Additively Manufactured 2D Truss Demonstration

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Abstract

Statically-loaded 2D trusses are the introduction to mechanical engineering courses for nearly every student. Visualization of forces within trusses can often create problems in communicating concepts to students. The 3D printed *2D Truss Demonstration* was created to aid in visualizing forces and to provide a modular system with the ability to create a variety of truss formations. By additively manufacturing interchangeable parts, educators and students are able to arrange the beams as they choose to study the effects of loads at different points within the truss.

Keywords

Active Learning, Truss, Statics, 3D Printing, Project

Introduction

Active learning is a teaching technique that may include visual learning, writing in class, inquiry and problem-based learning, computer-based instruction, cooperative learning, peer teaching, service learning, or team projects [1-4]. This teaching style has been shown to be an effective pedagogical tool [5-8]. Active learning has gained traction since its inception in the 1980s, and it has seen recent implementations at the K-12 and undergraduate levels. A meta-analysis revealed that this technique improves students' scores by approximately 6%, whereas students in traditional lecturing classes were 1.5 times more likely to fail [6]. In this project, an active learning demonstration was used to improve the understanding of trusses, which are a difficult introductory problem for statics students. A truss is a structure consisting of rigid elements that are connected by frictionless pin joints. In a typical statics class, all the external forces are applied at those pin joints. Simple trusses are trusses that can be created by adding two members at a time to a base triangle to create a larger structure. When analyzing a truss, the weight of the members may be neglected [9].

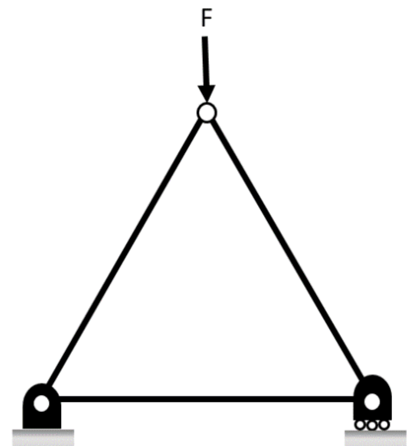


Figure 1. A Typical Triangular Truss under Load

The first step in analyzing a truss problem, whether it be by the *method of joints* or the *method of sections*, is to draw a free body diagram. In this process or the other listed analysis methods, it is extremely important to be able to visualize whether a member is in compression, tension, or neither. This aids in the summation of forces, which leads to the solution of the unknown force or forces. As this is an introductory concept and one that is a building block for future engineering courses, understanding how members react is an important visualization for students to grasp and understand. Therefore, simple visual aids that can be used in the classroom can be an asset to educators and a helpful tool for students learning the basics of engineering.

Problem Definition

To create a visual aid that can be used by educators all over the world, the design must be kept simple, manufacturing processes must be readily available, and costs must be kept to a minimum. In addition, the design must be able to adapt to solve a variety of truss arrangements. It must accurately depict the reactions going on within each member, to a degree where displacements are obvious to the naked eye. Finally, the tool must be able to withstand repeated forces from human input over its lifetime.

Problem Solution

Drawing inspiration from Tinker Toys and LEGOs, the choice was made to create a beam and spring design with multiple configurations to allow the possibility for endless truss structure combinations. In theory, educators or students can 3D print as many beams of different length as desired, then easily combine the beams in any arrangement to study the effects of forces at each pin joint location.

The first step in designing the beams was designing the pin connection at each end. A straightforward design was used and sized to avoid issues with 3D printing. All pieces were printed using a Markforged Mark II printer, while the external springs were purchased from McMaster-Carr. An isometric view of a preliminary design is shown in Figure 2. The width of the collar should be large enough to retain an external spring, while the length of the plunger is to user specification.

