Step Ladder

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Overview

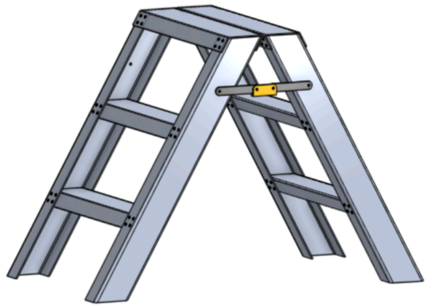
The step ladder project was a 3-week design and build process that consisted of an initial round of designs in OnShape and SOLIDWORKS, followed by an FEA in SOLIDWORKS to simulate loads on the final design. The build process took approximately two weeks, first done with initial testing on 1/32" and later 1/16" material before completing the final build. The resulting step ladder (step stool) could hold members of the building team with ease (up to 180lbs) and showed no obvious signs of stress after testing loads along the stool and even after jumping on it as well.

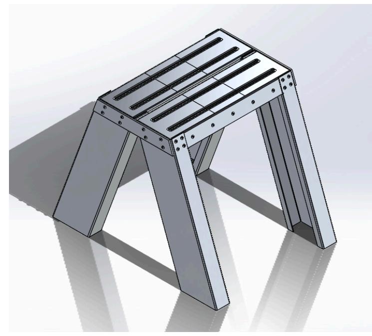
Project Goals

We chose to design and build a step stool with the goal of making something functional we could later use. We also wanted to get more familiar with the waterjet and the ironworker, both of which we ended up using heavily during the manufacturing of the project. Additionally, we wanted the experience of working with sheet metal, particularly thicker Aluminum to see how different manufacturing processes affected warping and fractures. We also wanted to develop our experience using modeling and simulation tools, and applying those softwares to manufacturing. This project served as a holistic summary to the topics discussed in the course.

Design and FEA

Tools: Onshape, SOLIDWORKS, SOLIDWORKS FEA



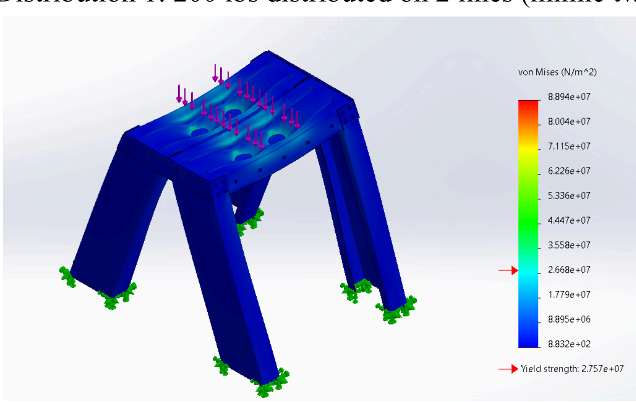


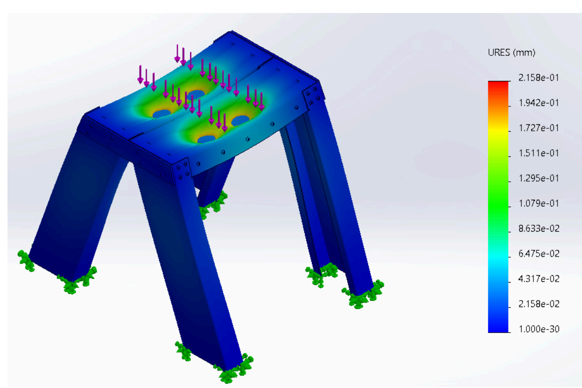
We worked collaboratively in Onshape to design the final model that we would build. This involved several iterations with different amounts of steps and different heights of the ladder. We ultimately decided on the one step design, due to material constraints and worries about stability. We also were hoping for a hinged/collapsible product, but due to stability and simplicity for the manufacturing time, we decided against that for the final design. We took inspiration from different products on the market, and analyzed them for how easily we could manufacture them using the available tools.

After completing the final SOLIDWORKS assembly using screw mates to mimic the joining present in our design, we moved onto the finite element analysis. Our goal was to mimic a variety of load distributions to ensure safety and pinpoint vulnerable areas.

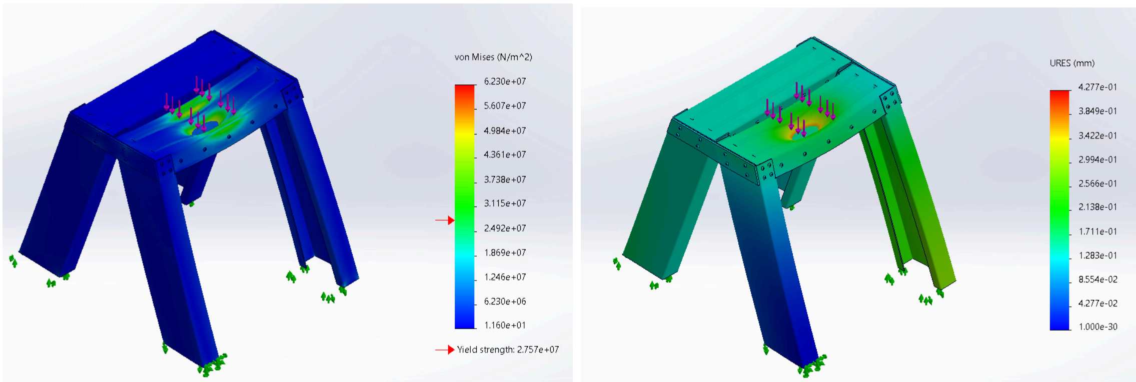
We tested with 3 different loading distributions using split lines to create multiple faces on the top step. Each distribution saw an applied force of 200 lbs. Fixed geometry was applied to the bottom of each frame to mimic frictional forces.

