FLYING FORCES: Adding Lift to Statics

Written By SARAH WODIN-SCHWARTZ
Worcester Polytechnic Institute

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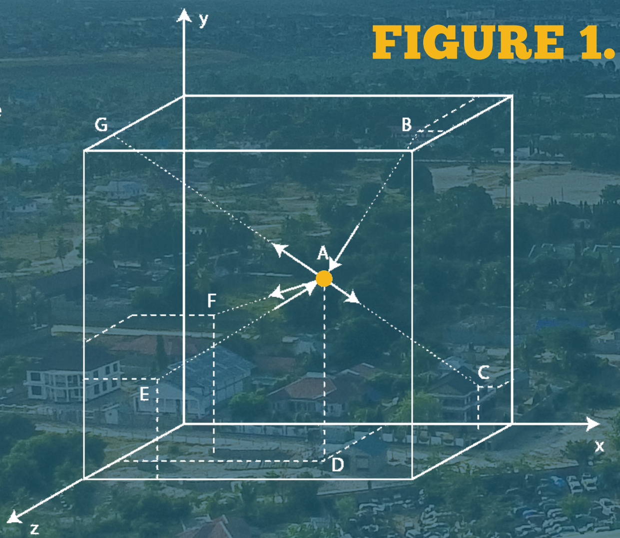
While statics is the study of stationary objects, this class gets students moving on their path to thinking like engineers! Most students begin my course at WPI excited to start their core engineering curriculum, but many have little to no idea about the ways in which statics will help them become engineers. They are often unsure how the course will be different from introductory physics, or why they are spending a whole course learning about things that don't even move. However, statics is so much more than learning the fundamentals of defining forces as vectors and applying equations of equilibrium. It's the course where students start seeing the world through the lens of mechanical engineers.

Introductory engineering courses typically include iterative \design approaches and decision-making tools. Design skills are often taught isolated from rigorous technical skills, causing students to think of skills as separate entities. When design is integrated into technical courses, students learn that their technical decisions significantly influence the larger design. Consequently, I have integrated EML into my course to give students the opportunity to balance engineering requirements with social and financial impacts when developing infrastructure in a community.

As an example, 3D particle equilibrium is one of the first techniques that I teach. In its most theoretical form, 3D particle equilibrium applies several known force vectors at a single point in space. An analysis of a problem involves the following steps shown in **Figure 1**.

This theoretical vector analysis is used to solve example problems such as suspending traffic lights. However, I want my students to see an even bigger picture and connect with the course content. By integrating an EML-based project into one of their first core engineering courses, students learn from the get-go that engineering is not an exact, straightforward process. There are high levels of complexity that require the integration of a broad range of skills.

FIGURE 1.



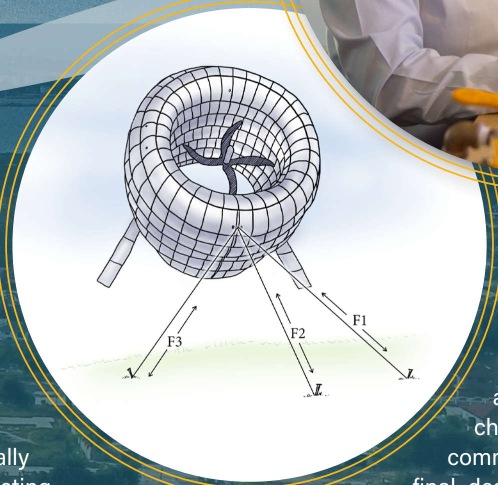
1. **Determining a point where all forces act**
2. **Drawing a free-body diagram showing all of the forces acting at this point**
3. **Calculating position vectors for all forces**
   $\overrightarrow{r_{BA}} = \overrightarrow{r_A} - \overrightarrow{r_B}$ **where** $\overrightarrow{r_A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$
   and $\overrightarrow{r_B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$
4. **Calculating unit vectors**
   $\hat{u}_{BA} = \frac{\overrightarrow{r_{BA}}}{r_{BA}}$ **where** $r_{BA} = \sqrt{(A_x - B_x)^2 + (A_y - B_y)^2 + (A_z - B_z)^2}$
5. **Writing applied and constraining force vectors in terms of their unit vectors and magnitudes**
   $\overrightarrow{F_{BA}} = F_{BA}\hat{u}_{BA}$
6. **Applying equations of equilibrium**
   $\vec{F}_{BA} = 0 = \overrightarrow{F_{BA}} + \overrightarrow{F_{AC}} + \overrightarrow{F_{EA}} + \overrightarrow{F_{AF}} + \overrightarrow{F_{AG}}$
7. **Calculating unknown forces**

I created an EML module about 3D particle equilibrium for two reasons:

1. **It can be a dry topic, heavy in mathematical vector manipulation.**
2. **Integrating EML early in the course sets the tone that technical engineering skills should be used in conjunction with reasoning and problem-solving skills.**

To start, student teams immerse themselves in a remote village in Sub-Saharan Africa, where USAID reports two out of three people lack access to electricity. Teams are tasked with developing an anchoring system to provide electric power to the community, based off a floating wind turbine design developed by Altaeros Energies. They are given the external forces acting on the turbine balloon and are directed to design a three-cable anchoring system that will hold the turbine in place without exceeding the maximum allowable tension in the cables.