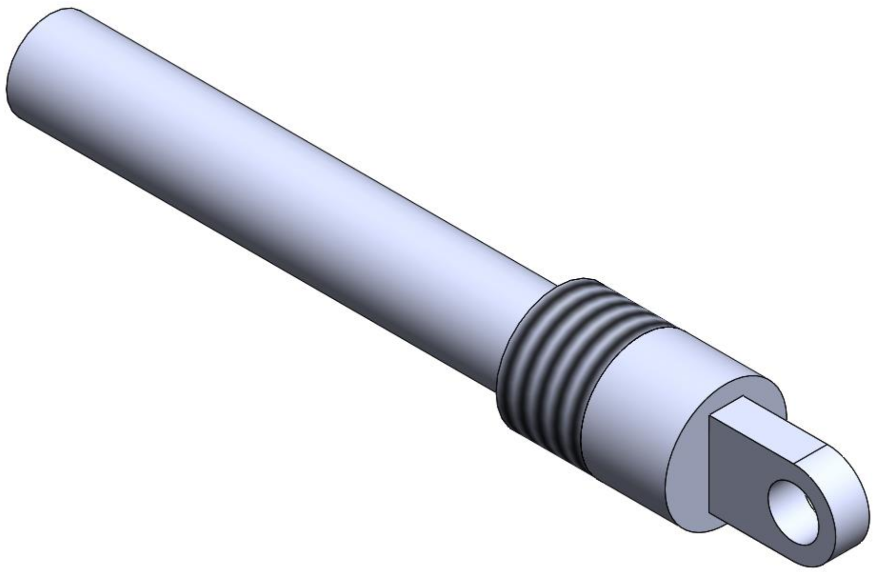


Figure 2. Isometric View of Pin Connection Plunger Preliminary Design

The next part in the assembly is the collar, in which the plunger with pin connections are inserted. The length of these collars is a user specification and dictates the length of each beam. The diameter of the collar should be such that the external spring threads onto the tapered outer surface and remains locked in place. A preliminary design is shown in Figure 3.

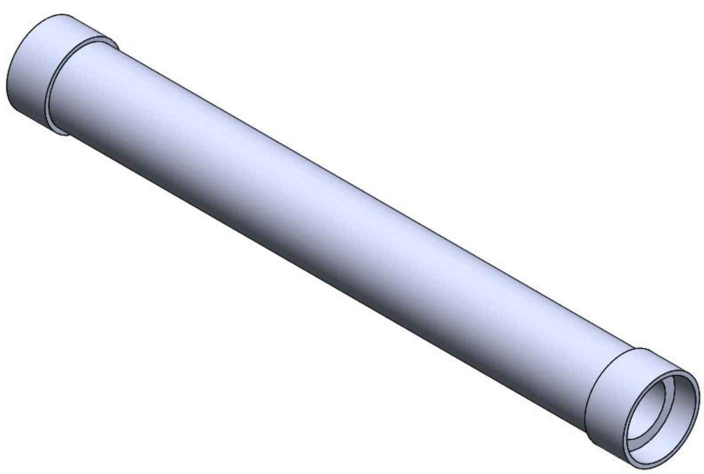


Figure 3. Preliminary Design of Collar

Assembling a truss begins with mounting the springs on the pin joint plungers. From there, the plungers and springs are mounted on the collar from both sides. A small pin, sized to fit, is inserted at each pin joint. These members can then be pinned together to form a truss. A completed beam is shown in Figure 4.

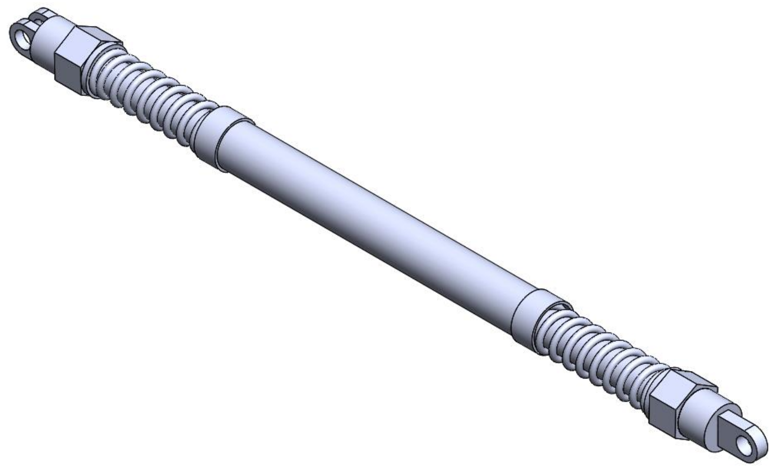


Figure 4. Completed Beam Assembly Preliminary Design

Additionally, a base pin joint and rolling wheel joint may be installed to display the truss in the vertical plane. This can be designed to user specification. These parts also aid in relating typical textbook problems to real world demonstrations using the truss assembly. Students are able to see the reactive forces within in each member while changing the end condition of each end of the truss.

