ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

A Thesis Submitted to School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University

In partial fulfillment of the requirement for degree of

Master of Science in Mechanical Engineering

(Specialization on Mechanical Design)

By

Tewodros Yibeltal

Advisor

Mr. Mulugeta H.

2019

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Design and Analysis of Lifting Mechanism on Wheelchair Seat to Transfer to Bed and Car Seat

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Approved by Board of Examiners

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Abstract

Wheelchair is a mobility gadget designed to be replacement for walking, moving physically disabled people (having injuries in their legs and arm) from one place to other with the help of attendee or by means of self-propelling. The wheelchair is divided into two categories based on the power used mobility: manually powered wheelchair and electrically powered wheel chair. This research typically focuses on design of lifting mechanism on wheelchair seat for easy transfer of users to bed and car seat. The aim is to design a portable wheelchair that can allow the user to transfer and lift him/her-self into a bed, car seat and finally place it at his/her side without having someone to help out. More specifically the designed wheelchair has to move upward/downward to come to a level with the bed and car seat.

The design stage initiated by gathering of literature review about the proposed design to know its development and defect from past to present day existing wheelchair designs. Different methodologies have been proposed based on human anthropometric data and test for improvement of lifting mechanism of the wheelchair to maximize the utility of the chair. The conventional method of using care givers to reach optimum height of the wheelchair encounter a lot of limitation (time and energy consumption, comfort, weight of patient that can be carried etc.). In this Research paper manually operated hydraulic scissor lift has been designed and it will be attached to the wheelchair seat. The geometry and joints of this mechanism were carefully arranged so that only one actuator needs to be controlled, enabling the wheelchair user to adjust the seat using manually operating hand pedal that can rise and lower the hydraulic scissor lift. On the theoretical part; the material selection, brief description of the proposed design, cylinder selection and hydraulic control system description were done.

The geometrical design; each component of the mechanism was designed using SOLIDWORK software, the hydraulic control system design was done using FLUID SIM software, the dynamic analysis and functionality simulation testing of the lifting mechanism of the design were done using MATLAB and ANSYS WORKBENCH soft wares. Finally, by comparing with the existing manual wheelchairs and survey data's about existing wheelchair standard sizes , the proposed mechanism design was comfortable and easily operated with less effort from patients having a seat lifting mechanism than can rise up to a height of 0.3m with a maximum load of 150Kg, which will increase the existing cost by 2500-3000ETB. It was intended to increase the independence of the end user while transferring to bed and car seats. Validation of the design was done and usage is found satisfactory.

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Chapter One

Introduction

1.1 Background

Historically the first records of wheel seats for transporting the disabled were used during 3^{rd} century later in China. The Chinese people used their invented wheelbarrow for moving people as well as carrying heavy objects. These wheeed chairs look like carts and were pulled by animals. Here are some of the historical backgrounds on wheelchair and with height adjustment mechanism along with it on the seat:

The first known dedicated wheelchair was invented in 1595 and called an invalids chair, which was made for Phillip II of Spain by an unknown inventor [11].In 1655, Stephen Farfel, a paraplegic watchmaker, built a self-propelling chair on a three-wheel chassis [11].and then the Bath Chair was developed in Bath, England, Invented by John Dawson in 1783 which had two large wheels, one small Wheel and Dominated the market of 19th century [1].

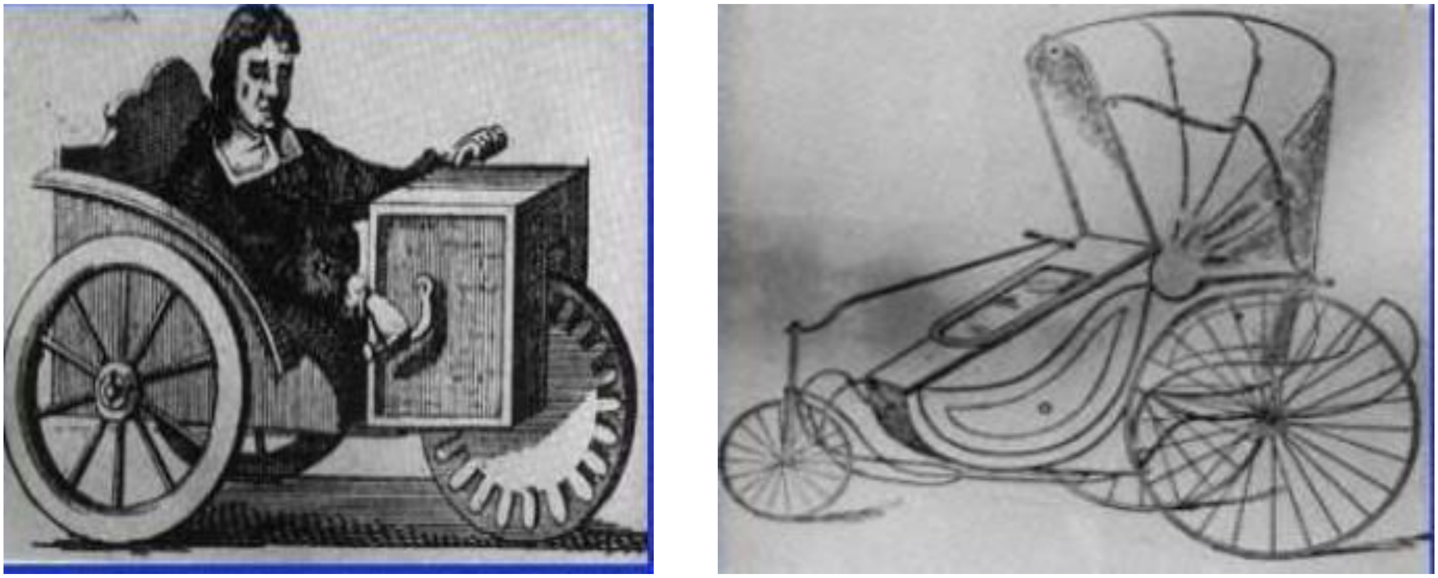


Fig.1.1 Self-Propelling and Bath Wheel chair[1]

The 18th Century Wheelchair was applied some design modifications on the sit and sit-back part that gives more Comfort for the disabled person and It is Convertible (reclining back and adjustable foot rests) chair. [1]

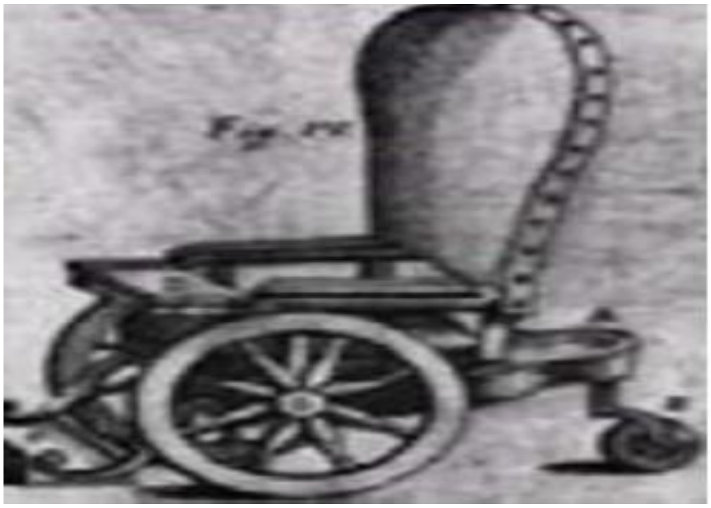


Fig.1.2 18th Century Wheelchair [1]

The Bath chair was not that comfortable and during the last half of the many improvements was made to wheelchairs. In 1869 patent for a wheelchair showed the first model with rear push wheels and small front caster wheels. Between, 1867 to 1875, inventors added new hollow rubber wheels similar to those used on bicycles on metal rims [3].

Harry Jennings and his disabled friend Herbert Everest, both mechanical engineers, invented the first folding, lightweight, steel, collapsible wheelchair in 1931. That was the initial wheelchair similar to what is in modern use today. That wheelchair was built for his paraplegic friend Herbert Everest. They founded a company together that monopolized the wheelchair market for many years. [13]

George Johann Klein, a Canadian inventor, invented electric wheelchair for the injured on veteran’s war. Electric wheelchair is one of Canada's greatest inventions that is found to have benefited the mankind. Electric wheelchairs invention is a result of the need to give them independence and mobility. Electric wheelchairs are somehow a heavier device than manual wheelchairs because the frame has to be stronger in order to accommodate the battery and motors. From just using standard batteries and a joy stick controller, right up to using microprocessor controlled gyroscopic circuitry which enables the chair to rise. [9]

From the above historical background of wheelchair and its development that needs to be improved. Existing wheelchair expects the lifting of the disabled by the caregiver underarms. The disabled person felt pain on their underarms when lifted. Improper lifting by caregiver sometimes causes bruises. The caregiver may also subject to big risk in back problem if they have to lift the disabled several times a day. Many caregivers complained that they have a hard time for lifting the patient particularly if his/her weight is more than 100kg. It may need two or more caregivers to perform their daily routine. It is very inconvenient for them and their family as most of latter need to work. Therefore, in this study improvement in the mechanism by adding a vertical lifting mechanism on wheelchair seat would be done to benefit the users and caregivers.

1.2 Problem Statement

Now a day in our country disabled peoples that uses wheelchair needs the help of caregivers in their day to day activities. These make them injured and also causes back problem on caregiver due to carrying the disabled several times in a day. Assistive technology (robotic devices) are too expensive to be used by a large population, while others (modified wheelchair lift designs) were developed without considering the real-world needs of the end user. It was expected that, there will be a great number of potential beneficiaries with the new modified device that can improve their quality of daily life and increase functional capabilities due to additional lifting function on the wheelchair seat for easy transfer to bed and car seat. Therefore, this study will focus on developing an effective hydraulic scissor lift mechanism on the existing wheelchair seat by considering all internal and external factors that can affect functionality of the new product design. The proposed lifting mechanism on wheelchair seat will target manual wheelchair users, offering both lowering and raising of the wheelchair seat, for lateral transfer to bed, car seat and vice versa. In addition to that its iterative user-centered design that gives more comfort, effective functionality, independency for the users and actionable insights geared toward the development of future assistive technology.

1.3 Objectives of the Study

General Objective

The Research is generally aimed at designing and simulating a hydraulically powered scissor lift on wheelchair seat to lift and lower the disabled and transfer from wheelchair to bed, to car seat and vice versa; with comfort and easy operation.

Specific Objective

Design of component parts and assembly of the entire lifting mechanism on the wheelchair seat using SOLIDWORK software.

Analyze dynamic (position, velocity and acceleration versus time) analysis of the scissor lift using MATLAB software.

To determine stress analysis of the lifting mechanism in accordance with the existing geometrical design and effect on system stability

Design of a hydraulic control system for the lifting mechanism

Analyzing effect of load on the scissor lift mechanism stability and safety of the proposed design.

Determination of stress, deformation and velocity analysis of the model design using ANSYS software simulation.

1.4 Scope of the Study

A wheelchair with a lifting function was designed to assist a caregiver when transferring an end user not only indoor but also for outdoor activities. The targeted user's area typically severely disabled person (i.e. upper and lower limbs disability) who needs the physical support when transferring from a bed and car to a wheelchair and so forth.

In this study a vertical lifting mechanism on the wheelchair seat will be designed by adding hydraulic scissor lift mechanism which is attached on the wheelchair seat. The design mechanism of hydraulic scissors lift is to lift up to a height of 300 mm and carrying capacity of less than 150kg (150 kilograms) with the available engineering materials. The modeling and stimulation of the new design is done using CATIA, SOLIDWORKS, ANSYS and MATLAB software's.

1.5 Methodology

To fulfill the objectives of the study, the following techniques have been used:

I. Literature Review: Survey of books, journal articles, related research papers, product design catalogues, and other relevant literatures.

II. Data Collection: data's regarding the wheel chair design are collected from different sources (design manual, related previous designs, and internet) that can give some clues for the new advanced design on wheelchair and Other data used in the thesis, are obtained from different related books, and handbooks.

III. Modeling and Analysis: the mathematical analysis of the lifting mechanism, the model design parts, assembly of the complete design, deformation analysis of the lifting mechanism and also dynamic analysis are performed using CATIA, SOLIDWORKS, ANSYS and MATLAB soft wares.

1.6 Organization of the Research

In the first chapter introduction, background and objective to be achieved are discussed, then it is followed by chapter two that deals about a review of literature related to the proposed design (i.e. lifting mechanism on wheelchair seat) is presented. In chapter three the research presents about the material selection, theoretical as well as analytical modeling of the proposed design were discussed; next to this it is followed by chapter four that deals about discussion for the simulation and dynamic analysis results done using multiphysics simulation software are presented. Finally, the summary of the thesis goes to chapter five, which deals about the simulation as well as analytical results conclusion and also the recommendations for future researchers were discussed here.

Chapter Two

Literature Review

Man's quest for improvement has never been satisfied. The drive towards better and greater scientific and technological outcome has made the world dynamic. Several attempts have been made to design an elevating seat for Existing wheelchairs. Prior art was investigated and references to seat height adjustment devices related to both wheelchair and non-wheelchair seats were found. Among the major resource for investigation of related works, key words such as "height adjustable seat" "wheelchair seat design" were used in the search. These papers contain literature review to mechanical and electrical seat height adjustment systems that may act as inspiration for the current design. Among those works that were done by several scientists, engineers and researchers were reviewed. Here are some the literatures related to the study:

Teo Chin Tengoctober's "Lifting Mechanism of Wheelchair", 2005: was done a research project to maximize the performance of the existing wheelchair. When the research starts, it was planned to design wheelchair that can reduce or minimize the handling process during transfer of the disabled from wheelchair and vice versa and also to design a wheelchair at a competitive cost with proper material selection. In this research a conventional wheelchair was used as an available resource to improve version. Power screw system was used for horizontal and vertical rise of the wheelchair seat mechanism of the proposed designed product. Further reliability test was done for safety and validation purpose. During the design process design evaluation, validity, reliability and product stability were done.

The limitation of the above work is that**:**

The lifting and transferring mechanism is operated with the help of power screw drivers. So that it's difficult to operate the system for the disabled to handle the mechanism cause its sort mechanism operation that needs too much force to operate the system so that it will bring additional stress and pain for the end users.

Additionally the power screw system was used to rise the seat and also the material selected for this part were high strength material and that will increase the weight of the wheelchair that causes balance and stability problems on the new product.

During a horizontal transfer it was difficult to transfer from the wheelchair without any support of the mechanism due to its balance problem, similarly during transferring time the wheelchair may side and fail along the direction of transfer.

On the Design of “wheelchair with Adjustable Seat” (2002), research paper a designed wheelchair which has an adjustable seat that can be raised and lowered. The height adjustable seat was done to enable a wheelchair-dependent person to gain access to the seat from ground level. Additionally the user could raise him or her from the ground level to the normal operating height, and reach things overhead more easily by themselves. The seat height was adjusted by rotation of the shaft in one direction, and the cables connected with shaft wind around the shaft to thereby raise the seat (Figure1.1). [16]

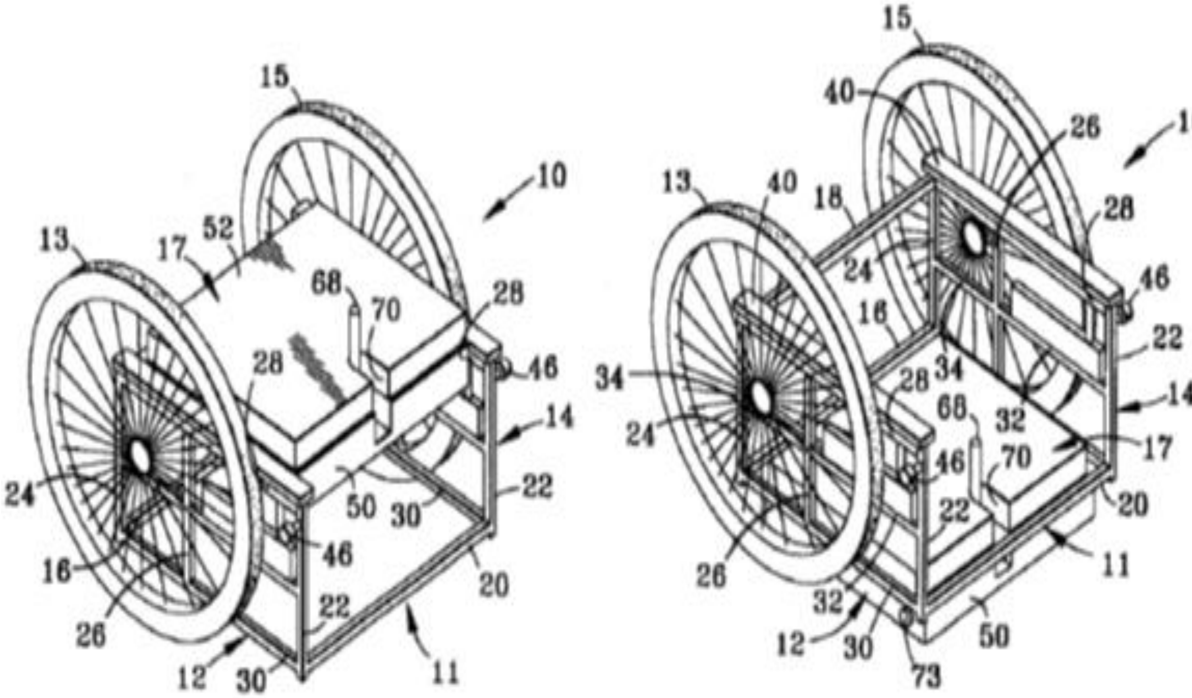


Fig.2.1 Wheel chair with adjustable seat [16]

The limitation of the above work is that**:**

The design product doesn’t have side support of the users if some failure was occurred it will cause extra damage to their bodies and also it was mechanically operated system that needs additional energy from the disabled, which will make them too tired and difficult to use in their day to day activity.

Additionally it causes extra duty for the care givers to lower the disabled from bed to the wheelchair seat at when the wheel seat is lowered.

"Effect of System Tilt and Seat-To-Backrest Angles on Load Sustained by Shoulder during Wheelchair Propulsion", was a research paper, then was designed a product having a height adjustable seat applying scissor frame mechanism as a lifting unit and a crank in front as the operation handle was done. Compared to the previous modified designs done it was relatively well improved. Even if it was better than the previous designs there were also defects that need modification (Figure 1.2). [17]

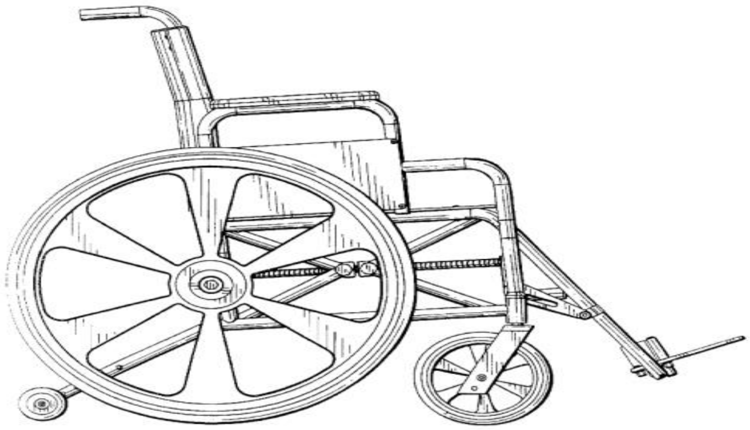


Fig.2.2 Wheelchair with vertically adjustable seat [17]

"Manually Operable Standing Wheelchair", Published in 2005, was designed simple structure wheelchair design. Position of seat was done fixed on the horizontal plane, but movable in vertical by installing back on the rod. Additionally it was used pure mechanical method to aid standing up. Due of its simple structure, this wheelchair has some problem when it works. [7]

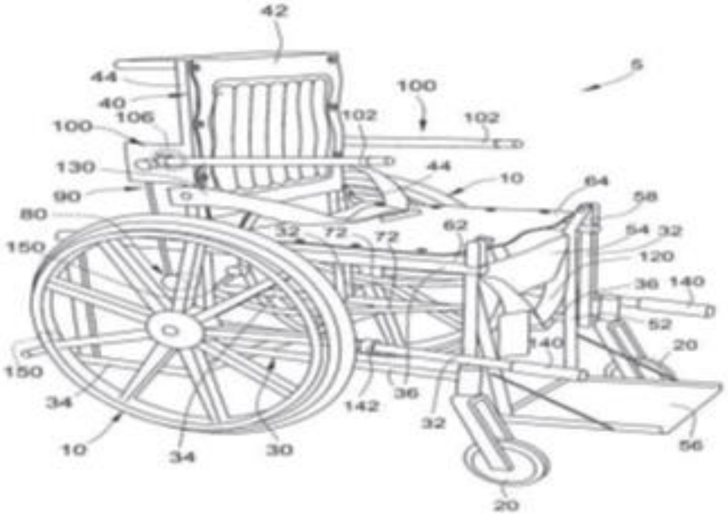


Fig.2.3 Manually operable standing wheelchair [7]

The limitation of the above work is that**:**

The wheelchair was operated manually, which means disabled people must have strong forearms to operate the wheelchair.

Additionally if the users were weak in stamina or have problems in their arms, they cannot operate this kind of wheelchair.

“Dual-Purpose Wheelchair Mechanism Design”: a research paper on the wheelchair, which was operated with electric devices. Additionally it was mechanically operated, compared to the previous wheelchair designs that were done it gives comfort for the users during standing positions. This design was not only used to aid standing, but also aimed to make people feel comfortable when standing up. So when people want to stand up, the wheelchair will make people lying down and then the wheelchair will turn to vertical position gradually. This will let people have more comfort than former designs. [9]

Fig.2.4Dual-Purpose Wheelchair [9]

The limitation of the above work is that**:**

This design uses additional power source (either battery or fuel system) for the operation. Due to this it will have expensive cost of operation and maintenance.

Additionally Due to its additional services cost of the wheelchair is not affordable for ordinary societies.

