Design and Simulation of Multipurpose Built-In Car Lifting Mechanism

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Abstract
Cars stuck in remote places may lead to catastrophic consequences, especially with the lack of suitable tools and the lack of food or water. most of the drivers may not know how to deal with a sticking situation, especially in a place where there is no one to help. Some even pass away because the help arrives too late. All these motivate us to think about a simple mechanism which could be installed in the car which could be battery operated to get the car away from the sticking spot. The proposed mechanism will run for many purposes, but it will mainly focus on getting the car out of its stuck. The mechanism will first lift the car a reasonable distance above the sticking place and after that, the car will be moved forward or backward. The mechanism will be fitted on the lower side of the chassis of the car, which is not that room taking, and it will be operated by the same car battery, or any external DC current whenever needed. The two prime movers of the two motions in the mechanism are operated and controlled by a hydraulic system. The goal of our design is to build a mechanism that is reliable, safe, and easy to operate compared to its function. The methodology we followed was to set the components of the mechanism with the right dimensions which fits certain categories of safari cars. Second, the mobility of the proposed mechanism was calculated to come up with enough inputs to fully control the motion of the mechanism. After that the force analysis was conducted at the worst position of for the best follow up design. Because of the limited time, we used two commercial codes to conduct the stress analysis for the stress validation purpose, where the Von Miss's theory of failure is adopted. Choosing the type of weld, materials and international standards is part of the methodology as well. As the project is still in progress, we are planning to manufacture a full-scale model and conduct some practical tests and hoping the success of the proposed mechanism to we can benefit our community and the international society as well.

Keywords
Lifting, Multi-Purpose, Mechanism, Built-in, Car-Battery-Operated.

1. Introduction
Since the introduction of cars companies tried their best to make their vehicles as safe as possible, from the introduction of seatbelts, airbags, and other essential safety systems, companies were inventing something new with every generation that could save the lives of people on the road, however, when it comes to the accidents that may happen off the road, there is not a lot of attention to said problem. Off-road accidents may vary, rollovers, crash, or even getting stuck in a difficult environment such as mud, sand and snow. When a car gets stuck in difficult environments, it requires from the driver a lot of skills, strength and sometimes some external help from other vehicles or using some external tools they can help the car get out of stuck. Those tools most of the times require some space in the car or even some skills to operate said tools. However, most of the times car users do not always have the required skills or strength, furthermore, they do not have these tool available, and other people help cannot be always

in hands reach. Therefore, there should be an answer for such a problem, the main pin points of this design are to make a device that require no skills and strength from the vehicle user, does not change in the shape of the car and do not take a lot of space of the car inventory.

1.1 Objectives

The objective of the current paper is to build a multi-purpose mechanism that would lift the car and move the vehicle while it is lifted, hence the mechanism can operate on-road and off-road for emergency and/or maintenance purpose. The proposal is based on already existing mechanisms and will not alter the original design of the vehicle or affect it structural integrity. To save up space in the vehicle the mechanism will be a built-in on the lower side of the two main chassis beams near the center of gravity of the car.

2. Literature Review

In the twentieth century cars became more and more popular, hence car repairs were in demand. To do such a thing mechanics used to dig up holes in the ground to make the repairs. In 1925, the first car lift mechanism was invented by Peter lunati. It was a hydraulic mechanism that was inspired in a hydraulic barber's chair. He notices how simple and easy to lift a body using that mechanism. Since then, the mechanism has opened doors to the car lifting in the modern days. The modern car lifts were rooted into three types, stationary, portable and built-in. The stationary car lifting mechanisms has been developed in 1925 and was the first car lifting mechanism. The latest stationary car lift mechanism is the shockwave. In the field of stationary car lifts, the idea of how tough the lift is giving the motivation for engineers to develop a portable scissor lift. Obviously, this mechanism is more convenient to be with the car all the time. Scissors lift mechanism, as shown in Figure1 (Rotary 2016). Race cars had a demand on quick tire changing, hence mechanics had to develop a built-in car lifting mechanisms that would lift the car quickly, as shown in Figure 2 (Tuning 2020).

Figure 1. Rotary Lift Double-Section Scissor Lift's

Figure 2. Air Jacks for the racing car

3. Methodology

This project aims to design a mechanism that can lift a vehicle. In addition, to design another mechanism to allow the vehicle to move forward and backward while lifted. These two mechanisms can be useful in the situation of getting stuck in the middle of the desert. This device will require no skill or heavy lifting. In the case of the lifting and moving forward and backward mechanisms, there are multiple mechanisms that can be considered as alternatives, and some will be shown below. A comparison with some constraints and criteria will be made. The criteria considered in this project are cost, maintenance, safety and endurance. After completing the comparison, a mechanism will be chosen for the project.

