Adapting Entrepreneurial Mindset Projects for Large Classes

Brett Austin McCandless and Anna K. T. Howard
North Carolina State University/North Carolina State University

Abstract

Ill-defined problems can help students connect material and harness their curiosity to explore. Engineering Unleashed holds many cards to help new faculty adapt these Entrepreneurial Mindset (EM) tenets to their classes. Many cards are more suited to smaller class sizes where grading is less prohibitively difficult. “The Flying Forces: Adding Lift to Statics" card asks students to solve a 3D particle equilibrium problem (a balloon making power in Africa) but allows students to set the anchor points for the particle with social and fiscal ramifications.[1] The current project adapted this card for more than 130 teams: students submitted four different assignments, each graded automatically or graded by a team of undergraduate graders. Files and formulae are available upon request and will eventually be added to Engineering Unleashed.

Keywords

Statics, Entrepreneurial Mindset, Ill-defined Problems, Student Projects, Teamwork

Introduction

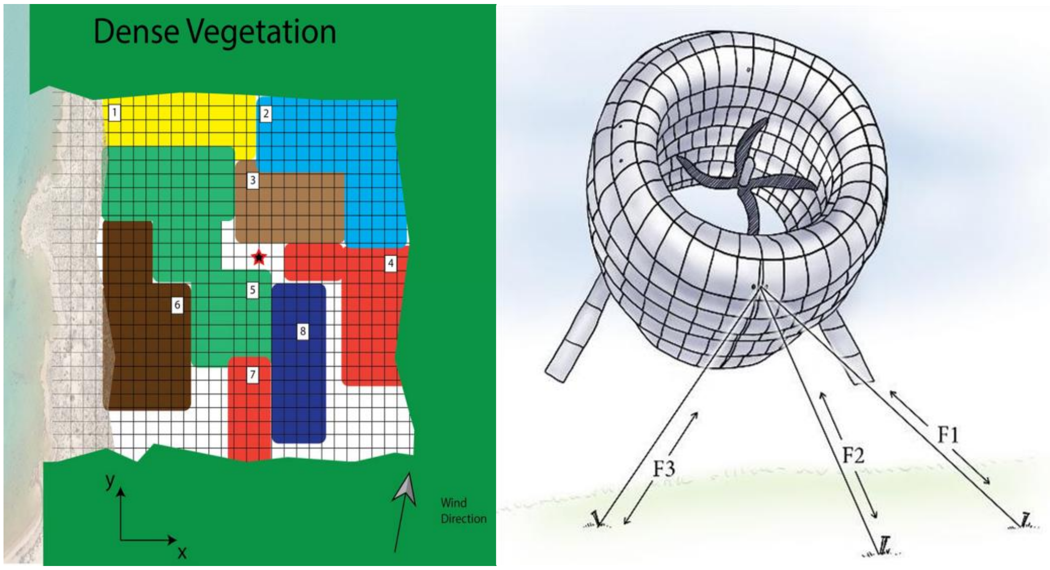
Engineering education improves when students move beyond lectures and textbook problems.[2-4] Project work can expose students to open-ended questions and design thinking.[5-6] However, for large-enrollment courses, grading becomes a limiting factor: it is time-consuming to grade hundreds of group projects or design reports. With this consumption of time in mind, instructors often limit the scope of a project to something very easily gradable: either collecting a report which is not checked for accuracy, or assigning a project where the outcome is known and identical for all teams. A project not checked for accuracy can encourage data fabrication, while one where the data is known can limit creativity and potentially encourage cheating. Large-enrollment classes often eschew open-ended projects, thus limiting the changes for students to develop the capacity for open-ended design thinking.