Distribution 1: 200 lbs distributed on 2 lines (mimic two feet standing)

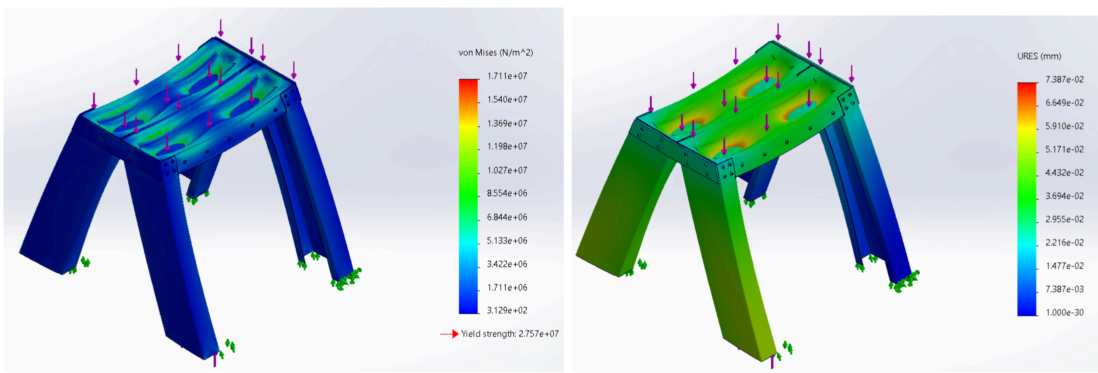




Distribution 2: 200 lbs on the center of one step (mimic the act of stepping onto the stool)



Distribution 3: 200 lbs distributed evenly across the two top steps



As can be seen in the simulations, the 200 pound load did result in plastic deformation and displacement of the assembly. While this would not be ideal in a product sold to consumers, for our project we determined that displacements of less than one millimeter would be acceptable. Certainly, when stepping on the manufactured product there is some displacement due to the load. Future work would allow us to develop a design that further minimized deformation and displacement. However, the project was valuable in applying what we learned about stress and different material properties.

Manufacturing

Processes/Machines: Iron Worker, Waterjet, Drill Press, Vertical Bandsaw, English Wheel, Bead Roller, Sheet Metal Bender Brake, Hydraulic Press, Riveting, Laser Cutter, and various sheet metal sanding and cutting processes



The manufacturing process began with testing on scrap 1/32” tick material. We tested cutting the step DXF files on the waterjet and using different methods to bend and cut the material to achieve the required angles. A major part of the testing process was devoted to testing different bead sizes on the steps to see what created the least warping in the material (even after using the English Roller to pre-warp the material ahead of beading). We also strength tested the steps after we made them, applying force using a hydraulic press in addition to standing on them. Once the 1/16” Aluminum sheets arrived, we applied the processes we had been testing on the thinner material and ran into some challenges.

Challenges:

Despite the fact that the final material (1/16” which we had also run the FEA on) was still relatively thin compared to other sheet metal options, the Sheet Metal Bender Brake we had used to achieve the 70° bends was not strong enough to bend the material to that extreme. Instead, we opted to use a combination of the Iron Worker and a table bender to reach the required bend angle. The thicker material made it more difficult to create bends at the precise angle and made it harder to align the parts when assembling the step ladder due to the slight deviations from the design. Furthermore, due to the increased thickness of the material we needed to use larger rivets so that we could connect three sheets together at once (a combined thickness of 3/16” rather than 3/32”). In addition, since the limit of the waterjet bed is a 12” by 12” square, we could not cut the sides for the step stool on it. Instead, we had to shear individual pieces off of the material using the Iron Worker to cut the shape of the side pieces before using a combination of a vertical bandsaw and sander to achieve the final shape. Once we had completed the bending of all of the parts, a whole new set of challenges arose with putting the pieces together. Despite our efforts, there were enough differences in the flexes of the parts that we had to redrill many holes in order to align the parts for riveting. In addition, some of the material had sprung back which forced us to use a vice and a press to push the steps together before being able to insert rivets. This likely created some unnecessary internal compression within the steps of the ladder.




Successes and Learning:

Despite the difficulties, we successfully created a step stool that we confidently stood on (and even jumped on!). We realized the true capabilities of the Iron Worker; we created an entire part with it using in combination its shearing, bending, and punching abilities. We gained the valuable lesson of learning to build tolerances into CAD designs and being aware of the tolerances during the manufacturing process.

On the CAD side, we practiced valuable skills in designing for production, with manufacturing processes in mind. We went through multiple iterations to develop a safe and stable product. We also gained valuable experience developing FEA simulations and modeling for real-life use.

Future Work:

If we had more time (and resources) we would have likely started testing with the 1/16” material rather than on the scrap 1/32” thick sheet aluminum. This would have eliminated unnecessary time spent testing manufacturing methods that didn’t end up working for the processing of our final material. We would probably only use the table bender for achieving angled bends rather than the Iron Worker, despite the additional physical work required, since the Iron Worker occasionally resulted in a “taco” shape when bending the sides, as the total bend length could not reach the length of the entire material (even with flipping it around). When table bending, we would likely be more cautious about potentially fracturing the material and bending slightly outside the measured lines to allow for greater tolerances when interfacing the different components. Given more time and material, we could have made this step stool the prototype build and followed up with the original design of a complete, foldable step ladder. To decrease total manufacturing time, we would like to explore designing a step ladder that can be cut entirely on the waterjet (12” x 12” range) yet still maintain the same strength, because using the Iron Worker instead of the waterjet for the sides made manufacturing them much more time-intensive.