There are two drivers for this device; hence a kinematic analysis will be conducted to make sure that the mobility of the device equals two. Moreover, a force analysis will be conducted to calculate the forces exerted on the different parts of the mechanism including the links and the joints. Next a stress analysis will be conducted using two commercial codes for confirmation purposes. The Von Miss's theory of failure is adopted and different constrains including space, cost, environment, and availability of the selected materials in the local Saudi market. Besides different standards used in all selections related to the materials and manufacturing methods. At the end and after the simulation and the stress analysis process, we are planning to manufacture a full-scale model and make some tests before seeking for the adoption of the proposed mechanism and marketing the product.

4. Some Alternatives Design

4.1 Hydraulic scissor jack and lead power screw jack

In this mechanism, the system is hybrid. The lifting is done by a hydraulic scissor jack, on the other hand, the forward-backward movement is done by a lead power screw mechanism. In fact, the addition of the hydraulic part is a good idea to be considered, as shown in Figure 3 (Bekir 2019).

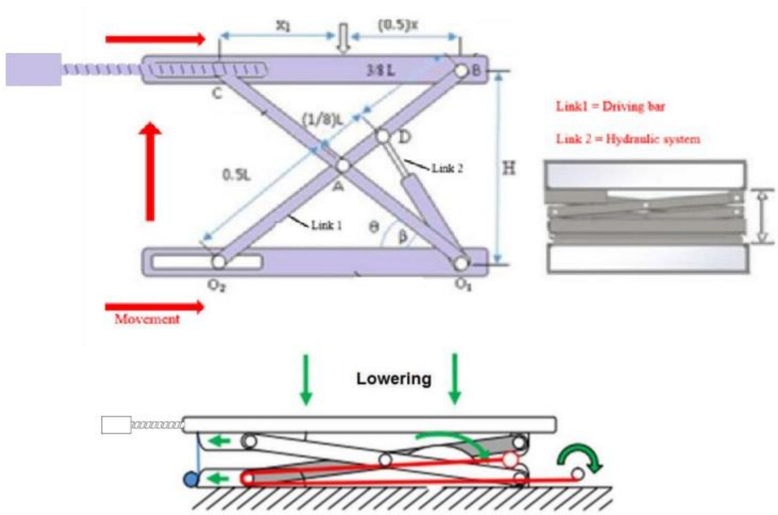

Figure 3. Hydraulic lifting mechanism

4.2 Running board and hydraulic system

The running board is mounted on the sides of the vehicle due to less amount of weight needed to be lifted. Hence, as an alternative, the running board mechanism will be added to the chassis to lift the car. In addition, a hydraulic system will be added to the running board to go all the way to the ground and lift the car eventually. The movement of forward-backward will be operated by a hydraulic system. This will safely time of the design because the mechanism already exists on some cars, as shown in Figure 4 (AMB 2019).

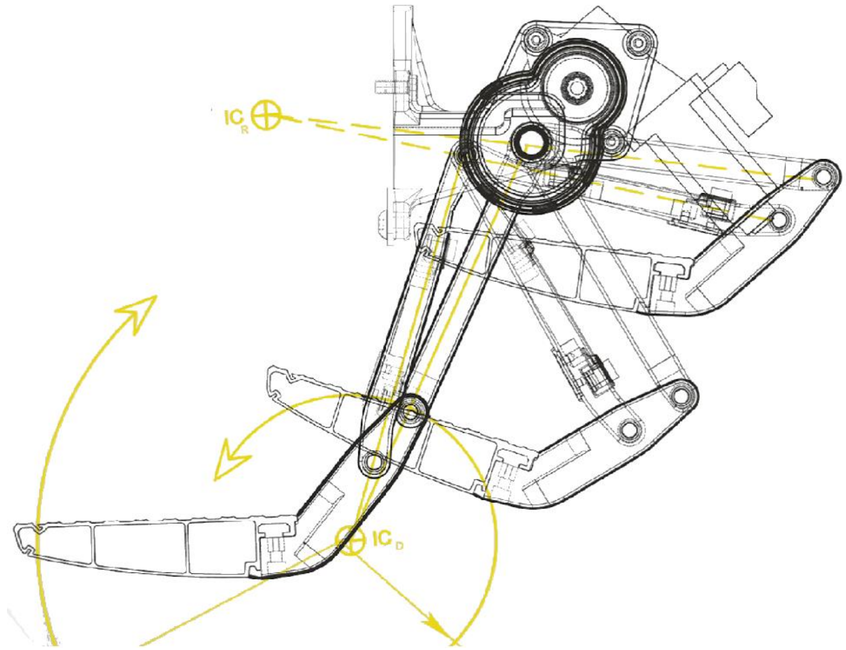

Figure 4. Running Board mechanism

4.3 Hydraulic scissor lift

A mechanical scissor lifting tool elevates and lowers a vehicle's platform so that it is at an ergonomic height for performing a particular repair work., as shown in Figure 5 (IQS). We came out with the decision of choosing the scissor lift to be our design mechanism that we will work with. Calculating kinematic and force analysis will take place in the next section.