Engineering Unleashed is an online repository from the Keen Foundation designed to connect faculty and staff interested in encouraging student learning. The Keen Foundation emphasizes using the entrepreneurial mindset (EM): encouraging curiosity, fostering connections between content and between the real world and the analysis, and teaching students to create value for their companies and the world. Members of the Engineering Unleashed community share their work with “cards,” which are snapshots and descriptions of course ideas that promote design thinking and an entrepreneurial mindset. Many of these cards contain outlines for projects that have been used by instructors in prior iterations of engineering courses at various universities. While these projects often promote design thinking and offer open-ended design inquiries, many of the projects are not feasible in their current forms for use in large engineering sections; grading these projects would simply not be feasible for hundreds of submissions.

Original Card

The original “The Flying Forces: Adding Lift to Statics" card is available on the web. Students were tasked with picking the placement of cable bases for an inflatable wind turbine. This project encouraged students to visualize three-dimensional particle equilibrium. Launched balloons produced energy which eventually offset the purchase price. Students calculated the payback time of their design. The locations for the cable endpoints cost different amounts based on a gridded map, with the balloon location indicated by a red star. (See Figure 1). Each unit square on the grid has a side length of 10 meters; different zones had stories like “a school is planned for this zone, which would be disrupted by your cable, which would irritate the populace.”

Figure 1: Field Map and Original Picture



Students were able to vary the height of the wind turbine between zero and 600 meters. A linear relationship (100 watts per meter) was given between the height of the balloon and the power that the turbine would generate, for the higher the elevation of the balloon is, the more wind it experiences. A force was applied to the balloon which the cables would have to support. In addition to the costs associated with construction, the balloon had a base cost of $175,000.

Wind Turbine Project Changes to Card

1) The initial project motivation was to be able to provide electricity to sub-Saharan African nations. This part was removed in order for students to create their own justifications for building and designing the turbine. On the first day of class, students were provided the basic outline of the project and asked to come up with their own application for such a thing. Students became invested in their own projects before any of the mathematical work began.

2) The initial project assigned a constant force that acted on the balloon. However, power generation for the balloon linearly varied with altitude. We changed the force on the balloon to also increase with altitude to increase the realism of the scenario.

3) The initial project only allowed for one type of cable to hold the balloon in place. This singular cable had a maximum tension of 2000 N. To increase the design options, we allowed the students to select the cables that they would like to use. The cable choices are shown below in Table 1.

Table 1: List of Cable Choices

Cable Name	Cost	Maximum Allowable Tension
Standard Cable	\$125/meter	2000 N
Carbon Nano-Cable	\$1000/meter	4500 N
Lite Cable	\$100/meter	1250 N

We allowed the student groups to use different materials for each cable to encourage optimization: the strongest, most-expensive choice is not always necessary when designing a system.

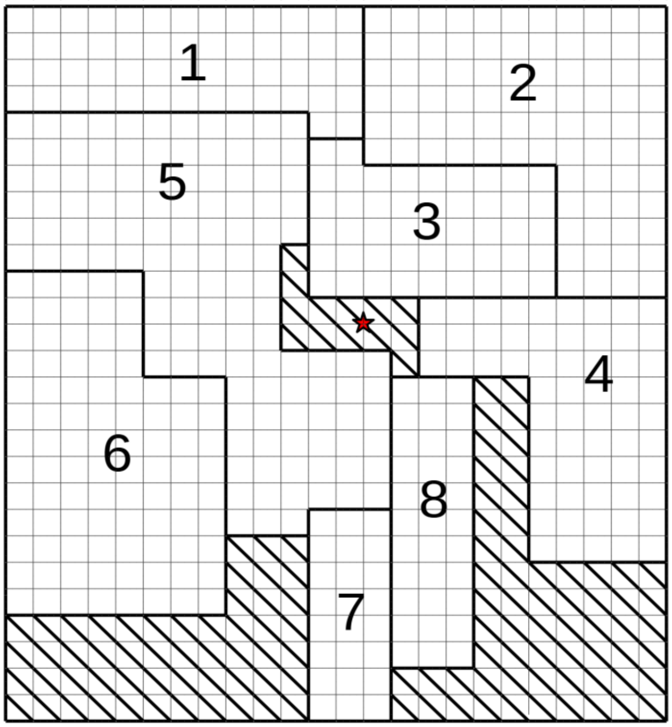
4) The initial project fixed the price of electricity sold. However, our project varied the price in electricity sold such that once the balloon was generating a certain amount of electricity, the price stepped downward. This reflects the potential for a market to oversaturate on the supply side, thus creating a scenario for diminished returns on the product being sold.