"Manually Height Seat Adjusting System Wheelchair" by Mascari, was designed a manual lifting system for adjusting the height of the seat via an in line turn buckle located under the seat was done. The device works by adjusting the spacing between the frame members and narrows the chair frame as the seat rises, which limits usability for users. The turnbuckle is not easy to reach while in the chair and provides little mechanical advantage (Figure 1.3). [12]

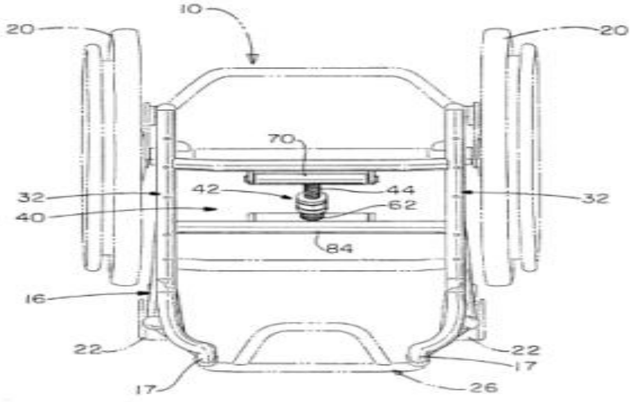


Fig.2.5 Wheelchair having a double turnbuckle height adjustment [12]

"A Retrofit Height Adjustable Seat for wheelchair" by Bell, a study that was designed a retrofit height adjustable seat for a chair. The lifting and lowering of seat was operated by retraction of two arms at each side of the seat (Figure 1.4) and Stop of the lifting of lowering is achieved by inserting and retraction of arm from a slot placed b side of seat. [19]

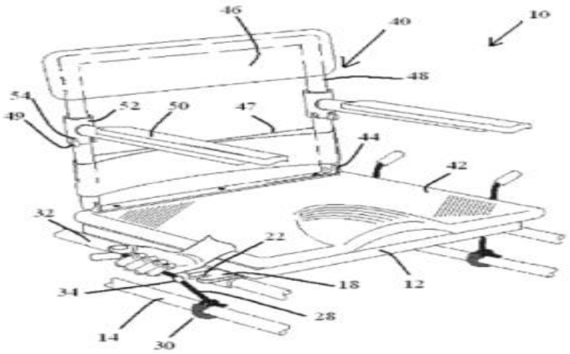


Fig.2.6 Retrofit height adjustable seat [19]

The limitation of the above work is that**:**

The biggest disadvantage of the above design was that it only works when user is out of the chair.

“Seat Height Adjustment Using Air Inflation” by Garman, was a design work which introduces a means of height adjustment by using air inflation (Figure 1.5). Based on the length of the hose connected to the bladder it may be possible to control such a system from both in and out of the chair. The time required to adjust the height in such a system will be determined by the ratio of volume difference between air container and pump. [7]

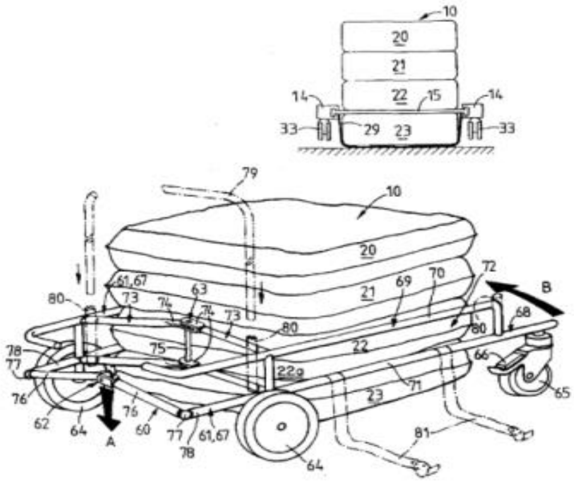


Fig.2.7Air Inflatable medical lifting device [7]

The limitation of the above work is that**:**

In this research the designed wheelchair was not size compatibility and also lack of side support on the mechanism.

Summary of the above literature review

Most of the above listed wheelchairs were rigid frame wheel chair and foldable X frame design. From the above observations limitations identified are listed below:

1. Observation shows that there is no adjustable armrest, knee rest and foot rest.
2. Observation shows that there is difficulty in shifting the users from wheel chair to beds, chairs and other vehicles due to its seat position of the wheelchair system.
3. Shortage of the height of the backrest, no adjustable and cushioned backrest, no head rest in the existing design.
4. Observation shows problem in shifting of patient to the bed and cars from wheel chair, removing, cleaning problem due to lack of horizontal and vertical lifting mechanisms on the existing wheelchair seat.
5. Observation shows that problem in reaching the table and non-adjustable height of table for ease of work, which increases repetitive stress injuries like wrist, back, shoulder injuries.

Based on the above listed defects, the existing wheelchair needs improvement. So that these items should be included:

- Protective pads for arms, elbows, and legs, and cushions from back.
- Improving manually operated hydraulic lifting systems (vertical lifting) on the seat of existing wheelchair.

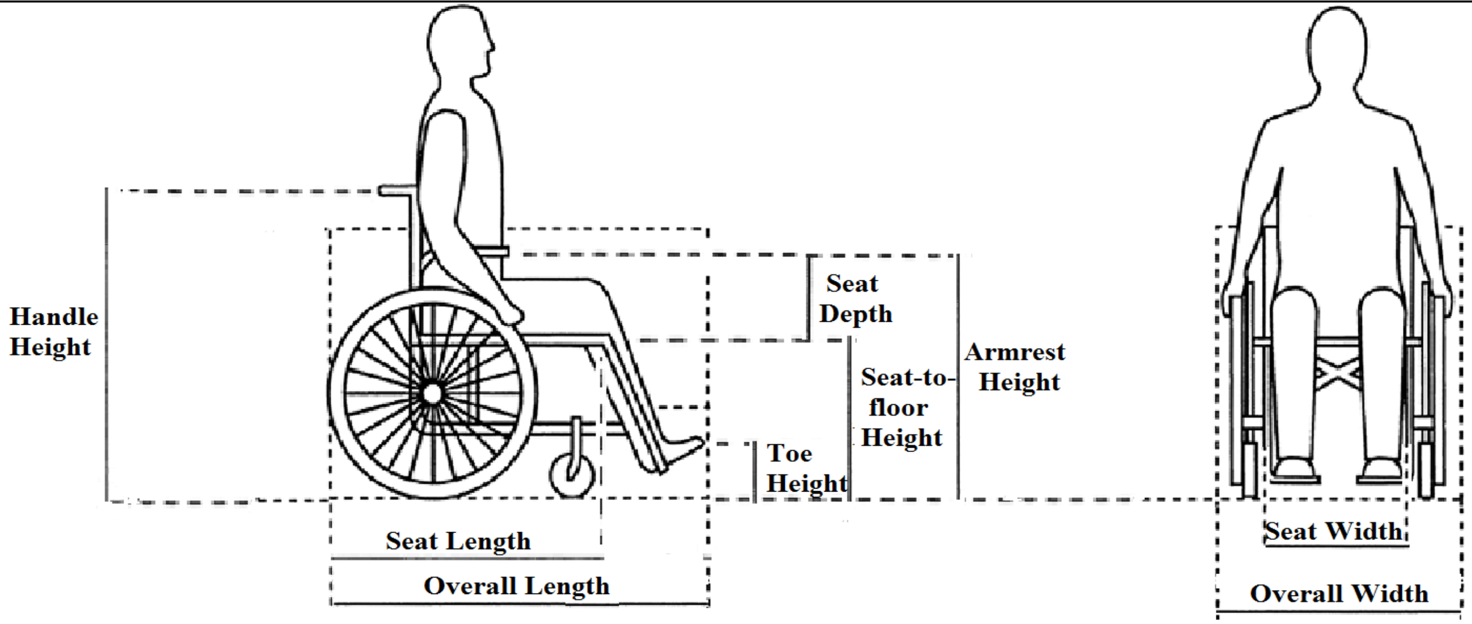
However, the existing wheelchair cannot provide the above services for the users. This research work will be mainly concentrating on the modification of the existing manual wheelchair by adding manually operated hydraulic scissor lifting mechanisms on wheelchair seat for vertical lifting of disabled individuals for easy transfer to bed and car seat. So, the final designed wheelchair will be provided less handling process subject to disabled people and by considering the additional services getting from the proposed design it’s comparatively an affordable price for the ordinary disabled users.

Chapter Three

Model Design and Analysis

Under this chapter material selection, sketches for the proposed design, hydraulic circuit control system of the mechanism and part(component)/assembly modeling (using CATIA and SOLIDWORKS software) were done based on standard procedures of the product design concepts.

3.1 Model Design Description



Features	Overall Length	Seat Length	Handle Height	Seat-to-floor Height	Overall Width	Seat Width	Seat Depth	Seat back Height	Weight Capacity	Total Weight
1	84 cm	46 cm	97 cm	47-50 cm	66 cm	40 cm	23 cm	45 cm	113 Kg	13 Kg
2	103 cm	45 cm	93 cm	50 cm	78 cm	40 cm	35 cm	46 cm	110 Kg	21 Kg
3	96 cm	46 cm	91 cm	50 cm	59.5 cm	40 cm	30 cm	41 cm	113 Kg	15 Kg
4	103 cm	46 cm	95 cm	49 cm	65 cm	41 cm	24 cm	47 cm	110 Kg	13.8 Kg
5	94 cm	48 cm	96 cm	48 cm	57.8 cm	40 cm	21 cm	47 cm	110 Kg	11 Kg
6	100 cm	50 cm	85.09-95.25 cm	44.45-49.53 cm	62.23-72.39 cm	40.64-45.72 cm	40.64 cm	40.64-45.72 cm	114 Kg	27 Kg
7	95 cm	48.5 cm	96 cm	49.53-53.34 cm	59.06 cm	40.64-50.8 cm	39.5 cm	41 cm	135 Kg	22 Kg
8	98 cm	51 cm	97 cm	50.6 cm	55.88-60.96 cm	42 cm	45.72 cm	45 cm	159Kg	25 Kg

Table 3.1 Standard Size and Capacity of d/t types of Manual Wheelchairs [32]

From the above standard dimensions of wheelchairs, the size and capacity of wheelchair selected for the proposed design is as follows:

Overall Length = 103cm
Overall Width = 65cm
Handle Height = 95cm
Seat-to-floor Height = 49cm
Seat Depth = 30cm

Seat Length = 43.8cm
Seat Width = 41cm
Total Weight = 13.8Kg
Maximum weighting Capacity =150kg
Seat back Height = 45cm

As stated on statement of problem hydraulic scissor lift mechanism is proposed for lifting of the disabled, having:

Maximum carrying capacity, Mass = 150kg
Maximum Raising height, Height = 0.3m
Number of arms of scissor lift = 4.

The top and base plate dimensions are
Length = 438mm
Width = 400mm and

The top plate has 80mm of height from the wheelchair seat at its closed position.

For the proposed design size and dimension were taken from wheelchairs standard size catalogue and observation of the literature review of the previous different modified designs.

3.2 Material Selection:

The material selection for the proposed design typically considers material strength, affordable cost, and easily functional product to be design. Here by considering mechanical properties of the material with their high resistance to load, deformation, fracture, rust and corrosion. Stainless steel material selected to use for designing all component of the proposed design. Material cost is the basic priorities for the proposed design due to its affordability for the ordinary individuals with cheap price. So that from the price which is getting from product components survey on the market it will cost additional price of 3000 ETB on the existing manually operated wheelchair. Compared with the service that gives for the users, it has an affordable price.

Stainless Steel:

It is steel with high rust and corrosion resistance to meet specific goal for the required purpose. It has also high strength, toughness, aesthetics and its less coefficient of friction were considered to meet all requirement. So that the choice of stainless steel for the lifting mechanism design is appropriate. Here the material cost of the proposed design should be analyzed.

Table 3.2 Material properties of stainless steel of grade 430 covered under ASTM A240/A240M. [30]

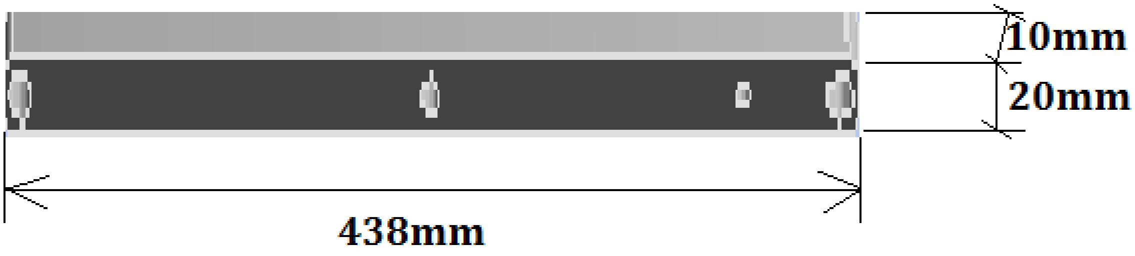
Mechanical Properties of Grade 430 Stainless Steel					
Grade	Tensile yield Strength (MPa) min	Ultimate tensile Strength (MPa) min	Elongation (% in 50mm) min	Hardness	
				Rockwell B (HR B) max	Brinell (HB) max
430	586	310	22	85	183

Physical Properties of Grade 430 Stainless Steel in The Annealed Condition									
Grade	Density (kg/m^3)	Elastic Modulus (GPa)	Mean Coefficient of Thermal Expansion (µm/m/°C)			Thermal Conductivity (W/m.K)		Specific Heat 0-100°C (J/kg.K)	Electrical Resistivity (nΩ.m)
			0-100°C	0-315°C	0-538°C	at 100°C	at 500°C		
430	7750	200	10.4	11.0	11.4	26.1	26.3	460	600

$\sigma_{allowable} = \frac{Tensile\ yield\ strength}{n}$ where n= factor of safety =1.5

$\sigma_{allowable} = \frac{586e+6}{1.5} = 390.67Mpa$ $\tau_{allowable} = 0.55 * \sigma_{allowable} = 214.87$Mpa

Thus, Cross-sectional area of the scissor arm



Width = w = 20mm = 0.02m, Thickness = t = 10mm = 0.01m and Height = h = 438mm = 0.438m

Volume of the scissor arm

$$V_{arm} = w*t*h = 0.02*0.01*0.438$$

$$V_{arm} = 87.6*10^{-6}\ m^3$$

Density of stainless steel = 7750 kg/m^3

$$M = d * V_{arm}$$

$$= 7750*87.6*10^{-6}\ m^3$$

$$M = 0.679\ kg$$

Total mass = 4*0.679= 2.716 kg

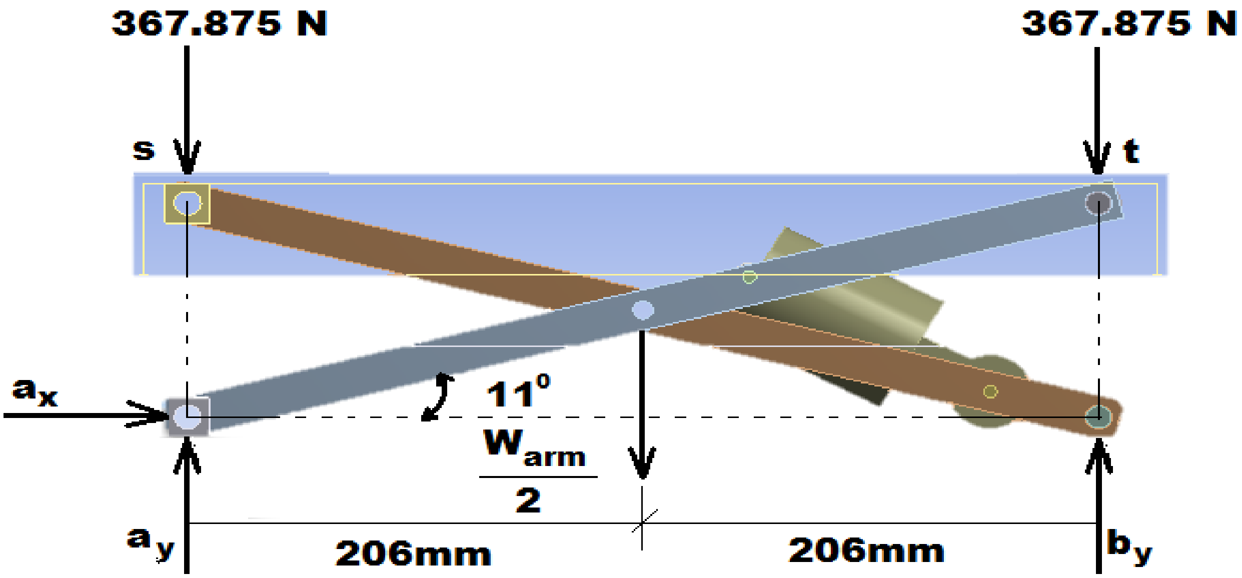
$$W_{arm} = 2.716 * 9.81$$

$$= 26.64\ N$$

Total Applied Load= mg = (150Kg) *(9.81)m/s^2= 1471.5N

Applied load on one arm = 1471.5N/4 = 367.875N

<u>At the closed position</u>



Where,

θ = link TA and link SB makes with the X-axis = 11^0 F_C = force of cylinder = 13307.83 N

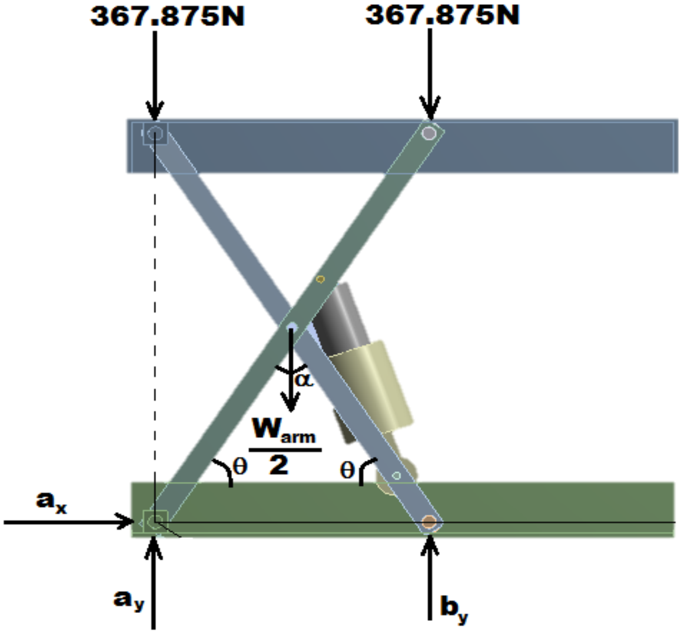
β = the hydraulic cylinder makes with the X-axis = 15^0

α = link TA and link SB makes with each other = 158^0

a_x = 98.43 N

a_y = 374.53 N b_y = 374.54 N

<u>At maximum Extension</u>



Where,

θ = link TA and link SB makes with the X-axis = 45.6^0 F_C = force of cylinder = 2995.71N

β = the hydraulic cylinder makes with the X-axis = 72.5^0

α = link TA and link SB makes with each other = 88.8^0

a_x = 75.84 N

a_y = 374.53 N

b_y= 374.54 N

3.3 Hydraulic Lift

Hydraulic lifts have developed overtime and at each stage of its development, critical problems are solved. A hydraulic piston powered by a manually operated hydraulic pump that replaces electric motor or generator operated type. One outstanding feature about this design is its independent operation and increased efficiency. The hydraulic lifts are of the following types.

1. Direct acting hydraulic lift and
2. Suspended hydraulic lift

For this study direct acting hydraulic lift is selected, which consists of a piston sliding in a cylinder. The top plate is fitted to the top end of a piston on which the persons may seat and the wheelchair seat moves in the downward direction when the liquid from the fixed cylinder is removed.

3.4 Cylinder Selection

By considering the above analytical results acting on the cylinder, selection of the hydraulic cylinder for the proposed design will be done. For this study single acting cylinder-spring return was selected. It uses hydraulic fluid to power the forward stroke, where as it will use mechanical spring force for return stroke. This makes them ideal for pushing and pulling within the different application they are suitable for full stroke working at slow speed. From the numerical analysis, forces acting on the cylinder at both its closed and maximum extending positions are:

F_c=13307.83N when closed

F_c=2995.71N at maximum extension

By considering the maximum result acting on the cylinder an appropriate and compatible cylinder for the lifting mechanism will be selected. For this design, operating pressure P= 40 bar= 4Mpa is selected from the hydraulic catalogue:

$$P = \frac{F_c}{A} \text{ where } P = 40\text{Mpa and } F_c = 13307.83\text{N}$$

$$A = \frac{F_c}{P} = \frac{13307.83}{4*10^6} (4*10^6)(\text{N}) = 33.27*10^{-4} \text{ m}^2$$

$$A = \frac{\pi * D^2}{4} D = \sqrt{(4 * A)/\pi} = \sqrt{(4 * 33.27 * 10 - 4)/\pi}$$

$$D = 0.06508\, m$$

$$D = 0.06508\, m$$

$$D = 65.08\, mm \approx 70mm$$

Therefore, I have selected 70mm diameter cylinder for the proposed design.

3.5 Detail parts and Assembly of the Proposed Design

The main components of the Hydraulic lift are shown on Figure below:

1. Hydraulic Cylinder: it is double acting type of cylinder used to rise and lower the wheelchair seat with the application of pump and an actuator attached to it.

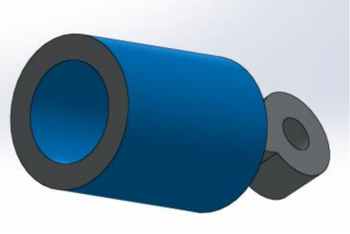


Figure 3.1 Hydraulic Cylinder

2. Scissor lift Arm 1: These are the main components of the mechanism which support the hall structure during the raising and lowering of the mechanism.

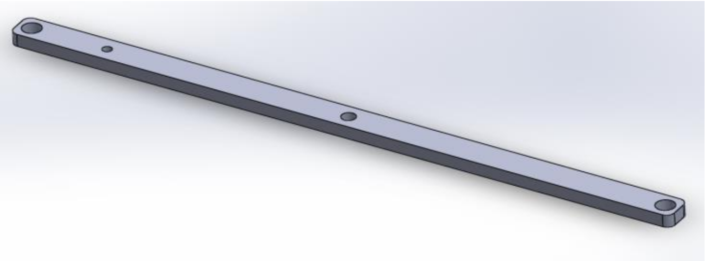


Figure 3.2 scissor lift Arm

3. Piston Rod: it's the rod acting on the hydraulic cylinder used to raise and lower the mechanism with the application of hydraulic fluid.

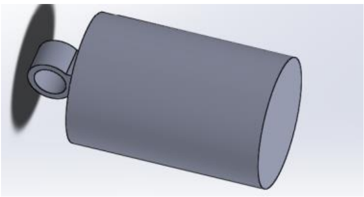


Figure 3.3 Piston Rod

4. Supporting Circular Shaft 1: it’s the upper joint shaft of the scissor arms for regular raising and lowering of the scissor lift mechanism.

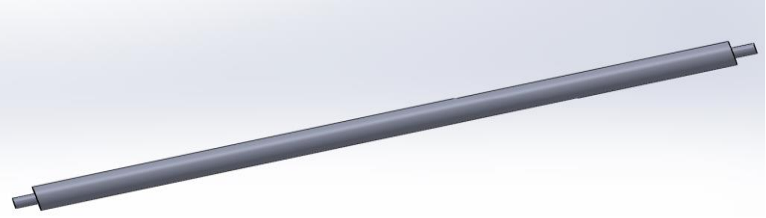


Figure 3.4 Supporting Circular Shaft 1

5. Supporting Circular Shaft 2: it’s the lower joint shaft of the scissor arms for regular raising and lowering of the scissor lift mechanism.