Figure 5. Hydraulic scissor lift

5. Data Collection

The following subsections contain all kinematic and force analysis.

5.1 Kinematic Analysis

To reach the desired goal, we decided to separate the two drivers and focus on a single driver which is the lifting driver. The degree of freedom for the lower mechanism must equal one, which is one movement upward and downward, and for that, one input will control the movement. Thus, the degree of freedom at Equ.1 (mobility), as shown in Figure 6, will be calculated in the following step:

$L = 6$
$J_1 = 7$
$J_2 = 0$
$M = 3(L-1) - 2J_1 - J_2 \ [\, Equ.1 \,]$
$M = 3\,(\,6 - 1\,) - 2 \times 7 - 0$
$M = 1$

So, the mobility of the mechanisms is:
M= 1 (constrained mechanism)
Thus, the assumption made above is right.

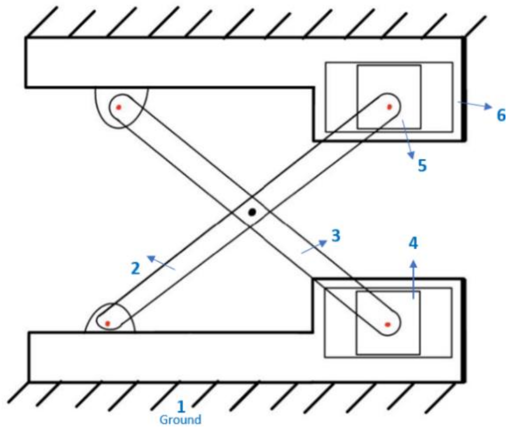

Figure 6. Kinematic Chain of the proposed design

Notice that the lower part of the mechanism which is causing the backward and the forward motion is the only considered mechanism in the above mobility analysis.

5.2 Mechanism Analysis

Figure 7a shows the main component of the proposed mechanism, and Figure 7b shows a simplified representation of the hydraulic system used in it for lifting and moving. In Figure 8, we calculated the height of chassis of Ford F-150 from the ground. We went with the height to be 3000 Kg, the chosen value of the car was way more than the original weight of the car to be in the safe side considering the worst-case scenario while calculating the factor of safety in stress analysis, the following symbols convey information about figures and forces, allowing us to describe complex ideas in detail.

F: Represent the weight of the car.
A: Is the location where the weight of the car acts on at the left side of the plate.
B: Is the location where the fixed pin at the top at 0.25m from left side of the plate.
C: Is the location where the pin in the slider at the top at 0.75m from left side of the plate.
D: Is the location where the fixed pin at the bottom at 0.25m from left side of the plate.
E: Is the location where the pin in the slider at the bottom at 0.75m from left side of the plate.
P: Is the location of the middle pin of the scissor where the hydraulic act on.
L: Represents the length of links (BE) and (CD).
F_N: Represent the normal force due to the friction on the lower plate.
F_P: Represent the force due to the hydraulic.
F_R: The reaction force of the bottom plate to the force F at location A.
M_R: The moment due to the shifting of the force F at location A to the mid-point.
θ_{max}: The maximum angle between the hydraulic and the plate.
R_B^y: The reaction of the fixed pin at vertical direction at point B.
R_B^x: The reaction of the fixed pin at horizontal direction at point B.
R_c^y: The reaction of the pin in the slider at vertical direction at point C.
R_c^x: The reaction of the pin in the slider at horizontal direction at point C.

R_D^y: Is the reaction of the fixed pin at vertical direction at point D.
R_D^x: Is the reaction of the fixed pin at horizontal direction at point D.
R_E^y: Is the reaction of the pin in the slider at vertical direction at point E.
R_E^x: Is the reaction of the pin in the slider at horizontal direction at point E.
R_P^y: Is the reaction of the fixed pin at vertical direction at point P.
R_P^x: Is the reaction of the fixed pin at horizontal direction at point P.