Students were able to recoup construction costs for the balloon depending on how much power was generated from the balloon. For the first 50 kW generated, students would be able to recoup \$0.11/kWh, and for any additional kW generated, students would recoup \$0.10/kWh. Based on the overall construction cost of the balloon and the amount of money recouped, students were asked to calculate the amount of time it would take for their group to recoup the construction cost of the overall system.

5) The initial project's map (Figure 1) was not neatly organized at their boundaries, which made it difficult to grade student social cost. Because we intended to grade the student work, we remade the Field Map (Figure 2) to clarify student cable placement. Students were not allowed to place cable bases on the boundaries between zones. Redoing the map reduced student questions and enabled computerized grading.

The initial project had some variable outcomes associated with certain cable base zones. For instance, in the initial project, the fourth zone had a 10% chance of containing a religious burial ground, and encountering this would change the costs associated with building in this zone. In an effort to make the project easier to mass-grade, any chance encounters or costs associated with each zone were eliminated.

Figure 2: Field Map



Administration and Grading of the Wind Turbine Project

The wind turbine project was administered to the students through a series of smaller assignments each due at noon on the next class day. (Classes are Monday-Wednesday-Friday.) On the first day of the course, students were introduced to the project. (See the Appendix for the assignments and rubrics developed.) Students wrote a reflection on why someone would want to put a balloon in the air to collect electricity, a preliminary proposal regarding the location of the three cables, a description of how the cables would pull on the balloon, and calculations regarding the social and financial costs of their preliminary design. This assignment was graded by undergraduate graders using the rubric in the Appendix. The undergraduate graders were previous statics students.

On the fifth class day, students were instructed to form teams of either two or three people. Student teams completed a team contract.[7] In addition to spelling out duties and allowing students to proactively address potential obstacles of group work, this exercise simply introduced many students to the concept of a team contract. This assignment was also graded by the undergraduate graders using Gradescope. The rubric for the team contact is shown in the Appendix. Grading was not difficult because there were no numerical calculations to check.

On the sixth day of the course, groups were instructed to design the cable system to hold the turbine in the proper location, per the initial project description. This assignment was collected in two parts: first, a Gradescope submission in which groups would clearly state and show their anchor locations, draw a free-body diagram of the system, demonstrate the calculations necessary to arrive at their design, and express the forces in each of their three cables in different forms. These were again graded by the undergraduate graders. Second, students also submitted their raw design values which they had settled on into a Google form. The Google form submissions automatically populated a spreadsheet where we coded the equations to match all the student calculations and assign values to their work. For this numerical submission, groups inputted the x- and y-coordinates for each cable base, the tension that was calculated in each cable, the length designated for each cable, the material of each cable, the designated balloon height, the calculated financial and social costs of the design, and the calculated payback time for the design. Our calculator allowed us to check all of the student calculations automatically, and using the grading criteria shown in the Appendix in Table 5, grades were automatically assigned with the spreadsheet calculator.

Finally, on the seventh day of the course, groups were asked to optimize their initial design. Students were told that they were now competing with other companies (teams) to bid on the balloon construction project. Having a highly optimized design would provide their company (team) with work, whereas a company that did not get the bid would have to search for work opportunities elsewhere. Teams were asked to submit new, optimized coordinates before coming to the eighth day of the course. Groups used a Google form to enter the x- and y-coordinates of their cable bases, the material of each cable, the height of the balloon, the calculated payback time, and the calculated social cost for their designs. These inputs were automatically drafted into a different Google sheet and checked there. We automatically compared each team's calculated social cost and payback time to the same values of all other groups: the grade that a particular group received for the competitive part of the project came from comparing a group's social cost and payback time relative to the largest and smallest values in each respective category. Rather than expressing their percentile of the list, however, we compared each team's grade based on whether they were with 5% of the value of the best team, etc. This grading style eliminated the possibility that many teams would be very close to the best and get grades that were not all very close.