When completely assembled, a simple truss may be seen in Figure 5. One of the representative joints may be seen in Figure 6.

Figure 5. Assembled Simple Truss

Figure 6. Zoomed View of Corner of Simple Truss

Force may be applied in any direction at any joint, and the appropriate reactions can be observed in the external springs of each member: a lengthened spring represents tension and a shortened spring represents compression.

Figure 7. A Simple Truss under Load

The engineering drawing detailing relevant dimensions is shown in Figure 8. It should be noted that all dimensions are relative and can be changed according to user preference, but these are shown as an example.

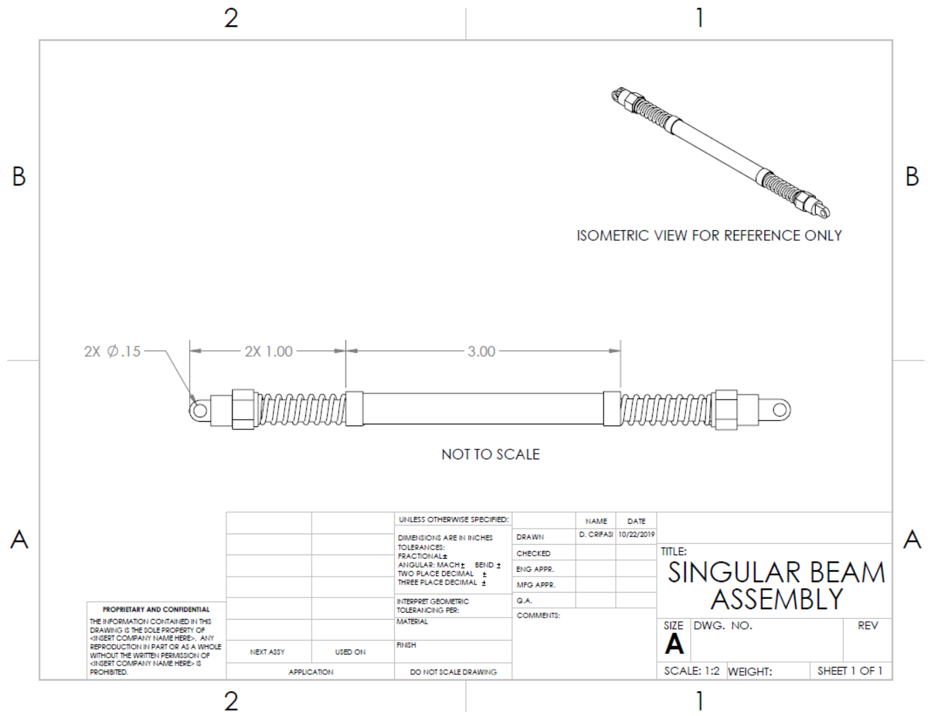
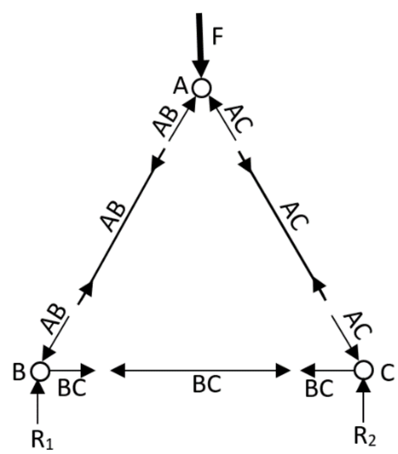


Figure 8. Engineering Drawing Detailing Example Dimensions

Sample Calculation

A simple force analysis for an equilateral triangular truss under vertical applied force F at A reveals that member AB and AC is under compression and member BC is under tension. For the designed truss, these forces can be visualized as the springs attached to AB and AC compress and the spring attached to BC stretches.



