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THEME

Static study and simulation of a double-layer scissor lift

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Acknowledgement

I thank God, who has blessed me with health, courage, and patience during these long days, which helped me complete this work.

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Thanks, everyone

Dedicate

I thank God who has enabled me to complete this work and blessed me with health, wellness and determination.

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After a lot of hard work and exhaustion, I end my university journey by dedicating this work to:

my dear parents. My family, all sisters and brothers and my dear friends for their support and their kindness.

To my supervisor Mr.KIRAD Abdelkader and all respected professors for their information and their help.

Abstract

Scissor lifts play a crucial role in various industries, providing safe and efficient operation. In this study, the determination of design parameters for a double-layer scissor lift (the platform height, the angle between scissor arms...etc.) and calculation of the reaction forces of each joint have been done using the parameters of the hydraulic cylinder mounting position and the equations obtained from the static study. The 3D model of the lift was conducted and simulated using Solidworks software. the results show that the model could safely lift the required load.

Keywords: scissor lifts, design parameters, double-layer scissor lift, reaction forces, joint, mounting position, hydraulic cylinder, static study, load, simulation, solidworks.

ملخص

تلعب الرافعات المقصية دورًا حاسمًا في مختلف الصناعات، مما يوفر تشغيلًا آمنًا وفعالًا. في هذه الدراسة، تم تحديد معلمات التصميم للرافعة المقصية مزدوجة الطبقة (ارتفاع المنصة، الزاوية بين أذرع المقص...إلخ) وحساب قوى التفاعل لكل مفصل باستخدام معلمات موضع تركيب أسطوانة الهيدروليكية والمعادلات التي تم الحصول عليها من الدراسة الساكنة. تم إجراء نموذج الرفع ثلاثي الأبعاد ومحاكاته باستخدام برنامج Solidworks. أظهرت النتائج أن النموذج يمكنه رفع الحمولة المطلوبة بأمان.

الكلمات المفتاحية: الرافعات المقصية، المعلمات التصميمية، الرافعة المقصية مزدوجة الطبقة، قوى التفاعل، المفصل، موضع تركيب، أسطوانة الهيدروليكية، دراسة ثابتة، الحمل، المحاكاة، solidworks.

Résumé

Élévateur à ciseaux jouent un rôle crucial dans diverses industries, assurant un fonctionnement sûr et efficace. Dans cette étude, la détermination des paramètres de conception d'une Élévateur à ciseaux à double niveau (la hauteur de la plate-forme, l'angle entre les bras à ciseaux... etc.) et le calcul des forces de réaction de chaque joint ont été calculées à l'aide des paramètres de la position de montage du vérin hydraulique et les équations obtenues lors de l'étude statique. Le modèle 3D de l'élévateur a été réalisé et simulé à l'aide du logiciel Solidworks. Les résultats montrent que le modèle pourrait soulever en toute sécurité la charge requise.

Mots clés : Élévateur à ciseaux, paramètres de conception, élévateur à ciseaux à double niveau, forces de réaction, joint, position de montage, vérin hydraulique, étude statique, charge, simulation, solidworks.

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$\boldsymbol{a}$**:** Length of one scissor's arm

$\boldsymbol{\beta_1}, \boldsymbol{\beta_2}$**:** Design parameters

$\boldsymbol{\lambda}$**:** Cylinder's length

$\boldsymbol{\gamma}$**:** The angle between the scissor arms

$\boldsymbol{\varphi}$**:** The angle between the cylinder and the scissor arm

$\boldsymbol{h}$**:** Platform height

$\boldsymbol{K_h}$: Lifting ratio.

$\boldsymbol{l}$**:** Distance between supports A and B on the platform

$\boldsymbol{l_G}$**:** Position of total load **PG** on the platform

$\boldsymbol{P'}$**:** Lift the weight of the objects/people

$\boldsymbol{W_G}$**:** Weight of the platform

$\boldsymbol{W}$**:** Weight of a scissor arm

$\boldsymbol{F_Q = F_{cyl}}$: Cylinder force

$\sum \boldsymbol{F_x}$**:** the sum of forces in x-axis

$\sum \boldsymbol{F_y}$**:** the sum of forces in y-axis

$\sum \boldsymbol{M}$**:** the sum of the moment

$\boldsymbol{N}$: Normal force

$\boldsymbol{Q}$: Shear force

$\boldsymbol{M}$: Bending moment

$\boldsymbol{\sigma_{all}}$: Allowable Stress

General introduction

Due to the revolution and development of science and technology, many problems have been solved, one of them is the ability to reach heights and lift people or objects with the help of scissor lifts.

The scissor lift is an ariel platform that has gained popularity as a commonly manufactured lifting structure due to higher worker productivity. Furthermore, the scissor lift can reach the desired height depending on the number of pantographs used, this is the aim concept of the layer scissor lift that enables workers to access multiple work areas at various heights by raising and lowering the platform, through this we can enhance productivity, efficiency, and flexibility while conserving valuable time.

This thesis aims to determine the design parameter of a double-layer scissor lift, the reaction force of each joint using the parameters of the hydraulic cylinder mounting position, also verify the lift's safety under the required load. Therefore, the structure of this thesis is planned as follows:

The first chapter will present an overview of scissor lifts, including their various types, their functions and applications. In addition, we will discover the advantages and disadvantages of scissor lifts.

The second chapter will focus on the hydraulic scissor lift, its components, the different types of hydraulic cylinders and its position. Then, we will determine the design parameter, and the reaction forces of each joint, and verify the safety of the design.

The third chapter will delve into simulating the double-layer scissor lift using SolidWorks software.

CHAPTER I:

Background and generalities

I.1. Introduction:

Scissor lifts are elevated work platform (EWP) used to lift individuals or objects to various heights using the upward motion of cross-shaped scissor arms in an "X" pattern known as a pantograph, they can also achieve desired heights depending on the number of pantographs used in scissor lift mechanism. Moreover, the scissor lift mechanism is a type of mechanism that allows raising the platform in an upward motion through the use of linked, folding supports, in a crisscross “X” pattern, by applying the force on the outside of the lowest set of supports, elongating the crossing pattern, and raising the platform vertically upwards. [1]

The first innovation of these tools was operated manually and worked under specific conditions. However, the advancement of technology has improved the operation process and made it more efficient and easier to use by powering these tools with different types of energy such as hydraulic, pneumatic, and mechanical.

In addition, these aerial platforms are commonly used in various areas including manufacturing, construction, and maintenance, offering the ability to accomplish any tasks. [2]

I.2. Different types of scissor lifts:

According to the type of energy used to raise and lower the platform in a vertical upward or downward movement, scissor lifts can be divided into the following categories:

I.2.1. Hydraulic lift:

The hydraulic lift uses the fluid pressure to raise the platform in a smooth movement, this power is gained by pressurised hydraulic oil, also the viscosity of the hydraulic oil can be affected by temperature fluctuations causing slight speed variation.

The hydraulic lift is easy to operate, commonly used due to its high-capacity lifting and can be found on construction sites and warehouses. On the other hand, the mechanism used in hydraulic lift counts various components which makes it difficult to design, costly as a result of using hydraulic oil and also requires a lot of maintenance caused by oil leakage, rust and corrosion.

Figure I.1 Hydraulic lift

I.2.2. Pneumatic lift:

The pneumatic lift is powered using air pressure by vacuuming and compressing atmospheric air to raise and lower the platform. it is also a suitable option for the environment and indoor facilities because air is available and emits no fumes.

However, this type has various components which makes it difficult to design, also in this system working fluid is air so there are maintenance problems and on highways it is not possible to maintain this system, and costly as a result of using an air compressor and control valve.

Figure I.2 Pneumatic lift

I.2.3. Mechanical lift:

The mechanical lift is extended through a rack and pinion system or power screw, that can convert rotational motion. The benefit of mechanical lift is that the teeth of its gear system prevent slippage essentially.

In addition, the mechanical lift is easy to design, also requires less maintenance due to the mechanical parts in the system, this type is less costly as a result of using a simple mechanism. [3] [4]

Figure I.3 Mechanical lift

I.3. Function of scissor lift:

Different power sources are used in scissor lifts to produce the necessary force to lift the platform, causing the same movement (upward and downward motion) in all of its types.

It starts to work when the power source is turned on and begins to fill the cylinder(s) with hydraulic fluid or compressed air. After that, the hydraulic fluid or compressed air is pushed from one area to another. In the end, the cylinder is pushed outwards and causes the scissor arm to push apart and the platform rises.

In case of lowering the platform, the operator will release the pressure or fluid in the scissor lift and begin the descent. [5]

I.4. Application of scissor lifts:

An industrial scissor lift is a device that employs a scissors mechanism to raise or lower goods and/or persons. these lifts are used to raise large, heavy loads through relatively small distances. Common applications include pallet handling, vehicle loading and work positioning.

- The scissor lift can raise a forklift so that maintenance to the underneath of the forklift can be performed.
- By employing a scissor lift in a warehouse, all heavy items can be lifted with ease. You can use it to stack boxes, pallets, and other heavy materials.
- Sheet metal is often stacked. The metal is usually too heavy for employees to try and lift for the stacking process. This is where a scissor lift table can help.
- Distributaries often use scissor lift tables for the lifting of merchandise.
- Scissor lift can be used to lift people and those in wheelchairs. By using a lesser-capacity scissor lift, you can lift people for outdoor chores such as cleaning gutters and windows. Those who use wheelchairs can use the lift to reach higher levels with less constraint.
- In major cities, you will often see scissor lifts used as platforms for maintenance and construction.
- Some scissor lifts are used as weight platforms to weigh machinery and other mechanisms.
- Use the lift as a deck extension during a major renovation or project. Scissor lift tables can help you in any renovation or remodel. It is useful for allowing people to reach higher areas of a building. [4]

I.5.Advantages and disadvantages of scissor lift:

Even though the scissor lift is a useful tool, it also has disadvantages which are as follows:

Advantages	Disadvantages
➢ Simple and safe to use ➢ Lower incident rates ➢ Ability to use in both indoor and outdoor activities	➢ Limited heights ➢ Regular maintenance

Table I.1 Advantages and disadvantages of scissor lifts

I.6.Conclusion:

Scissor lifts have become one of the most popular equipment used in many industries. It is also one of the essential tools for manufacturing and stocking purposes. They elevate workers with their equipment and materials while offering a working platform, they also provide efficient and productive ways to work at heights using different energy types and come in various shapes and sizes.

CHAPTER II:

Static study of a double-layer scissor lift

II.1. Introduction :

This chapter contains a static study of a double-layer scissor lift. The chapter begins by describing the system where we chose the hydraulic lift because is the perfect example in the mechanical field, we mention the main components of the lift. We also discover the different types of hydraulic cylinders and their position.

Additionally, this study provides us with the opportunity to determine and calculate the reaction forces of each joint, as well as verify the safety of the design.

II.2. System Description:

Despite all types of scissor lifts the most widely used type in industries is the hydraulic scissor lift. This type has five main components which are as follows:

Figure II.1 Hydraulic lift components

1. **Top platform:** also known as the lift table can be supplied in a variety of sizes, it provides the frame and the surface to accommodate the load. It also requires a design that allows it to operate under high loads. The top of this platform is where the lifted product sits.
2. **Scissor arms:** scissor arms play the most important role as they help achieve the variable height requirement by moving up and down while bearing the load of the lift.
3. **Hydraulic cylinder:** It provides the required force to lift and lower the lift table. The selection of the hydraulic cylinder is based on the required working pressure and the maximum force to lift. scissor lifts are actuated by one, two, or three single-acting hydraulic cylinders.
4. **Power source:** is the heart of the whole equipment. It provides power to the hydraulic pump by either an electric or air motor, to raise the lift table to the designated height.
5. **Base platform:** the lower part of the structure is located on the ground. It contains the path along which the scissor arms travel. It also comes in different sizes and shapes depending on the model. [6] [7]

II.3. Hydraulic cylinder:

II.3.1. Definition:

The hydraulic cylinder or the hydraulic actuator is the component that provides the necessary force to raise and lower the platform.

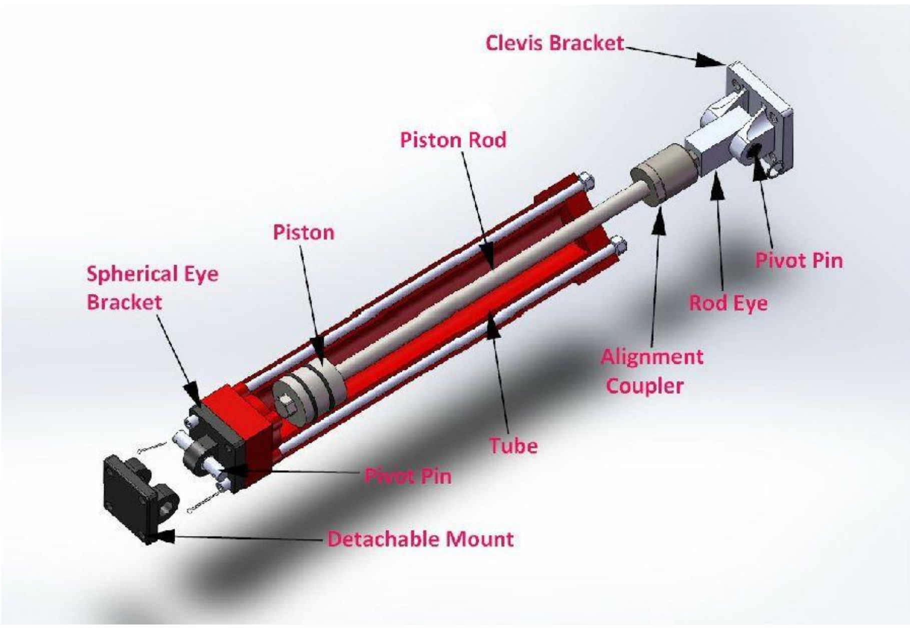


Figure II.2 Hydraulic cylinder

II.3.2. Different types of hydraulic cylinders:

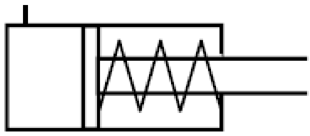
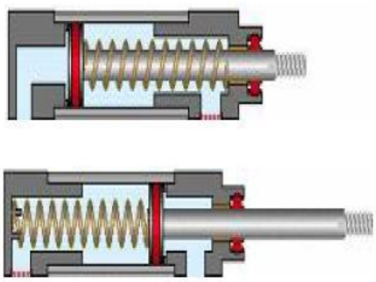
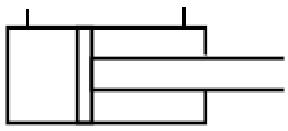
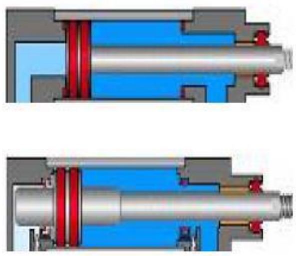
Type	symbol	schema
Single acting cylinder Single-acting cylinders use hydraulic oil to power stroke in one direction only. The return stroke is accomplished by a mechanical spring located inside the cylinder. For single-acting cylinders with no spring, an external force acting on the piston rod is required for its return.		
Double acting cylinder A double-acting cylinder uses compressed air or hydraulic fluid for both the forward and return strokes. making it suitable for pushing and pulling with the same application. These cylinders are ideal for full stroke working only at a slow speed which results in gentle contact at the ends of the stroke. [8]		

Table II.1 Different types of hydraulic cylinders

II.3.3. Hydraulic cylinder position:

Selecting a pantograph as a basic mechanism dynamic of the system also varies with the position of the hydraulic cylinder. The hydraulic cylinder acts as the actuating force for the model.

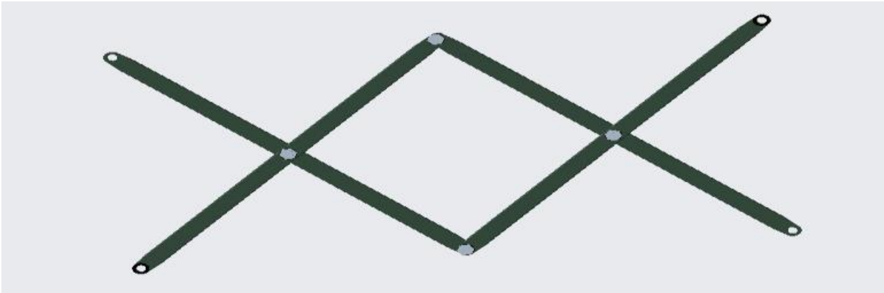


Figure II.3 Pantograph

There can be three different positions of the Hydraulic Cylinder:

- Attached horizontally at the base.
- Attached at an angle with the base.
- Attached at an angle to the end of scissor arms.

Position 1, has a few advantages the centre of mass will shift a little bit downwards as the cylinder will be placed at the base but this type of configuration will be useful and helpful in small scissor lifts having a single scissor arm pair on either side, as lifts having a greater number of scissor arm pairs will need support also between them.

Position 2, is the most commonly used in medium-scale scissor lifts it will distribute the force of the hydraulic cylinder among multiple scissor arms rather than being focused on a single arm. Moreover, it is attached between different scissor arm pairs using a support arm which will also provide support to scissor arm pairs.

Position 3, which hydraulic cylinders are attached to an angle to the end of scissor arms. The main disadvantage is that we need to use hydraulic cylinders in pairs to provide better stability and lifting capacity and balance the bending moment acting due to the cylinders to avoid the toppling of the system. [6]

Thus, we select position 3 for the double-layer scissor lift containing two cylinders, one on each side of the scissor mechanism to provide better stability and lifting capacity.

II.4. Static study of a double-layer scissor lift:

The static study of a mechanism enables us to analyze forces and moments at rest, predict behavior and ensure safe operation under static loads. In our case, this study will lead us to:

- Determine design parameter.
- Determine and calculate the reaction forces of each joint using the FBD.
- Verify the safety of the design.

II.4.1. Kinetic analysis:

We select a design of a double-layer scissor lift consisting of two cylinders and employ mathematical equations to find platform height, the angle between the scissor arm γ, the lifting ratio and the distance l. where we use the following parameters:

- a: Length of one scissor's arm.
- β_1, β_2: Design parameters.
- λ: Cylinder's length.
- γ: The angle between the scissor arms.

Figure II.4 shows the parameters of the system at the height position.