Students also submitted a design report for this final day; a one-page, double-spaced design report was provided by each group to accompany the final design submission. This report included the problem statement, the solution to the problem, the rationale for the design chosen, explanations for why changing the design from the optimized result would worsen the design, future steps to further develop the design, and uncertainties in the design. This assignment was submitted through Gradescope. The rubric for the design report is shown in the Appendix.

Discussion/Conclusion

The project went very well. Anecdotal student comments indicated that they enjoyed working on a team. Students' reasons for wanting such a thing included renewable energy and reducing greenhouse gases of course, but also included providing power for those living far from or off of the grid, saving money, or reducing land use from traditional power plants. The biggest problem we faced was that our new Field Map did not clearly identify an axis system or where the origin was to be. When we asked for coordinates, we were not all on the same page.

We had 134 teams. The team contracts also served to reiterate how student goals are really just to get an A, a useful thing to be reminded of as instructors, if discouraging. The student concepts of what the goals of the project were ranged from optimizing the social score to actually generating power. Some chose to put their cables in unfeasible positions just to get a better score on the rubric. Future tweaks will be needed to prioritize having a three-dimensional particle actually be in equilibrium.

Overall it was good to see the students try with ropes to understand how keeping the balloon above the star required ropes to oppose each other. "Ropes can't push," after all, and the students were able to discover that as they worked through their preliminary proposals. Students also seemed to gain insight into how the spacing of the cable bases would impact the forces carried by the cables by comparing their own preliminary proposals to those of their teammates, but also through iteration of their team designs.

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Brett Austin McCandless

Brett Austin McCandless is a graduate student at North Carolina State University, where he is pursuing a Ph.D. in Mechanical Engineering. He is also a course instructor at North Carolina State University and Campbell University. He is currently researching ultrasound propagation in bone, in the hopes that understanding the propagation will lead to better pre-screening methods for osteoporosis.

Anna K. T. Howard

Anna Howard is a Teaching Professor at NC State University in Mechanical and Aerospace Engineering where she has led the course redesign effort for Engineering Statics. She received her Ph.D. from the Rotorcraft Center of Excellence at Penn State University in 2001.

Appendix: Assignments and Grading Rubrics

Day 1 Homework

Over the next couple weeks, you'll be working to design a hot-air balloon wind turbine to convert winds aloft into electricity. [Original picture from Figure 1 and edited Field Map from Figure 2 included here.] You and your team need to design a cable system that holds the turbine in a given spot (shown on Figure 2 with a star). You'll need to pick the locations for the anchors as well as the height for the balloon. The balloon will provide a force of $F_B = 75\ \hat{\imath}+220\ \hat{\jmath}+2.5\cdot h\ \hat{k}$ N based on lift and wind, where h is the altitude of the balloon in meters.

You and your team will eventually propose a design including the locations of the tethers, the choice of cable material so they don't break, an analysis of the forces on the balloon, and the payback time in years based on the cost of electricity in that area. (Payback time = total cost of materials for cables & balloon plus construction based on the locations chosen divided by the power generation revenue from power sold to neighboring communities.)

Your homework for day 1 is to produce a first-cut proposal for where the tethers should be located and why.

