the facilities excessively and give them another design constraint, it did not factor as strongly in the Glider project. The open-ended nature of the glider project encouraged students to put their efforts into learning more about aerodynamics to improve their glider rather than optimizing their resources. Anecdotally, it also seems that students spent more time on the glider project than on the rocket project. Much of this additional time was spent in the machine shop using, and learning to use, the CNC milling machine.

Figure 1: Students launching rocket toward target area on last day of classes.

The equipment used in the Rocket Project includes:

- Multi-pack on Estes model rocket kits (Alpha model works well)
- Model rocket engines (recommend to use the small size “A” motors)
- Extra balsa wood for fins
- Material for nose cone weight (sand, modeling clay, wax)
- Scale with at least gram accuracy for rocket weight
- Load cell (< 10 lbf) for thrust stand
- Small wind tunnel with drag measurement
- Cart for launching rockets, with launch rail, level, and battery and igniter

Glider Project

The objective of the glider project is to build a glider out of foam. The launch speed is around 15 mph in level flight about 3 ft above the ground, and the team whose glider travels the furthest gets the highest score. As part of the glider design, students must first pick an airfoil shape and build an airfoil model and test it in the wind tunnel before building the full-scale glider. There is no constraint on the size and shape of the glider, but the glider wings must be able to clear the launch posts, which are about 2.5 ft apart. While student can use any airfoil shape they want, the NACA 4-digit series of airfoils is recommended. The NACA-4-digit series has the advantage that the geometry is completely and easily determined from the airfoil name. A discussion of the NACA 4-digit airfoil series can be found in the fluid mechanics textbook by Post[7]. A 2D aerodynamics CFD tool, such as XFOIL[8], FOILSIM[9,10], or JAVAFOIL[11] is used to predict the lift and drag coefficients of the airfoil section. These computations are compared with the wind tunnel test results, and then students pick a final airfoil shape to use on their gliders. A 3D solid model of the final glider design is made in drafting software such as AutoCAD, SolidWorks, or Pro-E, and then is made with a CNC milling machine. A rapid prototype machine might also work. Students are responsible for ensuring their glider design is dynamically stable in pitch, yaw, and roll. Students can change the location of the center of gravity by hollowing out part of the foam glider or adding extra glue to the nose.

The grade for the rocket project is divided into the following categories: Final Written Report (40%), Accuracy of Glider Trajectory Prediction (20%), Distance Glider Traveled (20%), Economic Efficiency (15%), Aesthetic Appeal of Glider (5%). Accuracy is based on how close the computed prediction of glider flight distance comes to the actual distance traveled in final testing. Students are charged "Bradley Bucks" for all material used, and for the use of equipment, including the wind tunnel and CNC milling machine, and consulting fees for seeking help from faculty. For the economics part of the contest, students pay Monopoly Money according to the following rates (the rates for the Rocket project were very similar):

Materials	**Rate**	**Minimum Charge**	
1. Foam	$1 per in^3	$5	
Facility fees			
1. Wind tunnel	$60/hour	$10	
2. Launch fee	$20/launch	$20	
Consulting fees			
1. Professor	$40/hour	$10	(first visit free)
2. TA	$20/hour	$10	
3. Students	$10/hour	$5	

Each team's glider was built from a single piece of 2 ft by 4 ft by 2" thick foam. The students thus had to consider the way in which they cut glider pieces out of the sheet in order to maximize the usage. As this was the first experience using a CNC milling machine for all of the students, many groups decided to make test pieces to test their manufacturing skills before beginning on the final glider. They discovered the importance of tool path, tool size, and tool shape in the quality of the final parts made. Each member of the team must contribute something tangible to the project. Each person on the team takes on a primary area of specialization such as: Prototype assembly, Modelling, Report Writing, Experiments, Launch Specialist, etc. By dividing the work this way, the project relates to the ABET outcome for Multidisciplinary Teams.