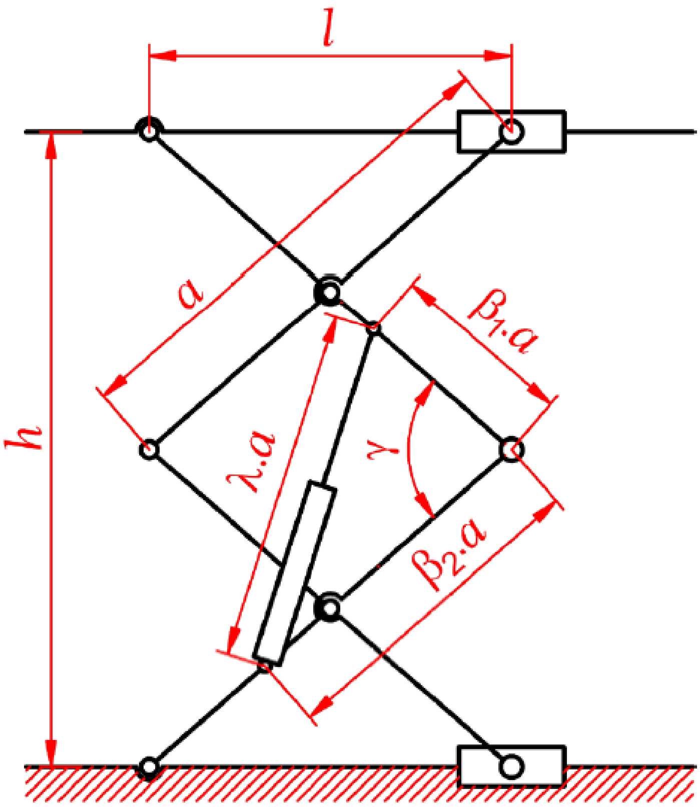


Figure II.4 Parameters of the system

The platform height h when the cylinder extends, can be determined by using the sine formula [9] :

$$sin\frac{\gamma}{2} = \frac{h/_2}{a}$$

$$\frac{h}{2} = \frac{sin\frac{\gamma}{2}}{a}$$

$$h = 2asin\frac{\gamma}{2}$$

By substituting the half-angle formula for sine: $\sin\frac{\theta}{2} = \sqrt{\frac{1-\cos\theta}{2}}$ [9],we obtain the platform height equation:

$$h = 2a\sqrt{\frac{1-\cos\gamma}{2}} \qquad (II.1)$$

We determine the angle γ by using the law of cosines: $a^2 = b^2 + c^2 - 2b.c.cosA$ [9]:

$$(\lambda.a)^2 = (\beta_1.a)^2 + (\beta_2.a)^2 - 2\beta_1 a.\beta_2 a.\cos\gamma$$

$$\lambda^2.a^2 = \beta_1{}^2.a^2 + \beta_2{}^2.a^2 - 2\beta_1\beta_2.a^2.\cos\gamma$$

$$2\beta_1\beta_2\cos\gamma = \beta_1{}^2 + \beta_2{}^2 - \lambda^2$$

$$\cos\gamma = \frac{\beta_1{}^2+\beta_2{}^2-\lambda^2}{2\beta_1\beta_2} \tag{II.2}$$

To obtain the Eq.(II.3) that determines the platform height, we insert Eq.(II.2) into Eq.(II.1):

$$h = 2a\sqrt{\frac{1-\frac{\beta_1{}^2+\beta_2{}^2-\lambda^2}{2\beta_1\beta_2}}{2}}$$

$$h = a\sqrt{\frac{\lambda^2-(\beta_1-\beta_2)^2}{\beta_1\beta_2}} \tag{II.3}$$

The lifting ratio can be determined by the lifting height of the platform when the cylinder extends its length from zero-stroke to full-stroke:

$$K_h = \frac{\Delta h}{a} = \frac{h_{max} - h_{min}}{a}$$

$$K_h = \frac{a\sqrt{\frac{\lambda_{max}{}^2-(\beta_1-\beta_2)^2}{\beta_1\beta_2}}}{a} - \frac{a\sqrt{\frac{\lambda_{min}{}^2-(\beta_1-\beta_2)^2}{\beta_1\beta_2}}}{a}$$

$$K_h = \frac{\lambda_{max}{}^2-\lambda_{min}{}^2}{\beta_1\beta_2} \tag{II.4}$$

As the platform rises, the loading distance l between supports decreases. On the other hand, the angle γ between the frames increases. This factor affects the stability of the lift [10], this distance is determined by using the cos formula [9]. Then, we utilize the half-angle formula of cosine $\cos\frac{\theta}{2} = \sqrt{\frac{1+\cos\theta}{2}}$ [9]:

$$\cos\frac{\gamma}{2} = \frac{l}{a}$$

$$l = a.\cos\frac{\gamma}{2}$$

$$l = a\sqrt{\frac{1+\cos\gamma}{2}}$$

$$l = a\sqrt{\frac{(\beta_1+\beta_2)^2-\lambda^2}{4\beta_1\beta_2}} \quad \text{(II.5)}$$

II.4.2. Force analysis :

We use the free-body diagram (FBD) to determine and calculate the reaction forces. in this method, the static equilibrium equations are constructed based on the free-body diagram (FBD) of each link, in each FBD all of the reactions and applied forces that act on the link are considered. This method allows us to simplify the analysis of complex structures by isolating each element and studying and analyzing it. [11]

The applied load on the platform is: $P_G = \frac{(P'+W_P)}{2}$

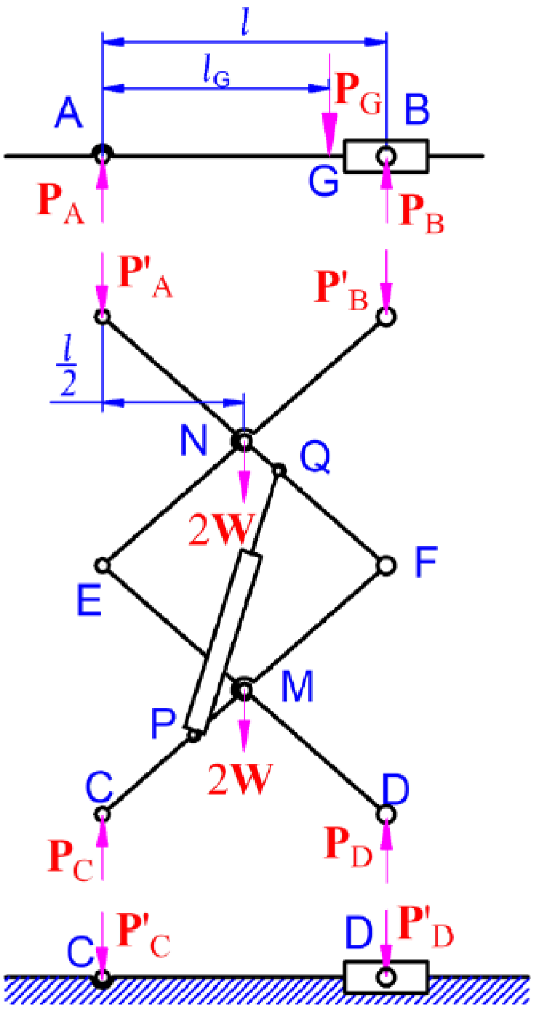


Figure II.5 Reaction forces at support A, B, C and D

The reactions at supports A and B can be determined using equilibrium equations:

$\sum F_x = 0$

$\sum F_y = 0 \quad \Rightarrow \quad P_A - P_G + P_B = 0$

$\Rightarrow \quad P_A = P_G - P_B$

$\sum M_A = 0 \quad \Rightarrow -P_G l_G + P_B l = 0$

$$\Rightarrow \quad P_B = \frac{P_G L_G}{l} \qquad \text{(II.6)}$$

$$\Rightarrow \quad P_A = P_G - P_B = P_G - \frac{P_G l_G}{l} \qquad \text{(II.7)}$$

$$P_A{}' = P_A$$

$$P_B{}' = P_B$$

The reactions at supports C and D can be determined using equilibrium equations:

$\sum F_x = 0$

$\sum F_y = 0 \quad \Rightarrow \quad P_C - 4W - P_G + P_D = 0$

$\Rightarrow \quad P_C = P_G + 4W - P_D$

$\sum M_C = 0 \quad \Rightarrow \quad 4W\frac{l}{2} + P_G l_G - P_D l = 0$

$$\Rightarrow \quad P_D = \frac{P_G l_G}{l} + 2W \qquad \text{(II.8)}$$

$\Rightarrow \quad P_C = P_G + 4w - \frac{P_G l_G}{l} - 2W$

$$\Rightarrow \quad P_C = P_G - \frac{P_G l_G}{l} + 2W \qquad \text{(II.9)}$$

$$P_C{}' = P_C$$

$$P_D{}' = P_D$$

Separate the reactions into directional components F_x and F_y at joints M and N (Figure II.5).

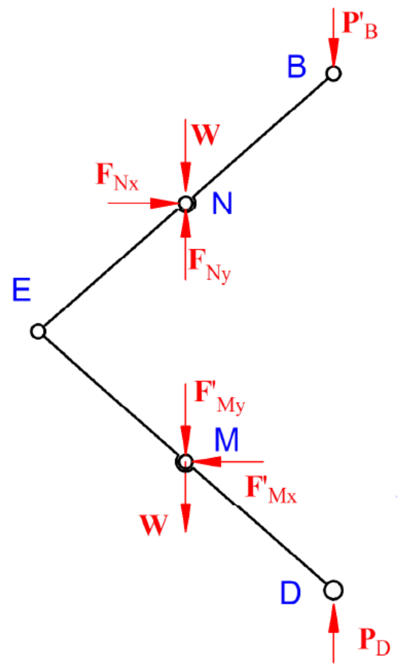


Figure II.6 Directional components Fx,Fy at joint N, M

We employ the moment equilibrium equation in frame BED:

$$\sum M_E = 0 \;\Rightarrow\; P_D a\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - 2W\frac{a}{2}\cos\frac{\gamma}{2} - F_{Mx}\frac{a}{2}\sin\frac{\gamma}{2} - F_{Nx}\frac{a}{2}\sin\frac{\gamma}{2} - F_{My}\frac{a}{2}\cos\frac{\gamma}{2} + F_{Ny}\frac{a}{2}\cos\frac{\gamma}{2} = 0$$

$$\Rightarrow\; (P_D - P'_B)a\cos\frac{a}{2} - (F_{Mx} - F_{Nx})\frac{a}{2}\sin\frac{\gamma}{2} + \left(F_{Ny} - F_{My} - 2W\right)\frac{a}{2}\cos\frac{\gamma}{2} = 0 \qquad \text{(II.10)}$$

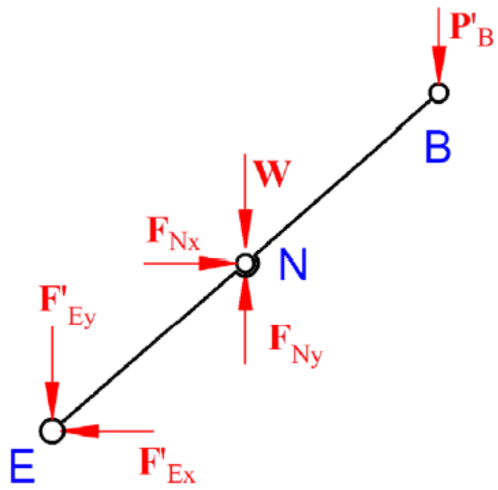


Figure II.7 FBD of link BE

We employ the moment equilibrium equation in link BE:

$$\sum M_E = 0 \;\Rightarrow\; -P'_B a\cos\frac{\gamma}{2} - W\frac{a}{2}\cos\frac{\gamma}{2} - F_{Nx}\frac{a}{2}\sin\frac{\gamma}{2} + F_{Ny}\frac{a}{2}\cos\frac{\gamma}{2} = 0$$

$$\Rightarrow\; \left(F_{Ny} - W\right)\frac{a}{2}\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - F_{Nx}\frac{a}{2}\sin\frac{\gamma}{2} = 0 \qquad \text{(II.11)}$$

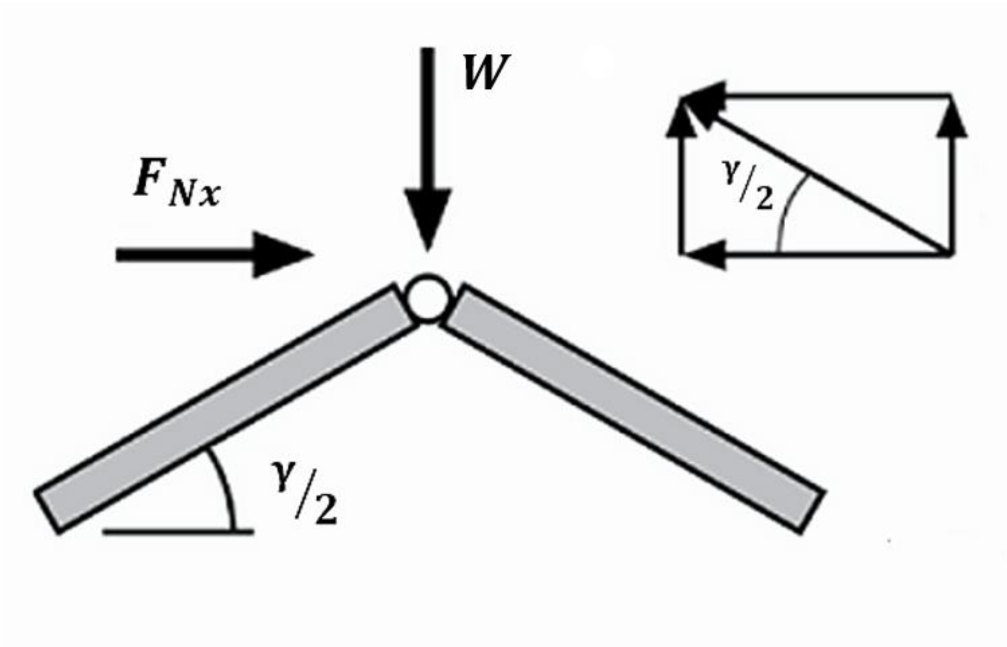


Figure II.8 Reaction forces at jiont N

We determine F_{Nx},F_{Mx} using the force equilibrium equation on the x-axis:

$$\sum F_x = 0 \;\Rightarrow\; F_{Nx} - F_{Mx} = 0$$

$$\Rightarrow\; F_{Nx} = F_{Mx}$$

$$\tan\frac{\gamma}{2} = \frac{W}{F_{Nx}}$$

$$F_{Nx} = \frac{W}{\tan\frac{\gamma}{2}}$$

$$F_{Nx} = F_{Mx} = \frac{W}{\tan\frac{\gamma}{2}} \qquad \text{(II.12)}$$

We determine F_{Ny} by substituting Eq. (II.12) into Eq. (II.11):

$$\sum M_E = \left(F_{Ny} - W\right)\frac{a}{2}\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - F_{Nx}\frac{a}{2}\sin\frac{a}{2} = 0$$

$$\Rightarrow \left(F_{Ny} - W\right)\frac{a}{2}\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - \frac{W}{\tan\frac{\gamma}{2}}\frac{a}{2}\sin\frac{a}{2} = 0$$

$$\Rightarrow \left(F_{Ny} - W\right)\frac{a}{2}\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - \frac{W}{\sin\frac{\gamma}{2}}\cos\frac{\gamma}{2}\frac{a}{2}\sin\frac{a}{2} = 0$$

$$\Rightarrow \left(F_{Ny} - W\right)\frac{a}{2}\cos\frac{\gamma}{2} - P'_B a\cos\frac{\gamma}{2} - W\frac{a}{2}\cos\frac{\gamma}{2} = 0$$

$$\Rightarrow a\cos\frac{\gamma}{2}\left(F_{Ny} - W - 2P'_B - W\right) = 0$$

$$\Rightarrow F_{Ny} - 2P'_B - 2W = 0$$

$$F_{Ny} = 2P'_B + 2W = 2\left(\frac{P_G L_G}{l} + W\right) \quad \text{(II.13)}$$

We determine F_{My} using the force equilibrium equation on the y-axis:

$$\sum F_y = 0 \quad \Rightarrow \quad P_D - P'_B - 2W - F'_{My} + F_{Ny} = 0$$

$$\Rightarrow \quad F'_{My} = P_D - P'_B - 2W + F_{Ny}$$

$$\Rightarrow \quad F'_{My} = \frac{P_G l_G}{l} + 2W - \frac{P_G L_G}{l} - 2W + 2\left(\frac{P_G L_G}{l} + W\right)$$

$$F'_{My} = 2\left(\frac{P_G L_G}{l} + W\right) \quad \text{(II.14)}$$

$$F'_{My} = F_{Ny}$$

We determine F_{Ex} using the force equilibrium equation on the x-axis:

$$\sum F_x = 0 \quad \Rightarrow \quad F_{Ex} + F_{Nx} = 0$$

$$\Rightarrow \quad F_{Ex} = -F_{Nx}$$

$$F_{Ex} = -\frac{W}{\tan\frac{\gamma}{2}} \quad \text{(II.15)}$$

We determine F_{Ey} using the force equilibrium equation on the y-axis:

$$\sum F_y = 0 \quad \Rightarrow -P'_B - W + F_{Ey} + F_{Ny} = 0$$

$$\Rightarrow \quad F_{Ey} = P'_B + W - F_{Ny}$$

$$\Rightarrow \quad F_{Ey} = \frac{P_G L_G}{l} + W - 2\left(\frac{P_G L_G}{l} + W\right)$$

$$F_{Ey} = -\left(\frac{P_G L_G}{l} + W\right) \qquad \text{(II.16)}$$

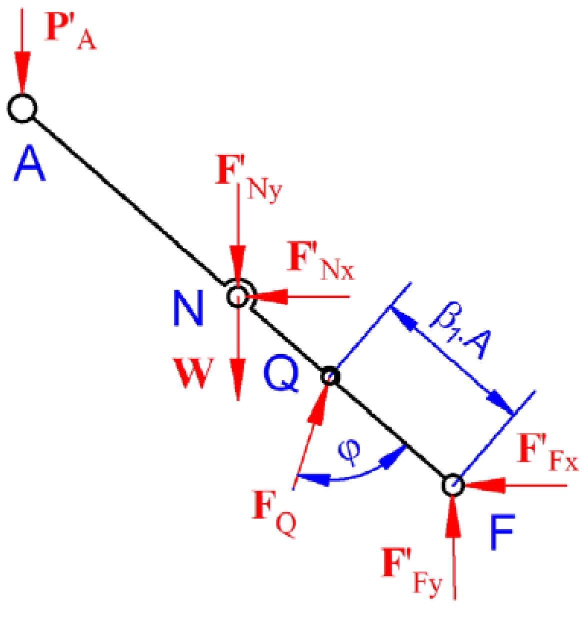


Figure II.9 FBD of link AF

We employ the moment equilibrium equation in link AF, to determine cylinder force F_Q:

$$\sum M_F = 0 \Rightarrow \; P'_A a\cos\frac{\gamma}{2} + F_{Ny}\frac{a}{2}\cos\frac{\gamma}{2} + W\frac{a}{2}\cos\frac{\gamma}{2} + F_{Nx}\frac{a}{2}\sin\frac{\gamma}{2} - F_Q\beta_1\sin\varphi = 0$$

$$\Rightarrow \; P'_A a\cos\frac{\gamma}{2} + \left(F_{Ny} + W\right)\frac{a}{2}\cos\frac{\gamma}{2} + F_{Nx}\frac{a}{2}\sin\frac{\gamma}{2} - F_Q\beta_1\sin\varphi = 0$$

$$\Rightarrow \left(P_G - \frac{P_G l_G}{l}\right)a\cos\frac{\gamma}{2} + \left(2\left(\frac{P_G l_G}{l} + W\right) + W\right)\frac{a}{2}\cos\frac{\gamma}{2} + \frac{W}{\tan\frac{\gamma}{2}}\frac{a}{2}\sin\frac{\gamma}{2} - F_Q\beta_1 a\sin\varphi = 0$$

