A Different Kind of "Statics" Project

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Abstract

Many freshman statics courses involve course projects, but most involve bridge design in one form or another. We have developed a freshman class that involves both statics and elementary mechanics of materials, and have created a course project/contest which includes both of these topics.

The course content includes traditional statics topics, except for second moments of areas (moments of inertia) and internal forces in beams. To replace these topics, we incorporate simple 1-D stress/strain concepts from a traditional mechanics of materials treatment. (We cover the first six chapters of **Statics and Mechanics of Materials**, by Riley, Sturges, and Morris.)

This arrangement allows us to integrate a project/contest which incorporates the failure of a link into the course. Student teams are given a goal—they must design the lightest possible dog-bone link to carry the load created by a blade spinning at 1300 rpm. Their final designs are submitted as graphics files, and cut from nylon sheet with a laser cutting machine. On "contest day", the links are tested, and the lightest link to survive the test is the winner. Contest grading is based on performance—A for the top third of the class, B for the middle third, and C for the bottom third. Failed links receive an F for the contest portion. Overall project grading consists of a grade for documentation as well as the contest score.

The goals of the project were to:

- Add another "real mechanical engineering" experience to the freshman year
- Break students out of the "topic of the day" mold into a broader design view
- Incorporate previously learned concepts from freshman graphics, computer applications, physics, and calculus
- Emphasize the importance of checking calculations
- Reinforce factor of safety concepts
- Develop student teamwork skills

Overall, the project was extremely successful in accomplishing our goals, and we will discuss the project/contest and the student responses to it in more detail in our presentation.

Key Words

Engineering Curricula, Freshman Engineering Programs

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Background and Motivation

In the Mechanical Engineering Department at Rose-Hulman, we have taught some form of statics in the final quarter of the freshman year for some time, and we have two overall goals for the course. (1) We would like the students to learn the basic engineering concepts contained in the course. (2) We would like the course to be an engaging and challenging introduction to a part of the field of mechanical engineering.

In the spring of 2003, we first added a project to the statics course, as a response to our second goal of engaging the students. (Up until that time, the course had generally been taught as a straight lecture/homework/exam course.) This project involved using truss design techniques from the course to create bridge designs that were then constructed from welded steel rod and tested to failure. The drawback to this project was that the failure mechanism for those structures was typically buckling, which required us to provide formulas for the students to apply to estimate the failure load. The students did not fully understand those formulas, and like all buckling estimates, they were quite approximate.

In the spring of 2006, we rearranged the coverage in the statics and mechanics of materials courses. In the freshman class we cover traditional statics topics, except for second moments of areas (moments of inertia) and internal forces in beams. To replace these topics, we incorporate simple 1-D stress/strain concepts from a traditional mechanics of materials treatment. The second class begins with a brief review of 1-D concepts, then moves directly to analysis of torsion in shafts. Internal forces in beams, shear and moment diagrams, and second moments of area are treated just before beam stresses. This arrangement of material is standard in some newer texts [1].

This change in the course material alleviated, to some extent, the problem that the students were applying formulas without understanding. The students now had an understanding of stress and strain in the tension members, and an understanding of tensile failure. However, they still did not have a basis for understanding the buckling formulas, and the buckling formulas only give a failure load range that varies by a factor of four—for instance, the students could predict that the bridge would fail somewhere between 100 and 400 pounds.

This led us to create a project for the Spring of 2007 that involves tensile failure of a link. This project allowed us to emphasize basic engineering concepts from the course, and was an engaging and challenging introduction to mechanical engineering. In addition, it removed the other project's issues with blind application of very approximate formulas. The remainder of this paper will address our approach to the project and reflections on its success.

Link Failure Project

To create an interesting and challenging tensile failure, we gave student teams a goal: they must design the lightest possible dog-bone link to carry the load created by a blade spinning at 1300 rpm.