Zones:

- Crossed out regions are residential areas, and you may not locate a cable there.
- You may not put all three cable bases in the same zone.
- The areas between zones are fenced off, and you may not put a cable base on the border between zones. Any cable base must go entirely within one of the drawn ones.
- There are small gas pockets in Zone 1. Putting a cable in this region will increase construction costs by $10,000 to determine the location of the gas pockets so they're not hit with the drill. Building in Zone 1 also incurs a social impact score of -4 for putting the community at potentially elevated risks for gas leaks in the future.
- Zone 2 has a massive eagle’s nest which serves as a tourist attraction for the area. There is a minimal cost for construction for this zone of $2500; however, you will be intruding on the eagle’s nest, resulting in a social impact score of -3.
- The community is planning on building a charter school in this Zone 3. There is an alternate school location in Zone 8 which will hold a smaller school. If you anchor a cable in Zone 3, then the school will be placed in Zone 8 and 1-in-50 students in the community will not be able to attend the charter school resulting in a social impact score of -4 and a construction cost of $5000.
- Zone 4 has a government subsidy to build in this area, but there is a religious burial ground in this zone. If you build here, the construction costs will increase by $5,000 (cost to relocate the remains minus the subsidy), and you will incur a -6 social score.
- Zone 5: This zone consists of swampy lands. Development of this site would release 20 kTonnes of CO2 resulting in a social impact score of -4 and construction costs of $10,000.
- Zone 6 is privately owned land. You must pay the land owner for land use. By developing this land, the owner will be able to use the money to start a local business that will employ 2 community members. Construction costs of $120,000 but a social score of +8.
- Zone 7 is a swampy region that has an infestation of mosquitoes. The swampy region is thick, so some extensive work would need to be done on the site before construction could be completed. However, construction on this land would reduce the mosquito population in the area. Construction costs $55,000 and social impact score of +4.
- Zone 8 is the alternative school site. Either zone 8 or zone 3 must be left undeveloped for the school. If Zone 8 is chosen for a tether, construction costs are $7,000 and there is no social impact.

Zone	Base Construction Cost	Social Impact Score
1	$10,000	-4
2	$2,500	-3
3	$5,000	-4
4	$5,000	-6

5	$10,000	-4
6	$120,000	+8
7	$55,000	+4
8	$7,000	0

Your response should include:

- a reflection on why someone would want such a thing. (What good is turning wind power into electricity?) Give an example of a situation where such a thing would be desirable.
- a drawing showing your proposal for the placement of the three cables
- the construction costs associated with the sites you've chosen and the social impact score
- your judgement of whether these three tether locations could succeed at pinning the balloon on the star with the force given. (For example, you can't have them all lined up in a line or any perturbation off that line will send the balloon flying to the side. Use your understanding of Physics to make sure your proposal is reasonable.)

Note: there is no correct answer here. You must balance conflicting priorities including your own.

Rubric (20 points total)

Table 2: Rubric for First Day Reflection

	0 points	2.5 points	5 points
Reflection on Purpose	Does not address why anyone would want such a thing	Provides one example of a possible use without much detail	Provides two or more examples of why someone would want such a thing
Proposal for Location of Cables Bases	Does not include a location for where the bases would be located	Includes a poor quality drawing or locations in words without a drawing	Includes a clear drawing of the zones and where the bases would be used
Understanding of Problem	Demonstrates little to no understanding of the tethering of the system	Begins to address how the cables will pull in the x and y directions	Clearly addresses how the cables will pull right and left, forward and backward to secure the balloon
Calculations of Social Cost and Fiscal Cost	Fails to include either cost	Includes a calculation of one but not both costs	Includes a calculation of both social and financial costs

Day 5 Homework:

Form a two- or three-person team to complete the balloon project from Day 1. Use this agenda for your first meeting. Fill in the group contract together, save it as a PDF, and upload it to Gradescope. Note: there are four slots because you'll use this later in the semester. This team is only 2-3 people.

ONE SUBMISSION PER TEAM. Use this as an opportunity to discover how to submit as a team. (You'll only get credit as part of a team, so make sure the person who uploads your contract adds you to the team submission.)

Learning objectives: understand what makes a team project fail and articulate between yourselves what strategies your team will use to avoid them.