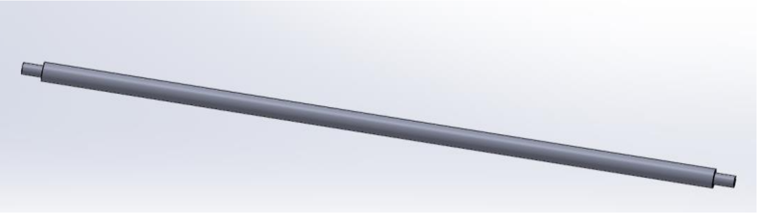


Figure 3.5 Supporting Circular Shaft 2

6. Top plates: it’s the top part of the scissor lift mechanism in which the user sits on it.

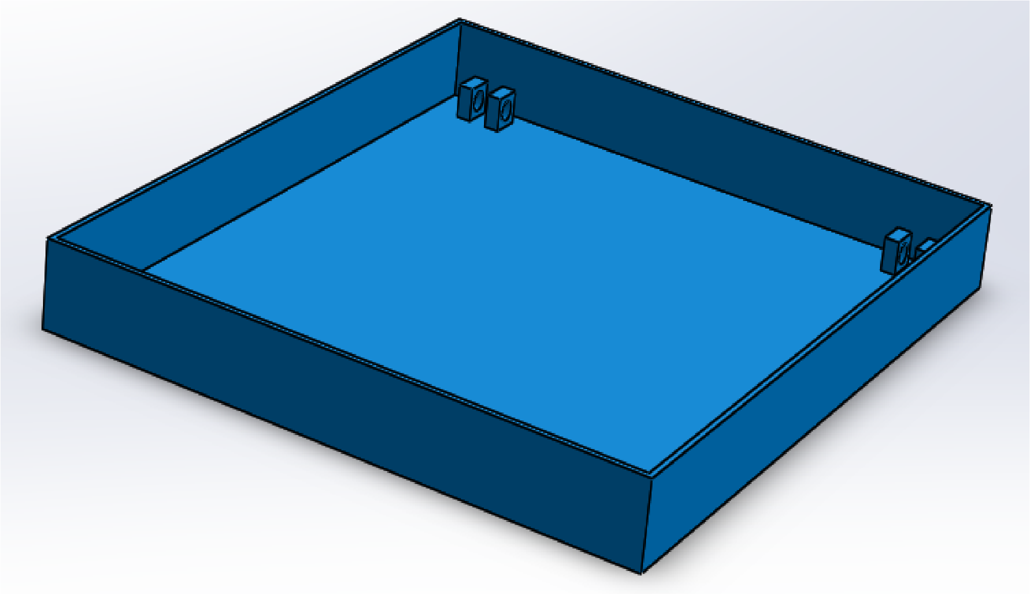


Fig. 3.6 Top plates

7. Roller: it’s part of the scissor lift used for raising and lowering the scissor arm by sliding on the base and top plate of the mechanism.

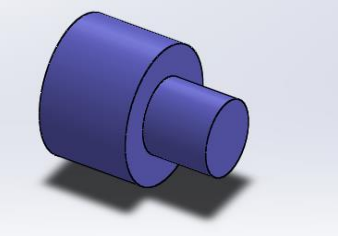


Figure 3.7 Roller

8. Base plate: the bottom structure of the scissor lifts mechanism that rests on the wheelchair plate.

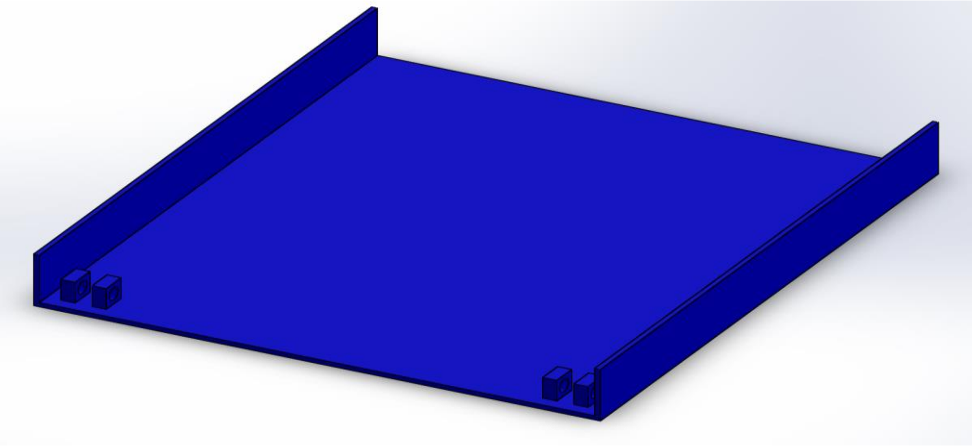


Fig. 3.8 Base Plate

9- Scissor lift arm 2: These are the main components of the mechanism which support the hall structure during the raising and lowering of the mechanism.

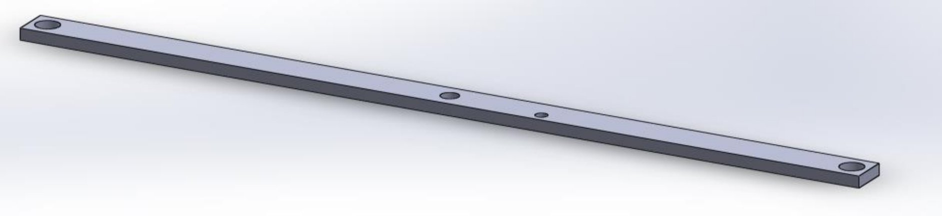


Fig. 3.9 scissor lift arm 2

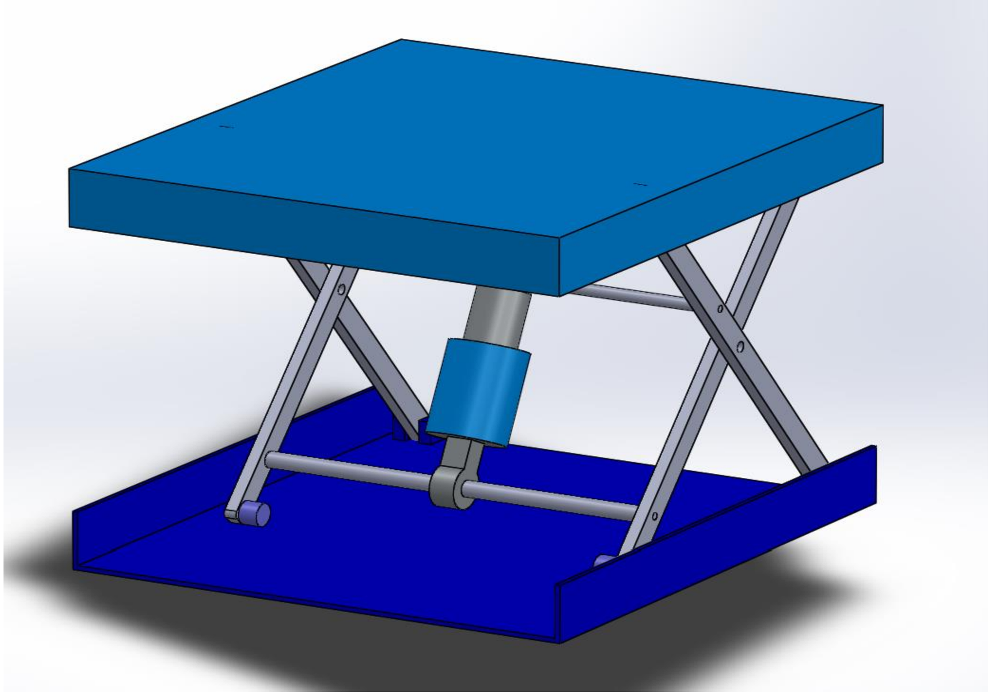


Figure 3.10 Assembly of the Hydraulic Scissor lift

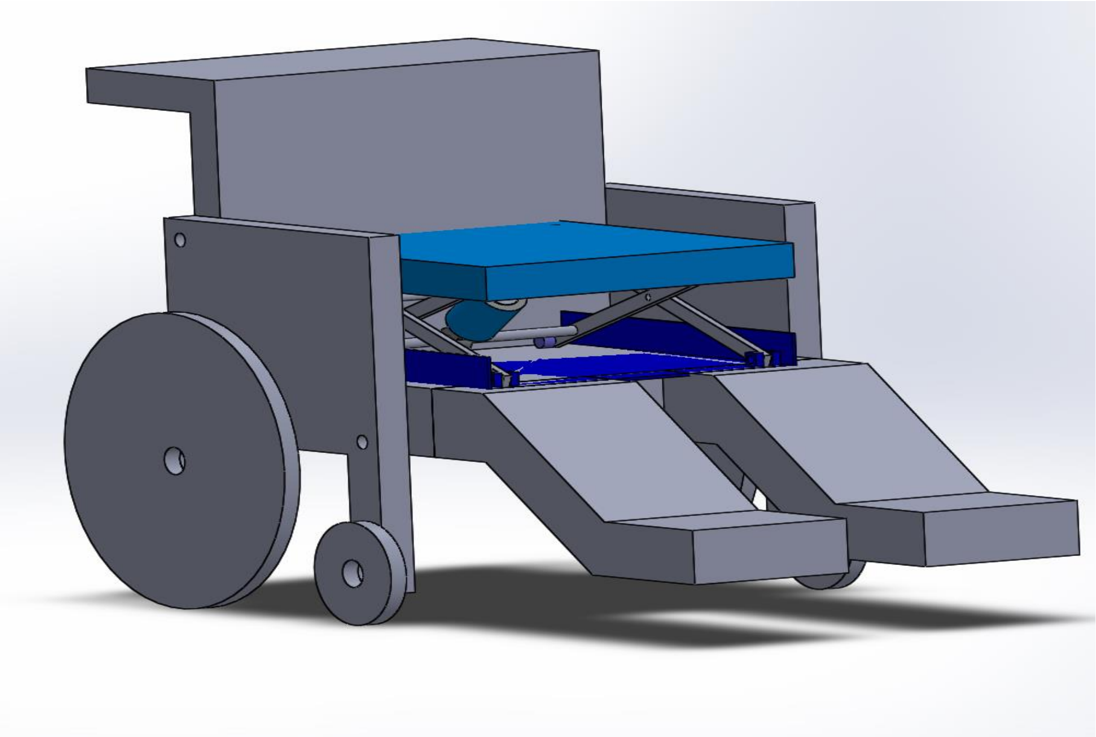


Figure 3.11 General overview of the wheelchair with lifting Mechanism

3.6 Hydraulic Control System

Hydraulics-is generation of forces and motion with the help of hydraulic fluids. So these Hydraulic fluids used as medium for power transmission.

Pascal's Law**:**

Pascal's law states that when a confined fluid is placed under pressure, the pressure is transmitted equally in all directions and on all faces of the container. This is the principle used to extend the ram on a hydraulic cylinder. By applying a force to move the piston on one end, the piston on the other end will move the same distance with same amount of force.

Components for the Hydraulic control system**:**

One of the most important functions in any fluid power system is control. If control components are not properly selected, the entire system will fail to deliver the required Output. It is important to know the primary function and operation of the various types of control components. This type of knowledge is not only required for a good functioning system, but it also leads to the discovery of innovative ways to improve a fluid power system for a given application.

The selection of these control components not only involves the type, but also the size, the actuating method and the manual control capability.

Cylinders**:** The function of the cylinder in hydraulic systems is to convert the hydraulic energy supplied by the pump into useful work.

- For this study single-acting spring return cylinder have been selected: due to its cheap price for the users, minimum maintenance cost and also easy for functionality of the end user.

Cylinder Diameter = 70mm, $F_c = 13307.83$ N, when it starts to extend

$F_c = 2995.71$N, when it starts to retract

This single-acting cylinder: is extended hydraulically and retracted with the help of spring attached to the piston and the cylinder end. Thus, an output force can be applied in two directions.

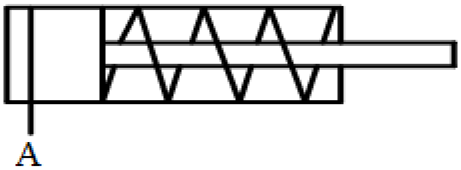


Fig 3.12 Hydraulic symbol of single acting-spring return hydraulic cylinder

The output force (F) and piston velocity of single acting cylinder are not the same for extension and retraction strokes.

- During the extension stroke, fluid enters the blank end (A) of the cylinder through the entire circular area of the piston (A_{Piston}).
- Whereas during retraction of cylinder, mechanical force will be there (*i.e* spring force) to push back the piston to its complete retracted position. Thus, ($A_{Piston} - A_{Piston\text{-}Rod}$),

Where A_{Piston} = Piston Area, and $A_{Piston\text{-}Rod}$ = Piston rod Area.

- Since $A_{Piston} > (A_{Piston} - A_{Piston\text{-}Rod})$, the retraction velocity is greater than the extension velocity since the pump flow rate is constant.

During the extension stroke, fluid pressure bears on the entire area of the piston (A_{Piston}).It can be seen from the above equations that force during extension stroke and velocity of piston during retraction stroke is greater for the same operating pressure and flow rate.

The power developed by a hydraulic cylinder for the extension stroke, can be found out by (velocity multiplied by force) or from (flow rate multiplied by operating pressure)
Power (kW) = v (m / s) * F (kN) = Q (m^3 / s) * P (kPa)

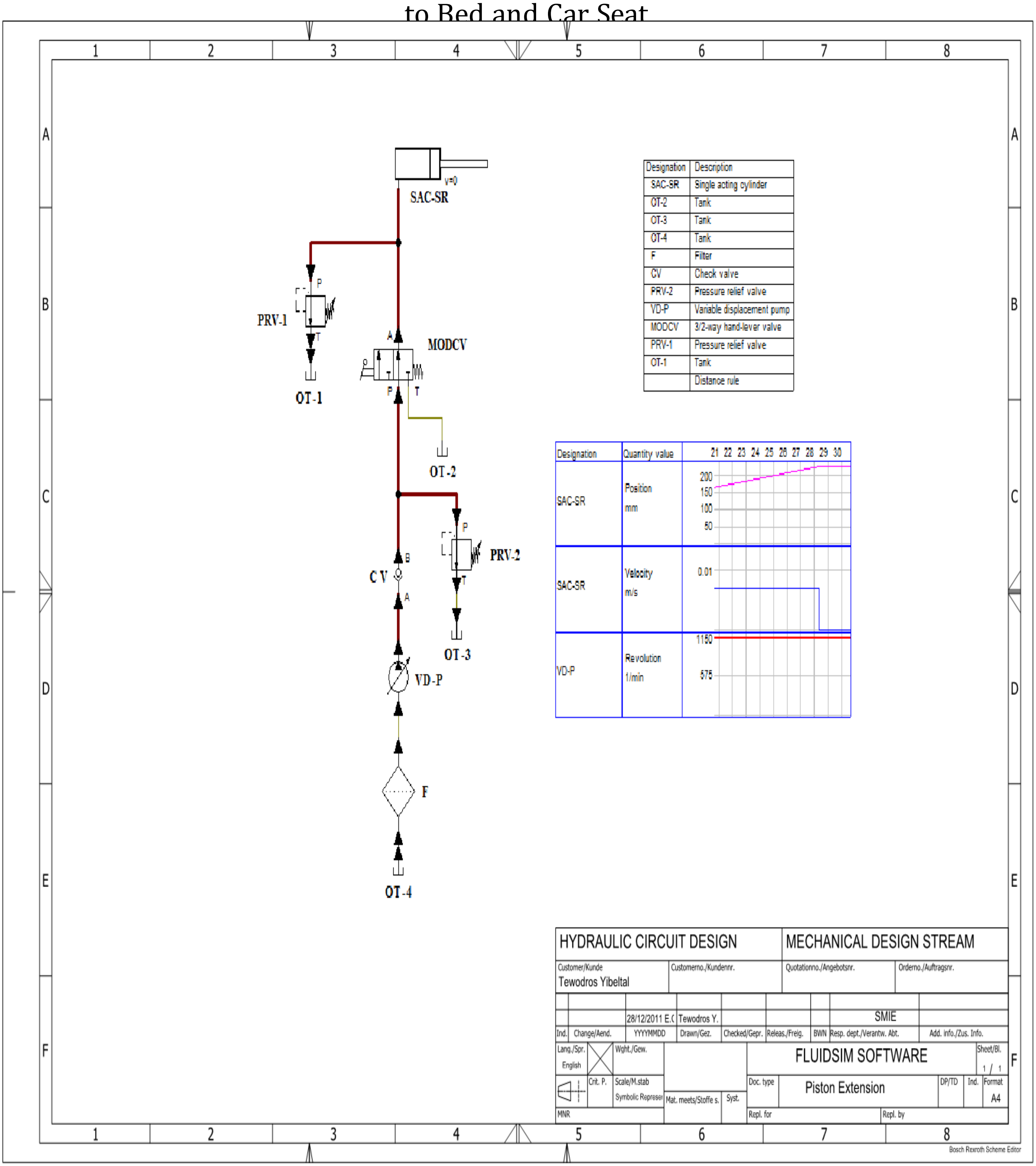
Pumps -A hydraulic pump is a mechanical source of power that Converts mechanical power into hydraulic energy (hydrostatic energy i.e., flow, pressure)

- For this study manually operated pumps have been selected, due to its high efficiency, cheap price and low maintenance cost.

Valves- are major component of the hydraulic control system that uses for the control of direction, flow rate and pressure of the hydraulic fluid in the entire hydraulic system. Thus,

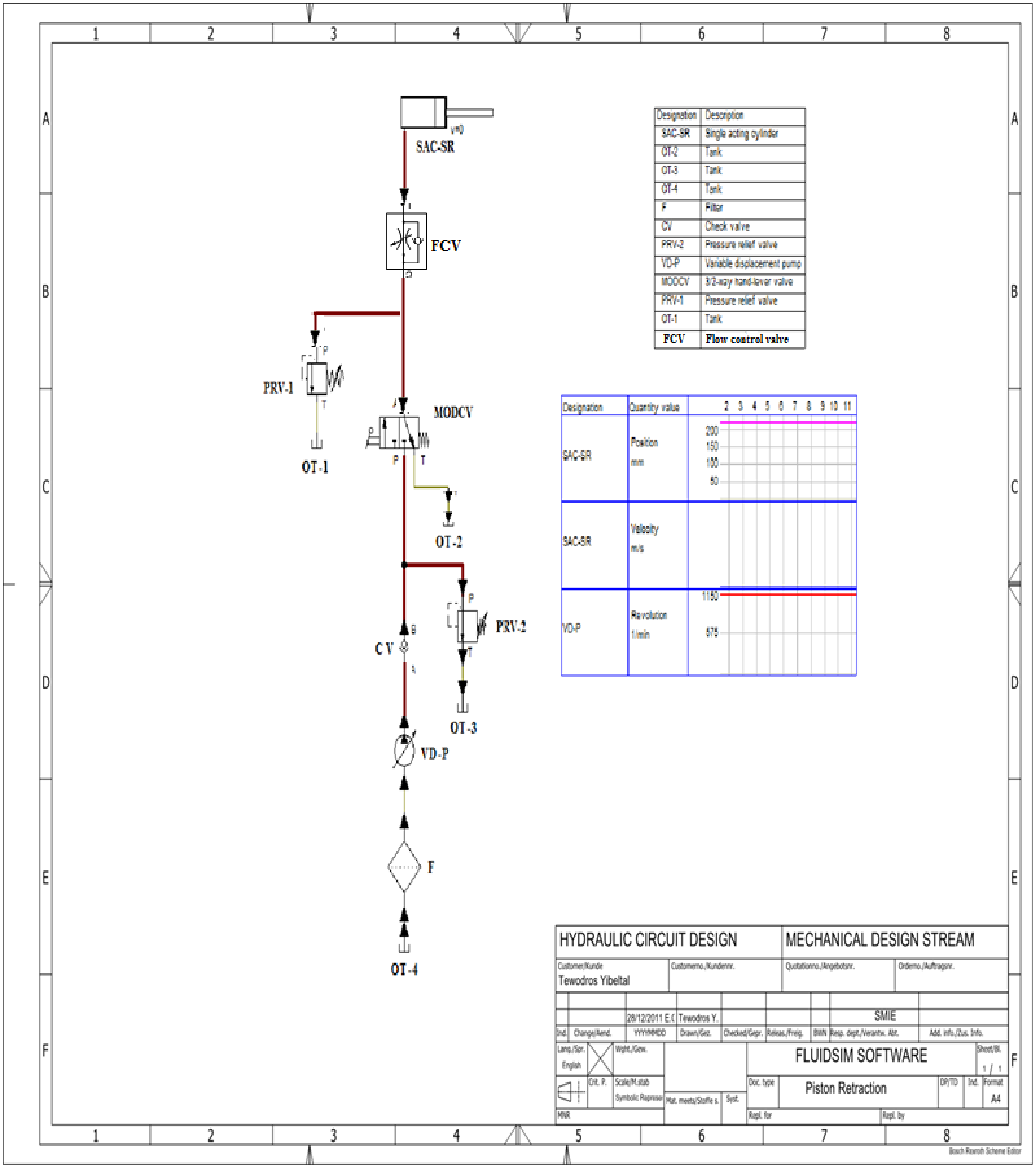
1. Directional control valves**:** are essentially used for distribution of energy in a hydraulic control system. These valves are used to control the start, stop and change in direction of flow of pressurized fluid.
    - For this study 3/2 manually operated directional control valve was selected and a check valves to change and control flow direction of the hydraulic fluids.
2. Pressure control valves**:** are protecting the system against such overpressure. Pressure relief valve, pressure reducing, sequence, unloading and counterbalance valve are different types of pressure control valves.
    - For this study Pressure Relief Valve (PRV) was selected for changing and controlling the pressures flow in the entire system.
3. Flow control valves-are used to protect the system against overflow of fluid in the Entire hydraulic system.

Hydraulic Tank/Reservoir**:** are component of hydraulic system which are used to store hydraulic fluid
Filters-are used to keep the fluid clean before entering into the entire hydraulic system with the help of pump. The oil in the filter can be modeled by a lumped volume or added to a lumped volume that describes the lines connected to the filter. The resistance of a filter is usually small and doesn‘t influence the dynamics of the complete system.



Designation	Description
SAC-SR	Single acting cylinder
OT-2	Tank
OT-3	Tank
OT-4	Tank
F	Filter
CV	Check valve
PRV-2	Pressure relief valve
VD-P	Variable displacement pump
MODCV	3/2-way hand-lever valve
PRV-1	Pressure relief valve
OT-1	Tank
	Distance rule

Figure 3.13 Hydraulic circuit Schematic diagrams during extending stroke



Designation	Description
SAC-SR	Single acting cylinder
OT-2	Tank
OT-3	Tank
OT-4	Tank
F	Filter
CV	Check valve
PRV-2	Pressure relief valve
VD-P	Variable displacement pump
MODCV	3/2-way hand-lever valve
PRV-1	Pressure relief valve
OT-1	Tank
FCV	**Flow control valve**

Figure 3.14 Hydraulic circuit Schematic diagrams during retracting stroke

3.7Working Principle of Single Acting Hydraulic Cylinder

Single acting hydraulic cylinders are the simplest form of hydraulic cylinder which is used for pulling, lifting, moving and holding the load. Single acting cylinder, as shown in figure below, will have one port i.e. cap end port. Single acting cylinder, as name indicates, will be operated hydraulically in one direction only. Hence piston will be operated hydraulically only in one direction i.e. during extension or forward direction. Retraction of cylinder will not be operated by hydraulic force but also it will be operated by mechanical force that is due to spring force For this study Single acting cylinder- Spring return type was selected due to its minimum cost and easy functionality.