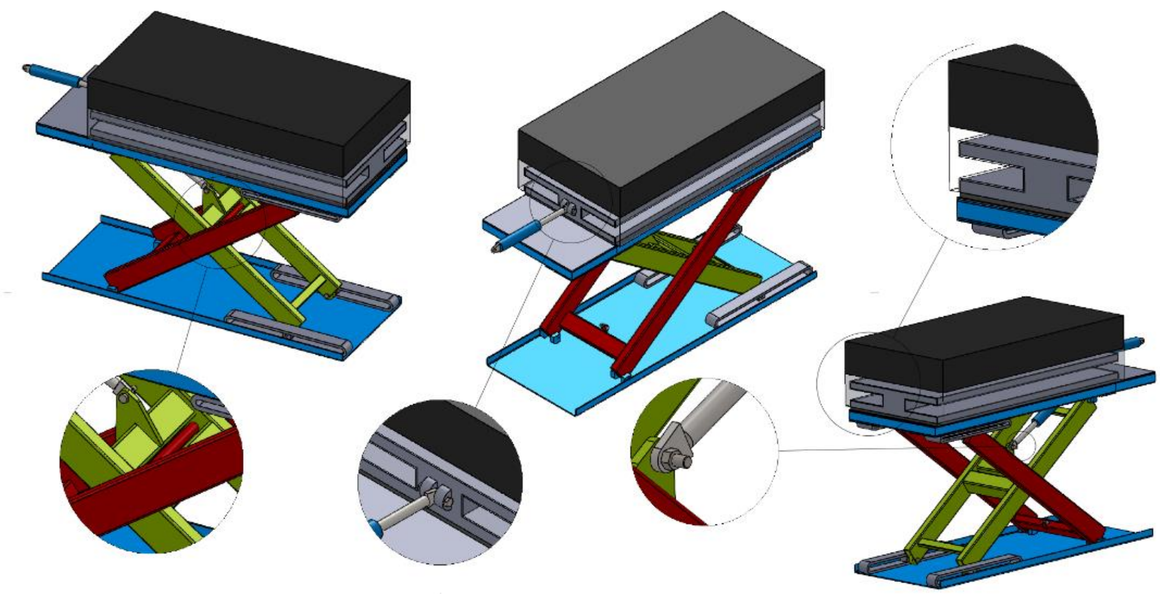

Figure 7a. Hydraulic scissor lift mechanism.

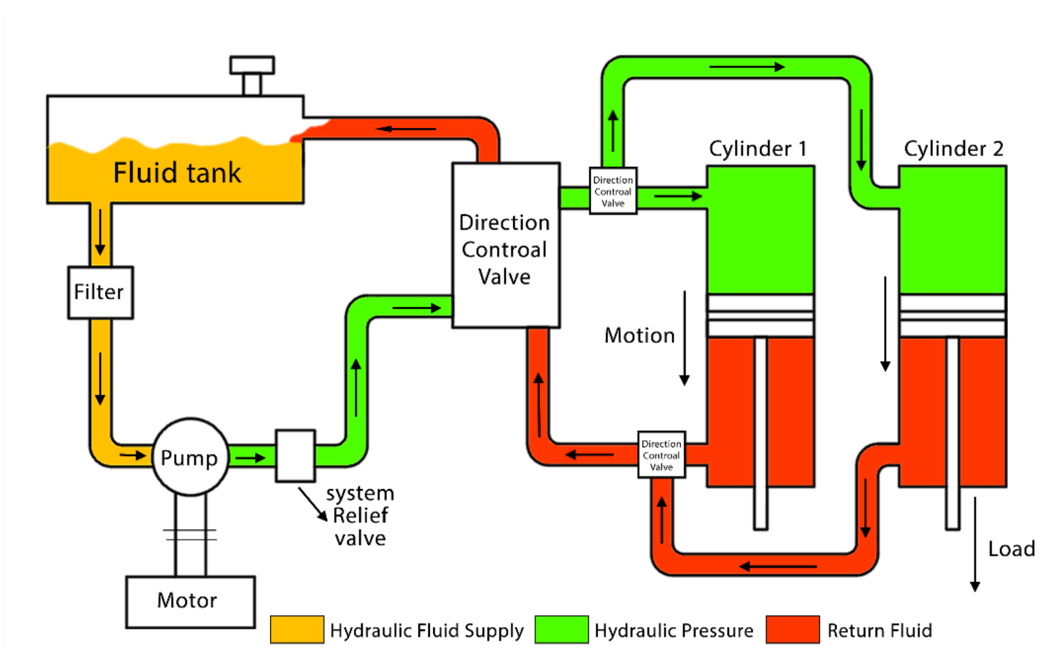

Figure 7b. Hydraulic System cycle.