Table 3: Rubric for Team Contract

	0	1.5	3
Plans and Expectations Addressed	Plans/expectations not addressed for team and team members	Some mention of who will do that	Clear and extensive duties spelled out
Time Discussions	No discussion of when the project will be completed or when the team members disparate schedules will be accommodated	Baseline time conflicts addressed	Time constraints specified with clear understanding of when the work will be accomplished with backup plans
Goals	Individual goals not addressed	Some discussion of how individual goals may differ	Clear evidence that individual project goals have been discussed
Potential Obstacles	No potential obstacles addressed	Potential obstacles moderately brainstormed but without procedures for dealing with them	Lays out procedures for discussing and overcoming obstacles
Decision Making	Fails to address how team decisions will be made	Moderately addressed how team decisions will be made	Satisfactorily addressed how team decisions will be made
Contact Info	Contact information and preferences not available for all team members		Contact information and preferences available for all team members
Signatures	Contract not signed by all team members		Contract signed by all team members (worth two points, not three)

Day 6 Homework:

With your team from Day 5, design a cable system that holds the turbine over the star. (See Day 1's homework.) The balloon owner would like to sell the generated power to recoup the initial purchase cost of the system. To anchor the turbine in this community, you and your team need to design a cable system that holds the turbine in a given spot (shown on Figure 2 with a star). The balloon will provide a force of $F_B = 75\,\hat{i} + 220\,\hat{j} + 2.5 \cdot h\,\hat{k}$ N based on lift and wind, where h is the altitude of the balloon in meters. Three cables will be used to hold the balloon in place. The maximum balloon altitude is 600 meters. Each block represents a 10 meter by 10 meter area.

You and your team should calculate the payback time in years. Payback time = total cost of materials (cables + balloon) and construction based on the locations chosen, divided by the power generation revenue from power sold to neighboring communities.

Hint: start with a discussion of where your cables should be located. Draw a FBD of your system and write equations of equilibrium. (You'll need them to submit anyway.) This homework is version 1 for your balloon submission. You'll be coming back to this again for Day 07 homework.

Additional Details:

Balloon Cost: $175,000

Cable Choices:
- Standard cable: $125/meter, max tension of 2000 N
- Carbon nano-cable: $1000/meter, max tension of 4500 N
- Lite cable: $100/meter, max tension of 1250 N

Power generated versus altitude: 100 W/meter of altitude (note this linear relationship is a very loose first-order approximation of actual wind phenomena)

Power generation revenue for power sold to neighboring communities: $0.11/kWh for the first 50 kW generated, then $0.10/kwh for any additional kW generated

Submission Details: Because every project will be unique, submissions will be in two places.

ONE SUBMISSION PER TEAM: Input your final numbers (coordinates for each cable base, the height of the balloon, and the material for each cable) in this Google form: https://forms.gle/CZJAwgPkrVBtyiBLA. The form will also ask for these calculations which will be graded for accuracy given your inputs (see rubric below):

- Calculated cable forces
- Calculated cable lengths
- Calculated final cost
- Calculated payback time
- Calculated social cost

ONE SUBMISSION PER TEAM: Upload your design to Day 06 in Gradescope. Your submission should include:

- The names of your team members. (This is a team submission: one person submits and selects teammates.)
- A plot of where your anchors lie
- A balloon FBD
- Equilibrium equations and solutions to the equilibrium equations
- The forces you calculated for each cable. As part of this upload, please specify your cable forces using each classification. (Each cable only needs one classification, but you must have all three.)
    - Magnitude along a line
    - Cartesian coordinates
    - Direction cosines
- Calculations for the social cost and financial cost for the project