The control of a single-acting, spring return cylinder using a three-way two-position manually actuated, spring offset direction-control valve (DCV). In the spring offset mode, full pump flow come from the oil tank through the filter and after that it crosses the check valve and the pressure-relief valve (PRV) go to DCV and then pump flow extends the cylinder. After full extension, pump flow goes through the relief valve. Deactivation of the DCV allows the cylinder to retract as the DCV shifts into its spring offset mode. Whereas if there is any over flow of oil from the manually operated pump the overflow oil directly returned back to the tank with the help of PRV-2. When the valve is manually actuated into its next position the spring in the rod end of the cylinder retracts the piston as the oil from the blank end drains back into the oil tank.

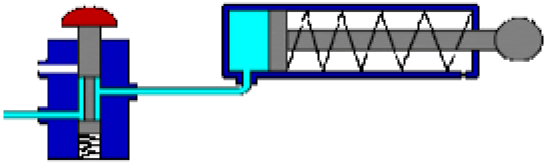


Figure 3.15 Single acting cylinder- Spring return

Extending Stroke

Single acting hydraulic cylinder will have one piston within a cylindrical housing. When hydraulic oil will be supplied to its cap end port, hydraulic pressure force will be applied over the piston or plunger and hence piston will be extended and this stroke of cylinder will be termed as forward stroke.

Retracting Stroke

During retraction of cylinder, mechanical force will be there (*i.e* spring force) to push back the piston to its complete retracted position. Once hydraulic pressure will be released and hydraulic fluid will be directed to reservoir from cylinder, piston will be retracted by spring force.

Chapter Four

Result and Discussion Using Software Analysis Results

Here is the geometrical analysis done to show the kinematics parameters (linear velocity, rotational velocity, angular position, linear and angular acceleration) relationship in each other of the hydraulic scissor lift mechanism.

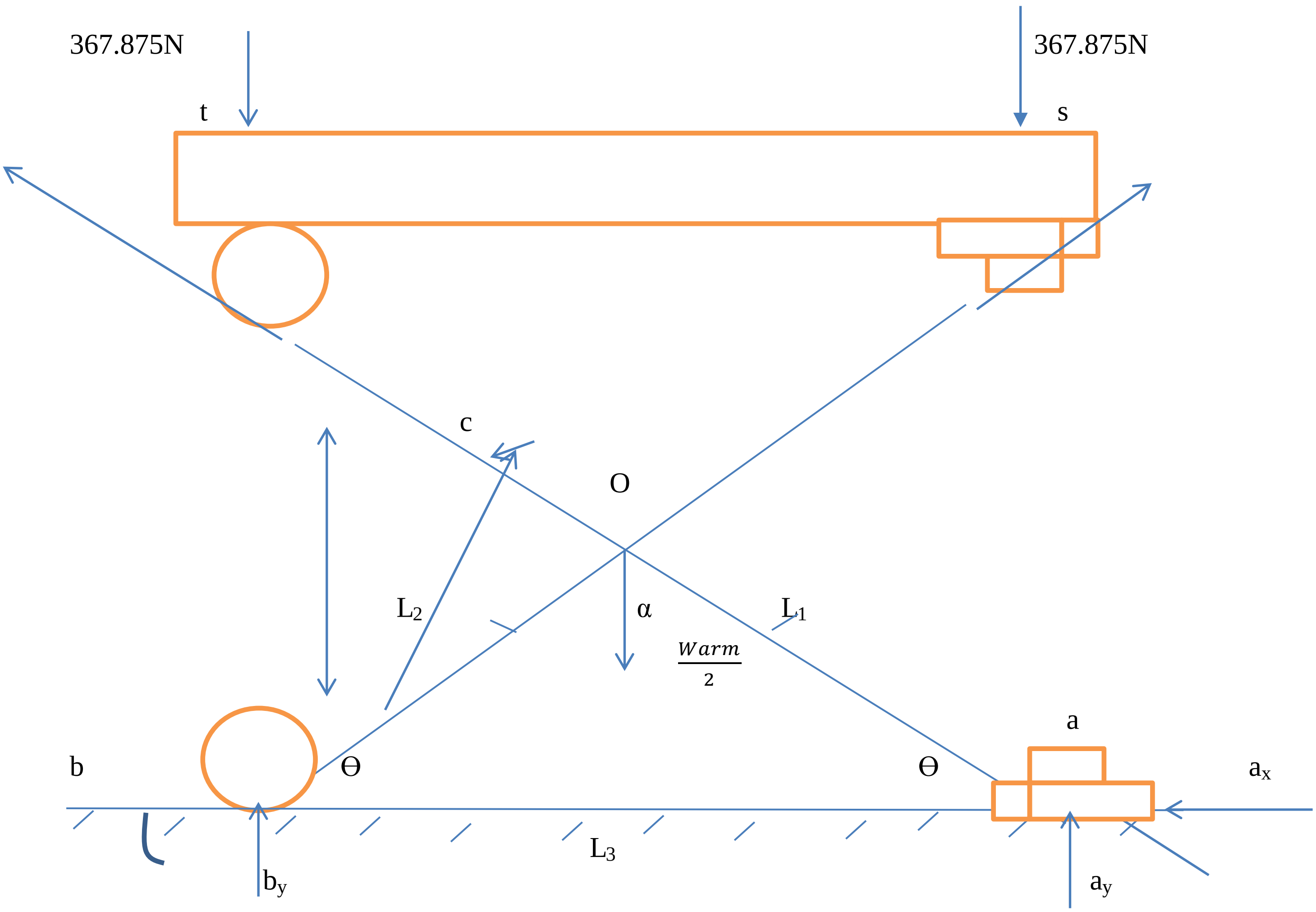


Figure4.1 Triangular linkage diagram of the hydraulic scissor lift mechanism

The lift-up mechanism driven by a hydraulic scissor lift is shown in Fig. the triangular linkages, where two links are shaped similar and dominate the lift-up mechanism span. The actuator and one link (L1) are joined by a crankshaft. When the actuator pushes or pulls the crankshaft, link L1 slide along the linear guides and contact with the rollers. The whole mechanism, similar to the motion-generation cam (Erdman et al., 1984), imparts the linear motion of the piston shaft to the linkages, which provide the lift-up mechanism with the general plane motion. Two linkages connected with two pins on the seat supporting frame configure another pairs of triangular linkages keeping the seat with horizontal attitude as the lift-up mechanism up and down. Kinematic analysis of the hydraulic scissor lift linkage mechanisms is done with Matlab software as shown below.

Here the input parameters of the mechanism at the closed and maximum extension position of the scissor lift:

At closed position		At maximum elevation	
Seat plate size (L*W*H*t)	(438*400*40*4mm)	Seat plate size (L*W*H*t)	(438*400*40*4mm)
Effective scissor arm size (L*W*t)	(420*20*10mm)	Effective scissor arm size (L*W*t)	(420*20*10mm)
Elevation from the base plate	80mm	Elevation from the base plate	300mm
Angle of the scissor arm with the horizontal plane(□)	11^0	Angle of the scissor arm with the horizontal plane(□)	45.6^0
Force of cylinder (F_c)	13307.83 N	Force of cylinder(F_c)	2995.71N
Total applied load(F)	1471.5N	Total applied load(F)	1471.5N
Reaction load (a_x, a_y and b_y)	(98.43N, 374.53N, 374.54N)	Reaction load (a_x, a_y and b_y)	(75.84N, 74.53N, 374.54N)

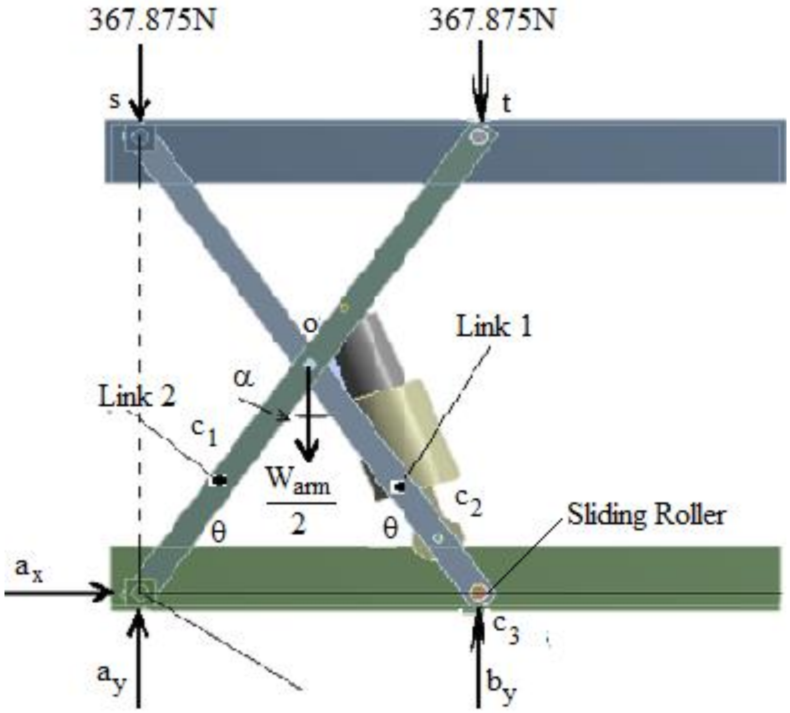


Figure 4.2Linear and Angular description of scissor lift mechanism

Where as

θ -Angle of link 1

α -Joint angle of link 1 and link 2

C_1=Center of mass of link 1

C_2= Center of mass of link 2

C_3= Center of mass of sliding roller 3

4.1 Result and Discussion of Dynamics Analysis Using Matlab Software

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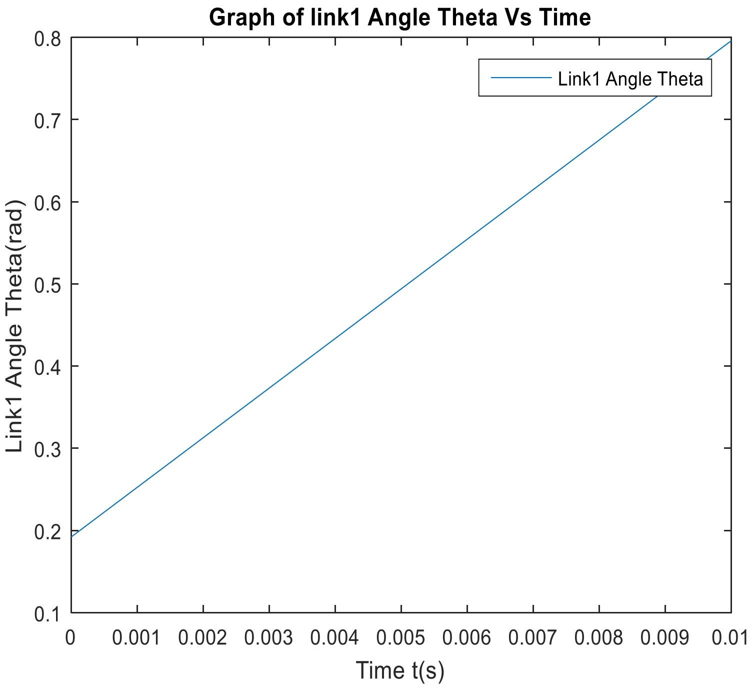
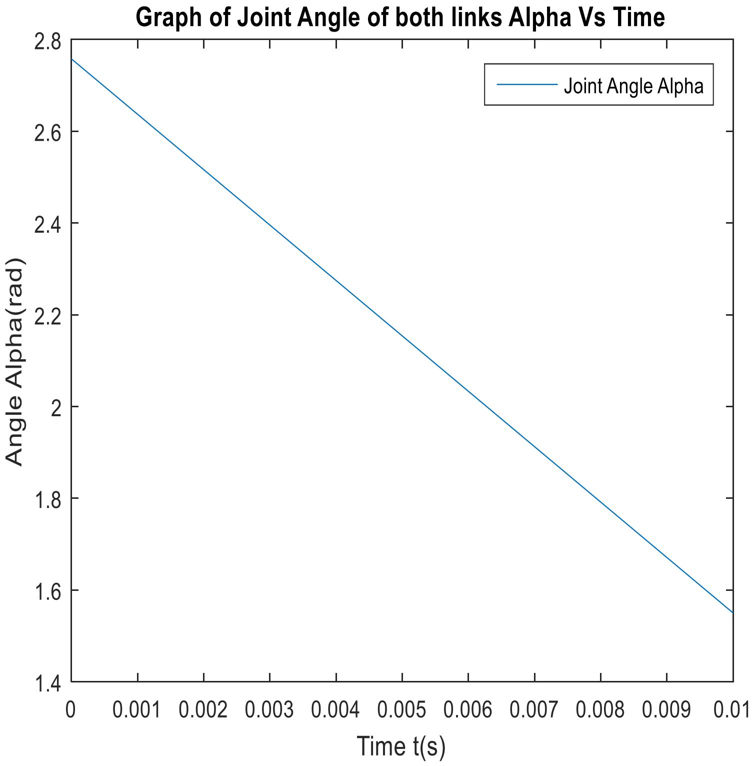
The result shown on graph 4.1 describes that angle Theta of link1 from the x-axis increase with time until the wheelchair seat reaches its proposed design height for easy transfer for the patient from bed, car seat to wheelchair and vice versa.

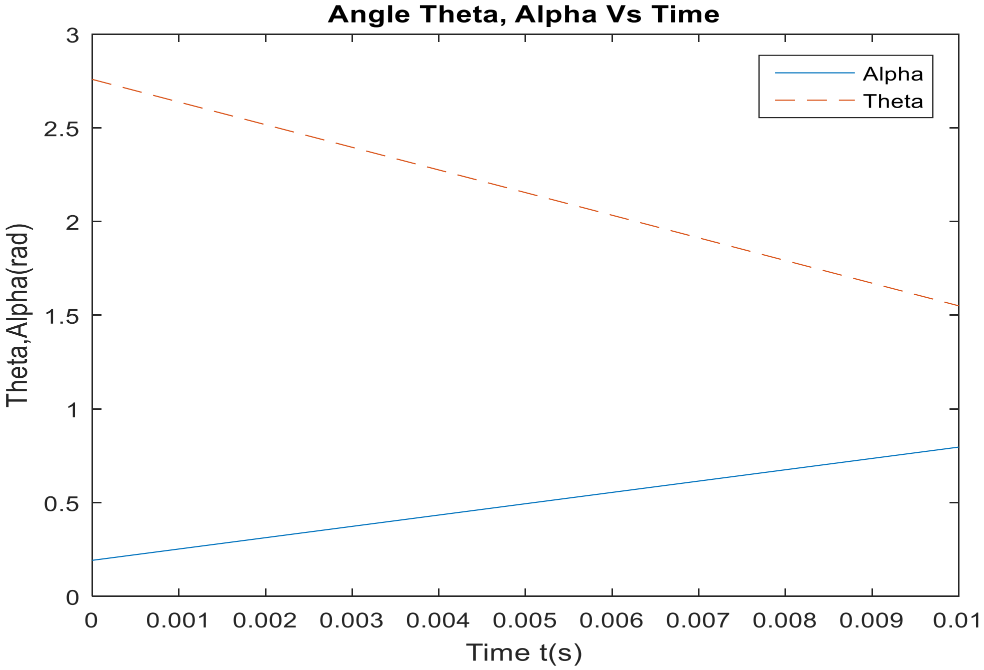


Graph4.1 Angle thetaVs Time

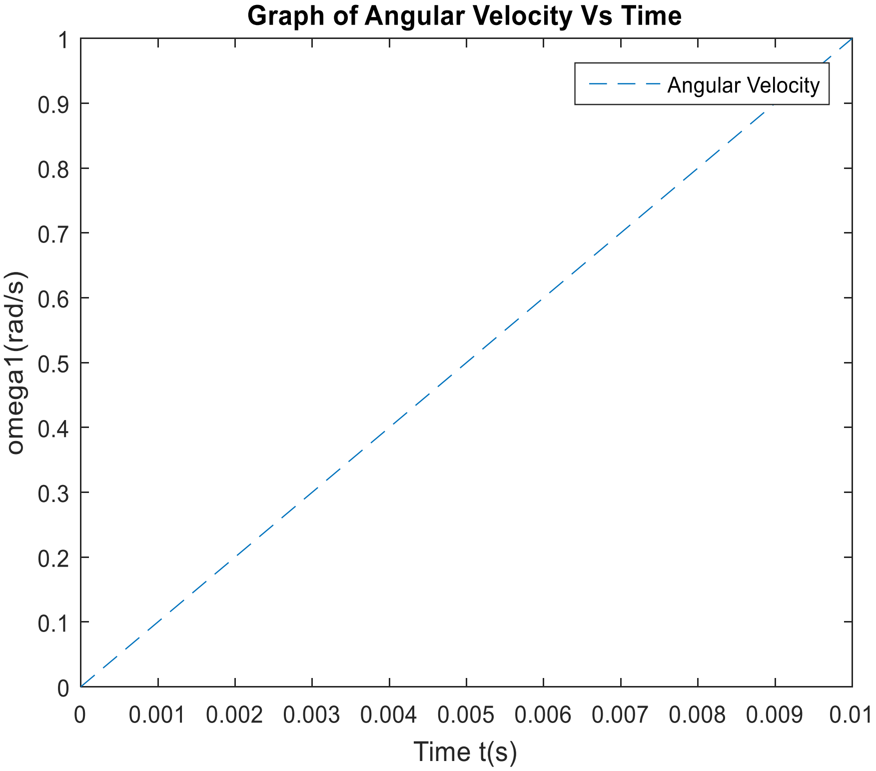
From graph 4.2 As time increases the scissor lift rises up the wheelchair seat and then the joint angle Alpha b/n the two link decreases until it reaches its maximum point of action.



Graph 4.2 Angle alpha Vs Time

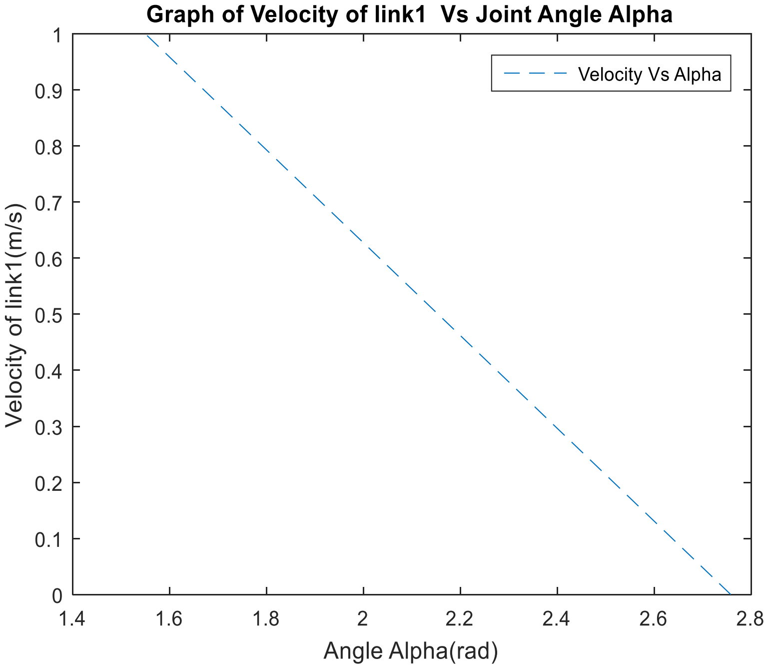


Graph 4.3 Both Angle theta and alpha Vs Time



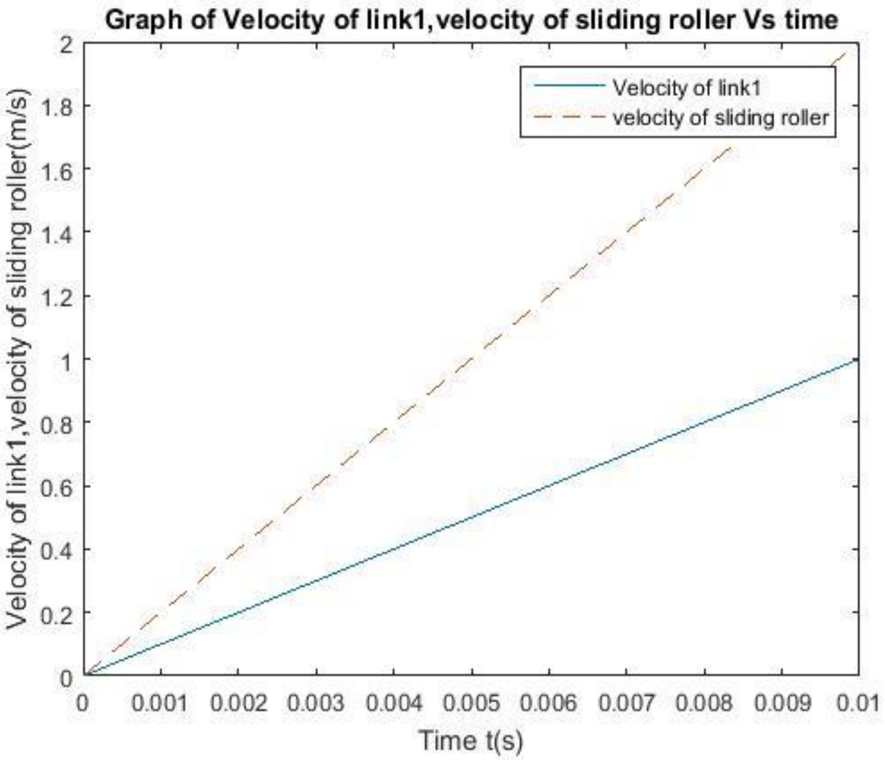
Graph 4.4 Angular velocity Vs Time

From graph 4.4 the rate of angle Theta (Omega 1) of link 1 increases from zero point of action to its maximum height of the lifting mechanism for easy transfer of the patient with respect to increasing value time.



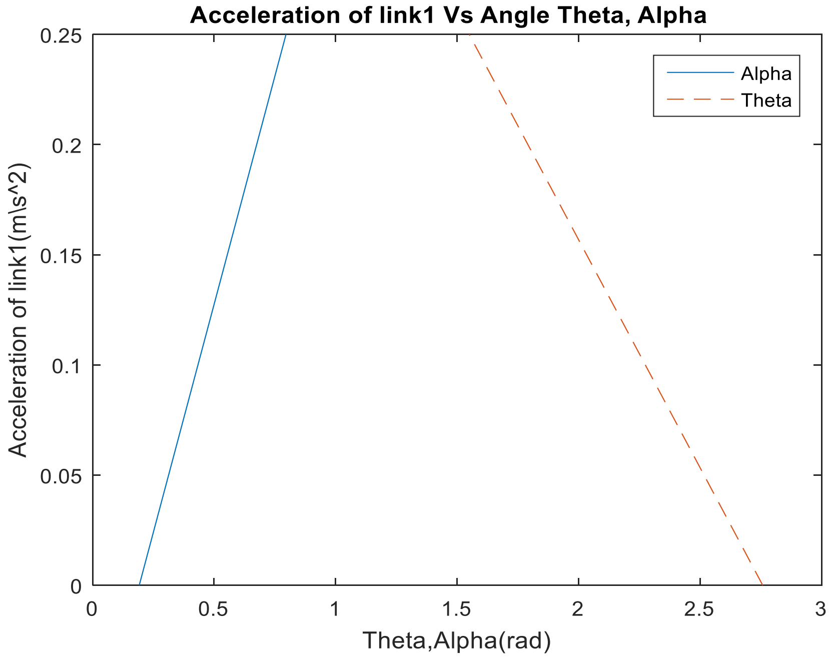
Observations from graph 4.5, when the scissor lift rises up with the result of increasing velocity the hydraulic piston the angle b/n the two links (link 1 & link 2) decreases until the scissor lift achieve at the maximum height of the wheelchair seat for easy transfer of the patient.