5.2.1 Force of whole mechanism

$\Sigma F_y = 0 \uparrow +$
$-F + F_R = 0$
$F_R = F$
$F_R = \left(\frac{3}{8}\right) \times 3000 \times 9.81$
$F_R = 11.04\ KN \uparrow$

$+\circlearrowright\ \Sigma M_A = 0$
$-(0.5 \times 11.04) + M_R = 0$
$M_R = 5.525\ kN$

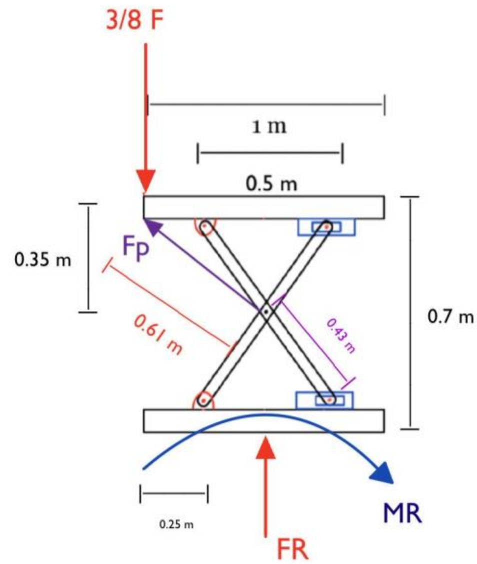

Figure 8. FBD of whole mechanism

5.2.2 Force of upper plate

$+\circlearrowright\ \Sigma \text{M at point C} = 0$
$R_B^y \times 0.5 + Fp \sin\theta \times 0.75 - F \times 0.75 = 0$
$R_B^y = \dfrac{F \times 0.75 - Fp \sin\theta \times 0.75}{0.5}$
$R_B^y = \dfrac{11.04 \times 0.75 - Fp \sin 35° \times 0.75}{0.5}$
$R_B^y = \dfrac{8.28 - 0.43 \times Fp}{0.5}$
$R_B^y = 16.56 - 0.86 \times Fp \quad [Equ. 2]$

$+\circlearrowright\ \Sigma \text{M at point B} = 0$
$Fp \sin\theta \times 0.25 - R_C^y \times 0.75 - F \times 0.25 = 0$
$R_C^y = \dfrac{Fp \sin\theta \times 0.25 - F \times 0.25}{0.75}$
$R_C^y = \dfrac{Fp \sin 35° \times 0.25 - 11.04 \times 0.25}{0.75}$
$R_C^y = 0.1434\ Fp - 3.68 \quad [Equ. 3]$

$\Sigma \text{Fy} = 0 \uparrow +$
$-\text{F} + \text{Fp} + R_C^y + R_B^y = 0$
$-\text{F} + \text{Fp} + (0.1434 \times \text{Fp} - 3.68)$
$+ (16.56 - 0.86 \times \text{Fp}) = 0$
$\text{Fp}\ (1 + 0.1434 - 0.86) = 11.04 - 16.56 + 3.68$
$Fp = \dfrac{11.04 - 16.56 + 3.68}{0.2834}$
$Fp = 6.5\ kN \downarrow$

Substitute FP in Equ.2 & Equ.3
$R_B^y = 16.56 - 0.86 \times (-6.5) \quad [Equ. 2]$
$R_B^y = 22.15\ kN \uparrow$

$R_C^y = 0.1434 \times (-6.5) - 3.68 \quad [Equ. 3]$
$R_C^y = 4.61\ kN \uparrow$

$\Sigma F_X = 0 + \rightarrow$
$R_C^x + R_B^x - Fp \cos\theta_{max} = 0\ [Equ. 4]$

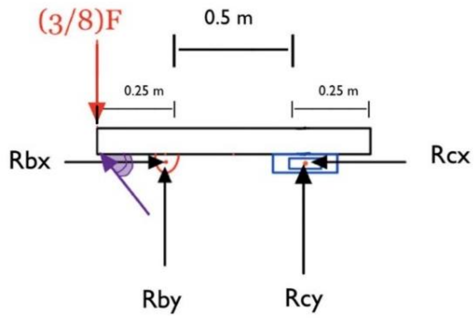

Figure 9. FBD of upper plate

5.2.3 Force of lower plate

$+\circlearrowright\ \Sigma M_D = 0$
$(-F_R \times 0.25) - (F_N \times 0.5) + (M_R) = 0$
$(-11.04 \times 0.25) - (F_N \times 0.5) + (5.525) = 0$
$F_N = 5.53\ kN\ \uparrow$

