Middle East Technical University

Department of Mechanical Engineering

ME 303 - Manufacturing Technologies

Spring 2025 - Final Project

Tower Build Challenge

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Introduction

This project defines a simple yet challenging engineering problem, how to design and build a stable structure using a lightweight and seemingly-weak material. The main objective is to construct a tower using a single A4 sheet of aluminum while maximizing the height and its load-carrying capacity. We are required to use manufacturing principles of metal sheet forming taught in class.

An important aim is to develop an efficient size and shape to fit the given dimensions, we will do this by incorporating triangular columns. Our design must overcome multiple obstacles which may cause failure such as: bending, buckling, fracture caused by compressive stresses. Furthermore, creating durable joints with the allowed adhesives will allow us to mainly focus on the aluminum itself and how to structure it to eliminate failure (at the required weights).

Theoretical Discussion

Our design is based on maximizing the structural efficiency by creating a stable three dimensional structure from the sheet metal aluminum. The central issue is the material's extremely low resistance to buckling under compressive stresses. Therefore, our design will be based on creating hollow, multi-sided triangular columns from layered sections. This geometry increases the moment of inertia and provides the stiffness required to support the weight of the tower itself along with the additional load without collapsing. The overall structure will be of tapered shape, width at 5x5 narrowing up to the top of the tower at 2x2 cm for the loading platform. The load at the top causes axial forces along the columns of the tower, spread evenly with the help of the 3D printed piece. To combat the foil's tendency to tear at stress concentrations, all free edges will be folded over and connections will be made using allowed glue and tape. This approach makes use of aluminum's high ductility which makes it easy for us to bend the sheet metal; we also minimize the amount of tape used in order to rely largely on the material's properties.

Maximum Load

When choosing a design for the tower it is important to consider the failure points before even starting the prototyping process. It is important to consider the failure scenarios and compute a maximum theoretical load so that we can make informed decisions when designing the tower.

Sources Of Failure :

1. **Failure due to compressive stresses :**

The simplest and most straightforward source of failure is the failure due to compression where the pressure is the greatest. Since the design consists of a loading platform which is essentially the minimum area, compressive failure is likely to occur at that point.

2. **Failure due to Buckling :**

Local buckling may occur in the central shaft or in the braces that support it since the aluminum foil is thin. This case is the most likely in this project and therefore will be the one we focus on the most.

3. **Joint Failure :**

Considering the nature of the connections and the joints it is likely that failure occurs due to there being insufficient scotch tape or glue. Even with extreme care while employing the glue and tape there still remains a factor of uncertainty greater than with the other sources of failure.

Theoretical Maximum Load :

Following up from the previous section it is apparent that we have to check the two main sources of failure i.e Localised Buckling and Failure due to Compressive Stresses.

For the following calculations the mechanical properties of an aluminum sheet which is 100 microns thick are taken into consideration. Commonly industry grade aluminum is represented in the form 1XXX and in our case of pure aluminum the values for the yield strength and the ultimate tensile strength are taken for the Aluminum 1050 :

$$\sigma_{UTS} = 221\, MPa$$

$$\sigma_{YS} = 105\, MPa$$

$$E = 71\, GPa$$

For this particular design buckling may occur in the central shaft or in any of the braces. The critical force values for each of the braces and the central shaft alongside the failure threshold due to compressive stresses for the loading platform are computed below.

For Buckling we will use :

$$P_{cr} = \frac{C \cdot \pi^2 \cdot E \cdot A}{\left(\frac{\ell}{k}\right)^2} \qquad k = \sqrt{\frac{I}{A}}$$

$$I = \frac{\pi(d_0^{\ 4} - d_i^{\ 4})}{64}$$

$$l = 21\, cm$$

Using the material properties of Aluminum Alloy 1050 (industry grade) and considering the end conditions as fixed for the column we can use C = 1.2, we find the critical force to be around 380 N which gives us about 37 kg of load that the column can handle. However as we will see this will not be the limiting factor for our design in theory and in practice.