$$AB = AC = \frac{F}{\sqrt{3}} \text{ (Compressive)}$$

$$\text{and } BC = \frac{F}{2\sqrt{3}} \text{ (Tensile)}$$

Student feedback

The truss was presented to the students while teaching trusses in Statics class. Afterwards, an online survey was conducted to gauge the students' learning experience using the truss. Here are some students' comments on "how the truss helped them to understand better" given below:

- "It gives visual confirmation/reaffirmation of material learned in class"
- "Being able to see abstract ideas such as force dispersion through a truss in a concrete manner helped better my understanding of the concept."
- "I think it helps since you can actually see the movement of the springs."
- "It helped me visual how loads are distributed between truss members and which members are under tension or compression."
- "It allowed me to see how the forces act on a truss in a real world situation"
- "It was a great visual of what was going on in a truss!"
- "It helped to understand how each component related to the others (i.e. which were in tension and which were in compression)."
- "It helped to see the force acting on the members as motion and not just sticks on a page."
- "The truss helped me get a better understanding as to why the triangle shape is used so much in engineering."
- "Being able to see the springs expand or contract due to a force being applied at some point on the truss helped me understand how forces affect different parts of the truss."
- "Seeing how the forces interact on a structure was very interesting"
- "Visualization of concepts helps better reinforce what the numbers and calculations all really mean. It gave good context to our current material which was much appreciated."

Figure 9 shows a Pie chart of the students' response to the survey question: "Did the truss help you to understand Truss behavior better?" Out of 15 students, 13 students (86.7%) believe that the truss helped them to understand truss behavior better.

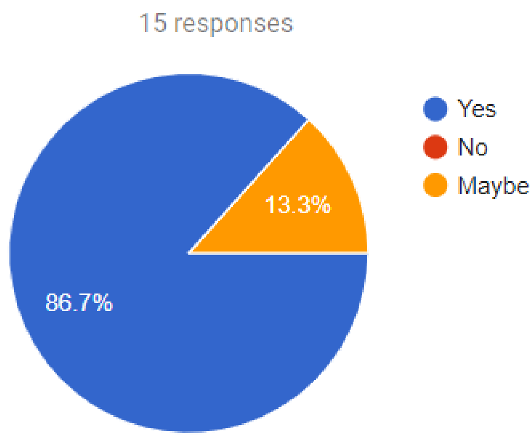


Figure 9. Response to the survey question "Did the truss help you to understand Truss behavior better?"

Figure 10 shows the students' response to the survey question "Do you think it is a good design?" In response to this question, 100% of the students believe that it was a good design, where the force in each member can be visually seen.

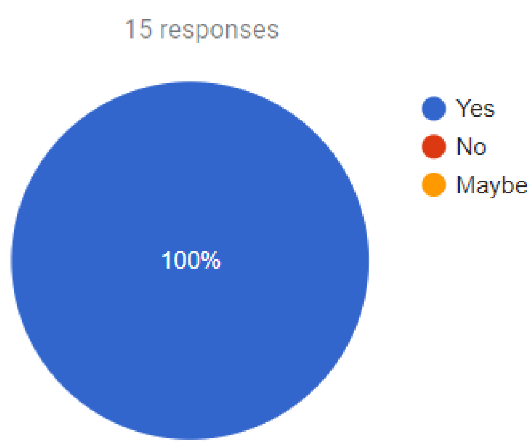


Figure 10. Response to the survey question "Do you think it is a good design?"

Summary and Conclusions

This paper describes the design and building of a plane truss structure. The applications of this modular 2D truss assembly go beyond the classroom of colleges and other higher learning institutions. High school educators and students, and even educators and students at lower levels, around the world can use this project as an easy introduction to engineering at a basic level. This project can also serve as an introduction for students to computer aided 3D modeling, as well as 3D printing. Whereas the past and present held popsicle stick bridges as an introduction to engineering, the future is moving towards accessible additive manufacturing for a variety of applications. This truss project will hopefully serve as a cost effective, simple, and powerful tool to aid current engineering students and to introduce future engineers to the basic concepts of statics.

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