Graph 4.5 Velocity of link1Vs Angle alpha



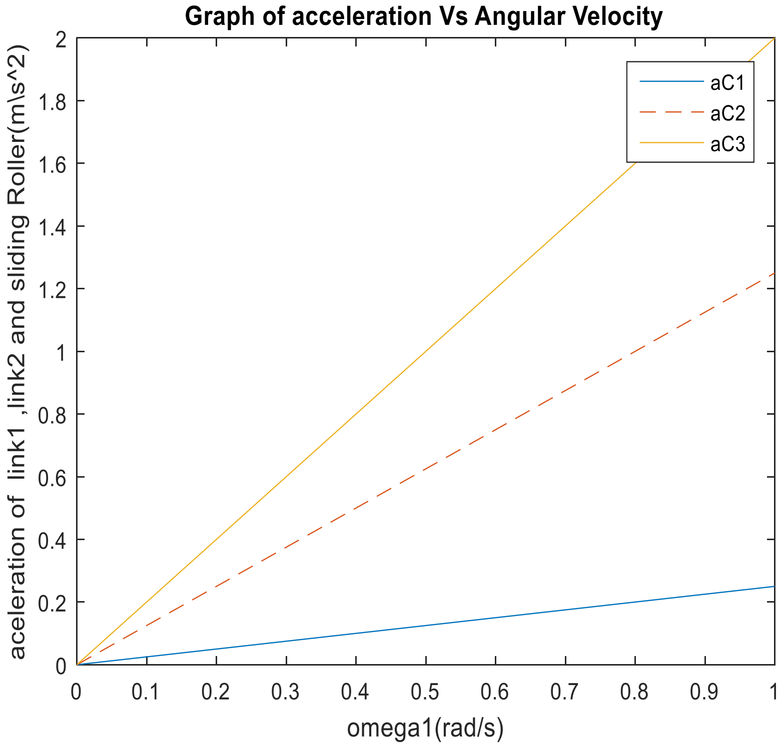
Graph 4.6 Velocity of link 1 & 2 Vs Time

Graph 4.6 compares the increasing velocity of link 1 and sliding roller with the increasing interval time.



graph 4.7 describe that when the link1 angle Theta increases and Joint Angle Alpha decreases the acceleration of link 1 increase its value up to which the scissor lift reaches at the maximum proposed design height.

Graph 4.7 Acceleration of link 1 Vs Angle theta &alpha



Graph 4.8 Acceleration of link 1,2& 3 Vs Angular velocity

Graph 4.8 states comparison of increasing acceleration of the two scissor links and sliding roller with respect to rotational velocity (omega 1) of link1.

4.2 Result and Discussion of Deflection, Force and Stress Analysis of the Hydraulic Scissor Lift Using Ansys Software

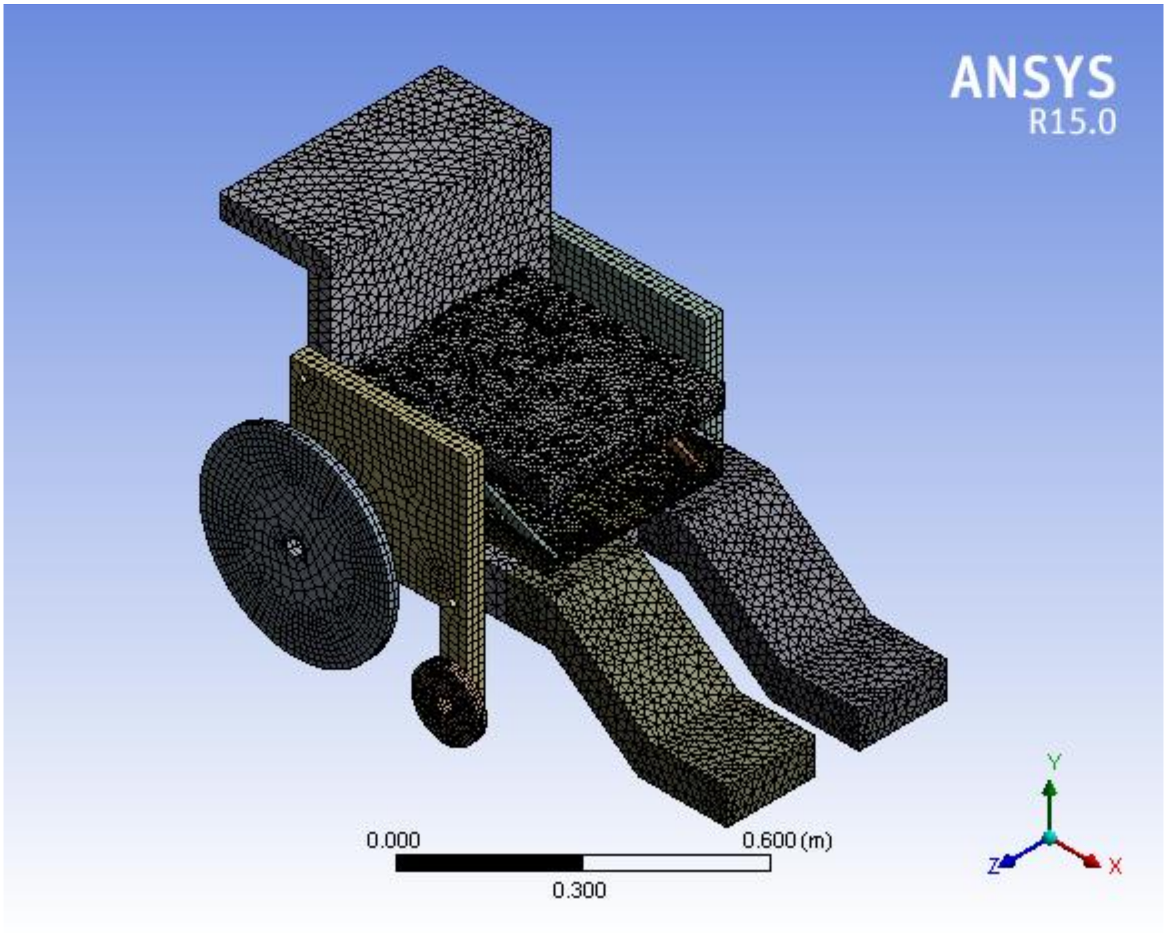


Figure 4.3Model design under meshing

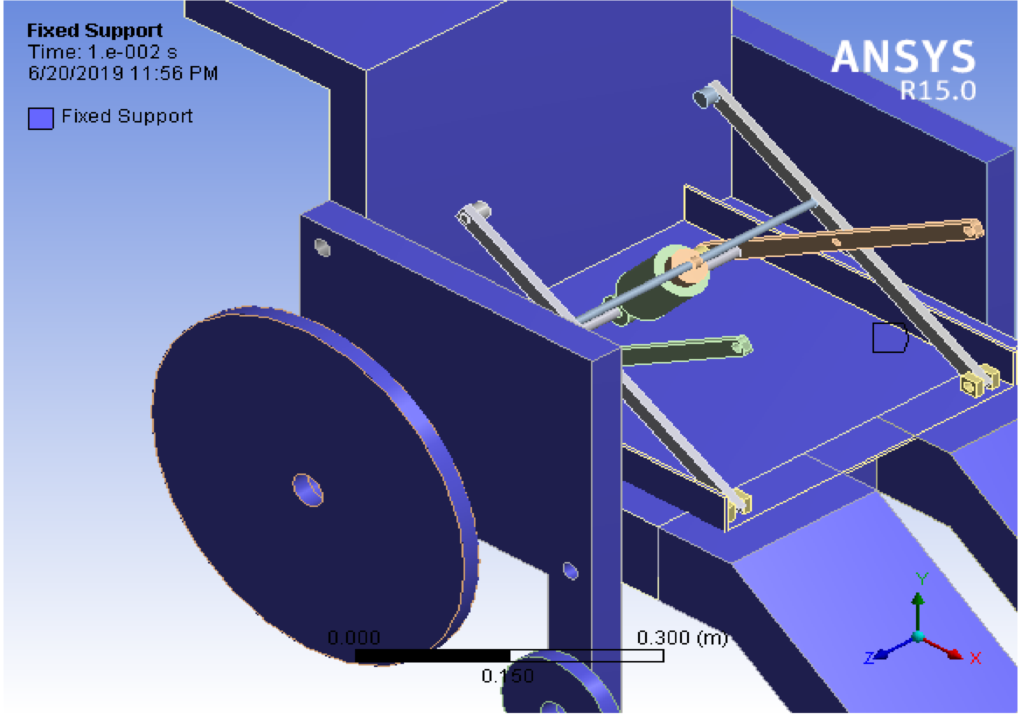


Figure 4.4 Model design under fixed support

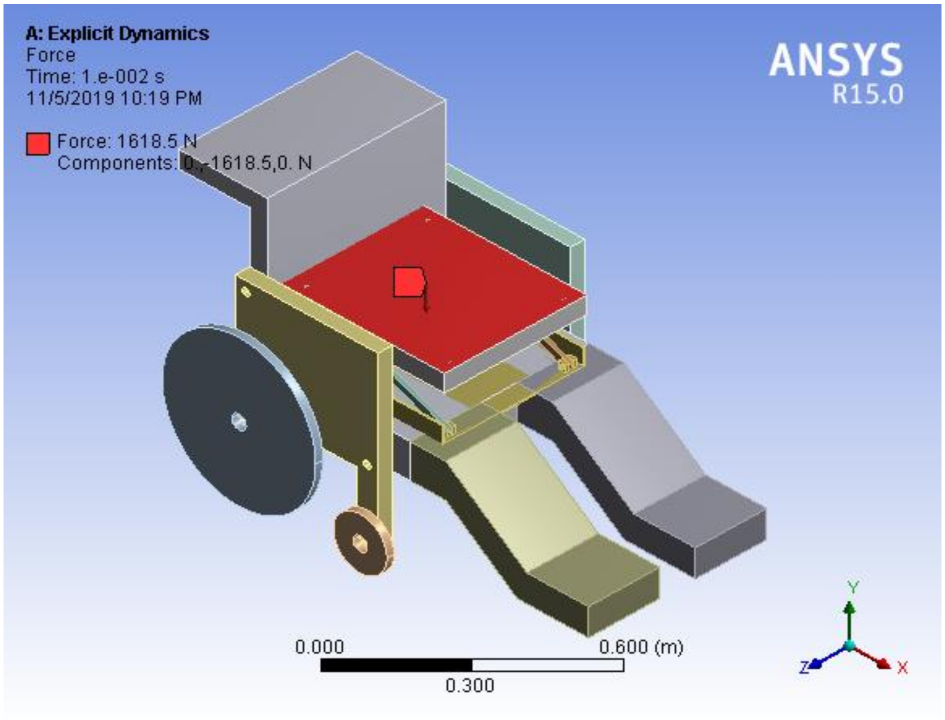


Figure 4.5Applied force on the flat seat plate of scissor lift

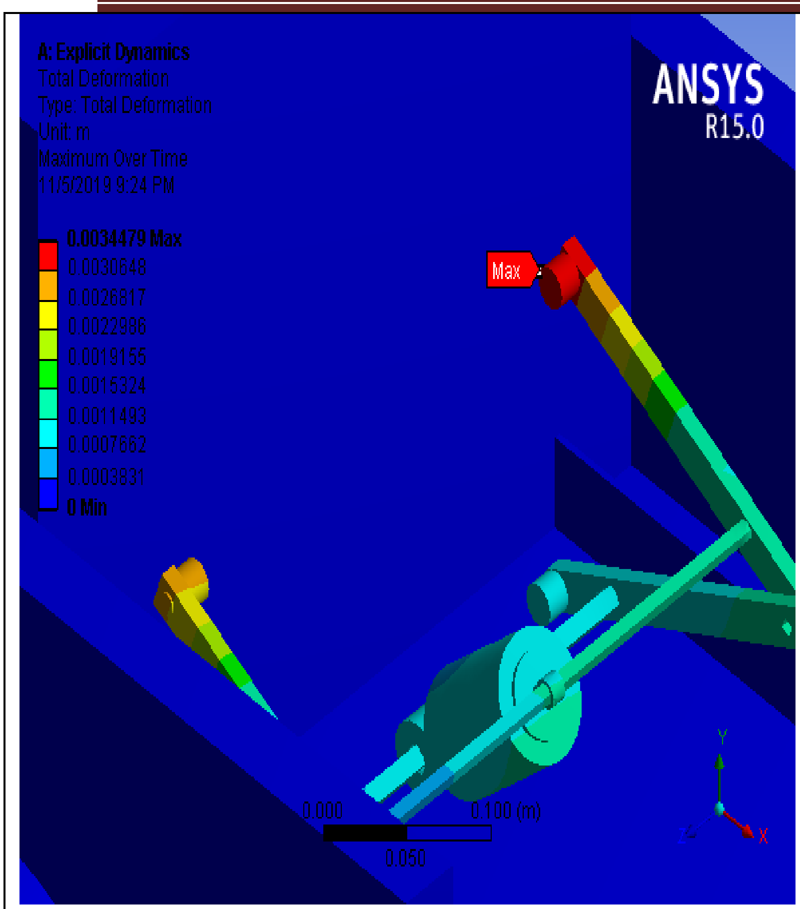
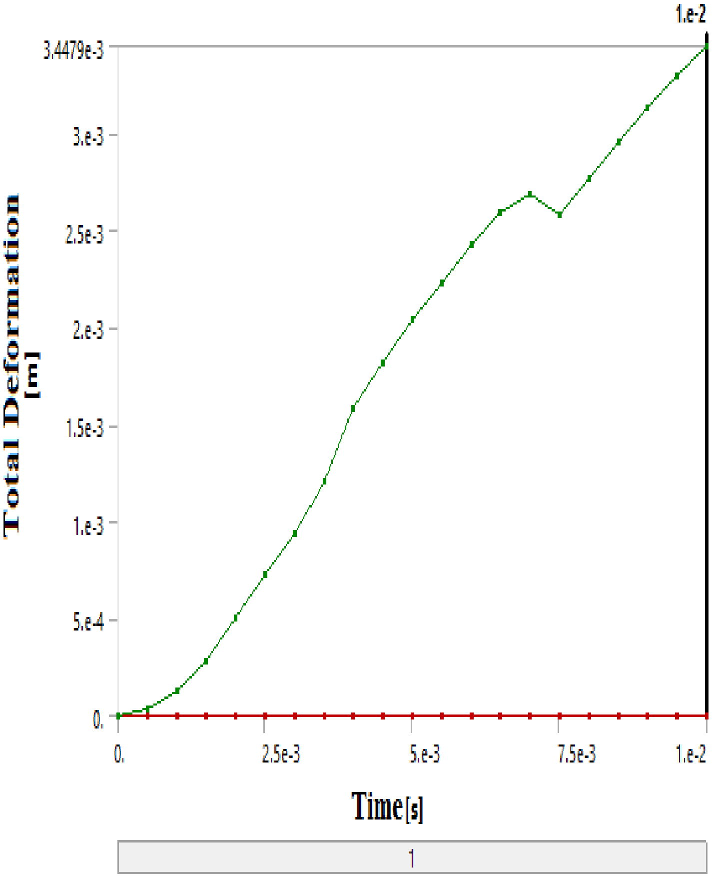


Figure 4.6Total deformation pattern for scissor lift mechanism



Graph 4.9 Total deformation of the scissor lift mechanism

The above simulation indicates that deformation occurs due to direct axial load acting on the wheelchair seat. As we see from the above figure, the simulation with light blue contour indicates less deformation zone in the mechanism whereas as time rises the simulation contour increases from light green to its maximum deformation zone of red contour at the time of maximum load is acting on the wheelchair sit, the scissor lift mechanism tends to deformation as time increases that deformation also increases linearly and comes to maximum at top back part of the mechanism which have roller end on the right side due to its motion on the sit the tendency to deform increases its value and reach 0.0034479mm at the time of 1e-2 sec which is not greater than the material physical property that tends to deformation that doesn't cause failure on the design mechanism, so that design is safe

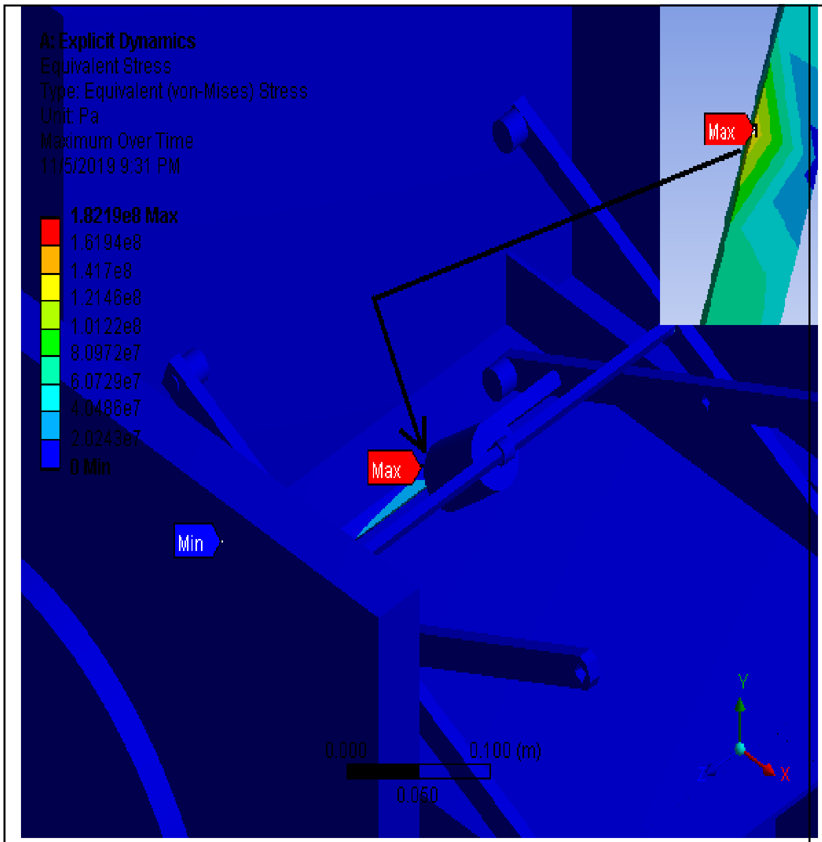
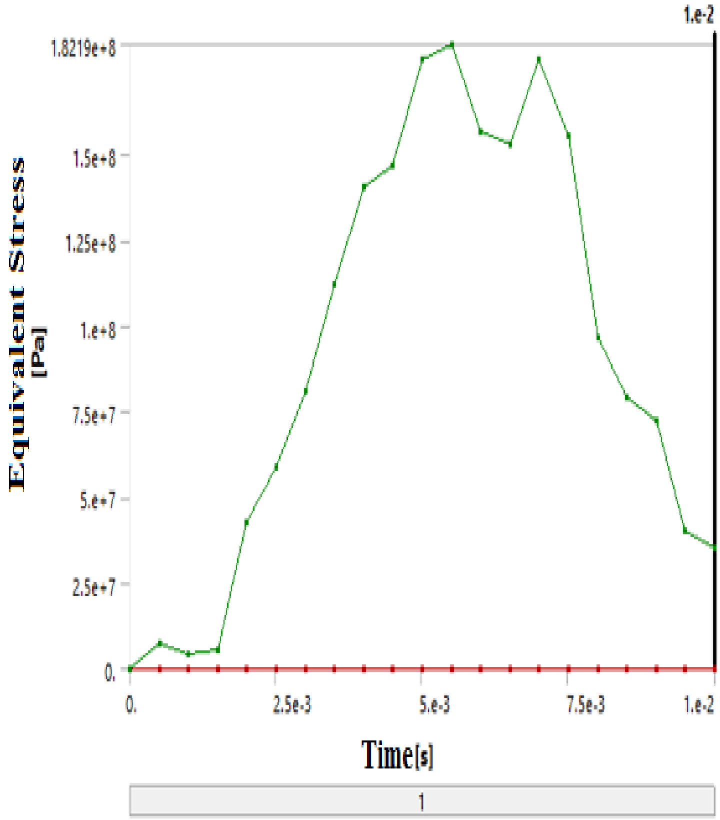


Figure 4.7 Equivalent stress analysis of the model design



Graph 4.10 Equivalent stress of the scissor lift mechanism

From the result seen as the user starts to raise the scissor lift the tensile stresses created on the mechanism gradually increases from the 0 stress value with blue contour on the simulation to its maximum value which is colored with the red contour. From this I can concluded that as time rises the equivalent stress increases until it reaches 2.346e-3 seconds then decreases as it reaches 4.468e-3 seconds due to uniformity of the applied load as well as stability of the users after this point it increases linearly and reaches maximum value of 1.8219e+008 Pa at time of 5.5e-003 seconds and then it decreases it’s result up to the final estimated time for simulation. From the above listed results, it can summarize that the equivalent stress occurred on the lifting mechanism doesn’t exceed from selected material yield strength (586Mpa) value, so that the mechanism is safe.