$\Sigma \mathrm{Fy} = 0 \downarrow +$
$R_d^y = F_N + F_R$
$R_d^y = 5.53 + 11.04$
$R_d^y = 16.57\ kN\ \downarrow$
$Hence\ \mu F_N = 0.33 \times 5.53 = 1.825\ kN$

$\Sigma \mathrm{Fx} = 0\ \rightarrow +$
$R_d^x = \mu F_N = 1.825\ kN\ \rightarrow$

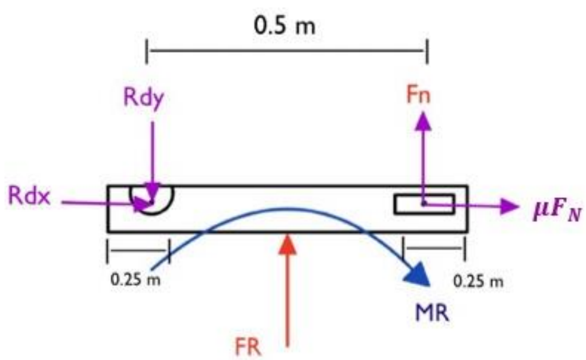

Figure 10. FBD of lower plate

5.2.4 Force of links

$\Sigma \mathrm{Fy} = 0 + \uparrow$
$R_e^y = R_C^y + R_d^y$
$R_e^y = 4.6121 + 16.57.$
$R_e^y = 21.18\ kN\ \uparrow$

$+\circlearrowright\ \Sigma \mathrm{M\ at\ point\ C} = 0$
$0.35 \times R_p^x + 0.7 \times R_d^x = 0$
$R_p^x = -\frac{0.7}{0.3} \times 3.06$
$R_p^x = 7.14\ kN\ \leftarrow$

$\Sigma \mathrm{Fx} = 0 \rightarrow +$
$R_C^x = R_d^x + R_p^x$
$R_C^x = 3.06 - 7.14$
$R_C^x = 4.08\ \mathrm{kN}\ \leftarrow$

$\mathrm{substitute}\ R_C^x\ \mathrm{in\ equ.4}$
$R_C^x + R_B^x - Fp \cos\theta_{max} = 0\ [equ.4]$
$-4.08 + R_B^x - (6.5 \times \cos 35\ °) = 0$
$R_B^x = (6.5 \times \cos 35°) + 4.08$
$R_B^x = 9.40\ \mathrm{kN}\ \rightarrow$

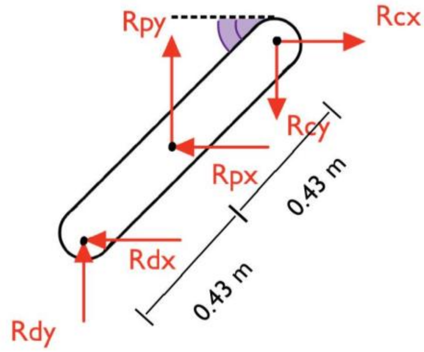

Figure 11. FBD of right link of Jack scissor

6. Results and Discussion

6.1 Numerical Results

Design and hand calculations of stress analysis is still in progress. Due to the lack of time the stress analysis and static theories of failure were done using SolidWorks and ANSYS.

6.2 Graphical Results

The following figure shows the stress variation in each part of the mechanisms and in some combined parts using ANSYS for the validation purpose. In the following tables, the mechanical properties of the adopted materials are listed down. The stresses at the critical points of the mechanism are also listed below.

6.2.1 Material Selection

The choice of material was 4140 Alloy Steel due to some points that can fit perfectly to our aim in the project. The requirements were the common use of the material and the previous experience.

Table 1. Property of the 4140 Alloy Steel

Property	Elastic modulus	Poisson's ratio	Shear Modulus	Mass density	Tensile strength	Yield strength	Thermal conductivity
value	210 GPa	0.28	79 GPa	7700 g/m^3	723.8256 MPa	620.422 MPa	50 W/(m.K)

6.2.2 Simulation Result of Links

In this section the critical points of the links stress, strain, deformation and life cycles were obtained as shown in the Table 2 and Figures 12-15.

