CONVERTIBLE WHEELCHAIR WITH ASSIST-FREE BED TRANSFER

A thesis submitted in partial fulfillment of the requirements for the award of the degree of

B. Tech

in

Production Engineering

By

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BONAFIDE CERTIFICATE

This is to certify that the project titled "**Convertible Wheelchair with Assist-free bed transfer"** is a bonafide record of the work done by

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Project Viva-Voce held on ______________________

Internal Examiner **External Examiner**

ABSTRACT

Keywords: Locomotive mechanism, Rack and pinion mechanism, device of independent living, convertible wheelchair, product design and validation (FEM Analysis).

The problem statement of devising a new product to facilitate the transfer of patients from wheelchair to bed is achieved by brainstorming methodologies, ideating many relative motions of the members of the device (tilting, sliding, and turning) and realizing them with the help of standard working mechanisms (Locomotive mechanism, Rack & Pinion mechanism, and revolute joint). This project aims at producing a novel method to solve the posed problem statement, and in turn construct a working design to check the effectiveness of the method. Furthermore, few design improvements are made to make the product design look more appealing and constraining to the physical real-world application. Finally, a finite element analysis (FEA) is performed to check the structural stability of the product, we used a research paper on the percentage of different body parts to ascertain the real-life boundary conditions, assigned material (Chromoly Steel) meshed it and extracted crucial solutions such as Equivalent stress, Equivalent strain, life, and factor of safety. Added to this we also did the analysis on shifting of center of mass for proper understanding of the product's structure as well as orientation in a stepwise manner. Finally, we have submitted our idea and design to the CEDI (Centre for Entrepreneurship Development and Incubation) Siemens Grant and got through the preliminary level (Level 1) and final level (Level 2) and waiting for the grant amount to start the fabrication of our product.

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CHAPTER 1

INTRODUCTION

1.1 Problem definition

Our solution to this issue is to design a modified wheelchair that converts to a horizontal platform along the bed, transfers the patient, and converts back to the wheelchair position. This ensures that the patient is transferred in the safest way and overcomes various limitations such as space, cost, and operation without external assistance. The proposed solution employs a locomotive four-bar mechanism to convert into a horizontal position and a rack and pinion mechanism to slide the platform along the bed.

1.2 Objectives

The product's primary beneficiaries are wheelchair users, including differently abled persons and paraplegics. The product's secondary beneficiaries include hospitals, emergency services, and people with leg injuries or who require a wheelchair for a period.

The device aims to ensure the safety and comfort of wheelchair users when they transfer from wheelchair to bed. The ability to work without any external aid provides them with a sense of independence and empowerment.

1.3 Subjects Exploited

The following subjects were exploited for the project: Kinematics and dynamics of machines, Design of machine elements, Mechanics of Solids, Machine drawing, CAD and CAE, Finite element methods, Optimization in Engineering Design, Product development strategies.

1.4 Software Exploited

3D CAD model was designed primarily in SolidWorks with some accessory parts in Autodesk Fusion 360. Structural and fatigue analysis were carried out in ANSYS Workbench. Other preliminary works were carried out in Siemens NX and COMSOL Multiphysics.

1.5 Novelty of Approach

Our solution is designed with ergonomic considerations of wheelchair users in mind. A telescopic mechanism is used at wheelchair legs to adhere to bed height. The locomotive mechanism for headrest and leg-rest regions are separate, thus providing the user with flexibility and maximum customizability. Rack and pinion mechanism is used for sliding along the bed surface, providing smooth and quick transfer.

Unlike many convertible chairs, our device deploys mechanisms that are easy to operate and maintain. Our approach also focuses on using minimal space for the operation and stationing of wheelchairs. The factors considered for this approach makes the device novel and more feasible than existing devices.

CHAPTER 2

LITERATURE SURVEY

2.1 Background Research

In India, as per Census 2011[1], there are 6 million people with walking disabilities. Most devices in our environment are not designed disability-friendly and differently abled people lack access to basic amenities that a normal person can easily utilize. They are more prone to unintentional injury and fall due to the said reasons.

One such overlooked device in our everyday life is the bed. Wheelchair users find moving from their wheelchair to bed and vice versa difficult and strenuous. Current methods to transfer patients from wheelchair to bed require external assistance and are not entirely safe.