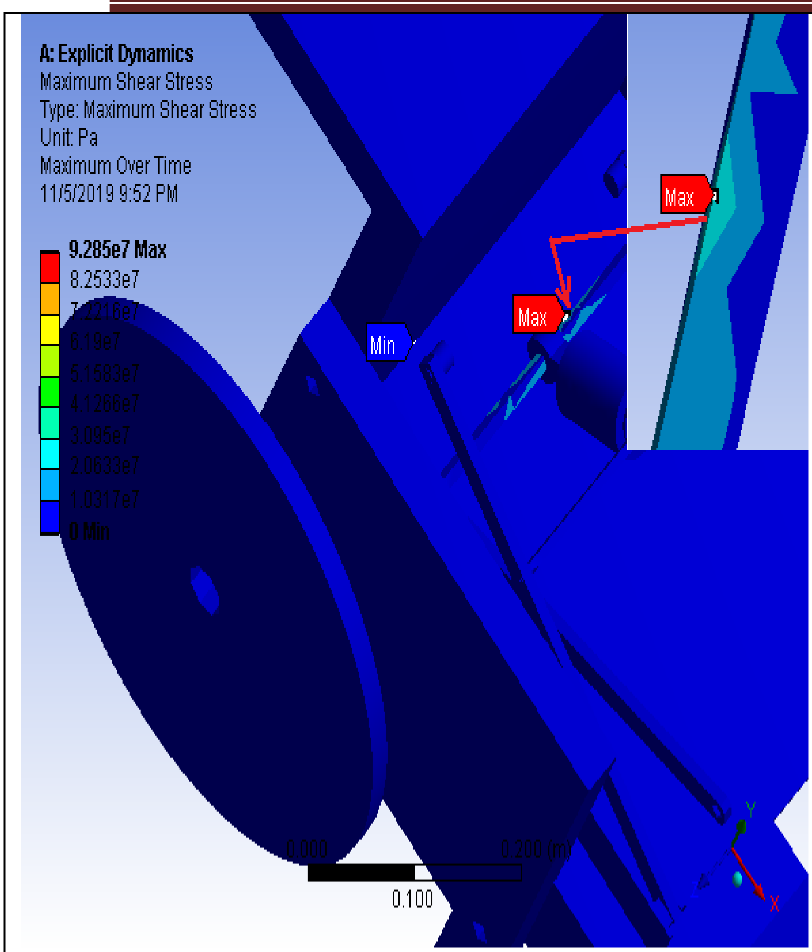
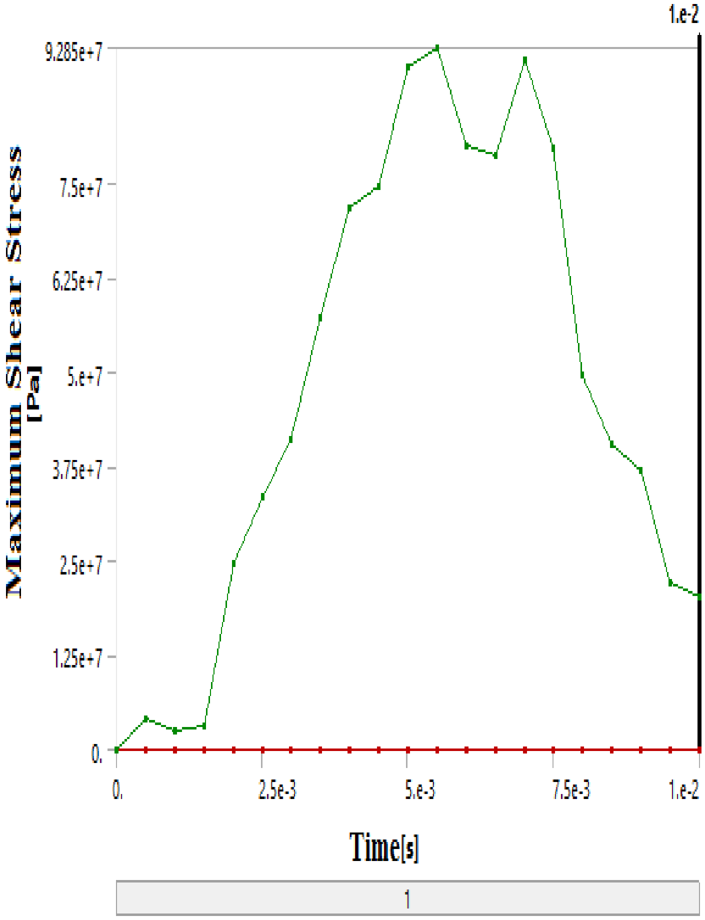


Figure 4.8 Maximum shear stress analysis of the model



Graph 4.11Maximum shear stress

The maximum Shear stresses on the whole lifting mechanism are created by direct shear due to the externally applied load on the wheelchair seat. The action on the wheelchair seat subjected to shear is a tendency to cut the element by exerting a stress downward on one face while simultaneously exerting a stress upward on the opposite, parallel face. from this simulation it was analyzed that the maximum shear stress result obtained was fluctuating from its light blue contour, which was having less value of shear stress up to its maximum result with red contour that happens at the upper joint of the shaft that held the hydraulic cylinder part of the scissor lift having a maximum result of 9.285e+007 Pa at 5.5e-003 second instant of time, which is less than the allowable shear stress(326Mpa), so the design is safe.

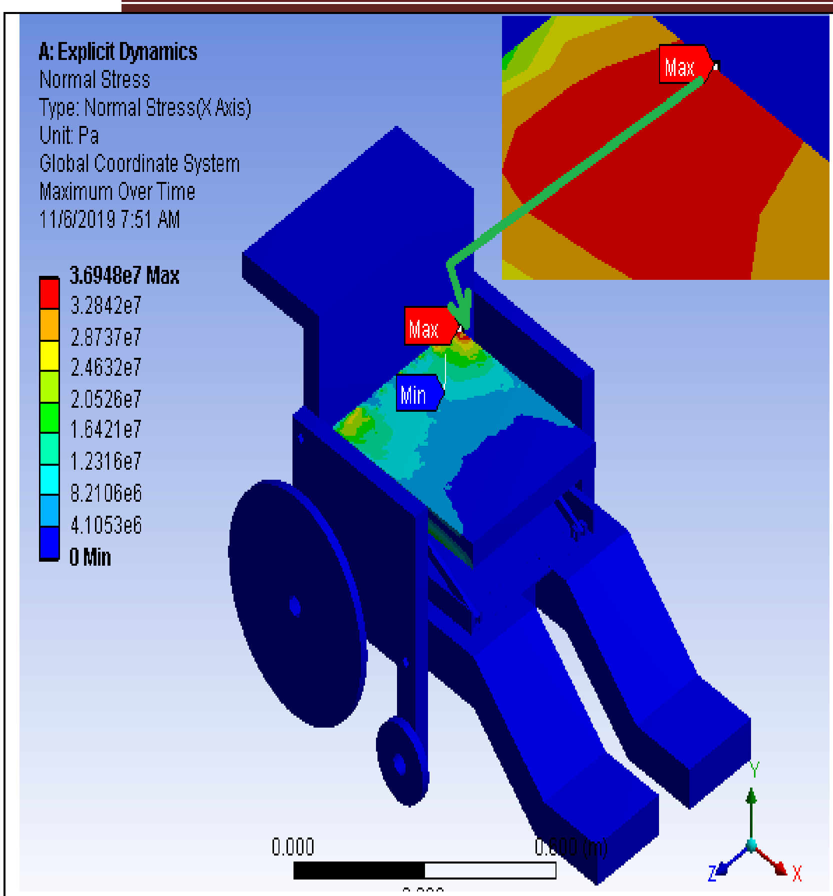
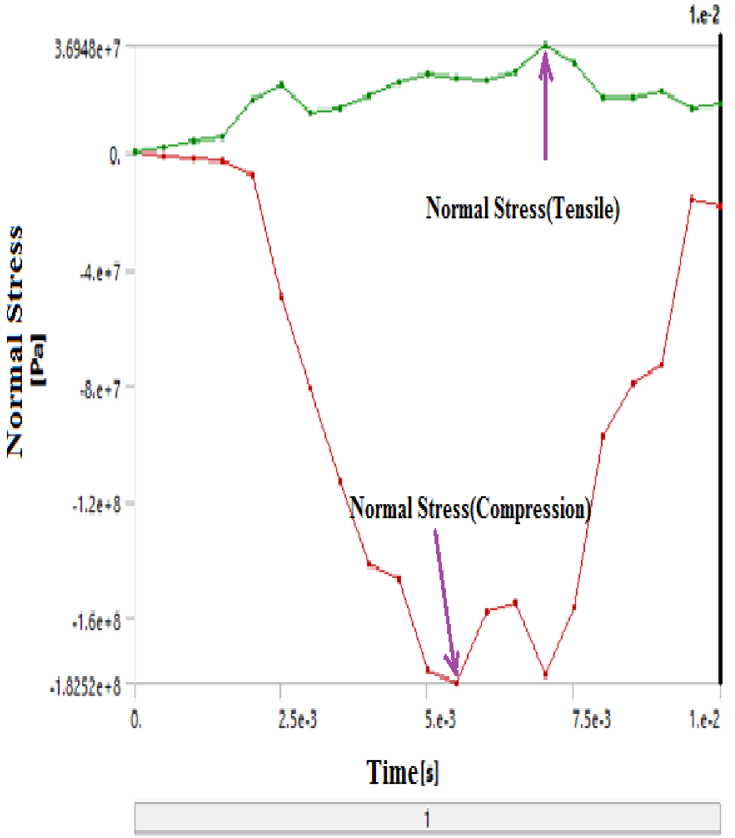


Figure 4.9 Normal stress analysis of the model



Graph 4.12 Normal stress

A plate is a structure that carries loads transverse to its axis. Such loads produce bending moments in the plate surface, which result in the development of normal stresses. These normal stresses are tensile results on the transverse surface and compressive result on the direction of applied load. The normal stress in a plate cross section will occur in the part farthest from the neutral axis of the section. The normal stress that acts along the X-axis will have Tensile and compression result values due to it the stress result taken from both face of the plate, which the applied load is acting.as we seen from the above simulation tensile and compression normal stresses (3.6948e+007Pa and -1.8252e+008Pa) resulted on the upper and lower part of the sit plate, which is attached with the scissor arms at the7.e-003 and 5.5e-003 second instant of time respectively. The above result obtained indicates that both the tensile and compression value are less than the ultimate stress value of the selected material, so that the estimated design is safe.

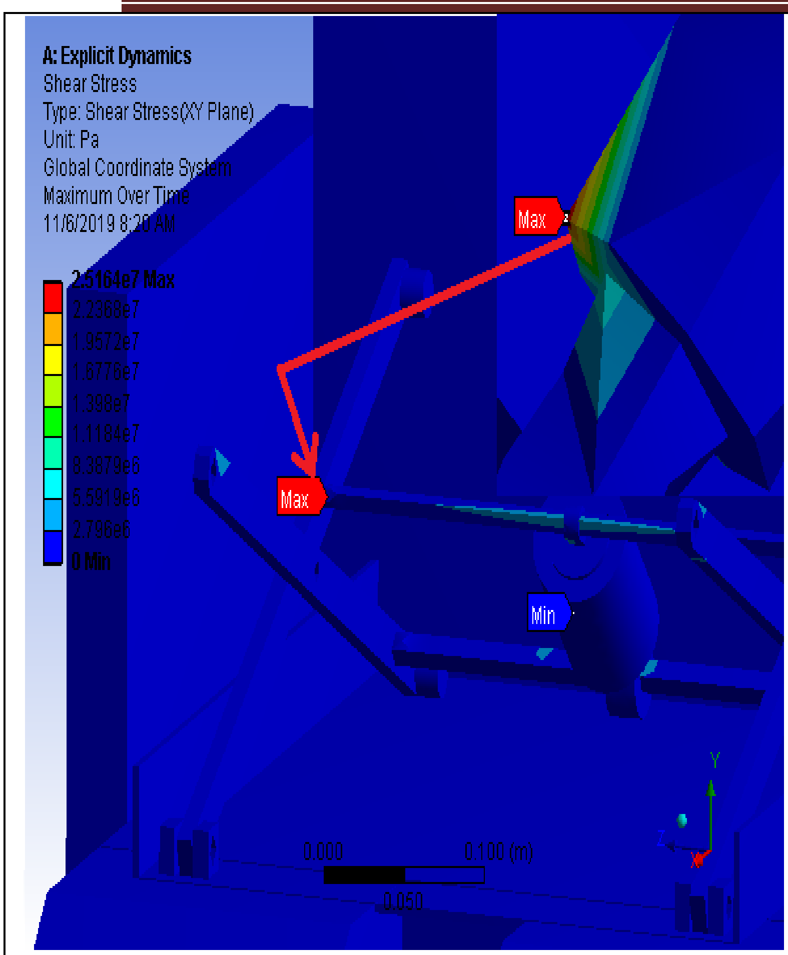
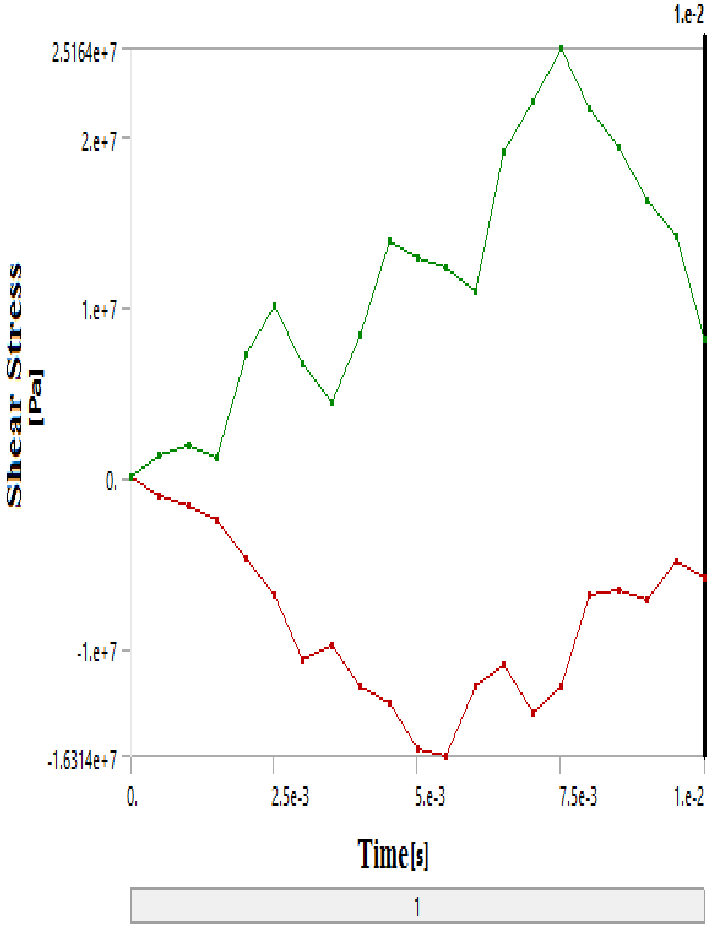


Figure 4.10 Shear stress analysis of the model



Graph 4.13 Shear stress

Here Shear stresses on the XY plane are created by direct shear due to the externally applied load on the wheelchair seat. The action on the XY plane subjected to shear is a tendency to cut the element by exerting a stress downward on one face while simultaneously exerting a stress upward on the opposite, parallel face. This action is that of a simple pair of shears on scissors, but note that if only one pair of shear stresses acts on a stress element, it will not be in equilibrium. Rather, it will tend to change in structure. Due to this here it has two components of shear stresses the XY and reverse (XY) plane. From the simulation the shear stresses result obtained were acting along the two opposite face specified plane have maximum values of (2.5164e+007 and -1.6314e+007) that occurs on the upper and lower part of the shaft that holds the cylinder piston rod on the left side of lifting mechanism and also on the lower right part of the scissor lift at 7.5.e-003and 5.5e-003second instant of time respectively. the (-ve) value resulted due to the shear stress result created on the opposite side of the shear plane which is less the allowable stress value of the selected materials, so that the design is safe.

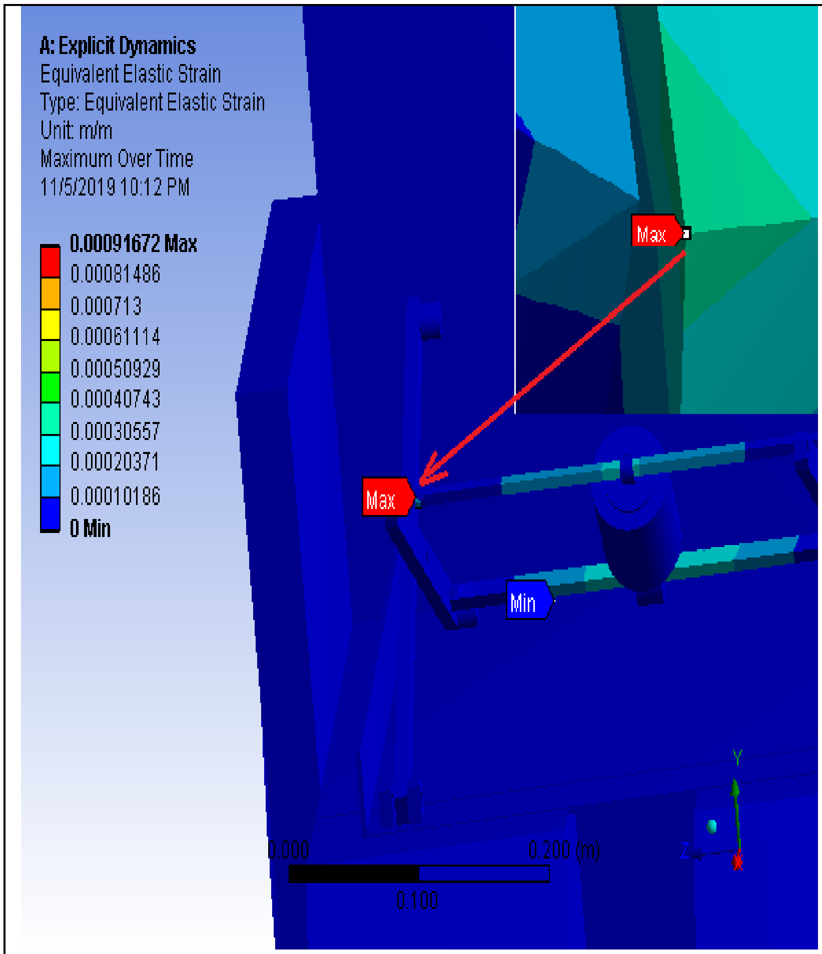
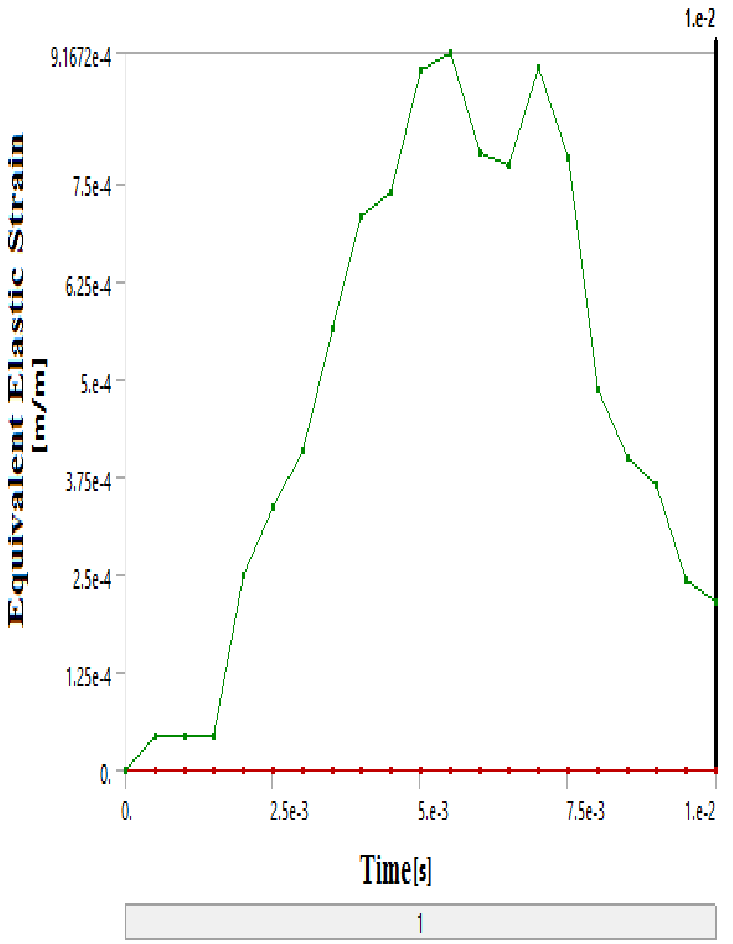


Figure 4.11 Equivalent elastic strain analysis of the model



Graph 4.14 Equivalent elastic strain

The result obtained from the simulation of the mechanism indicates that the maximum elastic strain occurs at the upper middle joint of the shaft the holds the piston rod of the scissor lift (i.e. in b/n roller and scissor arm joint) and minimum at rare(back-part) of the wheelchair seat. Generally the elastic strain result varies within the given interval of time, which is fluctuating it result until it reaches maximum value of 9.1672e-004m/m at 5.5e-003sec instant of time and then the elastic strain value decreases up to end of the simulation time.

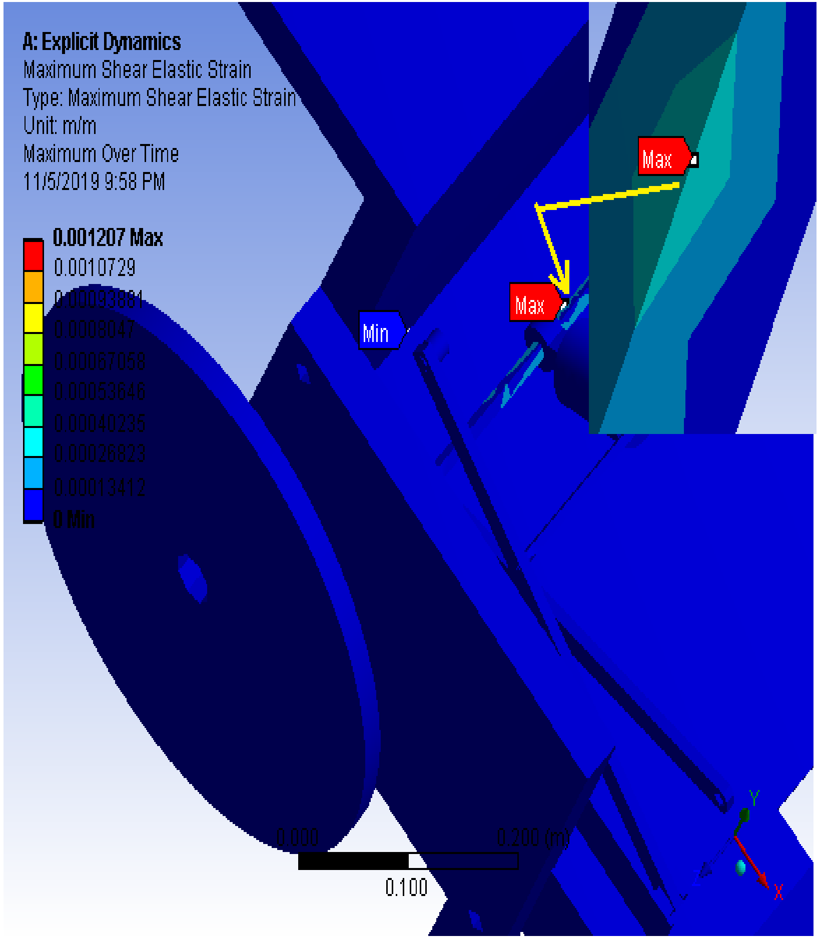
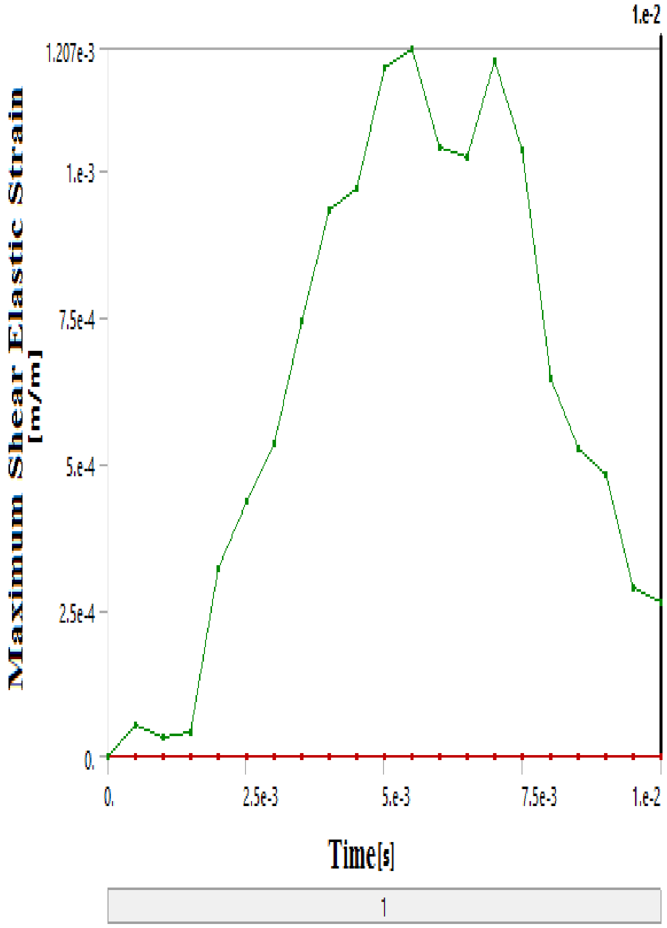


Fig.4.12 Maximum shear elastic strain analysis of the model



Graph 4.15 Maximum shear elastic Strain

The maximum shear elastic strain is change in shape between two line segments originally perpendicular acting on the lifting mechanism are created by direct axial load on the wheelchair seat. The action on the sitting plate subjected to change in shape on the plane to deform the element by exerting a downward force on one face while simultaneously exerting an upward force on the opposite parallel face. The Ansys simulation and graph shows that the maximum shear elastic strain appeared around the middle supporting rods that are holding the hydraulic cylinder and back-part of the wheelchair seat respectively which is created due to the maximum loads transferred from the scissors arm. The result values are fluctuating from time to time which is increasing linearly until it reaches 2.5e-3 sec and then it decreases it reaches to 4.5e-3 sec then it increases its value until it reaches its maximum value of 1.207e-003m/m at 5.5e-003sec instant of time after this it decreases up to end time of the simulation.