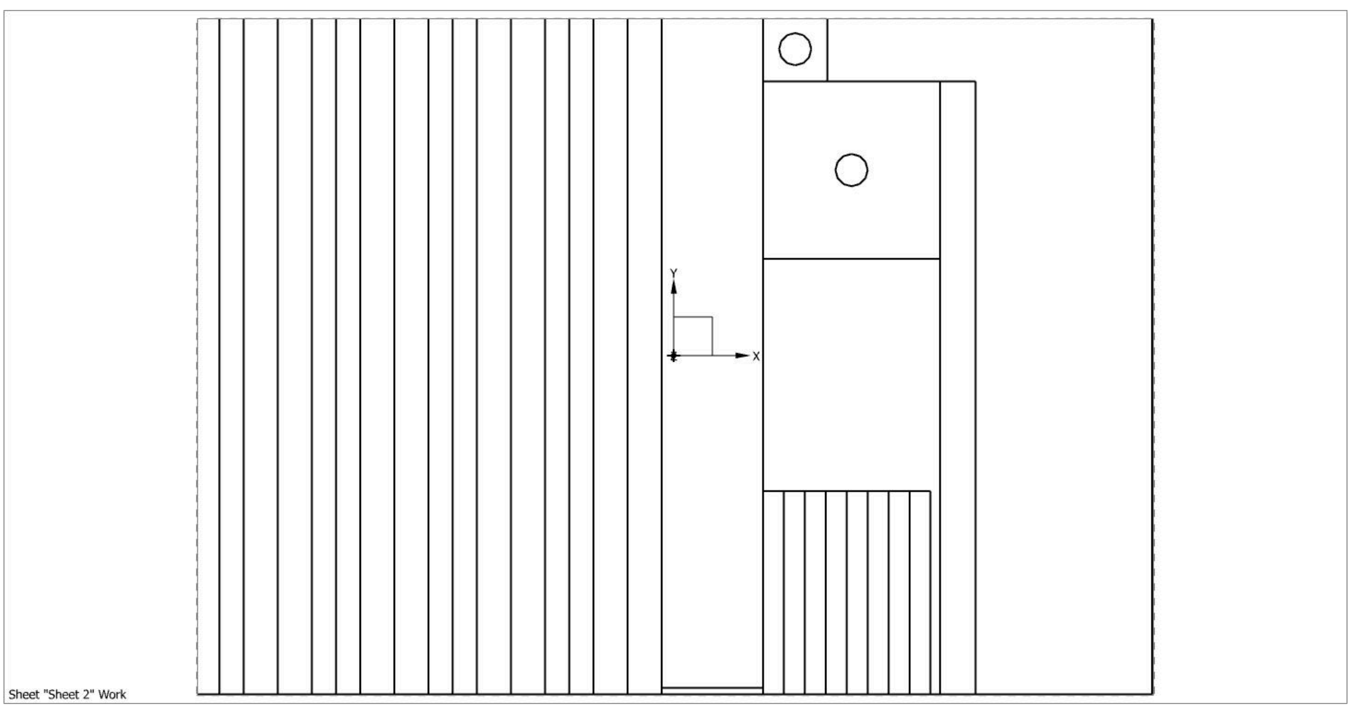
For the compressive stress we will use :