Table 2. Critical Results of links

Property	Minimum	Maximum	Average
Stress [MPa]	1.1147×10^{-12}	235.31	19.924
Strain [mm/mm]	1.7682×10^{-17}	1.4519×10^{-3}	1.0416×10^{-4}
Deformation [mm]	0	1.2249	0.34166
Life [cycles]	14448	1.0×10^{6}	9.9676×10^{5}

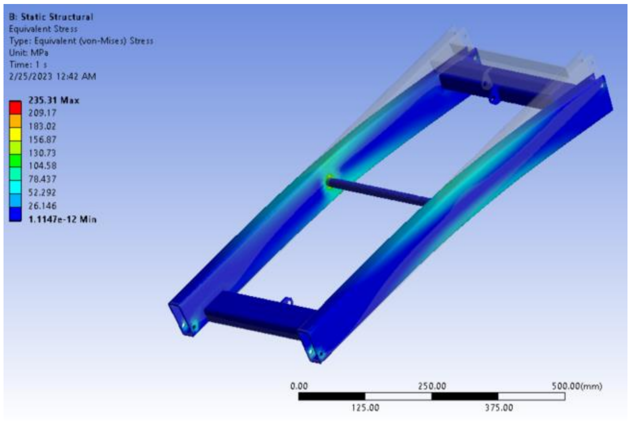

Figure 12. Equivalent Stress of link.

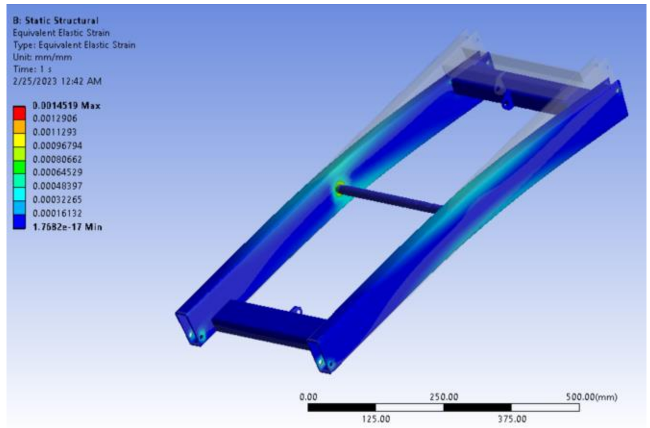

Figure 13. Equivalent Elastic Strain of link.

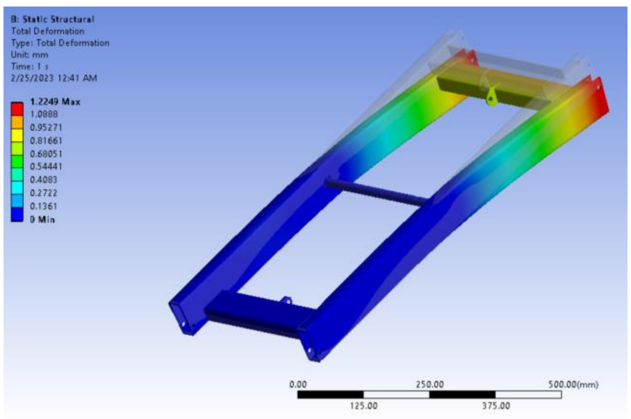

Figure 14. Total Deformation of link.

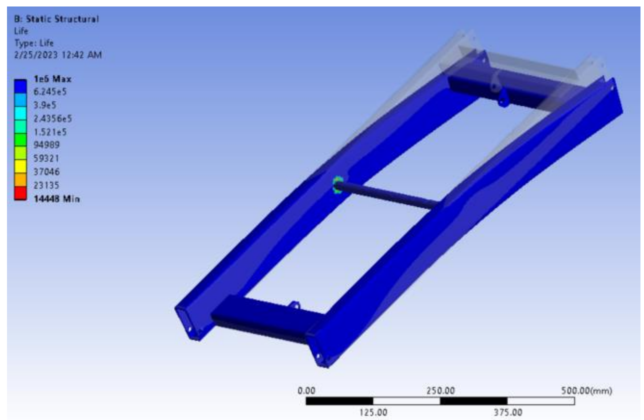

Figure 15. Life cycles of link.

6.2.3 Simulation Result of Upper Plate

In this section the critical points of upper plate stress, strain, deformation and life cycles were obtained as shown in the Table 3 and Figures 16-19.

Table 3. Final Result of links

Property	Minimum	Maximum	Average
Stress [MPa]	3.3734×10−2	115.7	8.0471
Strain [mm/mm]	2.9468×10^{-7}	6.8942×10^{-4}	5.0576×10^{-5}
Deformation [mm]	0	0.5091	6.693×10^{-2}
Life [cycles]	1.8953×10^{5}	1.0×10^{6}	9.9998×10^{5}

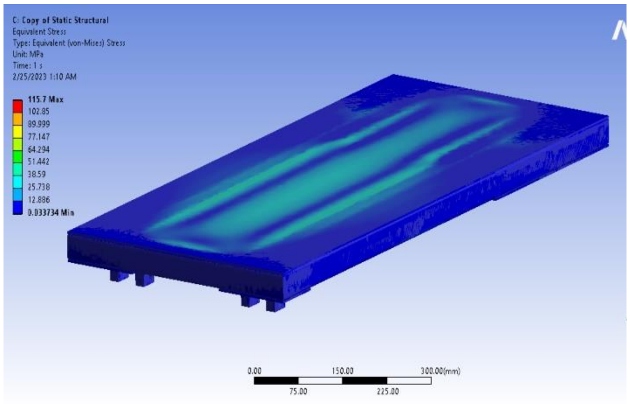

Figure 16. Equivalent Stress of Upper Plate.