Table 4: Rubric for First Gradescope Submission

	0	1	2	4
Anchor Locations	Does not include anchor locations		Includes locations but not on a nice diagram	Clearly indicates where the anchors will lie and includes a picture showing the zones and the anchor locations
Free-Body Diagram	Free body diagram not shown	Two or more forces are insufficiently defined, axes are missing	Axes are present, but one force on FBD is incorrectly drawn or insufficiently drawn	High quality free-body diagram with axes and each force labeled with a variable and sufficient information to write it in Cartesian form
Equations of Equilibrium	Includes no equations of equilibrium	Includes one or two equations of equilibrium but no solution	Includes equations of equilibrium but no solutions	Proper equilibrium equations written from FBD and solved
Cable Force Expression	Cable forces properly expressed in fewer than two different ways		Cables forces properly expressed in two different ways	Cable forces properly expressed in three different ways (direction cosines, Cartesian form, magnitude along a line)
Cost Calculations	Does not include social or fiscal cost calculations		Includes social or fiscal calculations but not both	Clearly identifies both social and financial costs for the balloon

Table 5: Rubric for Initial Google Form Submission

	0	0.5	1	2
Height of Balloon	Height of balloon exceeds acceptable range			Height of balloon falls within specified range
Cable Lengths	None of the cable lengths correspond to the height of the balloon	One of the three cable lengths corresponds to the height of the balloon	Two of the three cable lengths correspond to the height of the balloon	All three cable lengths correspond with the designated height of the balloon
Cable Force Values	No cable force is calculated correctly, based on cable placements	One of the three cable forces are correct, based on cable placements	Two of three cable forces are correct, based on cable placements	Cable forces are correct, based on cable base placements
Cables in Tension	Three cables in compression	Two cables in compression	One cable in compression	No cables in compression
Cables Breaking	One or more cables break			No cables break
Anchor Placement	At least one anchor placed on fence between zones or placed out of bounds			Anchors not placed on fences between zones or out of bounds
Zone Placement	All three anchors placed in the same zone			Anchors are in different zones
Cost	Total cost is incorrect			Total cost is correct, accounting for the cost of each construction zone, the cost of cables, and the cost of the balloon
Payback Time	Payback time improperly calculated or not reported			Payback time properly calculated and reported
Social Cost	No social cost calculated		Social cost reported but incorrect	Social cost calculated correctly

Day 7 Homework:

Truths about Engineering:

"The right answer" is a myth. Every engineering solution balances offsetting priorities.

Every customer can choose where to put their business. Even SpaceX has Boeing as a competitor. Simply finding a solution is no longer sufficient. Your design is now being compared to other teams' work.

Uncertainty lies behind every number. Not just measurement error or manufacturing variances: your customer may change what they're using your design for. The V-22 was designed for amphibious landings at sea-level and then used in the desert mountains in Afghanistan. Is it worth the cost to your project to go pay someone to produce a better model? The answer to that must be every engineer's choice.

Two questions, then:

1. How do engineers make decisions? We do the best we can with the information available at the time. Some uncertainties can be resolved with edge cases: examine the upper and lower bounds. Others can be resolved by probability distributions or Monte Carlo simulations. But some uncertainties are unknowable: if you've used a new technology in your design, what if it simply doesn't work? The really crucial bit is for every engineer to keep the uncertainties in mind. Work with teammates: my engineering judgement may not be the same as yours. Together we are less likely to have the earthquake destroy the building.

2. Why does school look so much like "Find the right formula, put the numbers in, and put a box around your answer" especially on tests where we're working alone? Because learning the basics is how you develop that engineering judgement. The practice makes you useful to your team. Your career in engineering at NC State will expose you to countless calculations. Your best learning comes when you reflect on the answers you get as often as you possibly can.

   a) How sure are you about your design or your calculation?
   b) What are the uncertainties in your inputs?
   c) What other ways are there to solve the problem you're looking at?

Your team has now been asked to compete with other companies to bid on the balloon construction project. Winning the project will provide your company with work. Companies that don't get the bid have to go find work elsewhere. Iterate on the design you had yesterday. Think about what you could change to make it better. What were your priorities? Improving those comes at the expense of what else? What would happen to your design if the height was allowed to be only 200 feet because the neighbors didn't like the look of your balloon? What if the cable company miscalculated their tensions and the allowable values were much higher or much lower?