Statement of Project Objective

The project objective, as stated for the students, is given below:

"Your team is to design a link which will secure a rotating blade while minimizing the weight of the link. Assume that a novel helicopter rotor blade has been developed which requires the blade to be offset from a radial line that passes through the center of rotation of the rotor. The concept for holding the blade in place has been developed and is shown in Figure 1.

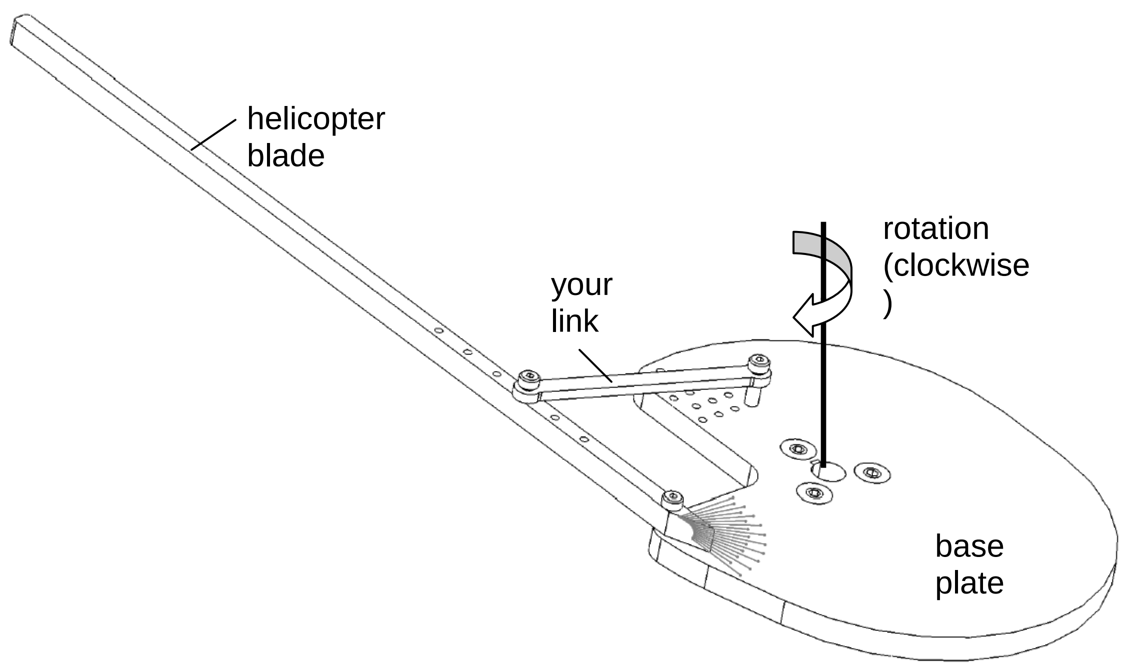

Figure 1
Isometric View of Rotor and Blade Assembly

"Your link must hold the blade in place without excessive deflection up to a rotational speed of 1300 rpm. To determine if there is excessive deflection or failure of the link, a small paper doll will be placed at a distance of 19 inches from the center of rotation of the rotor, which is just outside the circle traced by the spinning blade. If the doll is not damaged after the blade reaches 1300 rpm the deflection of the link will be judged acceptable."

(Details on the project are currently available at http://www.rose-hulman.edu/EM120/labs.shtml)

Project Organization

Student teams were assigned to create a two-dimensional link design, to select which attachment holes to use in the base plate and the helicopter blade, and to select one of four thicknesses of Nylon 6/6 for their part. The designs were created in SolidEdge^{TM}, and then saved as *.dxf files. These files, and material of the selected thickness, were used to create the parts with a computer controlled laser cutter.

To aid the students in their designs, experimental results for the failure *loads* of tensile test specimens (with and without holes) were provided for each material thickness.