Also, the action of wheelchair-to-bed transfer is prone to fall and injury and hence needed to be done with extreme care. Few existing devices, such as the devices developed by P. Arun Kumar et al. (2018) [2] and Rashid Ahmed et al. (2010) [3], that cater to this need are analyzed, and their pitfalls were identified. The primary concern identified with these devices were the ease of operate ability and the comfort of the customer.

Consensus shows that there is a need for a device to transfer users from wheelchair to bed and our device is designed to solve this problem.

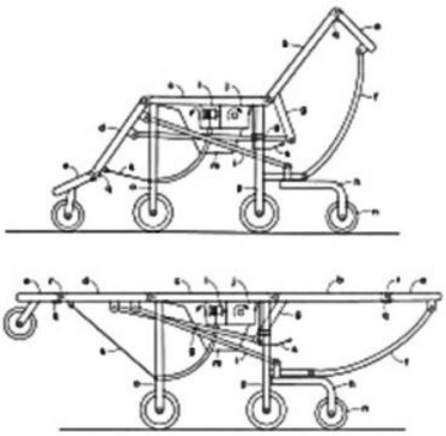
2.2 Review of Existing Products

Here is the list of existing products which are aimed at differently abled people and their shortcomings.

Table 2.1 Literature Review of Existing Products and their Shortcomings

Product Name	Supporting description and images	Shortcomings
Pneumatically Powered Wheelchair-Stretcher Device [3]	The product is a pneumatically powered stretcher-chair convertible device with movable support segments in an attempt to help such patients and caregivers. The caregiver can merely shift the patient from a bed on to the device while the device is in the form of a stretcher. Then the device can be converted into a wheelchair automatically with a press of a button.	• The cost of the device will be exorbitant due to the use of pneumatic systems • The number of components involved are high, resulting in frequent failure and low reliability, which could pose risk for the patient.

	 *Figure 2.1 Pneumatically powered wheelchair-stretcher device*	
Pneumatically Operated Wheelchair Convertible Ambulated Stretcher [2]	The product is an affordable multipurpose wheelchair which is pneumatically operated and can be converted into a Stretcher with the help of double for the required conversion, either into a wheelchair or into a stretcher. The setup of our project consists of a mild steel frame welded in the shape of a chair so that the disabled person can sit comfortably. Also, a head rest is provided which can be used to place the head while resting. The seat setup is connected with the pneumatic cylinder and a solenoid valve. The solenoid valve is used to allow air from the compressor to the pneumatic cylinder in order to actuate the cylinder. The connections are given to the pneumatic cylinder in a suitable way such that when the cylinder is actuated, the wheelchair extends such that it converts into a bed.	• The cost of the device will be exorbitant due to the use of pneumatic systems. • The number of components involved are high, resulting in frequent failure and low reliability, which could pose risk for the patient.

	 *Figure 2.2 Pneumatically operated wheelchair convertible ambulated stretcher*	
Wheelchair-to-Bed System Using Fluid Power [4]	The device uses a four-bar mechanism and reclining back mechanism, used in cars, to achieve the conversion from wheelchair to bed. The mechanism is powered by hydraulic systems.  *Figure 2.3 Hydraulically powered wheelchair-to-bed system*	• Hydraulic system is expensive and prone to failures easily. • The system needs to be docked to a bed for the patient to transfer to a bed. Docking mechanism is absent in this device, which could result in the device moving away from bed during transfer.
Convertible Bed and Wheelchair Unit [6]	A wheeled structure is readily convertible as between a full-sized single bed and a wheelchair. The structure comprises three pivotally interconnected sections, namely a foot section, a seat section, and a head section. In the bed forming position of the unit, the three sections are disposed horizontally to form a continuous mattress support surface. To convert the unit to the wheelchair forming position, the head section is swung upwardly and secured in position by latch members on the back ends of	• The device requires external assistance to transfer patient from wheelchair to bed and vice versa. • The device is prone to errors and could lead to