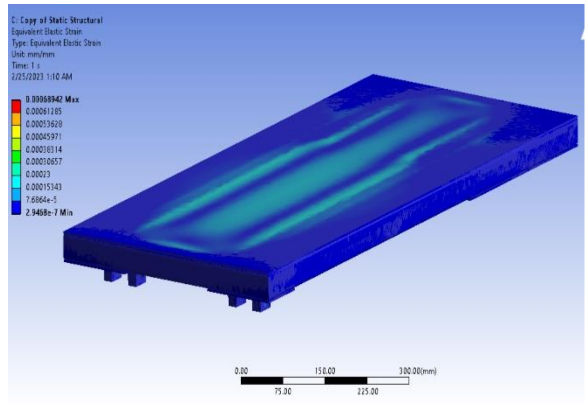

Figure 17. Equivalent Elastic Strain of Upper Plate.

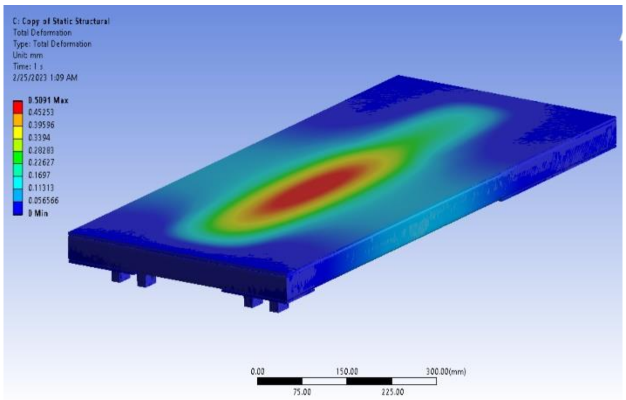

Figure 18. Total Deformation of Upper Plate.

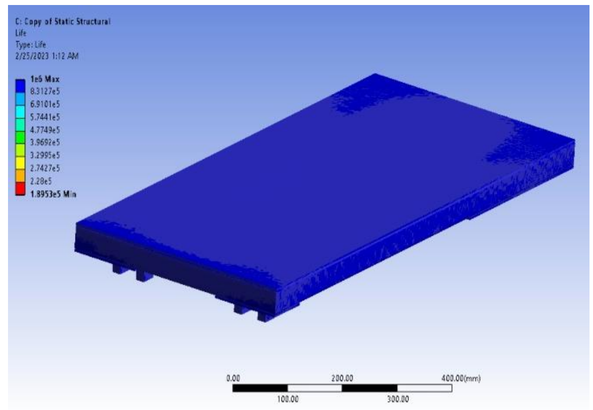

Figure 19. Life cycles of Upper Plate.

6.3 Proposed Improvements

As indicated by the outputs of Ansys, the results were successful. For more durability, we can add a linkage between the lower plate and piston for the forward and backward movement. A better material could be used for safety and space saving purposes. The hydraulic circuit could be replaced with a motorized power screw system as one of the prime mover alternatives that suits different non-dusty environment.

6.4 Discussion

In the provided project the target is to design a system that eventually lift a car with a weight of 3000 kg maximum. So based on the best result that we can get form our calculations the design should be considered. With the designed mechanism, a hydraulic system will operate the whole mechanism and it will be connected to the car battery to get the needed power. Whenever the mechanism should be used, this hydraulic jack will operate the mechanism to move for the preferred situation depending on what chassis should be considered and after placing the system the hydraulic will give an efficient amount of force to lift up the car and move it backward and forwards.

7. Conclusion

Based on the results of the kinematic and the stress analysis, the proposed mechanism is practically applicable and could be easily and cost-wise manufactured and installed on certain categories of safari cars. The proposed mechanism is a multi-purpose mechanism that could be safely and easily used in emergencies and maintenance situations. with the selection of better material, a smaller models could be manufactured for a smaller cars for the same purposes without any changes in the car chassis and affecting the structural integrity of the car.

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Biography

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