We determine the angle φ , using the law of sin [9]:

$$\frac{\sin\varphi}{\beta_2.a} = \frac{\sin\frac{\gamma}{2}}{\lambda.a} \;\Rightarrow\; \sin\varphi = \frac{\beta_2}{\lambda}\sin\frac{\gamma}{2}$$

By adding $\sin\varphi = \frac{\beta_2}{\lambda}\sin\frac{\gamma}{2}$ to the equation, we obtain:

$$\Rightarrow \left(P_G - \frac{P_G l_G}{l}\right)a\cos\frac{\gamma}{2} + \left(2\left(\frac{P_G l_G}{l} + W\right) + W\right)\frac{a}{2}\cos\frac{\gamma}{2} + \frac{W}{\frac{\sin\frac{\gamma}{2}}{\cos\frac{\gamma}{2}}}\frac{a}{2}\sin\frac{\gamma}{2} - F_Q\beta_1 a\frac{\beta_2}{\lambda}\sin\frac{\gamma}{2} = 0$$

$$\Rightarrow \left(P_G - \frac{P_G l_G}{l}\right) a\cos\frac{\gamma}{2} + \left(2\left(\frac{P_G l_G}{l} + W\right) + W\right)\frac{a}{2}\cos\frac{\gamma}{2} + W\frac{a}{2}\cos\frac{\gamma}{2} - F_Q \beta_1 a \frac{\beta_2}{\lambda}\sin\frac{\gamma}{2} = 0$$

$$\Rightarrow (P_G + 2W)\cos\frac{\gamma}{2} - F_Q\beta_1\frac{\beta_2}{\lambda}\sin\frac{\gamma}{2} = 0$$

$$\Rightarrow F_Q = \frac{(P_G + 2W)\lambda\cos\frac{\gamma}{2}}{2\beta_1\beta_2\sin\frac{\gamma}{2}}$$

$$F_Q = \frac{(P_G+2W)\lambda}{2\beta_1\beta_2\tan\frac{\gamma}{2}} \qquad \text{(II.17)}$$

We determine F_{Fx} using the force equilibrium equation on the x-axis:

$$\sum F_x = 0 \Rightarrow -F_{Nx} - F_{Fx} + F_Q\cos\left(\frac{\gamma}{2} + \varphi\right) = 0$$

$$\Rightarrow -F_{Fx} = F_{Nx} - F_Q\cos\left(\frac{\gamma}{2} + \varphi\right)$$

$$\Rightarrow F_{Fx} = F_Q\cos\left(\frac{\gamma}{2} + \varphi\right) - F_{Nx}$$

$$\Rightarrow F_{Fx} = F_Q\cos\left(\frac{\gamma}{2} + \varphi\right) - \frac{W}{\tan\frac{\gamma}{2}}$$

$$\Rightarrow F_{Fx} = \frac{(P_G + 2W)\lambda}{2\beta_1\beta_2\tan\frac{\gamma}{2}}\cos\left(\frac{\gamma}{2} + \varphi\right) - \frac{W}{\tan\frac{\gamma}{2}}$$

$$\Rightarrow F_{Fx} = \left[\frac{(P_G + 2W)\lambda}{2\beta_1\beta_2}\cos\left(\frac{\gamma}{2} + \varphi\right) - W\right]\frac{1}{\tan\frac{\gamma}{2}}$$

By adding $\frac{1}{\tan\frac{\gamma}{2}} = \frac{\cos\frac{\gamma}{2}}{\sin\frac{\gamma}{2}} = \frac{\frac{1}{2}\sqrt{\frac{(\beta_1+\beta_2)^2-\lambda^2}{\beta_1\beta_2}}}{\frac{1}{2}\sqrt{\frac{\lambda^2-(\beta_1-\beta_2)^2}{\beta_1\beta_2}}} = \sqrt{\frac{(\beta_1+\beta_2)^2-\lambda^2}{\lambda^2-(\beta_1-\beta_2)^2}}$ to the equation, we obtain:

$$F_{Fx} = \left[\frac{(P_G+2W)\lambda}{2\beta_1\beta_2}\cos\left(\frac{\gamma}{2} + \varphi\right) - W\right]\sqrt{\frac{(\beta_1+\beta_2)^2-\lambda^2}{\lambda^2-(\beta_1-\beta_2)^2}} \qquad \text{(II.18)}$$

We determine F_{Fy} using the force equilibrium equation on the y-axis:

$$\sum F_y = 0 \Rightarrow -P_A' - F_{Ny} - W + F_{Fy} + F_Q \sin\left(\varphi + \frac{\gamma}{2}\right) = 0$$

$$\Rightarrow \quad F_{Fy} = -F_Q \sin\left(\varphi + \frac{\gamma}{2}\right) + F_{Ny} + P_A' + W$$

$$\Rightarrow \quad F_{Fy} = -F_Q \sin\left(\varphi + \frac{\gamma}{2}\right) + 2\left(\frac{P_G l_G}{l} + W\right) + P_G - \frac{P_G l_G}{l} + W$$

By adding $l = a\sqrt{\frac{(\beta_1+\beta_2)^2-\lambda^2}{4\beta_1\beta_2}}$ to the equation, we obtain:

$$F_{Fy} = P_G + \frac{P_G l_G}{a}\sqrt{\frac{4\beta_1\beta_2}{(\beta_1+\beta_2)^2-\lambda^2}} + 3W - \frac{(P_G+2W)\lambda}{2\beta_1\beta_2 \tan\frac{\gamma}{2}} \sin\left(\varphi + \frac{\gamma}{2}\right) \quad \text{(II.19)}$$

We determine the total reaction of each joint by combining their directional components:

$$F_E = \sqrt{F_{Ex}^2 + F_{Ey}^2} \quad \text{(II.20)}$$

$$F_F = \sqrt{F_{Fx}^2 + F_{Fy}^2} \quad \text{(II.21)}$$

$$F_M = F_N = \sqrt{F_{Nx}^2 + F_{Ny}^2} \quad \text{(II.22)}$$

II.4.3. Results:

The lifting ratio calculated using Eq. (II.4) is $K_h = 2.1666$. it reflects the system's lifting efficiency.

$$a = 1m\ ; W = 75N\ ;\ P_G = 5000N\ ;\ l_G = 1m$$

Design parameter	Force	Results (N)
$\beta_1 = 0.3$	$F_Q = F_{cyl}$	6362.703
$\beta_2 = 0.6$	$F_N = F_M$	20768.597
$\lambda = 0.8$	F_F	9386.210
$l = 0.485$	F_E	10384.361

Table II.2 The reaction forces

Table II.2 presents the calculated reaction forces of each joint. The calculation of these forces is based on the obtained equations and selection of the parameter of the system.

Cylinder length(m)	Angle γ (deg °)	Cylinder force (N)	Platform displacement (m)
0.5	56.251	13381.625	0.942
0.55	65.812	12159.369	1.086
0.6	75.522	11081.133	1.224
0.65	85.618	10038.423	1.359
0.7	96.379	8956.752	1.490
0.75	108.209	7765.337	1.620
0.8	121.855	6362.703	1.748

Table II.3 Cylinder length, angle, cylinder force, platform displacement

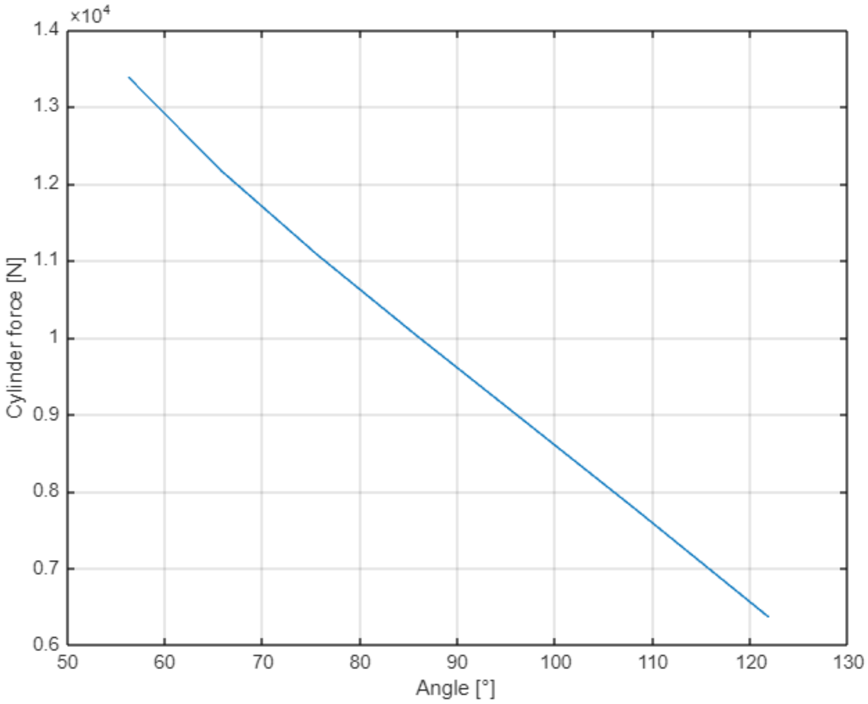


Figure II.10 Cylinder force and angle

Table II.3 presents the cylinder force and platform displacement when the cylinder extends from zero stroke to full stroke and figure II.10 shows how the cylinder force depends on the angle γ.

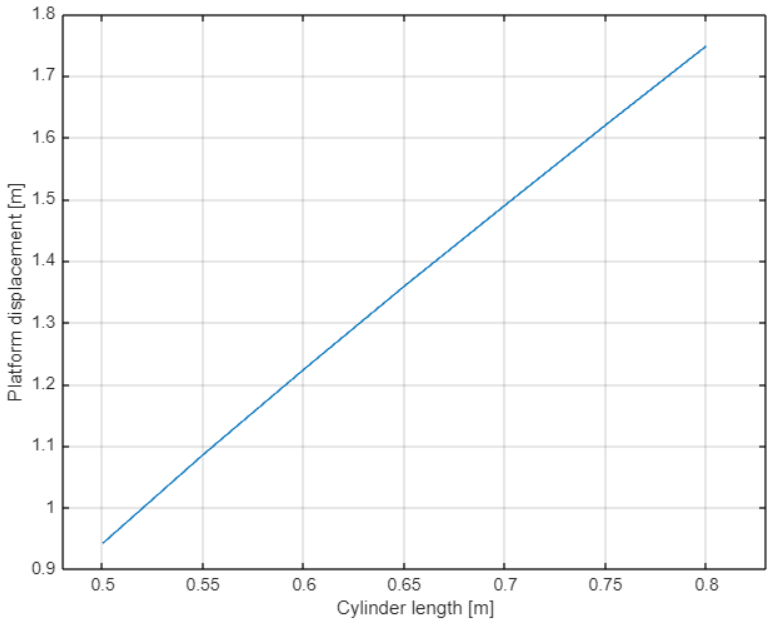


Figure II.11 Platform displacement

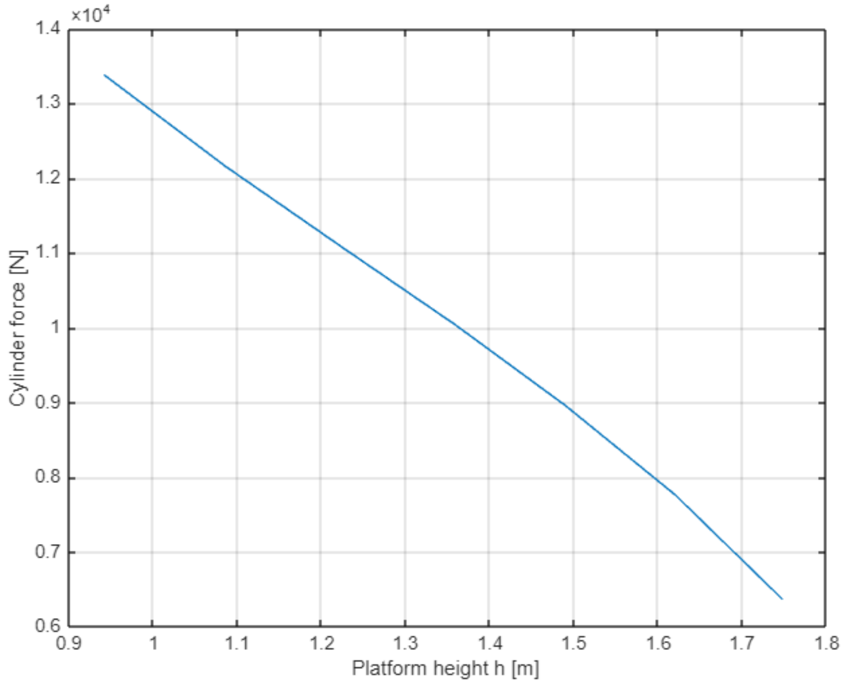


Figure II.12 Cylinder force and platform displacement

Figure II.11 shows platform displacement as the cylinder extends, lifting it from its lowest position to its height position.

Figure II.12 shows that the initial force needed from the cylinder to raise the platform from its lowest position is high. However, as the lift starts to operate to raise the platform, the force decreases and becomes low when the platform is at its highest position.

II.4.4. Piston rod strength verification:

We verify the buckling strength of the piston rod using the Euler formula [1]:

$$F_{cr} = \frac{\pi^2 \times E \times I_{(G,Z)}}{L^2} \Rightarrow L_{max} = \sqrt{\frac{\pi^2 \times E \times I_{(G,Z)}}{F_{cr}}}$$

Where:

- F_{cr}: is critical load.
- E: is the elastic modulus of material (alloy steel E=210000 MPa).
- $I_{(G, Z)}$: is the moment of inertia.
- L: is maximum buckling length.
- C: is piston stroke.

- K: is column effective length factor.
- d: is rod diameter.

$$I_{(G,Z)} = \frac{\pi \times d^2}{64} = \frac{\pi \times 30^4}{64} = 39760.782\ mm^4$$

$$C = \lambda_{max} - \lambda_{min} = 800 - 500 = 300\ mm$$

If we suppose that, the column effective length factor is 2 due to the type of mounting use [12]:

$$L = C \times K = 300 \times 2 = 600\ mm$$

$$L_{max} = \sqrt{\frac{\pi^2 \times 210000 \times 39760.782}{13381.625}} = 2481.604\ mm$$

$$L_{max} \geq L$$

Therefore, the buckling resistance of the cylinder rod has been verified. This indicates that the cylinder rod has been assessed and found to be capable of withstanding compressive forces without buckling.

II.4.5. Normal force, shear force, and bending moment :

Applied load (P_G) = 5000 N

Force (F) = m×g

Weight (w) = F/g =5000/9.81= 509.683 ≈ 510 Kg

In the scissor link, due to the applied force, the normal force occurs in the longitudinal direction of the link, and the shear force is perpendicular to the normal force. [1]

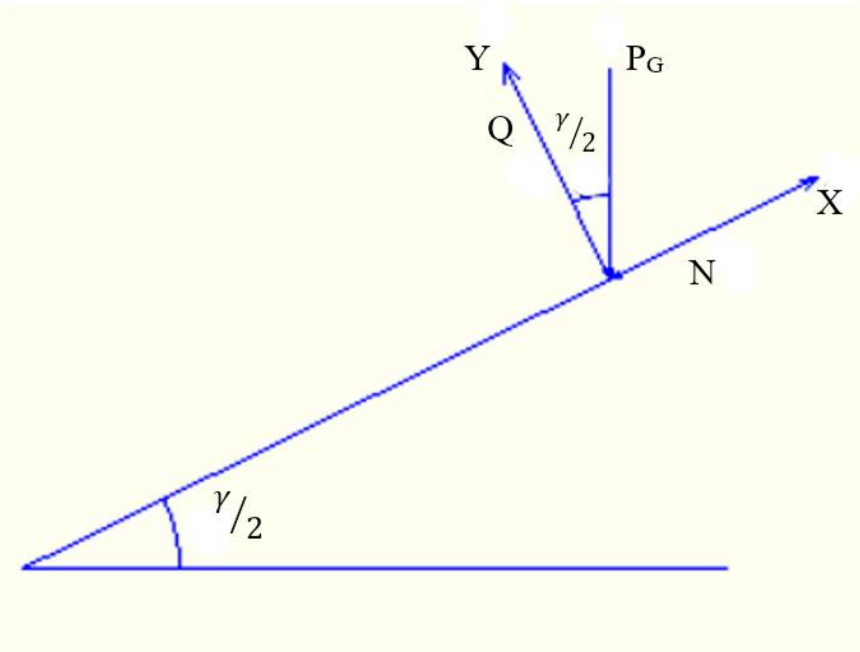


Figure II.13 Free-body diagram

Angle γ (°)	$N = \frac{P_G}{4}\sin\frac{\gamma}{2}$ **N**	$Q = \frac{P_G}{4}\cos\frac{\gamma}{2}$ **N**	$M = \frac{P_G}{4}\times\frac{l}{2}\times\cos\frac{\gamma}{2}$ **N m**
56.251	589.255	1102.396	486111
65.812	679.077	1049.453	440.541
75.522	765.461	988.215	390.627
85.618	849.445	917.028	336.376
96.379	931.692	833.336	277.779
108.209	1012.609	732.885	214.848
121.855	1092.506	607.394	147.571

Table II.4 Normal force, shear force and bending moment

Table II.4 shows, as the platform evaluates the normal force increases slightly due to the scissor arms creating horizontal forces that the links need to support the weight. On the other hand, the shear force and bending moment decrease because the load on the platform is evenly divided across the scissor arms.