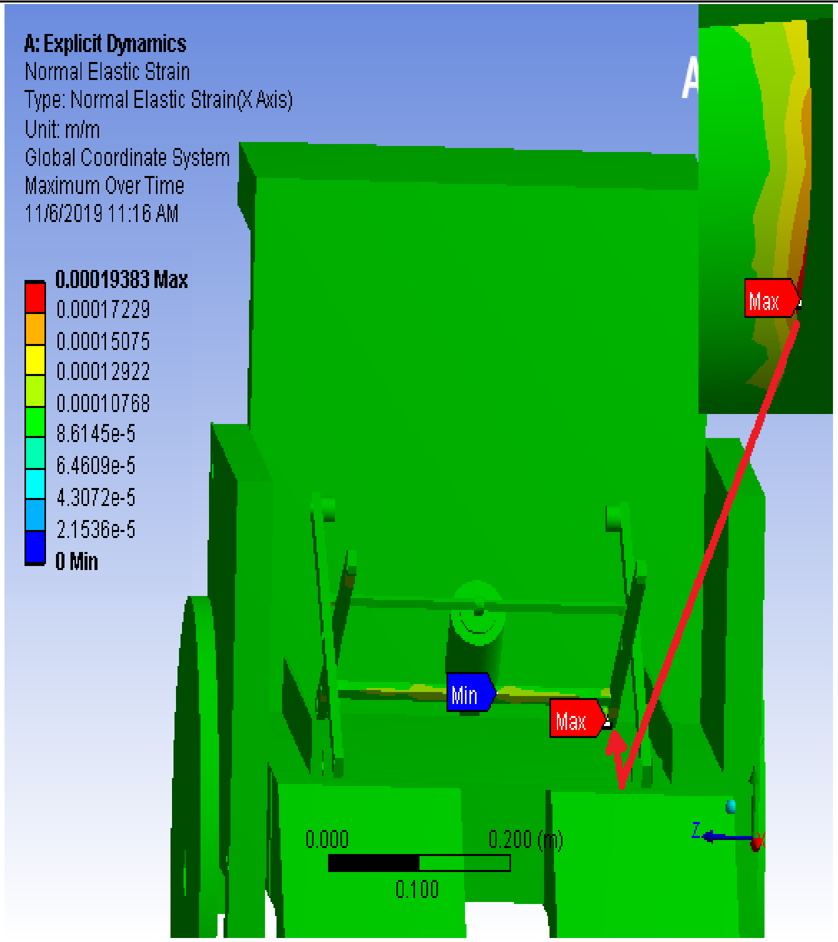
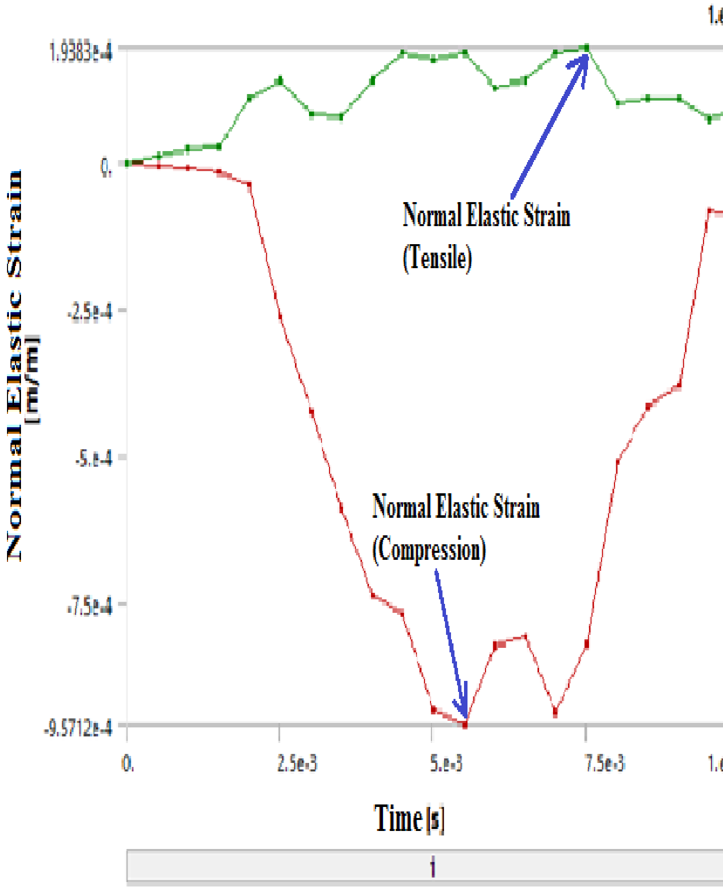


Figure 4.13 Normal elastic strain analysis of the model



Graph 4.16 Normal elastic strain

Normal elastic strain is elongation or contraction of a line segment in which the distorted body returns to its original shape and size when the deforming force is removed. Since this strain component is created due the applied load on the sit plate along a single axis (X-axis) it will have both tensile and compression components on the two face of the wheelchair sit that the applied load is acting on it having the +Ve and -–Ve direction of the estimated axis. From the simulation its analyzed, that the Tensile normal elastic strain result occurred at the lower part of the mechanism, which is on the right side of the scissor arm & roller joint end. Whereas, the compression result occurs at the lower joint part of the scissor lift having a values of 1.9383e-004 & -9.5712e-004 at the 7.5.e-003 sec and 5.5e-003sec instant of time respectively.

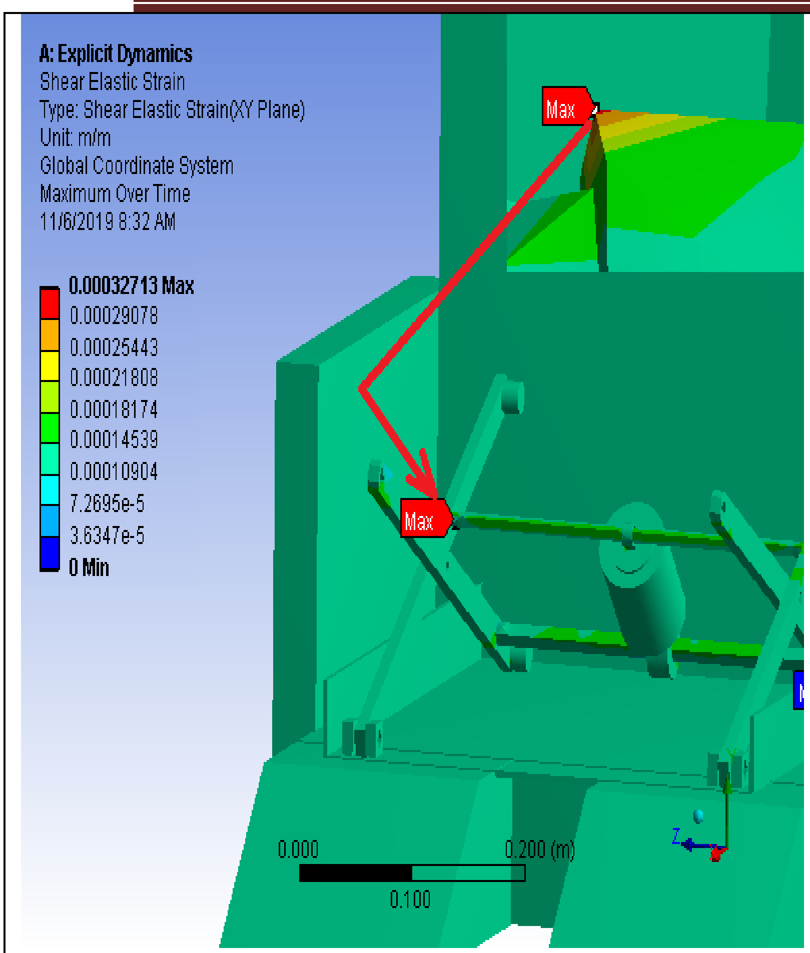
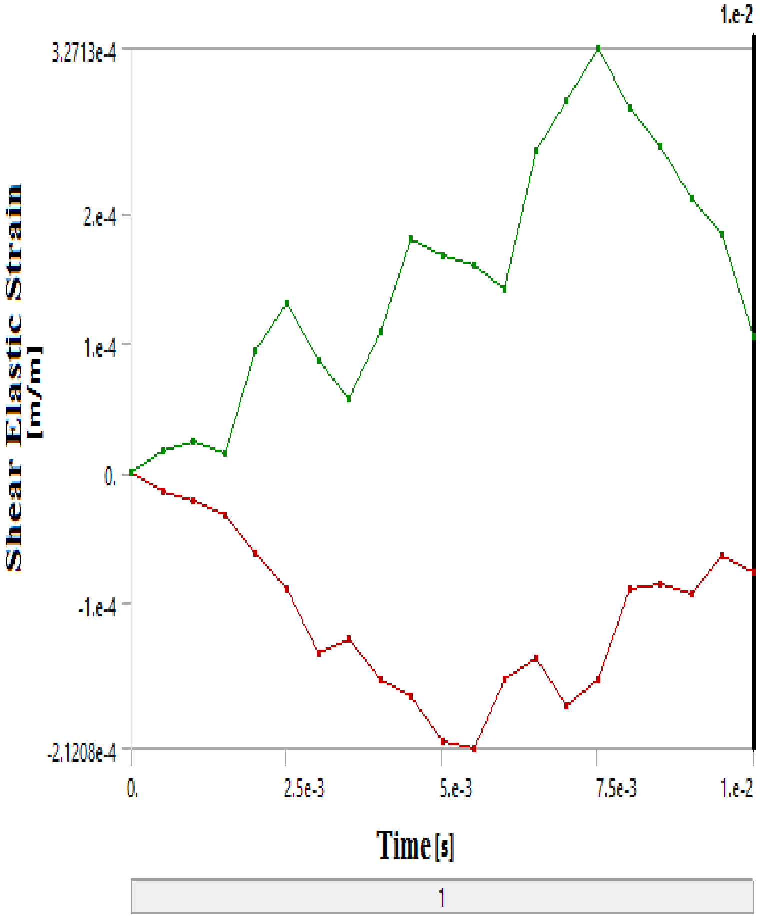


Figure 4.14 Shear elastic strain analysis of the model



Graph 4.17 Shear elastic Strain

Shear elastic strain is change in angle between two line segments originally perpendicular acting on the XY plane was created by direct axial load acting on the wheelchair seat. The action on the XY plane subjected to change in shape on the plane to deform the element by exerting a downward force on one face while simultaneously exerting an upward force on the opposite parallel face. This action is that of a simple pair of shears on the scissor lift, but note that if only one pair of shear strain acts on the element, it will not be in equilibrium. Rather, it will tend to change in structure. Due to this here it has two components of shear elastic strains the XY and reverse (YX) plane. It's summarized that since the strain component is acting along a single plane (XY-axis) it will have both maximum results due to the +Ve and –Ve direction of the selected plane. The result obtained from the simulation indicated that the maximum shear elastic strain ε_{xy} occurred on the upper and lower part of the shaft that holds the piston rod and its minimum shear elastic ε_{yx} strain result happens at the lower joint part of the scissor lift having a value of 3.2713e-004 & -2.1208e-004 at the 7.5.e-003 sec and 5.5e-003sec instant of time respectively.

4.3 Result summary

From the above results obtained using both mathematical and simulation soft wares, It can be summarized that the numerical result obtained from the numerical analysis is a little bit different. Variation of the results happened were due to consideration of kinematic as well as damping/ vibrational factors that happened on the mechanism during the explicit dynamics analysis, where as if we check the result obtained in both cases by considering the allowable normal and shear stress getting from their material properties it's below the estimated value so that proposed design is safe.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

In this study, the existing wheelchair was modified by addition of scissor lift mechanism on the wheelchair seat and making use of a hydraulic piston to drive the seat, connecting scissor lift linkages with the shaft mounted on the hydraulic piston.

Design of lifting mechanism on wheelchair seat is determined under static and dynamic conditions, the results of which are to be significant. The analysis includes stress and deflection responses of the scissor lift to the applied loads. The strength and liability of the proposed design is analyzed by simulation and motion analysis. The results obtained from system simulation and dynamic analysis of the proposed design, prove that;

- The hydraulic scissor lift structure experiences the lowest deflections and stresses due to random excitations caused by the applied load and materials property.
- The lifting structure, in any of the cases considered and has comparable deflection with the whole wheelchair structure. However, the level of stress, in any of the cases, is very low and incomparable to highly stressed points in the overall lifting system that indicates the scissor lift system to have optimum capacity of lifting a user on wheelchair seat up to 150 kg load.

Based on the testing and results from the analysis, the maximum deflection occurs at top back part of the mechanism which have roller end on both sides, whereas the maximum tensile stress occurs around the shaft that holds the hydraulic piston cylinder, which is less that the allowable value of the selected material. So that it was considered safe to use hydraulic scissor lift on wheelchair seat under certain specifications.

5.2 Recommendations

As it concludes, design of the lifting mechanism on wheelchair seat can never be ending process based on different users' basic requirements. Every design can play the vital role of outcome from previous design, as well as a reference to inform the next version.

The analysis performed in this research is based on some assumptions and restrictions. However, complete structural analysis, understanding behavior of the wheelchair is attained considering any possible details. Therefore, the following points are recommended for further future work extensions and elaborations on this research area.

- ➢ Effect of this lifting mechanism on wheelchair seat on the end users of the product.
- ➢ Design additional horizontal sliding mechanism for the users after vertical lift of the wheelchair seat
- ➢ Modify the scissor lift mechanism on wheelchair seat using other types of lifting mechanism (ex. Pneumatic lifting system)
- ➢ System stability based on dynamic stress histories of critically loaded points or sections of the wheelchair structure.

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Appendix 1

Matlab programming

```
%***************************************************************************
%NAME:  Tewodros Yibeltal
%course: Thesis
%date: February 2019
%details: plots the Kinematic  Variables  of the scissor lift  mechanism
%Position,  Velocity and Acceleration Analysis and graph of Wheel seat Scissor lift
mechanism%**************************************************************************

OC=0.21;  OD=0.21;Pi=3.14;
Theta=Pi/16.36;
Alpha=Pi-(2*Theta);
XC=0;YC=0;
rC=[XC  YC  0];
XO=OC*cos(Theta);
YO=OC*sin(Theta);
rO=[XO  YO  0];
YD=0;
time=0.01;
XD=XO+sqrt(OD^2-(YD-YO)^2);
rD=[XD  YD  0];
n=30/Pi;
omega1=[0  0 Pi*n/30];Thetadot=omega1;
alpha1=[0  0 0];
vC=[0  0 0];aC=[0  0 0];
vO1=vC+cross(omega1,rO);vO2=vO1;
aO1=aC+cross(alpha1,rO)-dot(omega1,omega1)*rO;
aO2=aO1;
omega2z=sym('omega2z','real');
vDx=sym('vDx','real');
omega2=[0  0 omega2z];vD=[vDx  0 0];
eqvD=vD-(vO2+cross(omega2,rD-rO));
eqvDx=eqvD(1);eqvDy=eqvD(2);
solvD=solve(eqvDx,eqvDy);
omega2zs=eval(solvD.omega2z);
vDxs=eval(solvD.vDx);vDs=[vDxs   0 0];
omega2=[0  0 omega2zs];
alpha2z=sym('alpha2z','real');
aDx=sym('aDx','real');
alpha2=[0  0 alpha2z];aD=[aDx  0 0];
eqaD=aD-(aO1+cross(alpha2,rD-rO)-dot(omega2,omega2)*(rD-rO));
eqaDx=eqaD(1);
eqaDy=eqaD(2);
solaD=solve(eqaDx,eqaDy);
alpha2zs=eval(solaD.alpha2z);
aDxs=eval(solaD.aDx);
alpha2=[0  0 alpha2zs];aDs=[aDxs  0 0];
alpha3=[0  0 0];
rD1=(rC+rO)/2;
fprintf('rC1=[%g,%g,%g](m)\n',rD1);rD2=(rO+rD)/2;
```

```
fprintf('rC2=[%g,%g,%g](m)\n',rD2);rD3=rD;
fprintf('rC3=[%g,%g,%g](m)\n',rD3);aD1=aO1/2;
fprintf('vO1=[%g,%g,%g](m)\n',vO1);vO2=vO1;
fprintf('aC1=[%g,%g,%g](m/s^2)\n',aD1);aD2=(aO1+aDs)/2;
fprintf('aC2=[%g,%g,%g](m/s^2)\n',aD2);aD3=aDs;
fprintf('aC3=[%g,%g,%g](m/s^2)\n',aD3)
%Position plots
t=[0 0.01];
Theta=[0.192 0.796];
figure (1);
axisequal;
plot(t,Theta,'-');hold on;
title ('Graph of link1 Angle Theta Vs Time');
xlabel'Time t(s)';
ylabel'Link1 Angle Theta(rad)' ;
legend('Link1 Angle Theta')
t=[0 0.01];
Alpha=[2.758 1.55];
figure (2);
axisequal;
plot(t,Alpha,'-');hold on;
title ('Graph of Joint Angle of both links Alpha Vs Time');
xlabel'Time t(s)';
ylabel'Angle Alpha(rad)' ;
legend('Joint Angle Alpha')
t=[0 0.01];
Theta=[0.192 0.796];
Alpha=[2.758 1.55];
figure (3);
axisequal;
plot(t,Theta,'-',t,Alpha,'--');hold on;
title ('Angle Theta, Alpha Vs Time');
xlabel'Time t(s)';
ylabel'Theta,Alpha(rad)' ;
legend('Alpha','Theta')
%Velocity plots
t=[0 0.01];
omega1=[0 Pi*n/30];
figure (4);
axisequal;
plot(t,omega1,'--');hold on;
title ('Graph of Angular Velocity Vs Time');
xlabel'Time t(s)';
ylabel'omega1(rad/s)' ;
legend('Angular Velocity')
Alpha=[2.758 1.55];
vO1=[0 1];
figure (5);
axisequal;
plot(Alpha,vO1,'--');hold on;
title ('Graph of Velocity of link1 Vs Joint Angle Alpha');
xlabel'Angle Alpha(rad)' ;
ylabel'Velocity of link1(m/s)';
legend(' Velocity Vs Alpha')
t=[0 0.01];
```

```
vO1=[0 1];
vC2=[0 2];
figure (6);
axis equal;
plot (t,vO1,'-',t,vC2,'--');hold on;
title ('Graph of Velocity of link1,velocity of link2 Vs time');
xlabel'Time t(s)';
ylabel'Velocity of link1,velocity of link2(m/s)';
legend('Velocity of link1','velocity of link2')
%acceleration plots
Theta=[0.192 0.796];
Alpha=[2.758 1.55];
aC1=[0 0.25];
figure (7);
axis equal;
plot(Theta,aC1,'-',Alpha,aC1,'--');hold on;
title ('Acceleration of link1 Vs Angle Theta, Alpha ');
xlabel'Theta,Alpha(rad)' ;
ylabel'Acceleration of link1(m\s^2)';
legend('Alpha','Theta','Acceleration of link1')
omega1=[0 Pi*n/30];
aC1=[0 0.25];
aC2=[0 1.25];
aC3=[0 2];
figure (8);
axis equal;
plot (omega1,aC1,'-',omega1,aC2,'--',omega1,aC3,'-');hold on;
title ('Graph of acceleration Vs Angular Velocity');
xlabel'omega1(rad/s)' ;
ylabel'aceleration of link1 ,link2 and sliding Roller(m\s^2)';
legend('aC1','aC2','aC3')
```

Appendix 2

Mathematical Modeling

Consider the entire lifting structure as a free body with the applied force acting at point s and t and the reaction forces acting at the fixed support at A and roller support at B shown in the above figure and solving for ax, ay and by, Thus

$\sum F_y = a_y + b_y - 367.875 - 367.875 - 13.32 = 0$

$a_y + b_y = 749.07$ N

$\sum M_a = 0$**;** $(0.412) b_y - 367.875(0.412) - \frac{W_{arm}}{2}(0.206) = 0$

$b_y = \frac{(367.875)(0.412)+(13.32)(0.206)}{0.412}$

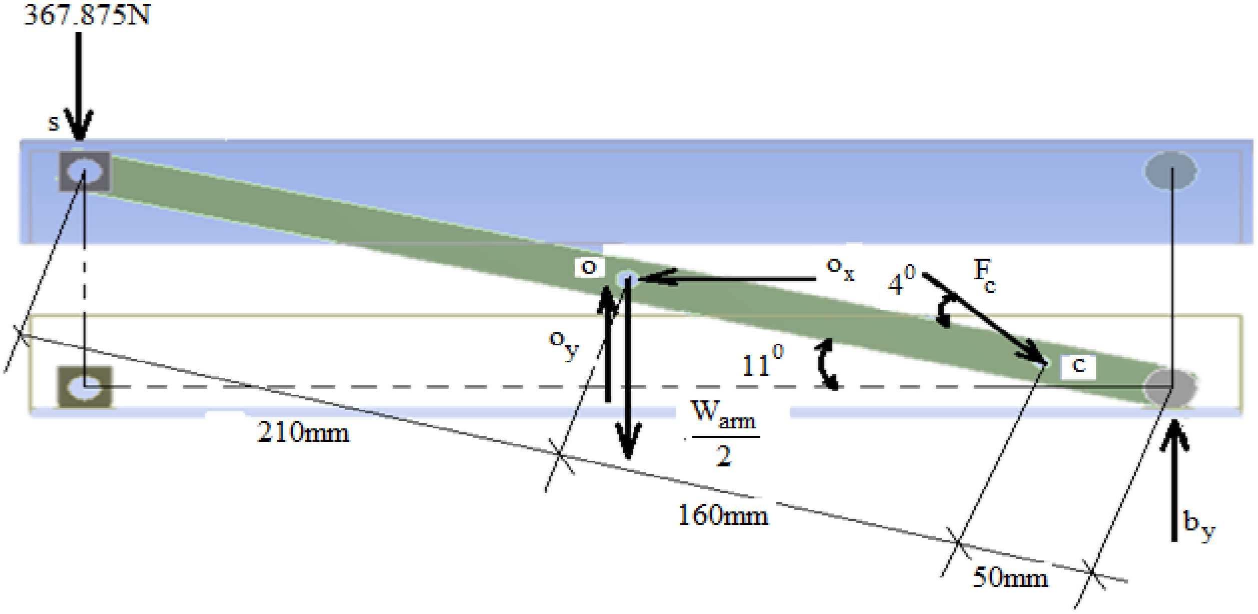
$b_y = 374.54$ N

$a_y + b_y = 749.07$ N

$a_y = 749.07 - 374.54$

$a_y = 374.53$ N

Next to this we will break the entire structure apart, so that each member is represented as a free body diagram, by showing all component forces acting at the joint. Let us start from the scissor arm 2 free body diagram