Although these steps were not laid out for the students, a successful design generally involved

- Creating a free body diagram for the blade, rotor, and link system.
- Calculating the air drag forces on the blade, based on information we supplied on drag force as a function of air speed. (For the blade we used, air drag was negligible, although the students needed to discover this for themselves.) This calculation involved finding the magnitude and line of action for a parabolic distributed load.
- Finding the inertial loading on the blade. Here we asked them to use knowledge from their physics classes.
- Solving for the link loads for various attachment hole locations (various angles).
- Correctly identifying the Nylon 6/6 sheet material with the largest failure *stress*, from the failure *load* data.
- Designing a link to the correct specifications, with adequate additional material around the holes to account for stress concentrations.

To emphasize the trade-offs between factor of safety and material cost in design, the grading for the *performance portion* of the project was given to the students as:

Does it Function? (at 1300 rpm is your doll uninjured?)

- No: your performance score is 55.
- Yes: your performance is based on the weight of your link (light is good)
    - Top in section: 100
    - Top third in section: 95
    - 2nd third in section : 85
    - Bottom third in section: 75

(The course is taught as 6 class sections of roughly 30 students each.) This grading scale was intended to emphasize trade-offs, but to avoid having them all take a no-risk approach the overall grading for the project is based 75% on documentation (teams create a web site) and 25% on performance. Hence, teams that produce excellent documentation of a failed link (including an engineering analysis which is complete and correct) can still receive a high B+ on the project. (The project is 15% of their course grade.)

Reflections

This project allowed us to accomplish several goals:

- Add another "real mechanical engineering" experience to the freshman year
- Break students out of the "topic of the day" mold into a broader design view
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We encountered no particular difficulties on "contest day"—the testing table performed well and the safety features were adequate. (For details on the construction of the testing table, contact Ronald.Hofmann@Rose-Hulman.edu.) It proved useful to start testing with the heaviest link in a section and work up to the lightest, and many sections had at least one link which failed with suitable drama. We also manufactured links that we knew were weak, so that every section could see a failed link.

Student evaluations of the course were conducted as usual, with no particular emphasis on the project. Of the 215 students registered, 140 total students filled out the evaluations, and Tables 1 through 3 show the students' comments on the project. Of the 35 students who commented on the project, only 11 gave negative comments.

For this spring's project we plan to modify the task slightly, in order to keep information about good designs from last year from being used this year. By adjusting the weight and speed of the blade, we hope to make the aerodynamic loads a more significant part of the total loading. In addition, we plan to incorporate a speed at which the link *should* fail.

Summary

Overall, switching from a bridge-type design project to a tensile link design project was well-received by the students and the faculty teaching the class. The new project reinforced basic engineering concepts, engaged the students in a "real" mechanical engineering problem, and the analytical performance predictions correlated well with actual link performance. We will continue to refine and modify the project in the future.

Bibliography

1. Riley, W.; Sturges, L.; and Morris, D. *Statics and Mechanics of Materials: An Integrated Approach,* Wiley, New York, 2nd edition, 2002.

Table 1. Spontaneous Student Evaluation Comments about the Project (Negative)

The project should focus more on statics and less on physics II. The project calculations were more of a physics II problem that a statics problem.
Also, I felt the project could have been described more.
I did not like the porject that we did this year. I thought that more information about the material needed to be provided. Also, the project employed topics that were not covered in the statics course (ie inertial loading).
The project seemed like more of a guessing game than actual calculations. There should be some kind of markers that the students can check to make sure they are in the same ballpark as what the project asks.
I think that the final project could be done a little differently. It would be nice to have a little more guidance in class at the beginning of the project. Other than that the course was very good.
The project seemed very open-ended as well. It was frustrating not being able to use any upperclassmen for help. Also, the way the project was designed, the profs couldn't give us any help because it wouldn't be fair and the students that really cared about winning the "competition" wouldn't help you either. Irony of the situation is, those are the kids that actually knew HOW to do the project. Everybody else that didn't really care about the competition and just wanted to get a passing grade had no idea how to do the project so they weren't of any help either. As you can see, the project was quite frustrating in its design because we had no clue what to do and felt very helpless.
the project was difficult for me, because I hadn't had ME120. I had no idea how to write websites and felt as though a majority of the project grade was out of my hands!
the link project seemed like a last-minute afterthought.
we didn't know everything we needed to know to design the link until about a week before the design was due.
Decide on something else to do the project on. The project was not that fun and didn't fit too well with the course. I like the idea of a Tower of Power better.
The final project could be changed to make it more relevant. The penalty was too high if your link broke and hardly anyone wanted to risk they're link breaking and thus recieving an F for the testing part. It kind of defeats the purpose to put all the work into the calculations and stuff to just pick a link that you know is way too big. I think I could have taken 5 minutes and drew out a link without any calculations or anything that was pretty much the same size as the one we made. I would suggest making it not that big of deal if your link broke so that everyone would make their link small and see how close their calculations really were to real life. Also, the swinging metal bar was kind of gay compared to the expected sharp metal blade "blade of death" we were told about.