II.4.6. Normal stress due to normal force and bending:

We calculate the scissor lift link's normal stress values due to normal force and bending.

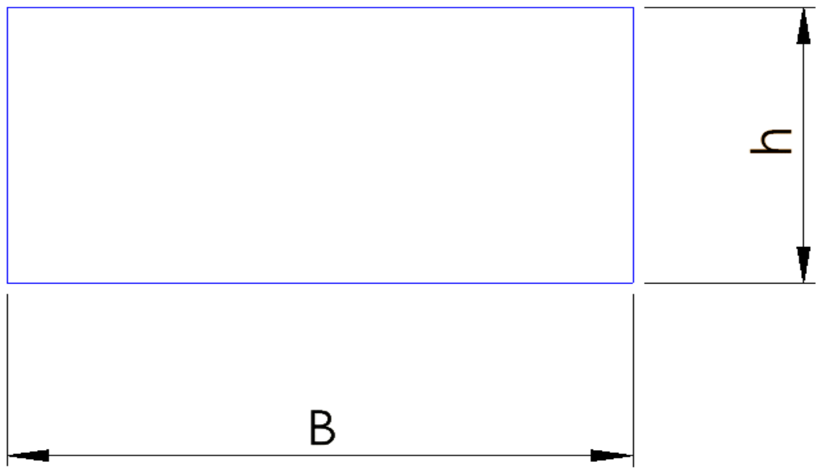


Figure II.14 Cross section of the link

Width, B =50 mm

Height, h =25 mm

Applied load, P_G=5000 N

Normal stress due to normal force, $\boldsymbol{\sigma}\ (\mathbf{N}) = \frac{\mathbf{N}}{\mathbf{A}}$

Where:

- σ: is the normal stress.
- F: is the axial force.
- A: is the cross-sectional area.

Normal stress due to bending, $\boldsymbol{\sigma}\ (\boldsymbol{M}) = \frac{\mathbf{M}}{\boldsymbol{W_x}}$

$$\boldsymbol{W_x} = \frac{\boldsymbol{I_x}}{\boldsymbol{Y_{max}}} \quad \text{And} \quad \boldsymbol{I_x} = \frac{\boldsymbol{Bh^3}}{\mathbf{12}}$$

Where:

- M: is the bending moment.
- I_x: is the moment of inertia.
- Ymax: is the distance from the neutral axis to the outermost fiber (Ymax = h/2).

Angle γ (°)	$\sigma\,(N) = \frac{N}{A}$ **MPa**	$\sigma\,(M) = \frac{M}{W_x}$ **MPa**	$\sum \in_x = \sigma\,(N) + \sigma\,(M)$ **MPa**
56.251	0.471	93.333	93.804
65.812	0.543	84.583	85.126
75.522	0.612	75	75.612
85.618	0.679	64.584	65.263
96.379	0.745	53.333	54.078
108.209	0.810	41.250	42.06
121.855	0.874	28.333	29.207

Table II.5 Normal and bending stress

Allowable Stress = Yield Strength / Factor of Safety [11]. If we suppose that the factor of safety is equal to 1.5 and the yield strength of alloy steel is 620.422 MPa, the allowable Stress will be:

σ_{all}= 620.422/1.5= 413.614 MPa

$\sum \in_x \leq \sigma_{all}$ (Condition is accepted. The design is safe). [1]

II.5. Conclusion :

This chapter has explored the main components of hydraulic lift, different types of hydraulic cylinders and their position. Then, we determine the important information such as the platform height, cylinder force, and the reaction forces of each joint using the cylinder mounting position and the equations obtained from the static study. Furthermore, we verify the safety of the lift by calculating the normal and bending stress and the results show that the design is safe.

CHAPTER III:

Simulation of a double-layer scissor lift

III.1. Introduction:

Simulation is a powerful tool that allows us to create a virtual model to illustrate and validate the proposed solutions for the initial design of an object that does not have a real existence. This process considers factors such as the model's dimensions, material properties, boundary condition loadings, and the presentation of the results.

Thus, we design a 3D model of a double-layer scissor lift consisting of two cylinders using SolidWorks software and run a simulation using the same program to evaluate the performance of the double-layer scissor lift.

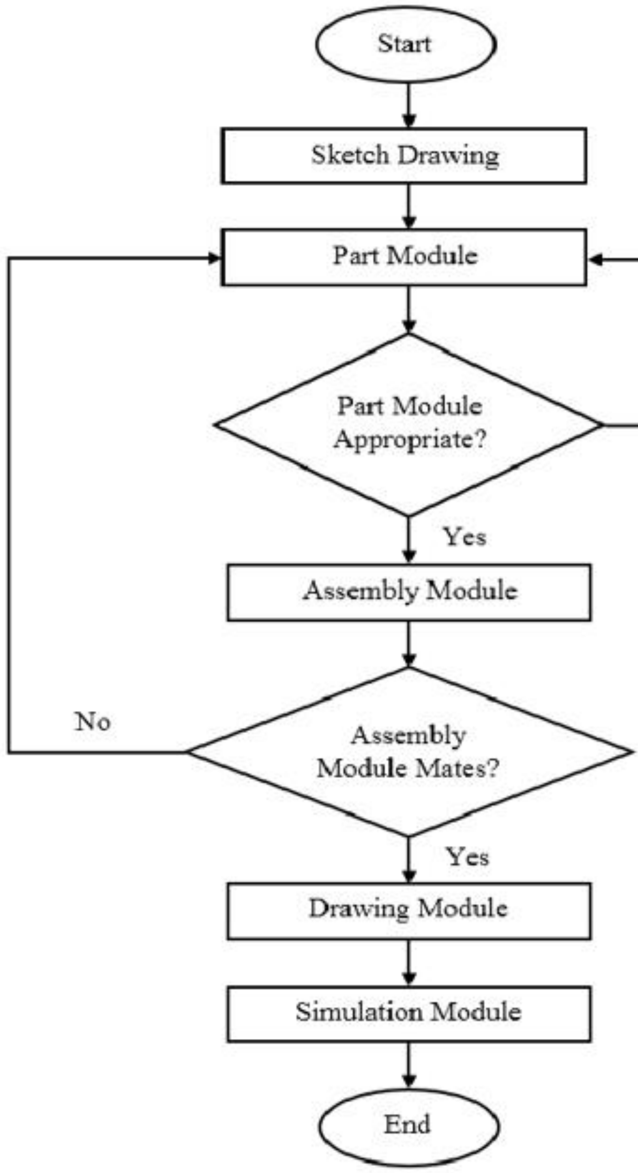


Figure III.1 Simulation cycle

III.2. Specifications:

The model specifications are as follows:

1. Maximum Lifting height = 1.748 m.
2. Maximum Loading capacity = 510 kg (5000 N).
3. Minimum Lifting height = 0.942 m.

III.3. Material selection:

One of the most important factors in simulating a model is material selection. thus, we select alloy steel based on:

- Strength and lifting capacity: alloy steel’s high tensile strength enables the safe operation of the lift with high lifting capacities.
- Weight optimization: alloy steel's lighter weight optimizes lifting capacity.
- Safety and durability: alloy steel’s strength ensures safe operation and minimizes maintenance for long-lasting scissor lift performance.

III.4. Modeling and assembly:

The utilization of SolidWorks software is essential for 3D modeling. It enables us to design and create different parts including complex geometries and mechanisms, it also facilitates the assembly of each part, allowing us to model how different components interact with each other to achieve the desired final product model.

As a result, the 3D model of each part and assembly of the double-layer scissor lift is as follows:

1. **Top platform:**

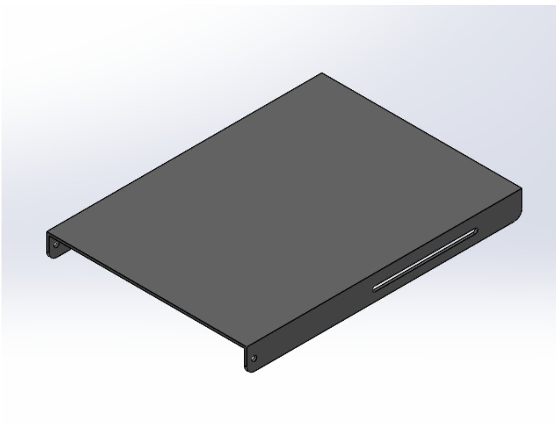


Figure III.2 Top platform

2. **Base platform:**

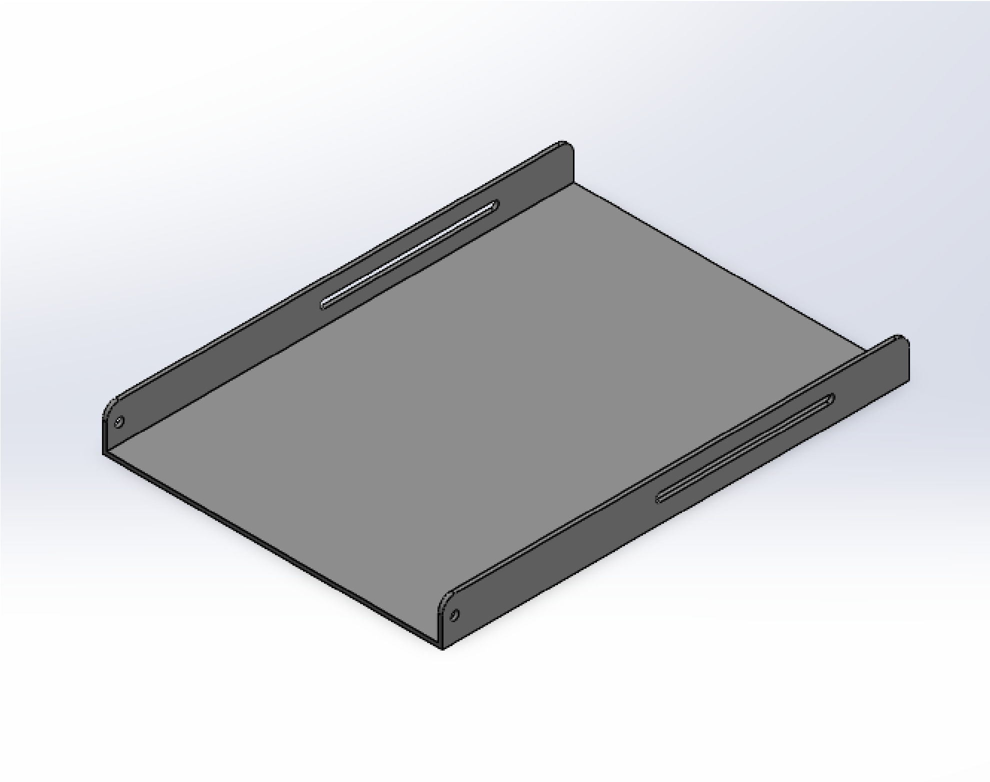


Figure III.3 Base platform

3. **Scissor arm:**

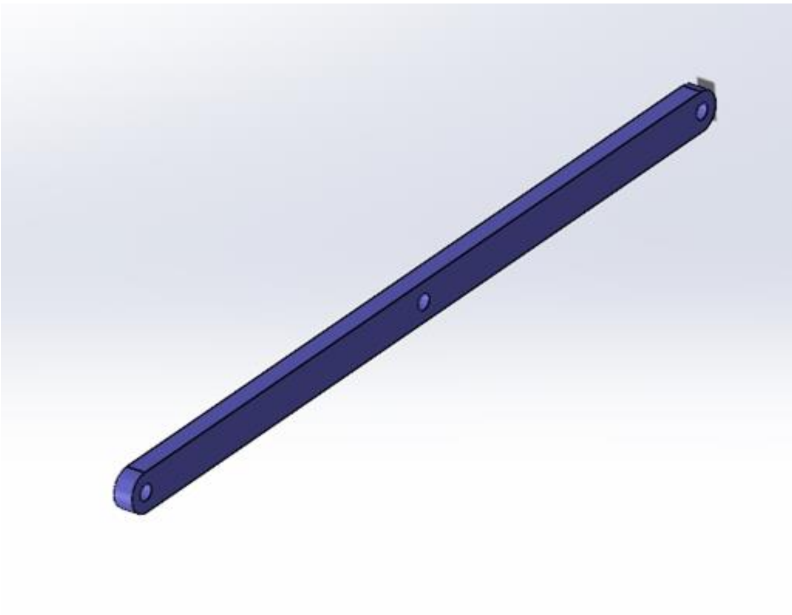


Figure III.4 Scissor arm

4. **Pin:**

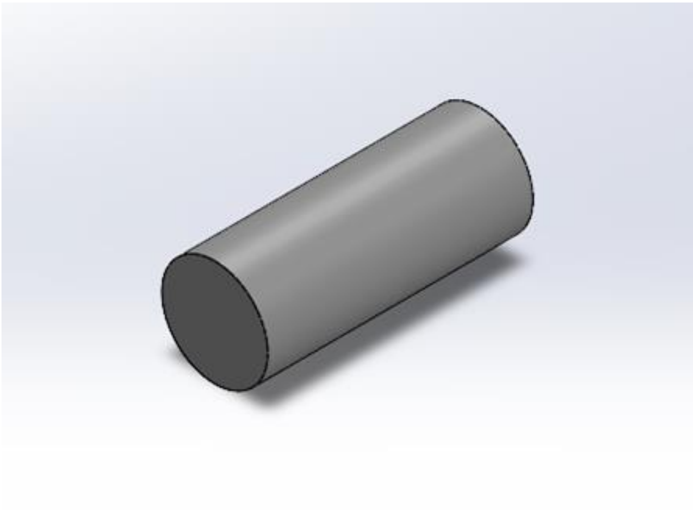


Figure III.5 Pin

5. **Hydraulic cylinder:**

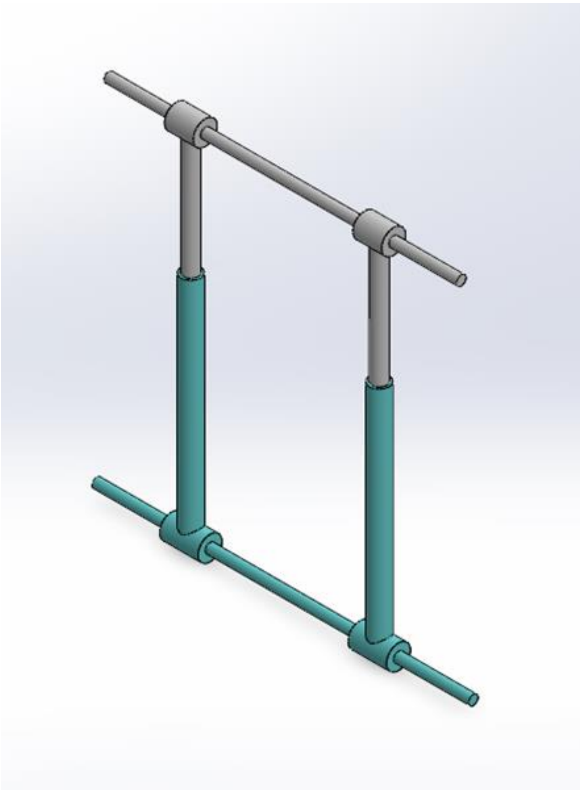


Figure III.6 Hydraulic cylinder

6. Shaft:

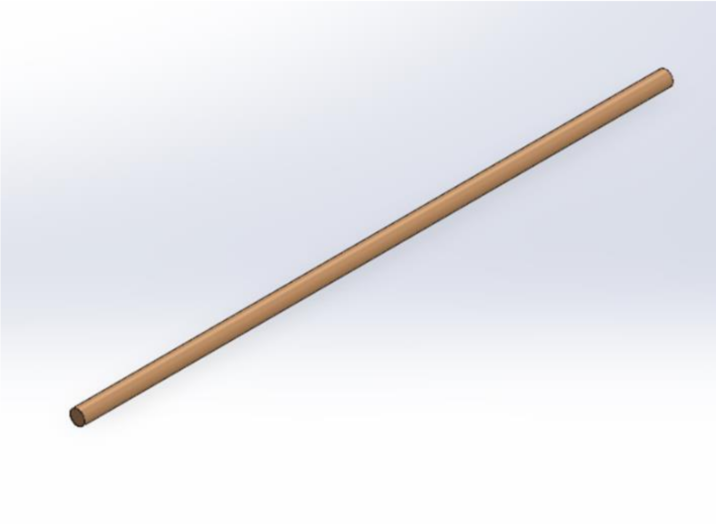


Figure III.7 Shaft

7. Assembly:

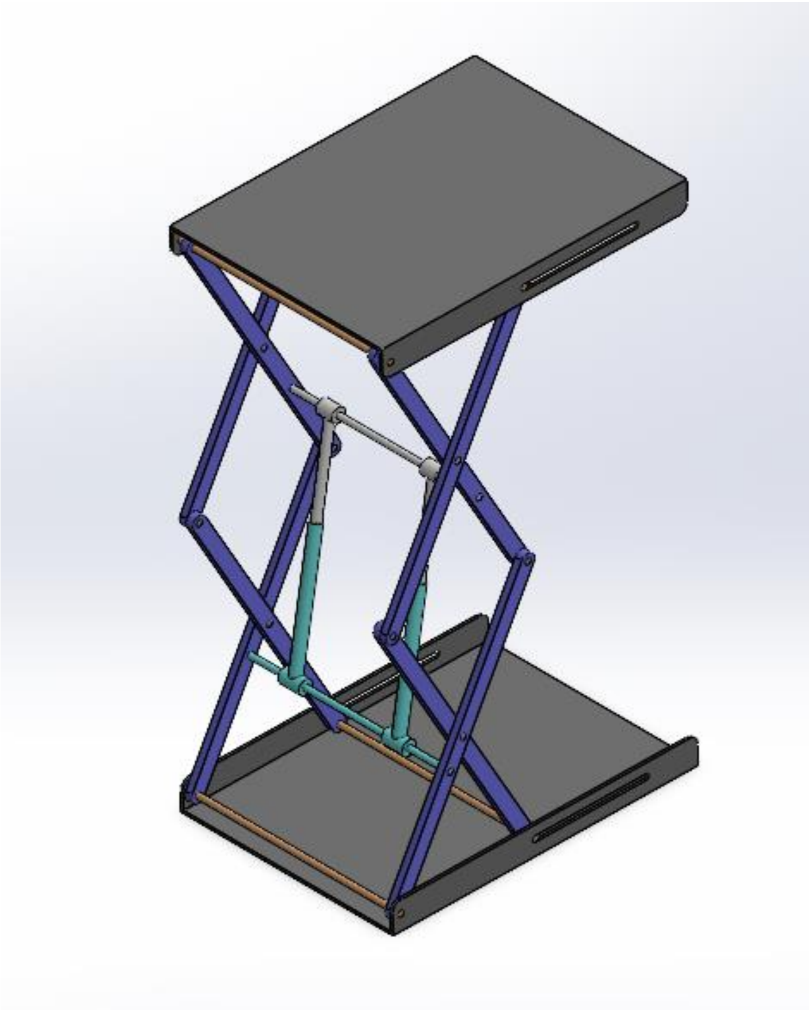


Figure III.8 Assembly of double-layer scissor lift

III.5. Working principle:

The hydraulic scissor lift is operated using the pressurized hydraulic fluid that raises the platform due to the outward movement of the piston in the cylinder forcing the scissor arm apart, and by releasing the hydraulic fluid out of the hydraulic cylinder through pressure releasing valve, it lowers the platform due to the inward movement of the piston that close the scissor arms.