Free-body diagram of arm 2 of the scissor lift mechanism at its lowest position

$\sum F_x = 0$

$-\,P\cos 15^0 + O_x = 0$

$O_x = 0.966F_c$

$\sum F_y = 0$

$b_y + O_y - 367.875 - \frac{W_{arm}}{2} + F_c \cos 15^0 = 0$

$O_y = 0.259F_c + 6.66$

$\sum M_0 = 0$

$a_y - O_y + F_c \cos 75^0 - \frac{W_{arm}}{2} - 367.875 = 0$

$367.875(0.21\cos 11^0) + b_y(0.21\cos 11^0) + F_c \sin 15^0(0.16\cos 11^0) - F_c \cos 15^0(0.16\sin 11^0) = 0$

Since $b_y = 374.54$ N

$0.0115F_c = 153.04$N

F_c = 13307.83 N

Using the above results I will solve for the reaction forces O_x and O_y

O_x = 0.966F_c

O_x = 0.966(13307.83N)

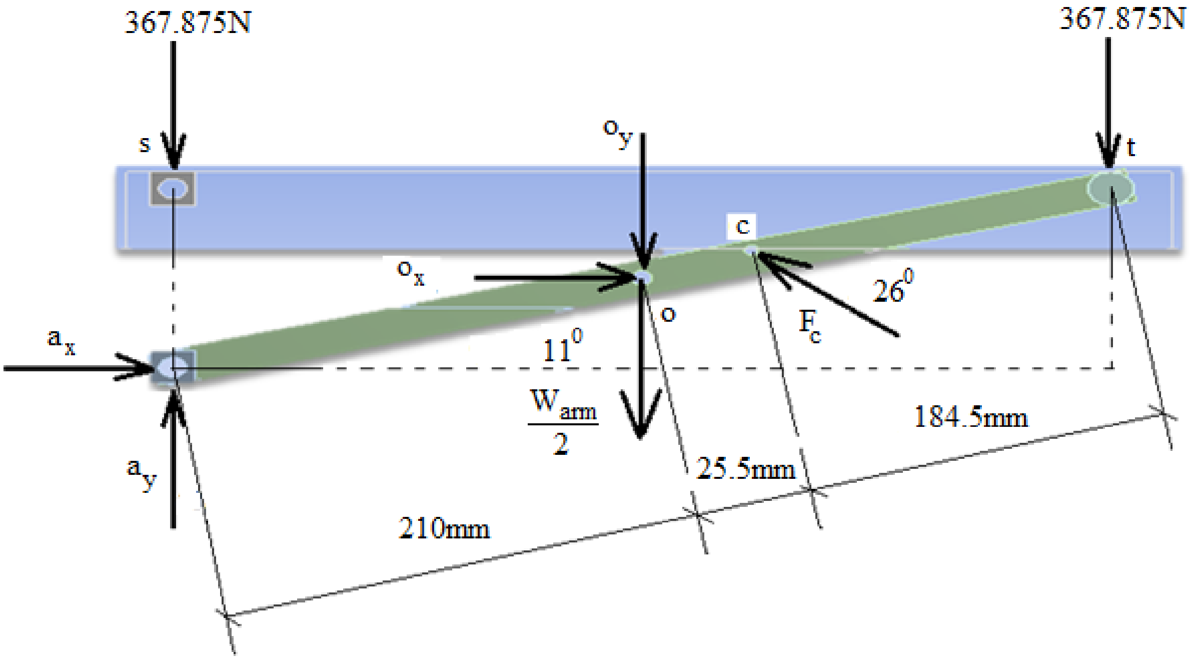
O_x = 12855.364N

O_y = 0.259P + 6.66

O_y = 0.259(13307.83N) + 6.66

O_y = 3453.387N

I will consider the piston cylinder as a two force member, we can solve for reaction forces on scissor arm 1 using the free body diagram of scissor arm 1. Thus,



Free-body diagram of arm 1 of the scissor lift mechanism at its lowest position

$\sum F_x = 0$

$a_x + O_x - F_c \sin 75^0 = 0$ where $F_c = 13307.83$ N

$a_x + O_x - (13307.83)\sin 75^0 = 0$ $\quad$ $a_x + O_x = 12854.38$ N

$\sum F_y = 0$

$a_y - O_y + F_c \cos 75^0 - \frac{W_{arm}}{2} - 367.875 = 0$

$374.54 - O_y + 0.259F_c - 13.32 - 367.875 = 0$

$O_y = 0.259F_c - 6.66$ $\quad$ where $F_c = 13307.83$ N

$O_y = 0.259(13307.83) - 6.66$ $\quad$ $O_y = 3440.07$ N

$\sum M_0 = 0$

$-a_y(0.21\, cos\, 11^0) + a_x(0.21 \sin 11^0) + F_c \cos 75^0 (0.0255 \cos 11^0) + F_c \sin 75^0 (0.0255 \sin 11^0) - 367.875(0.21 cos\, 11^0) = 0$

$-0.206a_y + 0.04a_x + 0.0065F_c + 0.0047F_c - 75.83 = 0$ $\quad$ where $F_c = 13307.83$ N, $O_y = 3440.07$ N

$a_x = \frac{75.83 + 0.206O_y - 0.0112F_c}{0.04}$

$= \frac{75.83 + 0.206(374.53) - 0.0112(13307.83)}{0.04}$

$a_x = 98.43$ N,Then we will solve for O_x

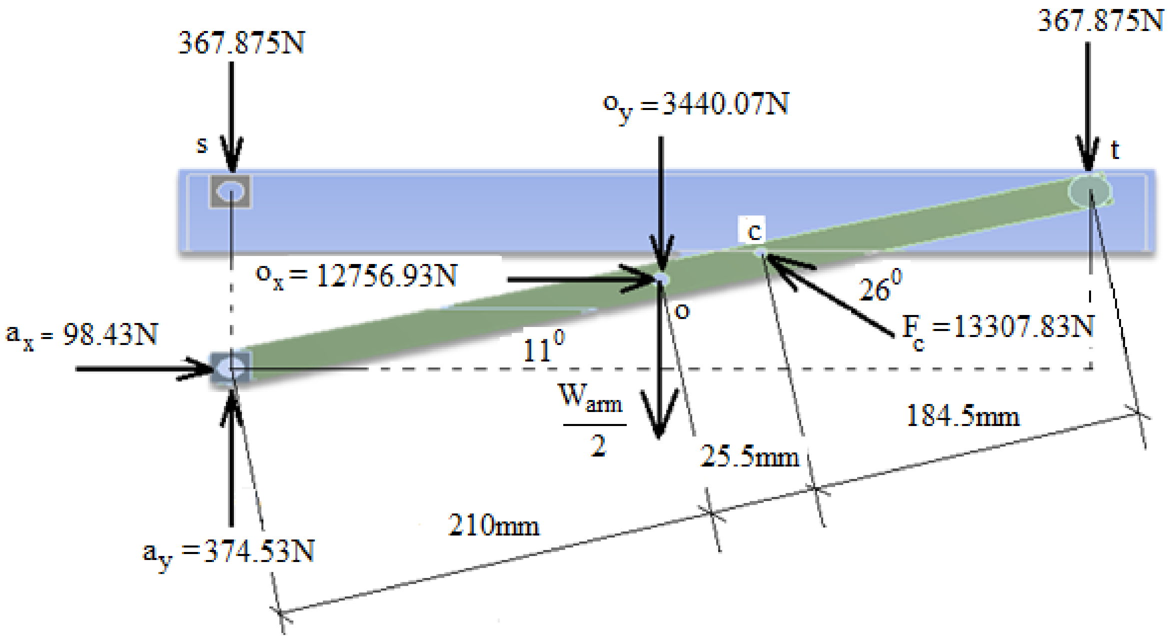
$a_x + O_x = 12854.38$ N

$O_x = 12854.38 - a_x$

$= 12855.38 - 98.43$

$= 12756.93$ N

Then we will show these reaction force results on the free body diagram of both scissor arms



Free-body diagram of all applied and reaction forces on scissor arm 1

Then, after getting all component and reaction forces on the arm, we can solve for axial and shear force components of the arm used for determining the normal and shear stresses on the arm. Thus,

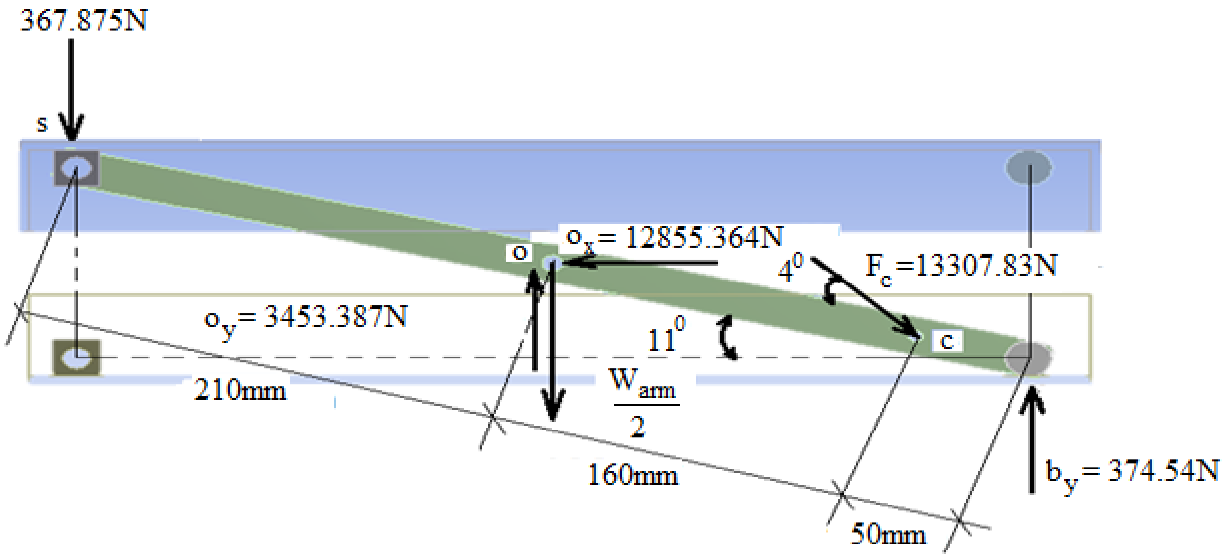
Result table of Force (Axial, Shear) and Stress (Axial, Shear) of Scissor Arm 1 at its lowest position

Reaction and applied Force components	Axial force component	Shear force components	Longitudinal Cross sectional area(A)	Normal stress	Lateral cross sectional area(A)	Shear stress
a_x=98.43N	$(98.43\,cos\,11^0) + (375.53\cos 79^0)$ = 168.28 N	-$(98.43\,sin\,11^0) + (375.53\sin 79^0)$ =349.86N	A= 200e -6 m^2	0.84Mpa	A= 8760e -6 m^2	0.04Mpa .
a_y=375.53N						
O_x=12756.93N	$(12756.93\,cos\,11^0)$ $(3440.07\cos 79^0)$ $-(13.32\cos 79^0)$ = 11863.61N	- $(12756.93\,sin\,11^0)$- $(3440.07\sin 79^0)$– $(13.32\sin 79^0)$ = -5824.09 N	A= 200e -6 m^2	59.32Mpa	A= 8760e -6 m^2	- 0.6649 Mpa
O_y=3440.07N						
$\frac{W_{arm}}{2}$=13.32N						

F_c=13307.83N	-13307.83$cos\ 26^0$= -11960.99 N	13307.83$sin\ 26^0$= 5833.77 N	A= 200e -6 m^2	-59.80Mpa	A= 8760e -6 m^2	0.666Mpa
Applied load=367.875N	-367.875$cos\ 79^0$= -70.19 N	-367.875$sin\ 79^0$= - 361.12 N	A= 200e -6 m^2	-0.35Mpa	A= 8760e -6 m^2	-0.0412 Mpa

From the above table the maximum normal stress occurs from point o to c which is σ=59.32Mpa and maximum shear stress occurs from point c to ti.e τ =0.666Mpa.

$$\sigma_{all} = \sqrt{\sigma^2 + \tau^2} = \sqrt{59.32^2 + 0.666^2} = 59.324\text{Mpa}$$



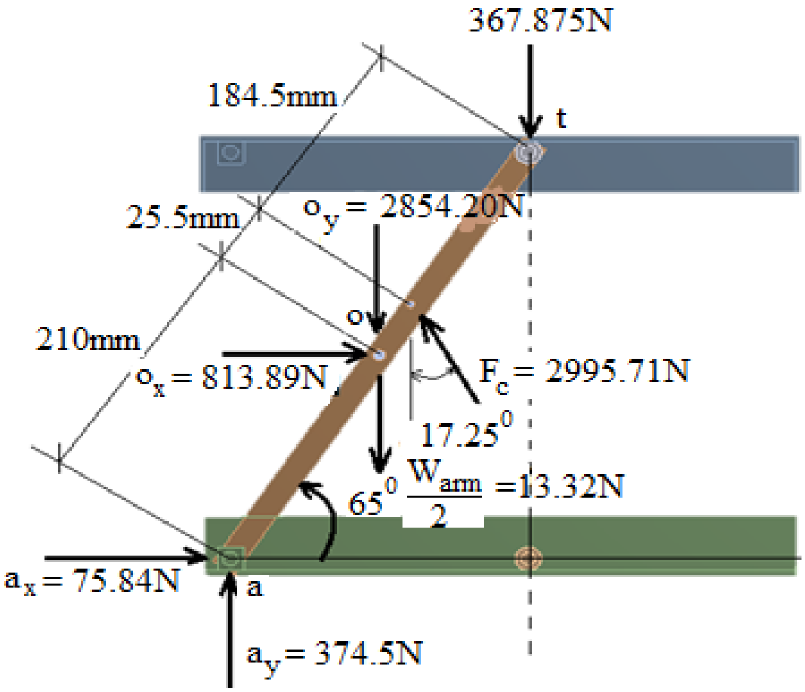
Free-body diagram of all applied and reaction forces on scissor arm 2

Result table of Force (Axial, Shear) and Stress (Axial, Shear) of Scissor Arm 2 at its lowest position

Reaction and applied Force components	Axial force component	Shear force components	Longitudinal Cross sectional area(A)	Normal stress	Lateral cross sectional Area(A)	Shear stress
b_y=375.54N	$-(375.54\cos 79^0)$ = -71.66 N	$(375.54 \sin 79^0)$ =-368.64N	A= 200e -6 m^2	-0.358Mpa	A=8760e -6 m^2	0.0421 Mpa.
F_c=13307.83N	$13307.83\cos 4^0$= 13275.41 N	- $13307.83\sin 4^0$= -928.31N	A= 200e -6 m^2	66.38Mpa	A=8760e -6 m^2	- 0.106Mpa
O_x=12855.367 N	- $(12855.36\cos 11^0)$– $(3454.39\cos 79^0)$ $+(13.32\cos 79^0)$ = - 13275.75 N	- $(12855.36\sin 11$ $(3454.39\sin 79^0$)– $(13.32\sin 79^0)$ =924.92 N	A= 200e -6 m^2	-66.38Mpa	A=8760e - $6m^2$	0.106Mpa
O_y=3453.387N						
$\frac{W_{arm}}{2}$=13.32N						
Applied load=367.875 N	$367.875\cos 79^0$= 70.19 N	- $367.875\sin 79^0$= -361.12 N	A= 200e -6 m^2	0.35Mpa	A=8760e - $6m^2$	- 0.0412 Mpa

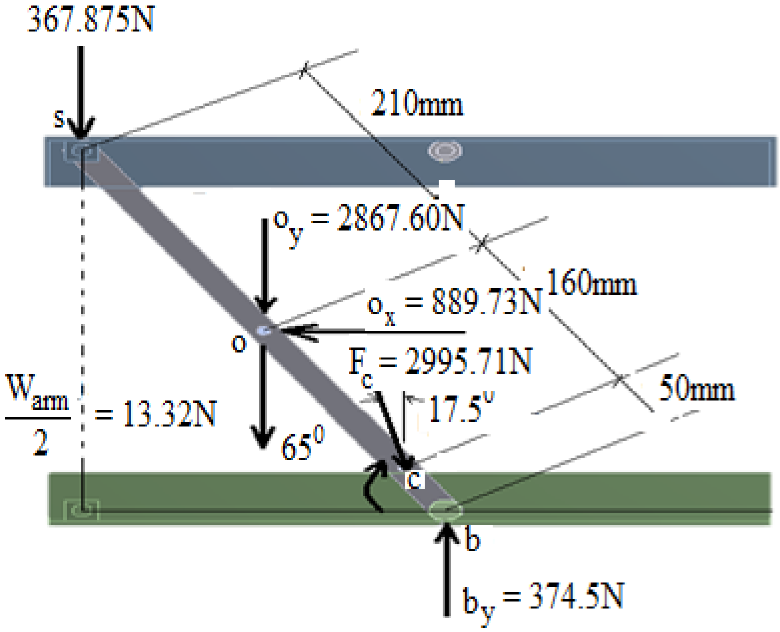
From the above table the maximum normal stress occurs from point c to o which is σ=66.38Mpa and maximum shear stress occurs from point O to s i.e τ=0.106Mpa. $\sigma_{all} = \sqrt{\sigma^2 + \tau^2} = \sqrt{66.38^2 + 0.106^2}$ = 66.38Mpa.The above result indicates the normal and shear stress result for the lift at its seat position. Next to this I will show the axial force, shear force, axial stress and shear stress results of the scissor lift **at the maximum elevation** of the mechanism are shown below both on graphical and numerical representation.

Scissor Arm 1



Free-body diagram of all applied and reaction forces on scissor arm 1 at its Highest position

Scissor Arm 2



Free-body diagram of all applied and reaction forces on scissor arm 2 at its Highest position

Result table of Force (Axial, Shear) and Stress (Axial, Shear) of Scissor Arm 1 at its at maximum extension

Reaction and applied Force components	Axial force component	Shear force components	Longitudinal Cross sectional area(A)	Normal stress	Lateral cross sectional area(A)	Shear stress
a_x=75.84N	$(75.84\,cos\,65^0)+(374.5\cos 25^0)$ = 371.38N	-$(75.84\,sin\,65^0)+(374.5\sin 25^0)$ =89.7N	A= 200e -6 m^2	1.86Mpa	A= 8760e -6 m^2	0.01Mpa.
a_y=374.5N						
O_x=813.89N	$(813.89\,cos\,65^0)-(2854.2\cos 25^0)-(13.32\cos 25^0)$ = -2253.71N	-$(813.89\,sin\,65^0)-(2854.2\sin 25^0)-(13.32\sin 25^0)$ = -1950.34N	A= 200e -6 m^2	-11.27Mpa	A= 8760e -6 m^2	-0.223Mpa
O_y=2854.2N						
$\frac{W_{arm}}{2}$=13.32N						
F_c=2995.71N	2995.71 $cos\,42.25^0$= 2216.83N	2995.71$sin\,42.25^0$= 2013.12N	A= 200e -6 m^2	11.08Mpa	A= 8760e -6 m^2	0.2298Mpa
Applied load=367.875 N	-367.875$cos\,25^0$ = -333.29N	-367.875$sin\,25^0$= -155.61N	A= 200e -6 m^2	-1.67Mpa	A= 8760e -6 m^2	-0.018Mpa

From the above table the maximum normal stress occurs from point c to t which is σ=11..8Mpa and maximum shear stress occurs from point O to t i.e τ=0.2298Mpa.

$$\sigma_{all}=\sqrt{\sigma^2+\tau^2} = \sqrt{11.8^2+0.2298^2} = 11.802\text{Mpa}$$

Result table of Force (Axial, Shear) and Stress (Axial, Shear) of Scissor Arm 2 at its at maximum extension

Reaction and applied Force components	Axial force component	Shear force components	Longitudinal Cross sectional area(A)	Normal stress	Lateral cross sectional Area(A)	Shear stress
b_y=374.5N	-$(374.5\cos 25^0)$ = -339.297 N	$(374.5\sin 25^0)$ =-158.414N	A= 200e -6 m^2	-1.697Mpa	A=8760e-6 m^2	0.018Mpa.
F_c=2995.71N	2995.71cos 7.75^0 = 2968.75 N	-2995.71sin 7.75^0= -404.42N	A= 200e -6 m^2	14.84Mpa	A=8760e-6 m^2	-0.046Mpa
O_x=889.73N	-$(889.73\, cos\, 65^0)$–$(2867.60\cos 25^0)$ +$(13.32\cos 25^0)$ = -2962.34 N	-$(889.73\, sin\, 65^0)$ + $(2867.60\sin 25^0)$–$(13.32\sin 25^0)$ =401.27 N	A= 200e -6 m^2	-14.81Mpa	A=8760e-6m^2	0.0458Mpa
O_y=2867.60N						
$\frac{W_{arm}}{2}$=13.32N						
Applied load=367.875 N	367.875cos 25^0= 333.29 N	-367.875sin 25^0=-155.61 N	A= 200e -6 m^2	1.67Mpa	A=8760e-6m^2	-0.0178Mpa

From the above table the maximum normal stress occurs from point c to o which is σ=14.84Mpa and maximum shear stress occurs from point O to t i.eτ=0.0458Mpa.

$$\sigma_{all}=\sqrt{\sigma^2+\tau^2} = \sqrt{14.84^2+0.0458^2} = 14.84\text{Mpa}$$

Most lifting devices are powered by either electricity, manual or Hydraulicmeans.Hydraulic systems are used to operate and control the entire lifting system.The idea of a hydraulically powered scissors lift is based on *Pascal's law* employed in car jacks and hydraulic rams which states that "pressure exerted anywhere in a conformed incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio remains the same" [25].

I declare that this research work is my original work and has not presented for a degree in here and any other university, also all sources of the materials are well acknowledged.

Name: Tewodros Yibeltal

Signature: ___________________

Thesis Title: Design and Analysis of Lifting Mechanism on Wheelchair Seat to Transfer to Bed and Car Seat

Dean of SMIE: __Dr. Yilma ___

Signature: ___________________

Advisor: ___Mr. Mulugeta H.__

Signature: ___________________