$$\sigma = \frac{F}{A}$$

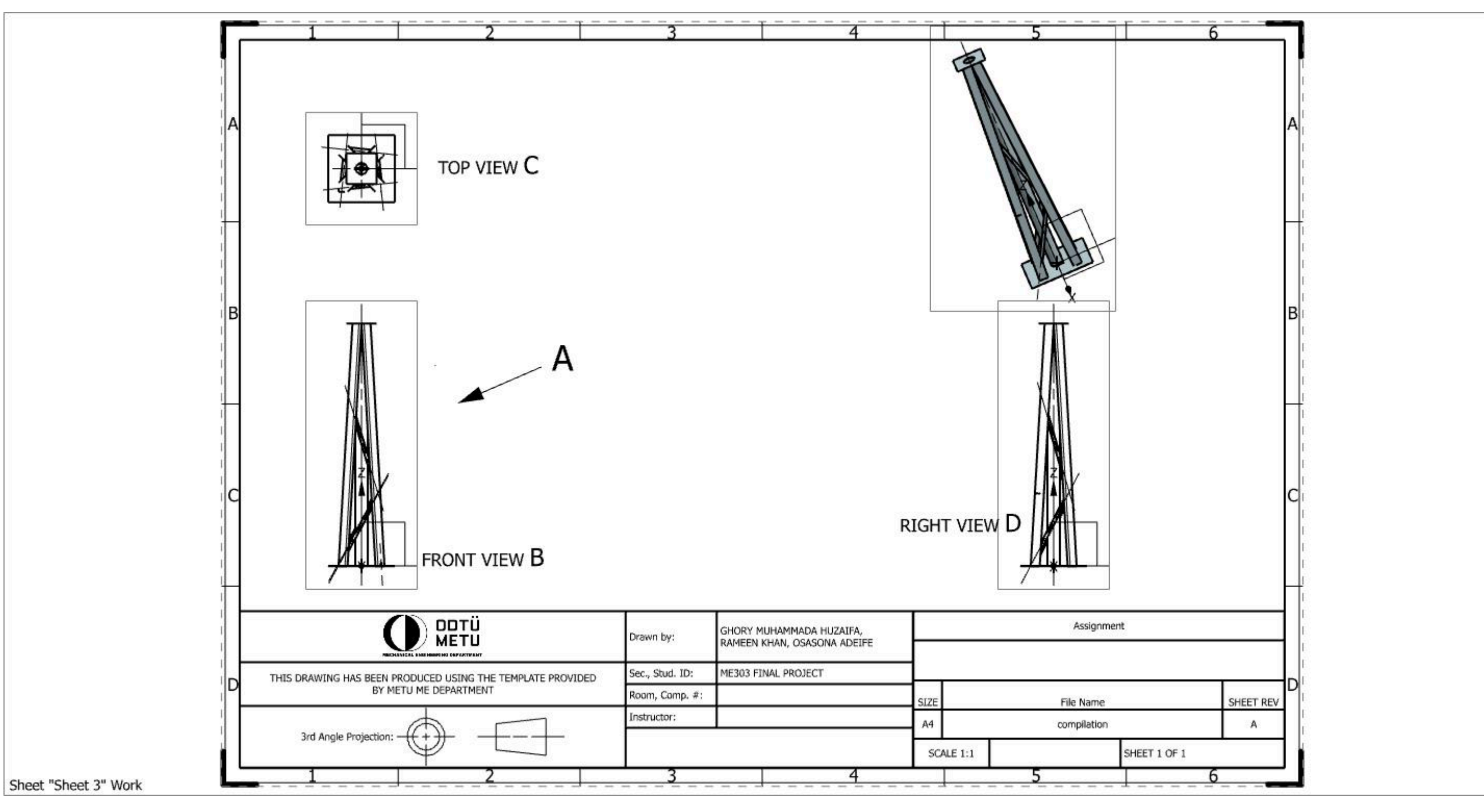
We obtain the maximum force by using the thickness of the 100 micron sheet and the yield strength of the aluminum and find it to be 0.47 N. Since in our design we have 4 shafts supporting the area with trusses this force is expected to be much higher in our actual design.

Considering joint failure is also very important and it might be in our case the limiting factor. Keeping in mind the minimal glue usage, the weight of the aluminum and scotch tape we were able to reinforce every joint to a limited extent. This might lead to early catastrophic failure of our design considering the constraints.

Layout Print :



Assembly Drawings :



End Text Reference

Budynas, R. G., & Nisbett, J. K. (2020). *Shigley's Mechanical Engineering Design* (11th ed.). McGraw-Hill Education.

https://www.azom.com/article.aspx?ArticleID=2798

Appendix

Tentative loading (uneven) applied at the top of the tower.