III.6. Simulation procedure:

After completing the design process in SolidWorks, we conduct a simulation using solidworks software to evaluate the model's performance and behavior under the load of 5000N. Through this simulation, we obtain the result of stress, displacement, strain and factor of safety.

III.6.1. Analysis details:

Name	Static
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

Table III.1 Analysis details

III.6.2. Material properties:

Material	Alloy Steel
Model type	Linear Elastic Isotropic
Yield strength (N/m^2)	6.20422e+08
Tensile strength (N/m^2)	7.23826e+08
Elastic modulus (N/m^2)	2.1e+11
Poisson's ratio	0.28
Mass density (kg/m^3)	7,700
Shear modulus (N/m^2)	7.9e+10
Thermal expansion coefficient (Kelvin)	1.3e-05

Table III.2 Material properties

III.6.3. Simulation conditions:

III.6.3.1. Top platform:

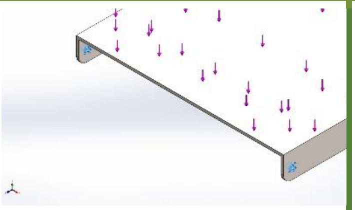
Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	2 face(s) Fixed Geometry

Table III.3 Fixation

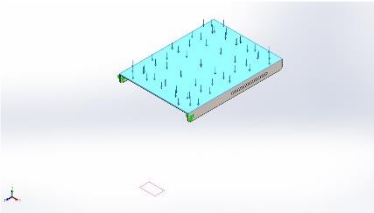
Load name	Load Image	Load Details	
Force-1		**Entities:** **Type:** **Value:**	1 face(s), 1 plane(s) Apply normal force 5,000 N

Table III.4 Applied load

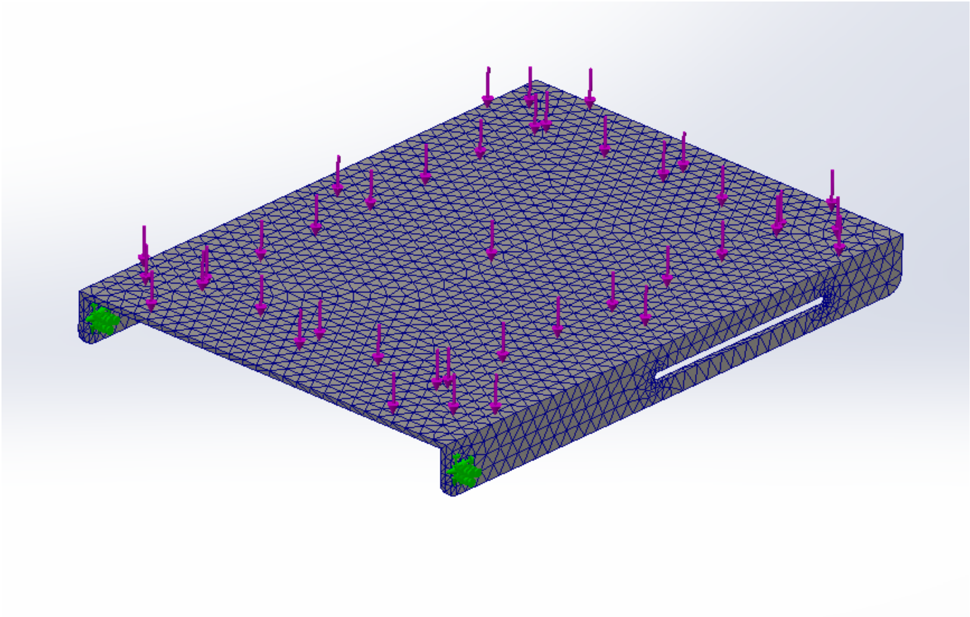


Figure III.9 Mesh structure of top platform

III.6.3.2. Scissor lift mechanism:

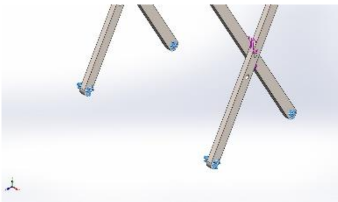
Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	4 face(s) Fixed Geometry

Table III.5 Fixation

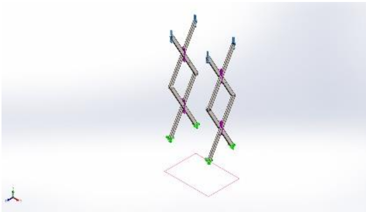
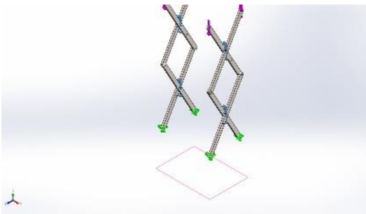
Load name	Load Image	Load Details	
Force-1		**Entities:** **Reference:** **Type:** **Values:**	4 face(s), 1 plane(s) Top Plane Apply force ---, ---, -1,250 N
Force-2		**Entities:** **Reference:** **Type:** **Values:**	4 face(s), 1 plane(s) Top Plane Apply force ---, ---, -75 N

Table III.6 Applied load

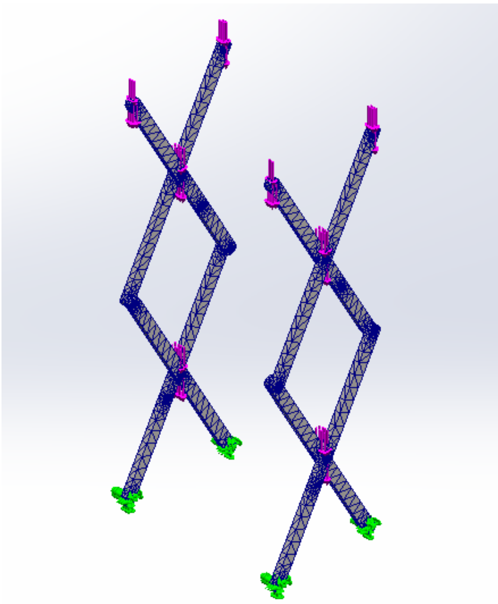


Figure III.10 Mesh structure of scissor lift mechanism

III.6.3.3. Assembly of the double-layer scissor lift:

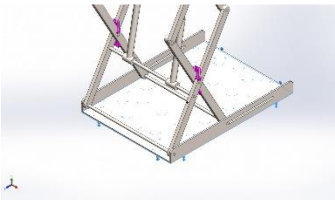
Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	1 face(s) Fixed Geometry

Table III.7 Fixation

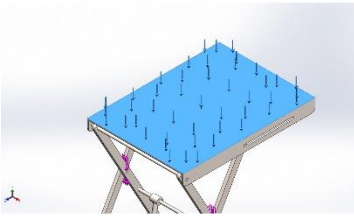
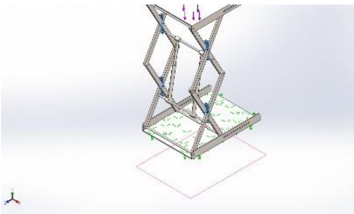
Load name	Load Image	Load Details	
Force-1		**Entities:** **Type:** **Value:**	1 face(s) Apply normal force 5,000 N
Force-2		**Entities:** **Reference:** **Type:** **Values:**	4 face(s), 1 plane(s) Top Plane Apply force ---, ---, -75 N

Table III.8 Applied load

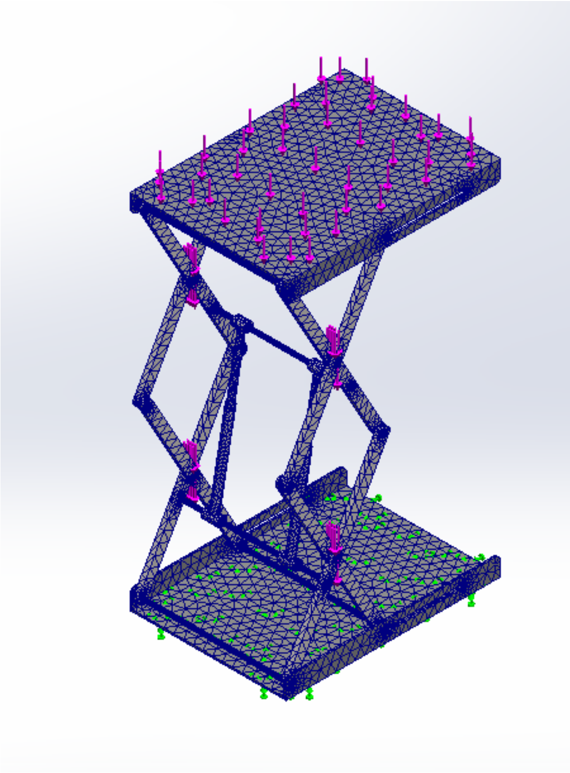


Figure III.11 Mesh structure of assembly

III.6.4. Results and discussion:

After completing the simulation, we obtain the following results:

III.6.4.1. Top platform:

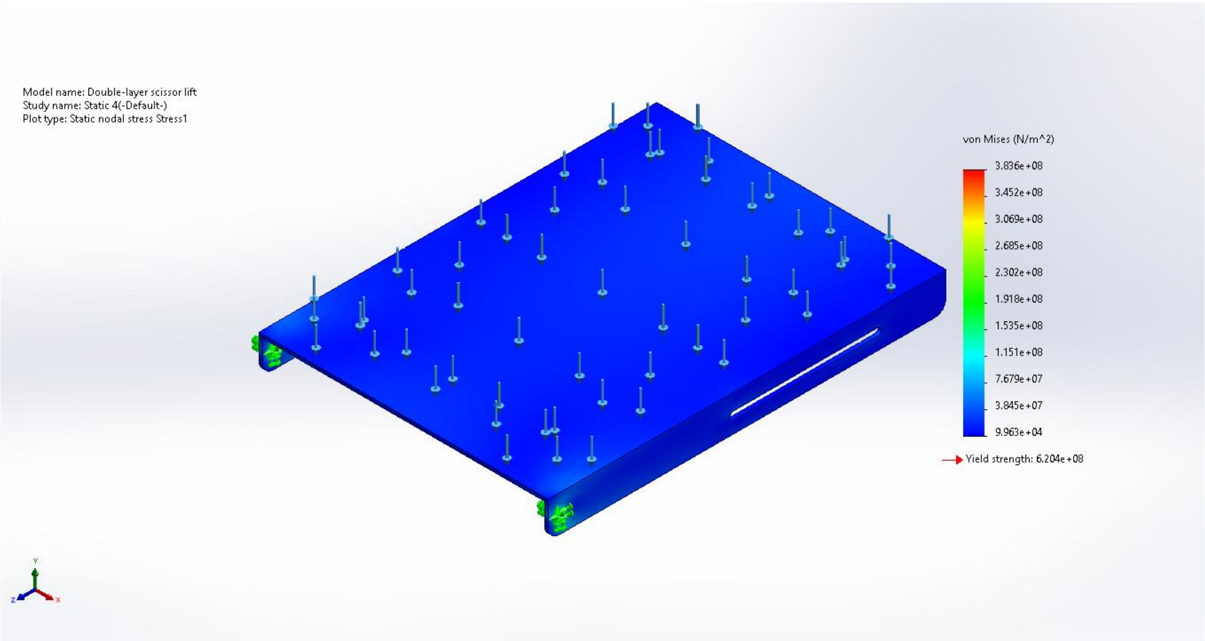


Figure III.12 Von Mises stress

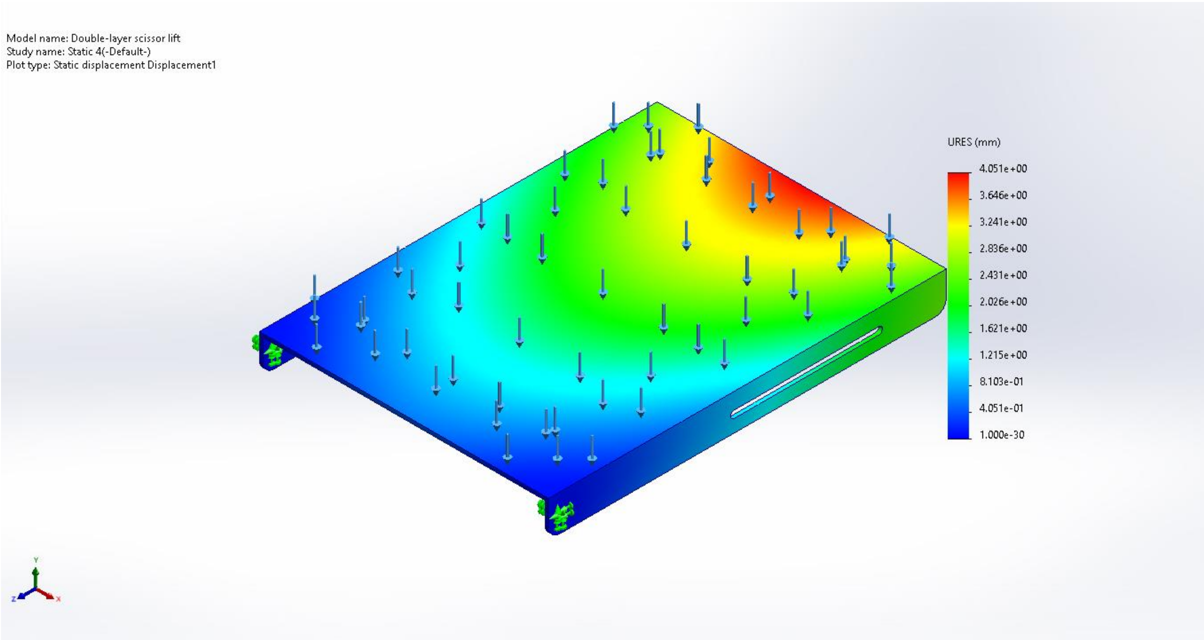


Figure III.13 Displacement

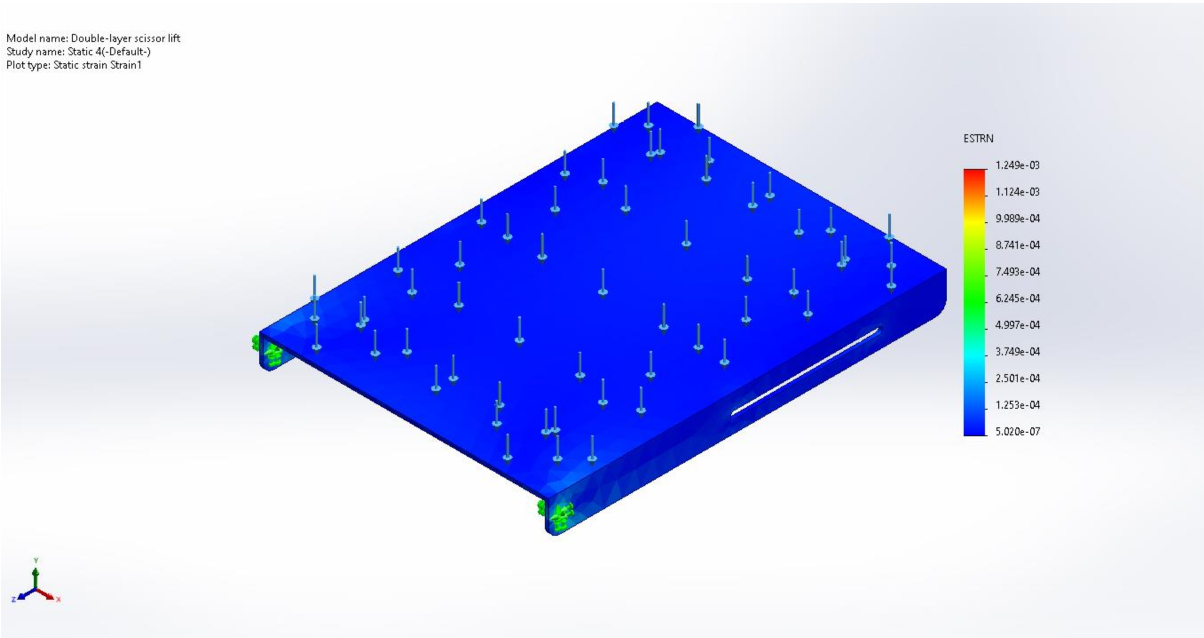


Figure III.14 Equivalent strain

III.6.4.2. Scissor lift mechanism:

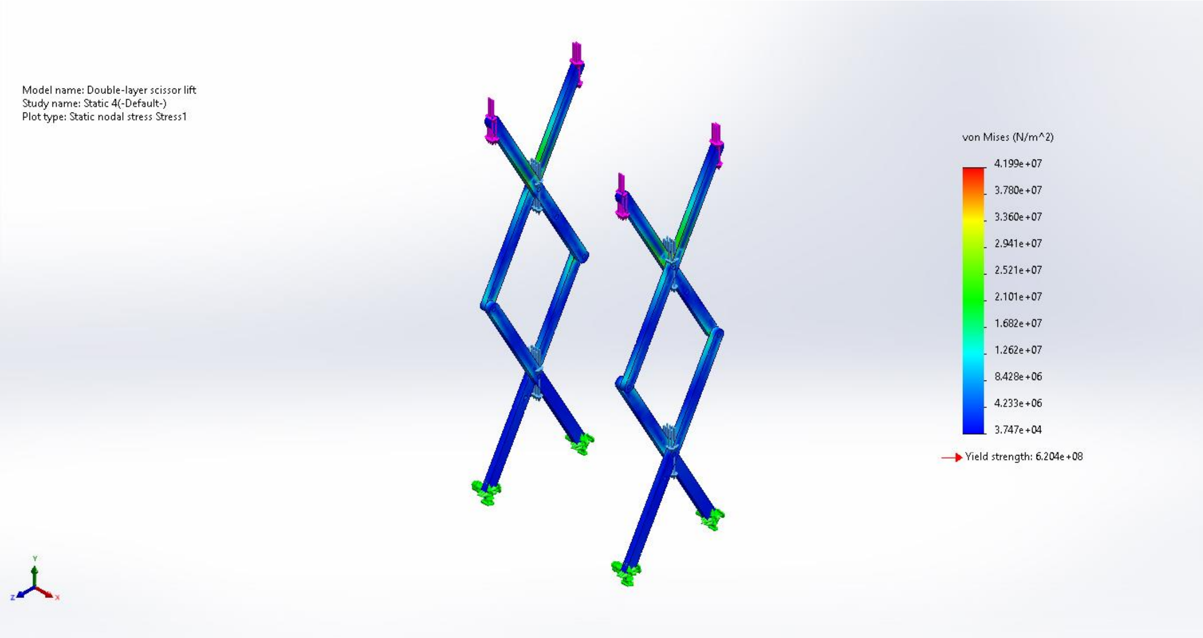


Figure III.15 Von Mises stress

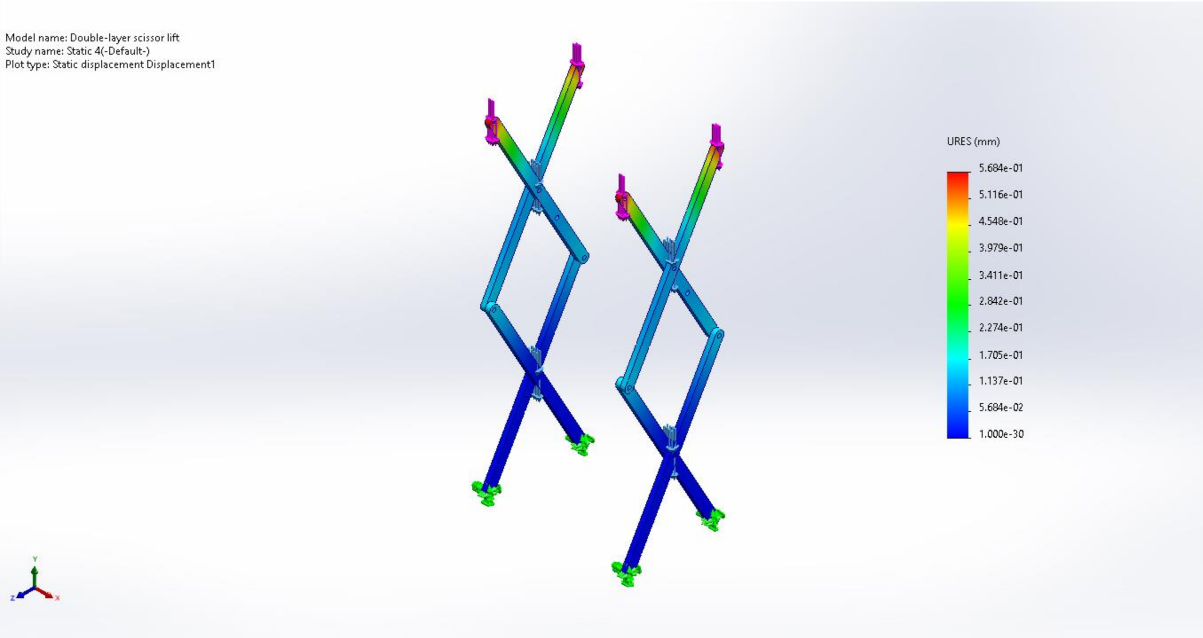


Figure III.16 Displacement

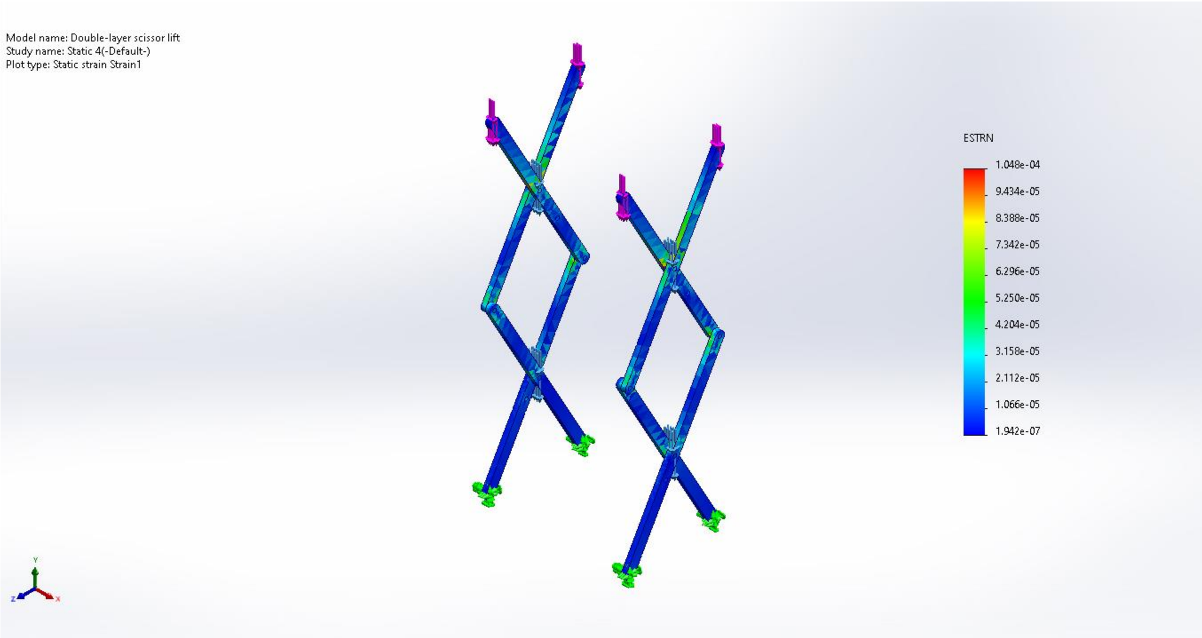


Figure III.15 Equivalent strain

III.6.4.3. Assembly of double-layer scissor lift:

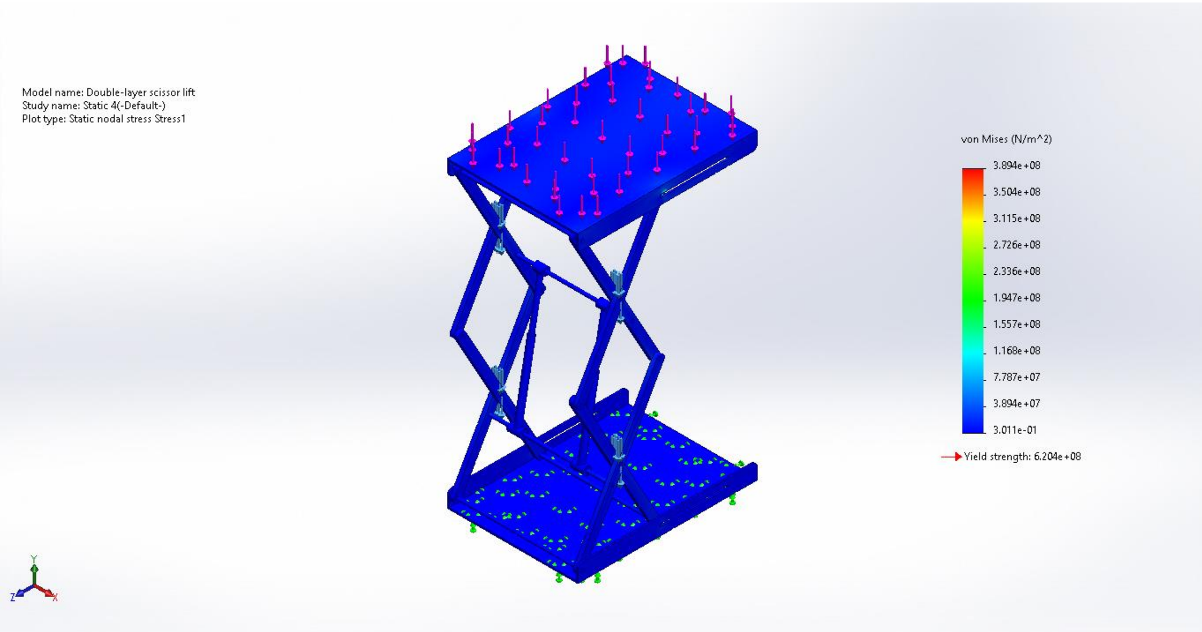


Figure III.18 Von Mises stress

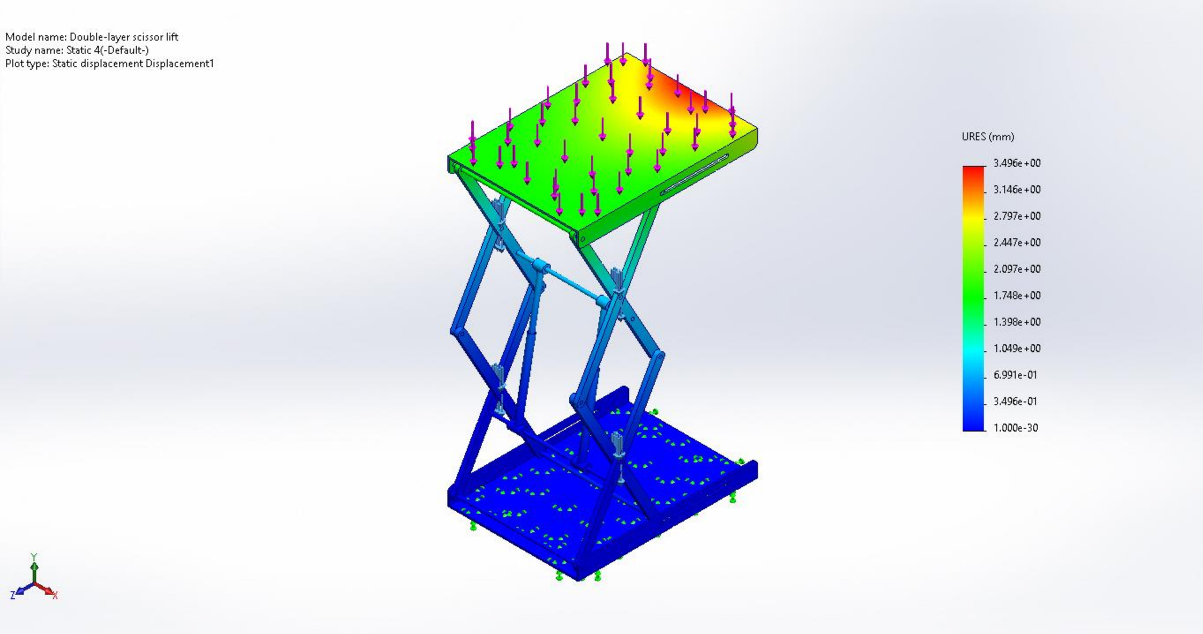


Figure III.19 Displacement

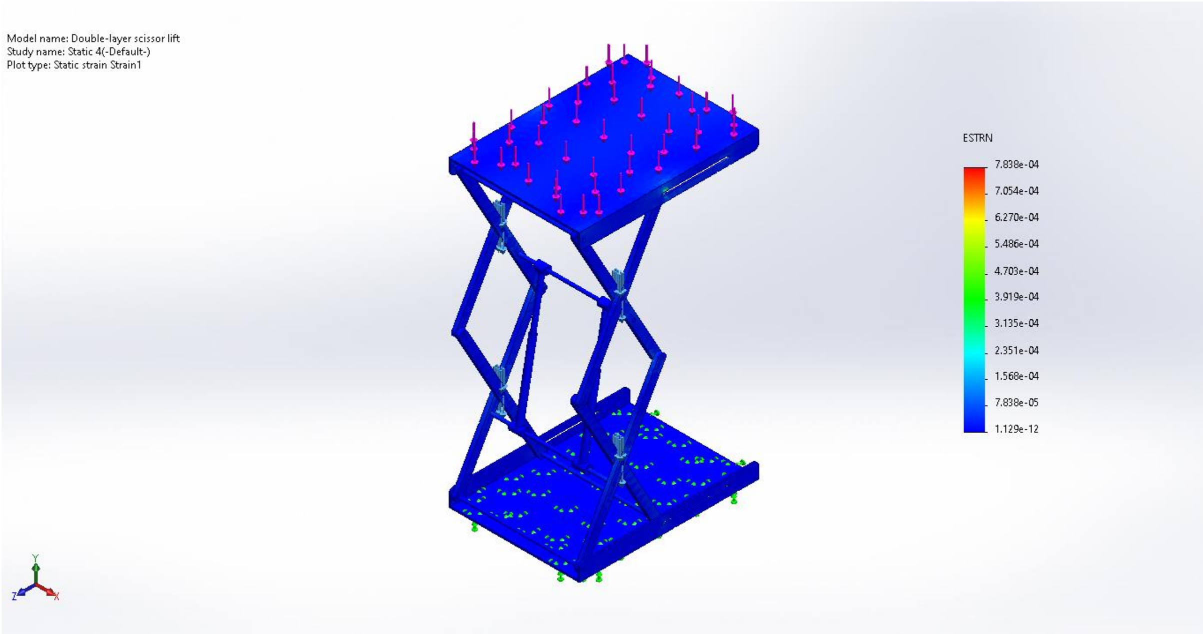


Figure III.20 Equivalent strain

III.6.4.4. Discussion:

	Von Mises Stress (N/m^2)		Displacement (mm)		Equivalent Strain (mm)	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Top platform	$9.963e^{+4}$	$3.836e^{+8}$	0	4.051	$5.020e^{-7}$	$1.249e^{-3}$
Scissor lift mechanism	$3.747e^{+4}$	$4.199e^{+7}$	0	$5.684e^{-1}$	$1.942e^{-7}$	$1.048e^{-4}$
Assembly	$3.011e^{-1}$	$3.894e^{+8}$	0	3.496	$1.129e^{-12}$	$7.838e^{-4}$

Table III.9 Simulation results

The results show that:

For the top platform, the value of Von Mises Stress (3.836e+8 N/m^2) is inferior to the yield strength (6.20422e+08 N/m^2), the maximum amount of displacement is 4.051mm, while the value of Equivalent Strain (1.249e-3mm) is negligible distortion. Due to this, it resists.

For the scissor lift mechanism, the value of Von Mises Stress (4.199e+7 N/m^2) is inferior to the yield strength (6.20422e+08 N/m^2), the maximum amount of displacement is 5.684e-1 mm, the value of Equivalent Strain (1.048e-4mm) is negligible distortion. Due to this, it resists.

For the assembly, the value of Von Mises Stress (3.894e+8 N/m^2) is inferior to the yield strength (6.20422e+08 N/m^2), the maximum amount of displacement is 3.496 mm, the value of Equivalent Strain (7.838e-4 mm) is negligible distortion, demonstrating a safe design that can withstand the applied load.

III.7. Conclusion:

The simulation conducted in this chapter plays an important role in determining the results of stress, displacement, strain for the top platform, scissor lift mechanism and the model. Based on the obtained results, the model is safe for lifting a load of 5000 N.

General conclusion

In conclusion, this thesis has mentioned general information about scissor lifts such as their different types according to the type of energy used (hydraulic, pneumatic, and mechanical), their function by raising and lowering the platform and their application in the industry. It also discusses the advantages and disadvantages of scissor lift.

After that, we covered the hydraulic lift, its components, the different types of hydraulic cylinders and its position. In addition, we obtained from the static study the necessary equations to determine important information such as the platform height, cylinder force, and the reaction forces of each joint. We also calculate the normal stress after applying the load of 5000 N, and the results show that the design is safe to lift the load.

Finally, we simulate a 3D model of the double-layer scissor lift using Solidworks software and the results revealed that the model is able to lift the required load (5000 N).

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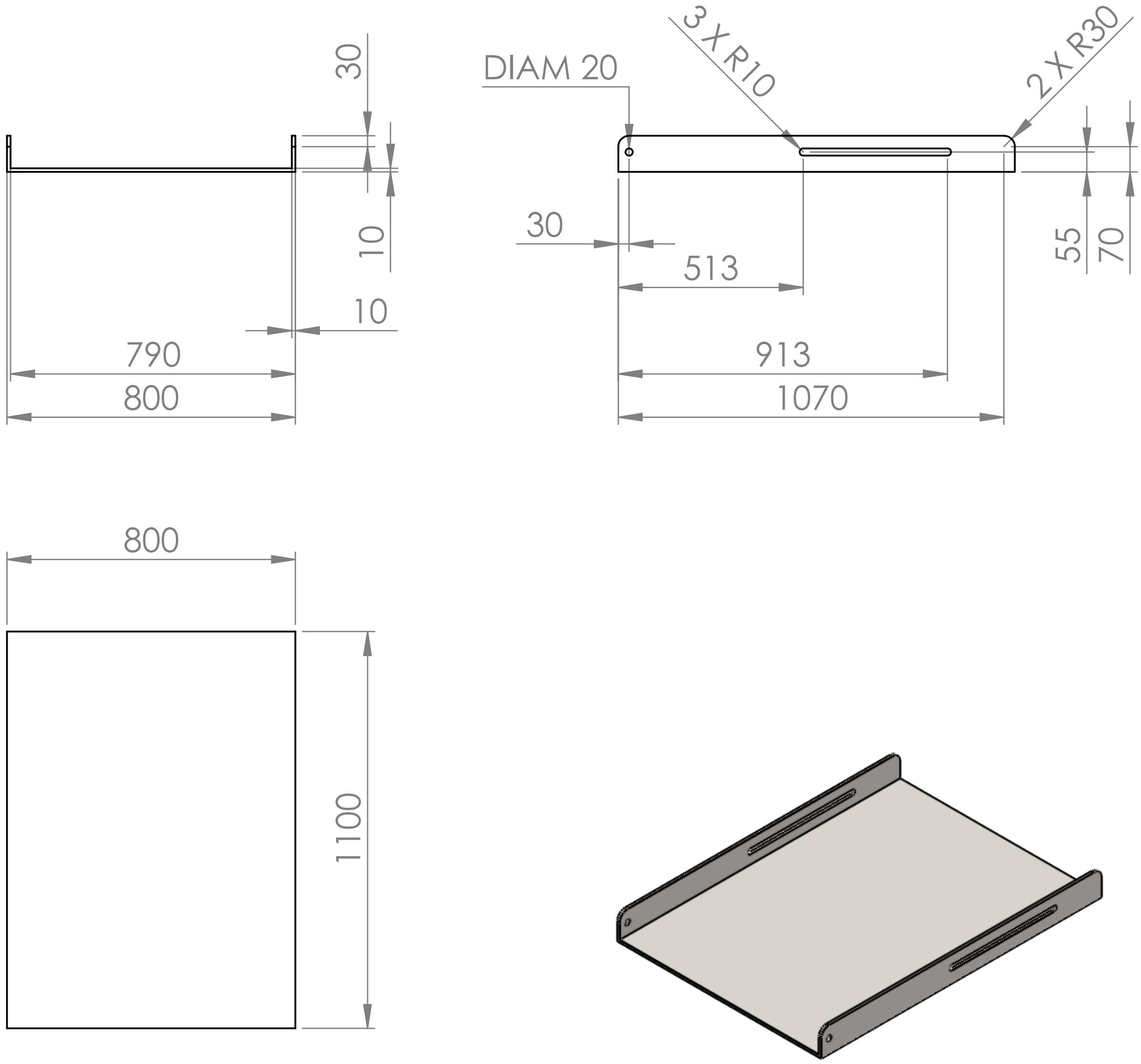
Appendix