Designing the cable anchoring system involves selecting three locations to place the turbine anchors as well as determining the height of the turbine. Students are given a fictional map of the village, which includes descriptions of eight zones in which the village is divided. Based on the scenario within each zone, there is a construction cost and a social impact score. Negative zone scenarios include environmental effects such as CO² emissions from developing swamp lands and potentially constructing on religious burial grounds. Positive zone scenarios include the reduction of mosquitoes that may spread infectious disease and developing private land to allow the owner to start a business and hire local workers. Student teams must weigh the pros and cons of the regions while simultaneously calculating cable tensions for the anchoring system.



Technical, social, and financial effects are determined not only by anchor locations, butalso turbine altitude. The power output potential is an essential element of the system design. Students brainstorm electrical power uses within the community to determine the local power requirements. I add an additional entrepreneurial aspect to the project by informing the students that the village would like to sell power to neighboring villages in order to pay back the initial cost of the balloon. The higher the balloon, the more power they will generate, leading to a faster return on the initial investment. The students use their own values to determine the social impact score and balance payback time.

Each team then develops two different cable-anchoring systems and chooses one to pitch to the community. They present their final designs to the fictional community through a digital poster and a short persuasive essay. Projects tend to fall into one of two schools of thought when choosing between the two anchor designs:

1. **A higher social impact score outweighs the necessity for a shorter payback time on the balloon investment. One team wrote, even though this option might cost more for your community, the social benefits are well worthwhile.**
2. **The payback time should be minimized so that the village is more likely to purchase the turbine and receive the benefits of having power in their village. Another team wrote, it is the profit money that makes the first design better than the second design. The extra $100 per day means the community will be debt free much quicker and will also bring more capital into the economy.**

ZONES:

1 There are small gas pockets in this region. There is a 5% chance that while drilling for the anchor that a gas pocket could be breached. If breached, there would be a $15,000 clean-up cost. However, if a gas pocket is not breached, there is a construction cost of $500. If you pick this location, you will have to pay a $5,000 deposit in to begin to cover costs in the event you hit a gas pocket. You must justify this deposit and additional risk to your investors. Building at the site incurs a social impact score of -4 for putting the community at potentially elevated risks.

2 In this zone, there is a rhinoceros migration route. There is a low cost for construction in this zone, however, for intruding on the migration route, there is a -3 social score.

3 The community is planning on building a school in this zone. There is an alternate school location in Zone 8. If the cable is placed in Zone 3, and the school is placed in Zone 8, then 1 in 500 students will get so sick from the swamp gasses coming from Zone 5 that they will not be able to attend school.

4 In this zone, there are no construction costs as there is a government subsidy to build in this area. However, there is a 10% chance that you will encounter a religious burial ground at this zone. If you build here, you will have to pay $500 to relocate the remains if they are found and you will incur a -6 social score.

5 This zone is swampy lands. Development of this site would release 20 kTonnes of CO^2.

6 This zone 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 two community members.

7 This zone is a swampy region that has an infestation of mosquitoes. Construction on this land would reduce the mosquito population and help reduce disease in the region.

8 This zone would provide an alternative school site. Either Zone 8 or Zone 3 must be left undeveloped for the school.

Map Notes

- Blank regions = no construction in these zones
- Each grid spacing is equal to ten meters
- You cannot build on the beach or in the dense vegetation as the anchors will not hold in the sand and the vegetation will tangle the cables

While there is no right answer, teams with either viewpoint evaluate the impact that their decisions would have on the village. Debating the importance of different types of social impact while simultaneously solving design challenges gives students the chance to engage with a larger social system and at the same time, learn fundamental engineering skills. After the first implementation of the project, I shared the course content with Professor Glenn Gaudette for use in his statics course. He worked with Professors Curtis Abel and Leslie Dodson to enhance the project by adding a stakeholder analysis so that students practice seeing the infrastructure from multiple perspectives and delve more deeply into how their decisions affect the people within the community. The process of content sharing and exchange of ideas between instructors gives students the benefit of multiple project designers, further enriching the project experience. Iterating between instructors proved to be even more beneficial than I anticipated. In addition to providing students with improved content, we as instructors get to learn from each other's wealth of knowledge and teaching styles.

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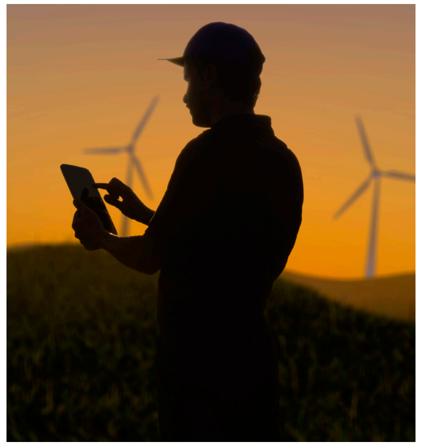

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