Submissions:

ONE SUBMISSION PER TEAM: Enter a new version of your balloon into the "Final Balloon" google form: https://forms.gle/4SJAPSpLjcpeRnew8. (Don't use the link from last time or you won't get credit.) If your balloon was perfect on day 6, then you can enter your previous results. (Note in the rubric below that your costs will be compared to others.) You do not need to redo any of your calculations, but it is important that your design is still feasible. For example, your cables shouldn't suddenly be made of gossamer silk in compression!

ONE SUBMISSION PER TEAM: Produce a one-page, double-spaced design report to accompany your final balloon. (~500 words) to On-Paper Homework for Day 07 in Gradescope. (If you have pictures or tables or something, hurray! They don't count toward your one-page length. And no, if it spills onto the second page, that's not a huge problem. Guideline, not a rule.) Make sure your submitter enters all the teammates into the Gradescope submission.

Include:

- The Problem (~3 or 4 sentences, maybe a table or picture)
    - Objectives: What was the goal of this project? What problem were you trying to solve? What would be a "good" solution?
    - Design Variables / Manipulators: What were the things you were allowed to change? What variables could you control?
    - Constraints on the Solution: What limitations were present on the design variables? What "walls"would your solution bump up against?
- Your Solution (~5 sentences, pictures & graphs are awesome)
    - Give a description of your final solution. Note this is not a "This is what I did on my summer vacation." This is just stating your optimized solution.
    - Describe how each of the design variables meet or exceed the constraints.
- The Sales Job (~5-7 sentences)
    - Explain the rationale for your design. Why did you choose the decisions you did? What were your priorities?
    - Explain how you varied the design variables to pick the solution you're proposing. Explain that changing them to something else would make a worse solution.

- Future Work (~3 or 4 sentences)
  - What would the next steps be to further develop this design? What did you not have time to really fix that you would fix in the future?
  - What uncertainties in the design could be pinned down and how?

Table 6: Rubric for Google Form Optimized Solution Submission

	0	2	4	6	8
Feasible Design	Fails in two of more of the problem constraints	Fail to meet one of the problem constraints	Design meets problem constraints (height, cable in compression or broke, zone placement not over star, anchor placement on fence line)		
Social Costs (Competitive)	Team social cost is missing or not within 75% of the best team in the class	Team social cost is within 75% of the best team in the class	Team social cost is within 50% of the best team in the class	Team social cost is within 30% of the best team in the class	Team social cost is the best or within 8% of best
Monetary Costs (Competitive)	Team payback time is missing or not within 75% of the best team in the class	Team payback time is within 75% of the best team in the class	Team payback time is within 50% of the best team in the class	Team payback time is within 30% of the best team in the class	Team payback time is the best or within 8% of best

Competition scores will be based on how close your team came to the best team cost.
Social cost score: value needed to score = rounddown(top-(top-bottom)*percentage).
Financial cost is backwards: value needed to score = roundup(bottom + (top-bottom)*percentage)

Example: the best team in the class has a social cost of +8. The worst team in the class has a social cost of -4. The spread in that range is 13. In this example, teams with social scores of 11, 12, or 13 will score 8 points. Teams whose social scores were -4, -3, -2, or -1 will score 0 points.

Table 7: Rubric for Gradescope Optimized Solution Submission

	0	2	4
Problem	Does not address the project goals	Some mention of what the point of this project was	Clear list of project goals
Solution	Does not present the team's optimized solution	Presents solution haphazardly or with considerable unnecessary detail	Optimized solution is clearly and succinctly presented
Sales Job	Does not discuss how the team's solution meets the project requirements, unconvincing	Some discussion of how your solution has been optimized	Clear discussion of how each design variable has been considered
Future Work	Mentions no future upgrades for the project	Some discussion of uncertainty or optimization	Clear discussion of uncertainty and optimization steps

Style and Grammar	Excessive passive voice, multiple English or grammar mistakes, difficult to read	Few grammatical mistakes, relatively easy to follow	Well written. Uses first person "we" to describe team. No substantive grammatical or English mistakes. Proofread.