While most groups built fairly conventional designs, there were some interesting variations. One group built an adjustable tail. All of the 8 teams went with a conventional design with a basic tail. 6 of the teams went with a straight-wing design while 2 went with a swept-wing design. Actual travel distances varied from 7 ft to 68 ft, with an average of 32 ft. The students were surveyed about the project at the end of the semester and asked the following question:

The amount I learned from doing the Glider Project was worth the time and effort I put into it.
a) agree b) disagree
a – 87%, b – 13%

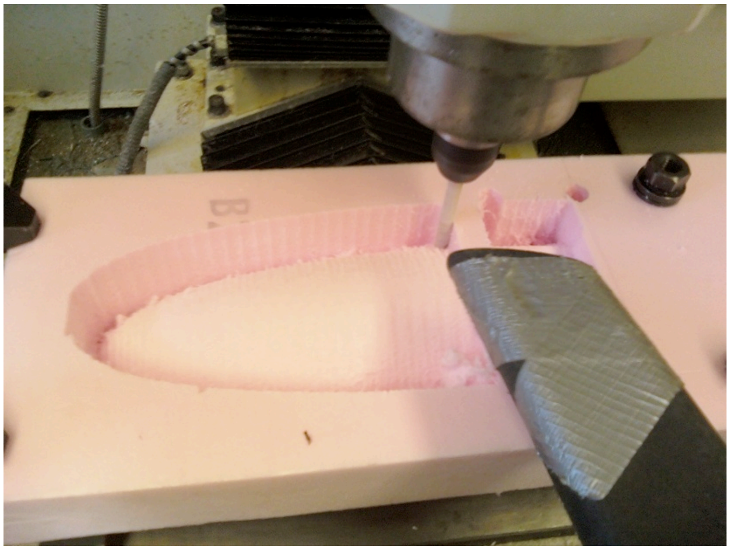

Figure 2: CNC Mill Machining Half of the Fuselage.

Figure 3: Students at glider launching on last day of class.

The equipment used in the Glider Project includes:

- 2” thick insulating foam from a local hardware store
- CNC milling machine
- Adhesive to attach wings to fuselage
- Scale with at least gram accuracy for rocket weight
- Small wind tunnel with lift and drag measurements
- Elastic band launcher

Wind Turbine Project

The wind turbine project is currently underway this semester. The goal of the wind turbine project is for the student teams to design, build, and test a scale model of a horizontal-axis wind turbine (HAWT). The grading for the project will be divided between a final written report, a final oral presentation, the efficiency of the wind turbine, and individual participation. The Written Report must contain a Literature Review, which must include at least one book and at least 3 journal articles or technical papers (such as ASME, AIAA papers, Sandia DOE reports, NASA Technical Reports, Wind Energy journal). Additional requirements are for the students to discuss in their report how wind turbines relate to the nation's energy needs and air pollution issues. They should also discuss the economics of wind turbines for a central Illinois installation. Thus the project relates to the ABET outcomes for lifelong learning (the ability to review the technical literature) and the impact of engineering projects in a global and societal context, as well as contemporary issues.

The size of the wind turbine is limited to a maximum or three inches in diameter, and the wind tunnel will be limited to speeds of 60 mph and below, which should limit the maximum power of the student wind turbines to 1/8 hp (~100 W). While true dynamic similarity with commercial-scale wind turbines will not be achieved, the focus of the project is on the design process. For their final testing report students will plot efficiency vs. tip speed ratio, and determine the optimum tip speed ratio for their design, the starting torque/wind speed for the design, and discuss the load-speed curve. They must also justify their design decisions, in comparison with their classmates' designs, which will be presented during the oral presentations. There is surprisingly little in the technical literature on wind tunnel testing of wind turbine designs[12] so this may be an area that is ripe for technical study.

The equipment used in the Glider Project includes:
- Small wind tunnel
- CNC milling machine or rapid prototype machine
- Electric generator with variable speed/load

Photographs of the projects and additional information can be found at:
http://hilltop.bradley.edu/~spost/contests.html

Conclusions

The author has already observed what has commonly been reported in the technical literature that team work improves students' learning of course materials. Students are also motivated by the opportunity of design project relative to cookie-cutter labs and basic homework. Most students want to take their rockets or gliders home at the conclusion of the projects. By developing a number of different design projects that can be used and rotated through different semesters, the author hopes to minimize the temptation of students to copy from previous semesters work. Potential ideas for other design projects could include boats or submarines for fluid mechanics-related projects, or trebuchets or RC cars for other courses.

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