Table 2. Spontaneous Student Evaluation Comments about the Project (Neutral)

Allow other designs for project. Multiple holes, triangles, etc.
The link project applied the material we learned in class.
The project should also be a little more involved, it was suggested that instead of minimizing a link for a specific force, that the link be designed such that it could withstand a certain amount of force, but would be able to break for a higher force.

Table 3. Spontaneous Student Evaluation Comments about the Project (Positive)

The teaching was very good and the project really made us apply what we learned in the class. It really helps you with many aspects of engineering and physics. plus the project wasnt too hard and not too easy and it really encompassed what we learned this quarter

The best aspects of this course were the practice with drawing force systems, the section on stress, and the final project. I think the project did a great job of connecting everything we learned without being overly stressful. Very fun; I had a good time!

Also, the grading system for the project was good. It didn't reward teams very much for picking a risky FOS.

The course provided an excellent overview of static problems, and had a project that was relevant to what we had learned.

The lab work (project) definitely reinforced the class material. It was a very fun project.

The design project was a great way to integrate teachings in class with actual enthusiasm from the students. The catastrophic nature of a potential failure kept students on the edge of their seats and had them debating design concepts actively in their free time.

I really liked the project at the end of the quarter. It had a good summing of knowledge effect by applying what we learned through out the quarter to solve a system. Although I think that it was a bit harsh to give a score of 55 for a link that failed when the calculations for it were good and theoritically it should not have failed.

The project was well corelated with the class.

I liked the way the course was taught and the final project was a good way to combine the things that we learned in the class.

The lab experiment/competition at the end reinforced the material we went over in class and was very fun to witness (although made you worry when the blade started speeding up).

The Project was a nice re-enforcement of what we had learned and helped to put all of the topics together to make sure we knew what we were doing.

In seriousness, the class was great. If the project at the end had a little more variance it would have been better. It was pretty easy. The only variability was in the factor of safety once you solved for the best holes.

The project was very challenging, yet still fun.

We got to apply what we learned by designing a link as our course project.

That the material is so applicable, even to low-level engineering. The contest was seriously the highlight of my year, because designing the link was enjoyable and I actually understood what I was doing.

The project was good because we actually had to use statics to solve the problem

The final project taught us how to work well as a group.

I like how we learned how to do statics throughout the course, and then applied it to real life by the project at the end of the quarter!

I liked the final design project, it was fun to apply the knowledge gained during the class.

I really enjoyed the project that went with this course. This was my first class at Rose that had a project and I really wnjoyed working in teams and building something that had to be successful.

The project tied together all of the principles that we learned over the quarter making it a project that reinforced the material.

Lorraine G. Olson is currently a Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. Before starting at Rose-Hulman in the Fall of 2002, she taught at University of Michigan, Illinois Institute of Technology, and University of Nebraska. She has a broad background in the area of non-traditional applications of finite element analysis. Her teaching experience at Rose-Hulman includes courses in solid mechanics, finite elements, thermal/fluids, computer applications, and laboratory courses.

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