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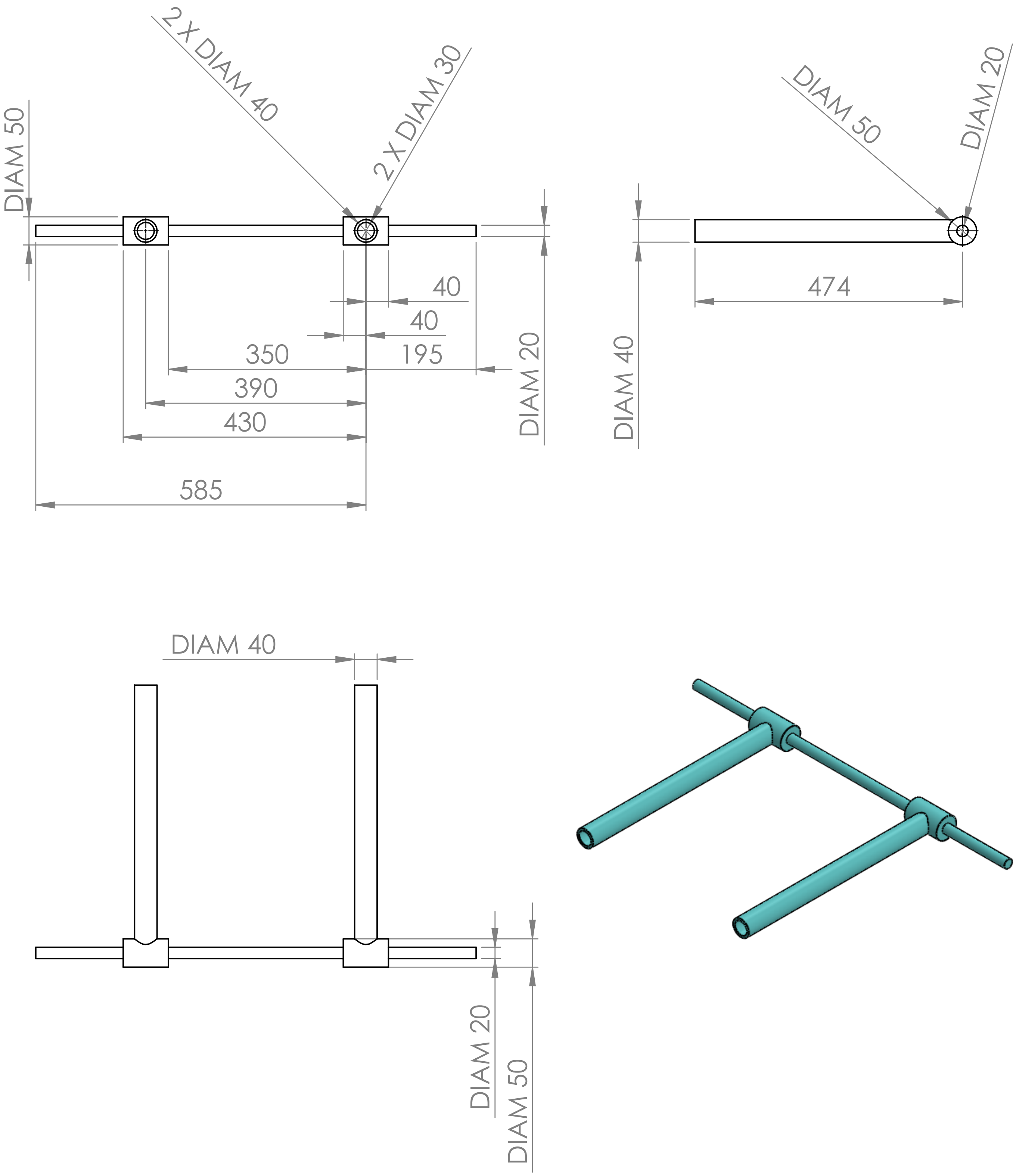

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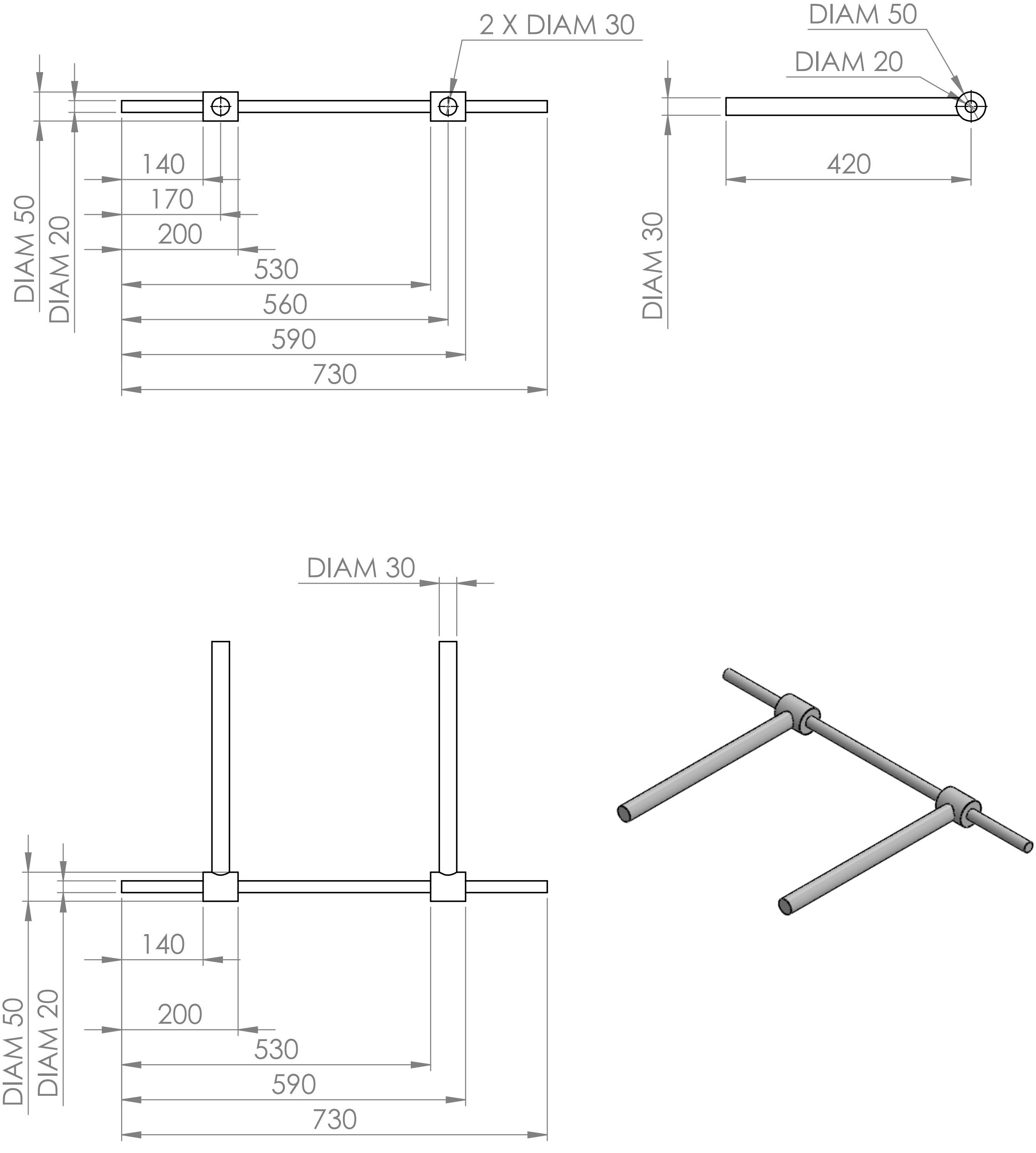

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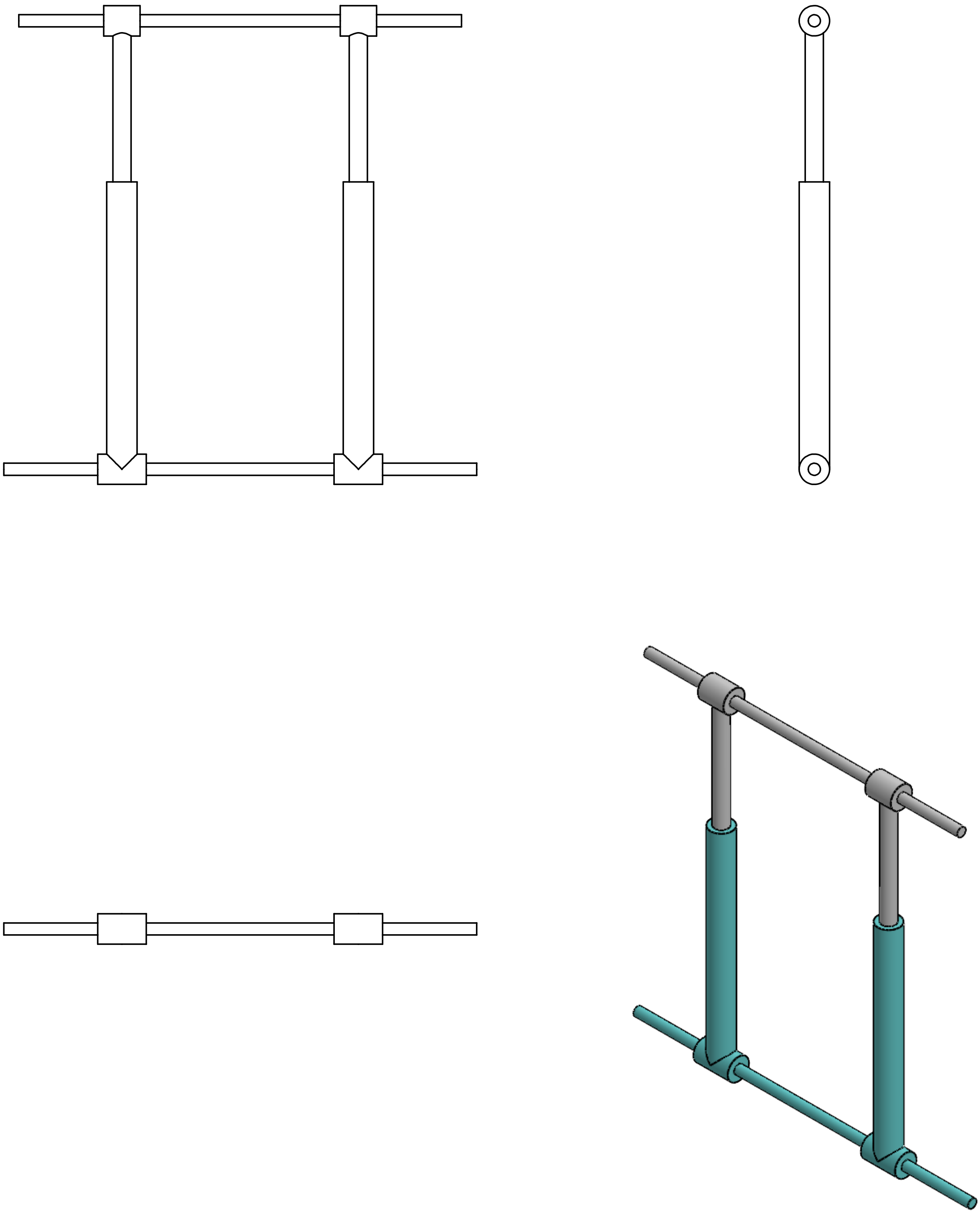

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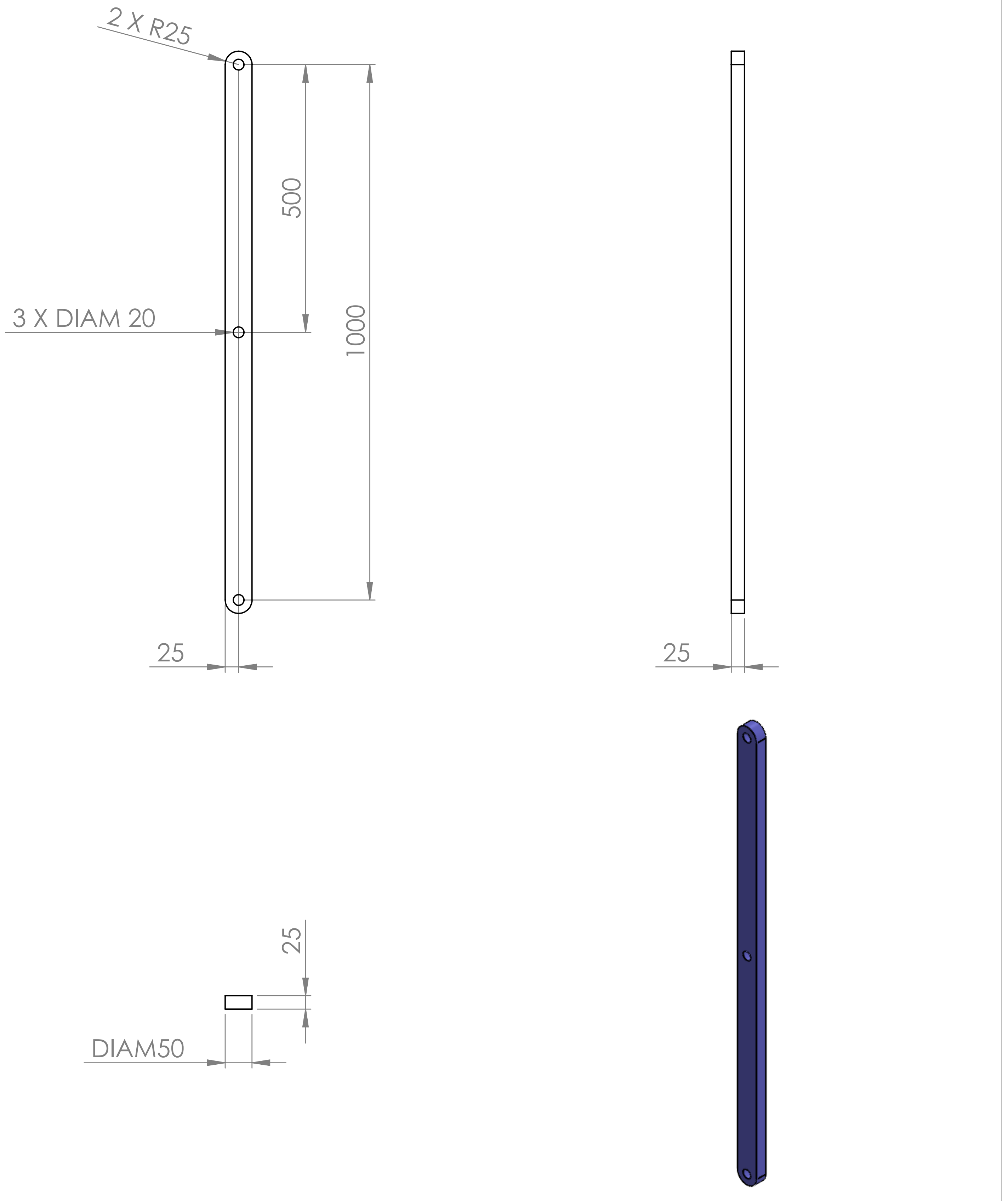

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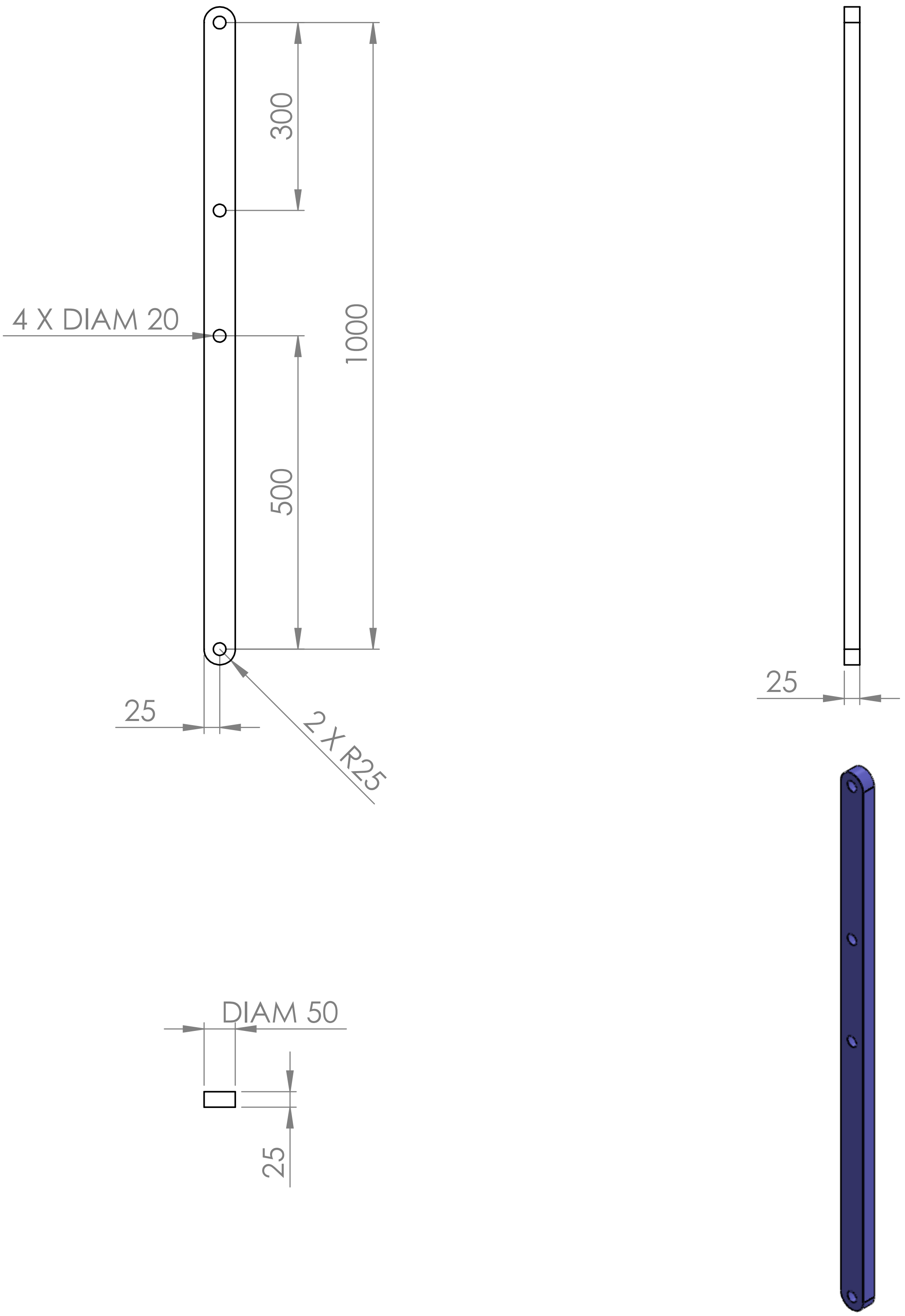

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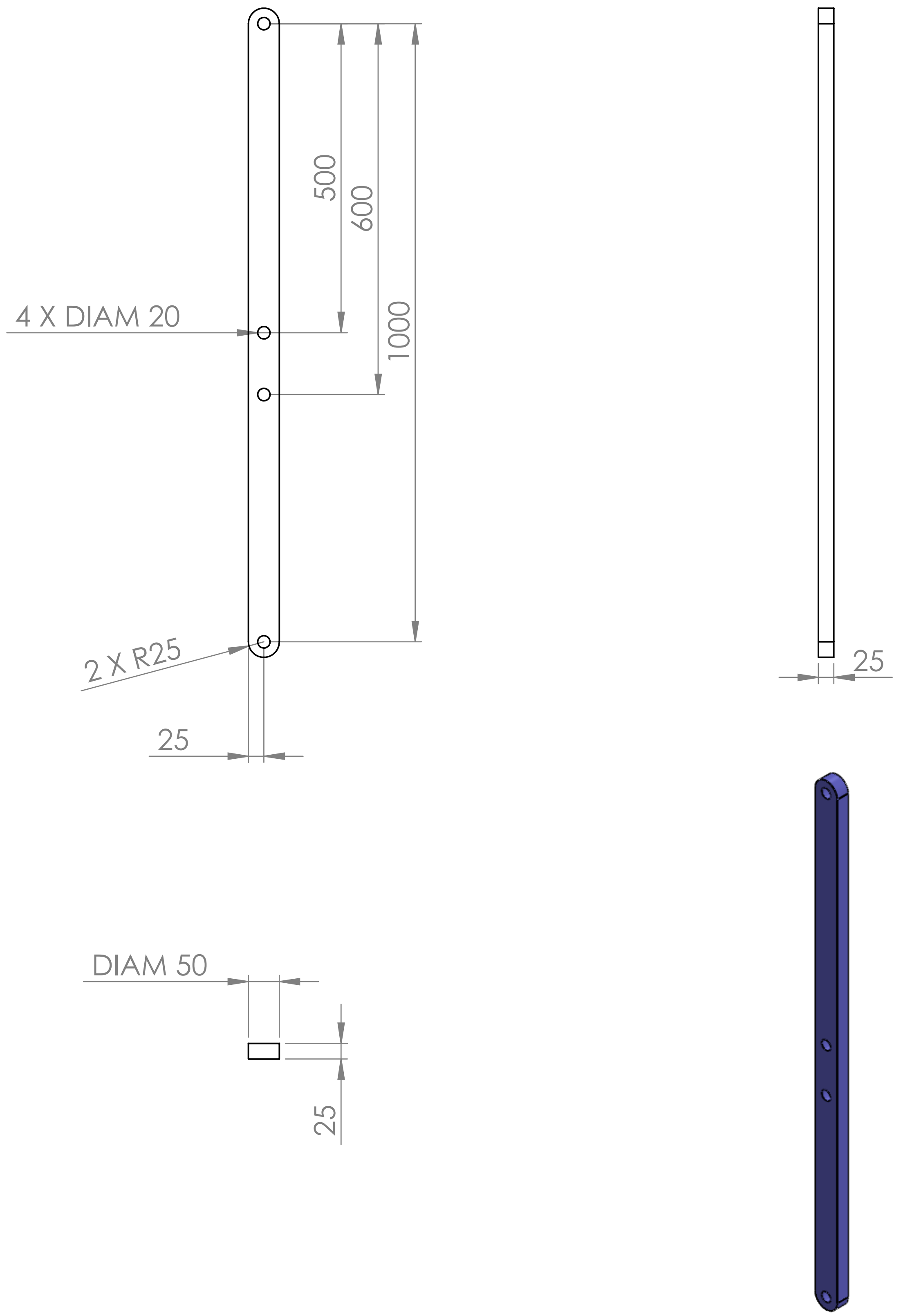

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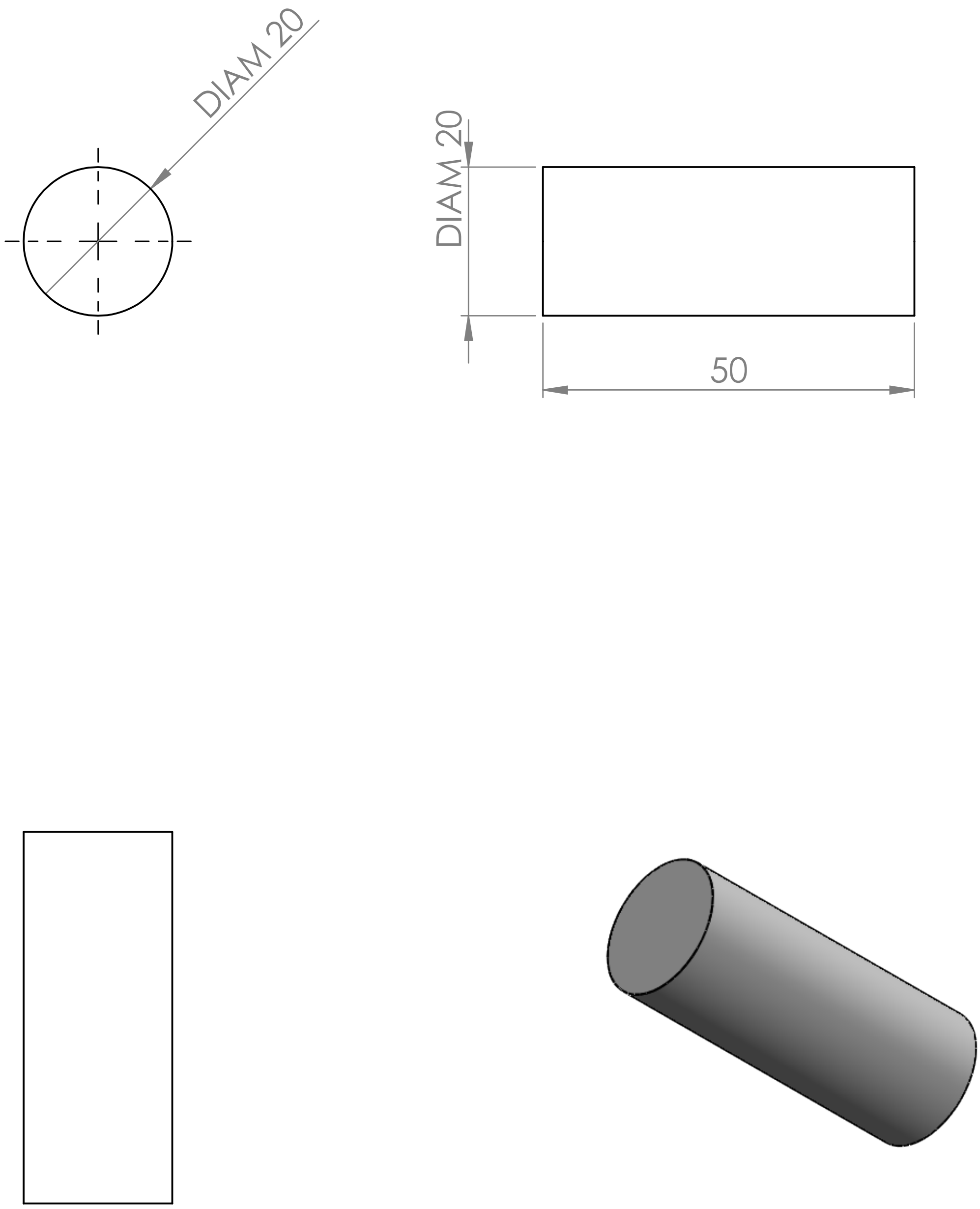

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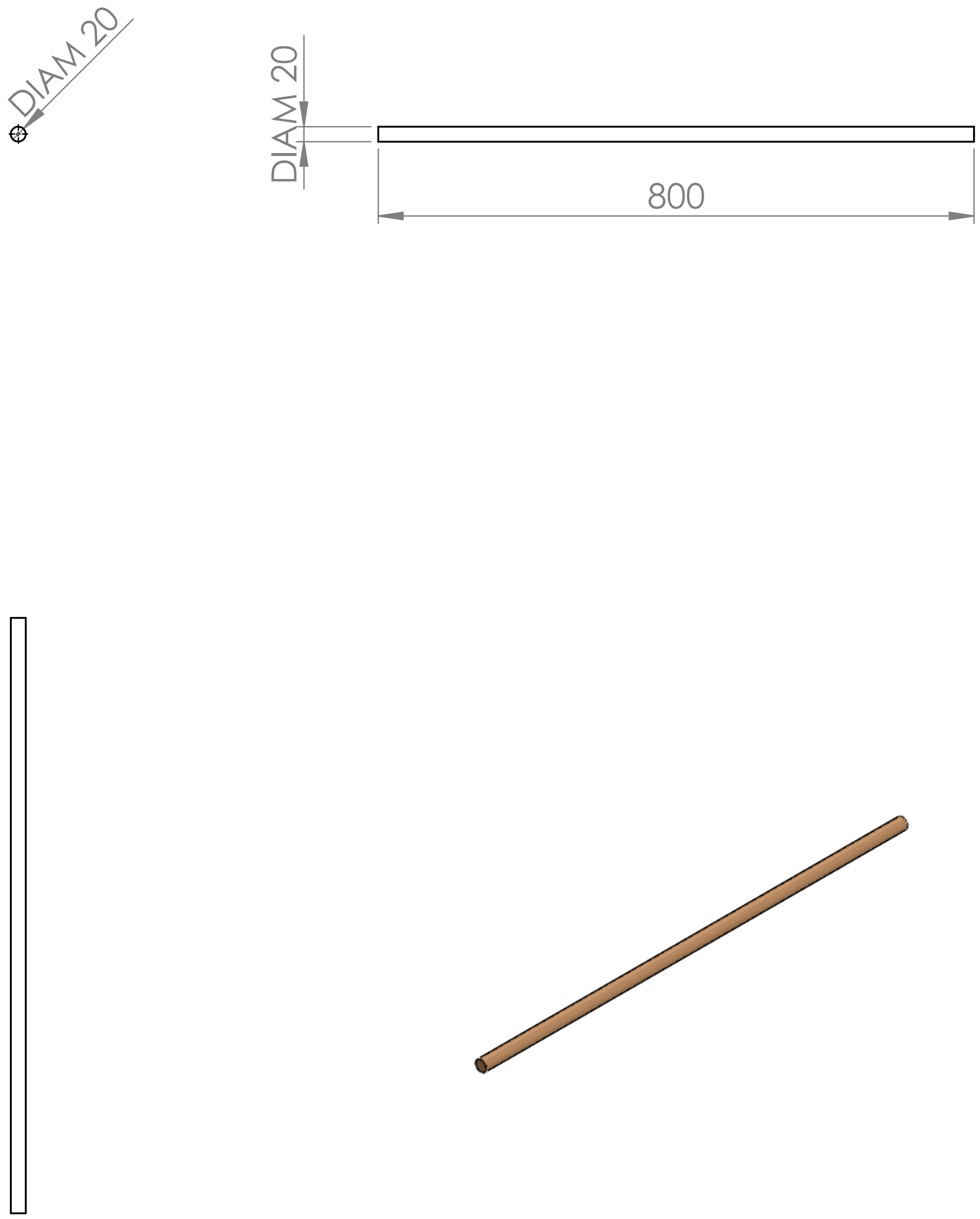

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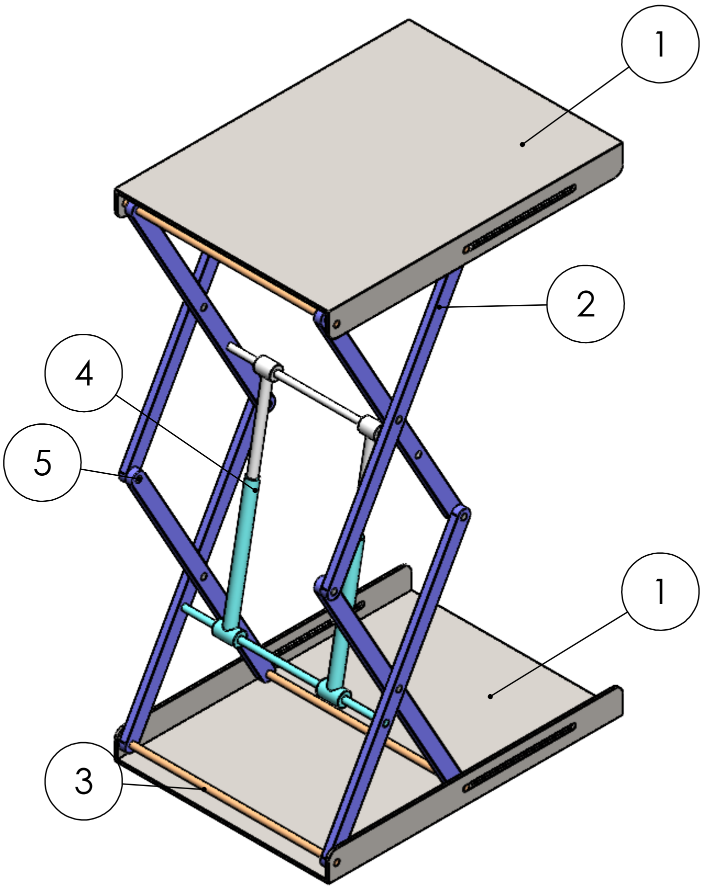

ITEM NO.	PART NUMBER	QTY.
1	Top and base platform	2
2	Scissor arm	8
3	Shaft	4
4	Hydraulic cylinder	2
5	Pin	8

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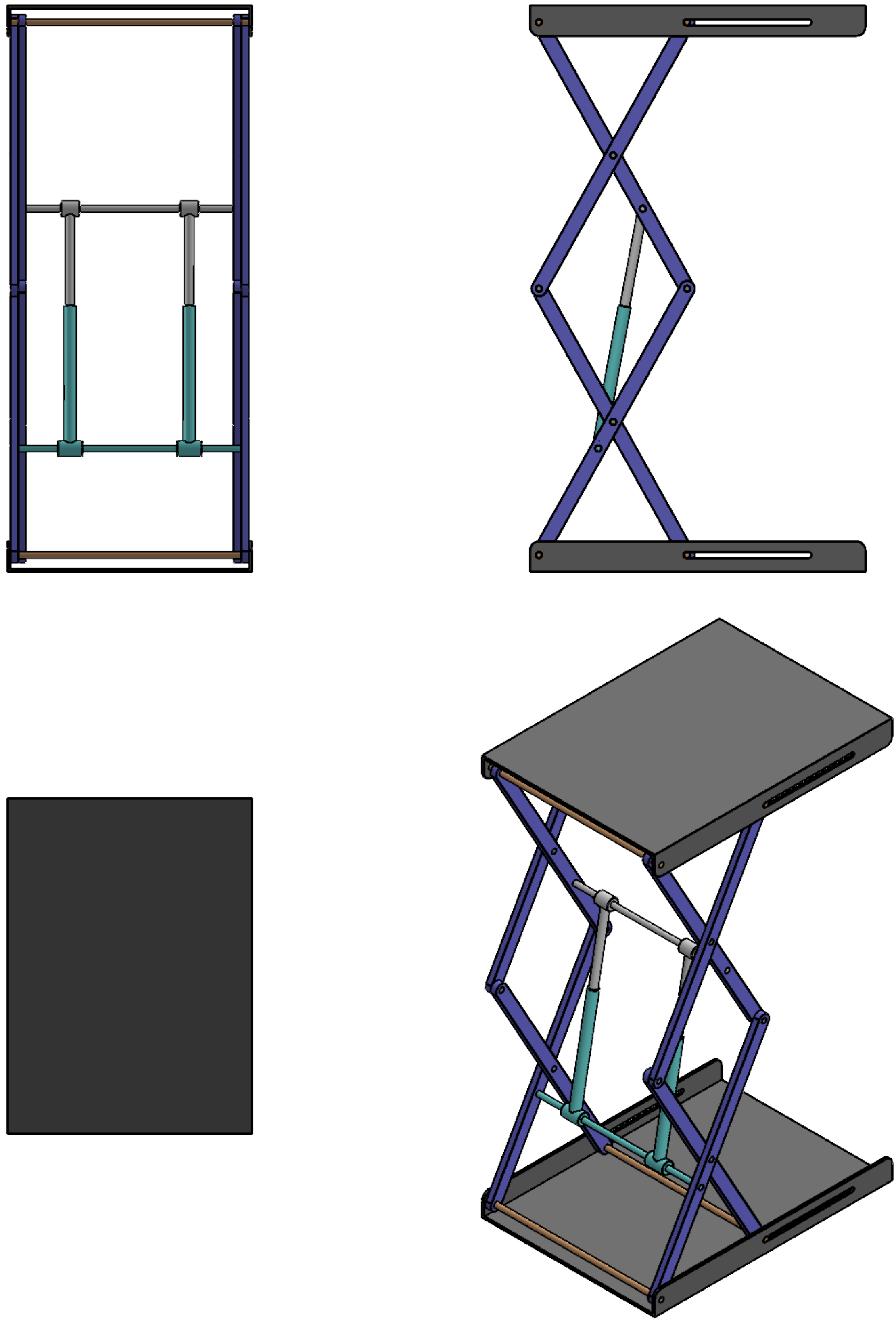

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