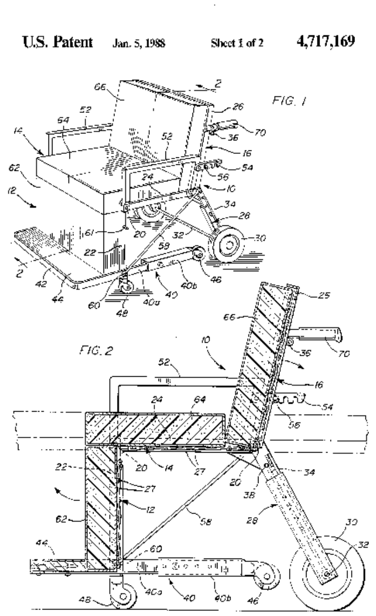
	pivotal armrests. The foot section is swung down into vertical orientation and secured to the seat section by bracing rods. The device is simple to convert as between the wheelchair and bed forming positions.  *Figure 2.4 Convertible wheelchair*	injuries while patient transfer.
Maattam – Retrofittable Stretcher Transfer [7]	The mechanism works similar to a treadmill having a moving platform with a wide conveyor fabric belt and rollers on either end. Motor drives one roller and the other roller is driven with a belt assembly. The moving platform connected to 2-way sliders at its either ends makes it move in both directions to collect / transfer the patient, the motion being controlled by a rack and pinion attached with a crank. Maattam being a retrofit can be put on top of any wheeled stretcher with flat top surface and height adjustment facility, converting it into a transfer stretcher. This can be then moved next to any stretcher where patient is lying. With the motor rotating the roller in clockwise direction, the fabric rotates. The moving platform is moved next to the patient by hand cranking. As it goes underneath the patient, the body is collected and eventually when whole body comes on top of it, the platform is moved back to its position, and the patient is transferred.	• While excellent for bed-to-bed transfer, it does not serve the purpose of bed to wheelchair transfer or its vice versa.

	 *Figure 2.5 Retrofit stretcher transfer device*	
Patient Hoist Systems [8]	Patient hoists are commonly used devices that transfer a patient from bed and wheelchair with the help of cloth-like material that wraps around the patient and carries them up.  *Figure 2.6 Patient hoist system*	• The device requires external assistance for patient to transfer from wheelchair to bed. • The device poses risks, especially is prone to back injuries and fall injuries. • The chances of human error and device failure occurring is high in these devices.

CHAPTER 3

METHODOLOGY

3.1 Initial Idea or Line of Thought

The initial line of thought is to convert the wheelchair into a horizontal platform from which the patient will roll over to the bed. Alternatives brainstormed include keeping the horizontal platform alongside the bed instead of on the bed, but it posed the trouble of docking with the bed to avoid unnecessary movement.

We determined the sequence of actions to be taken and drafted a preliminary solution containing mechanisms necessary to undergo the actions.

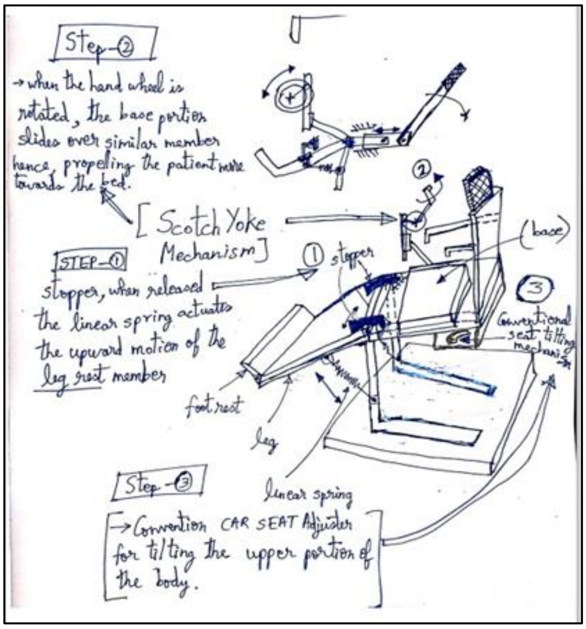


Figure 3.1 Preliminary Design Sketch

<u>Changes implemented in further iterations of the design:</u>
Revolute joint was used to tilt the armrest with its axis along the patient's arm. The revolute joint was simple and effective, so didn't undergo any changes in further iterations of the design.

A linear spring actuation was selected initially for lifting leg rest seat. However, linear spring actuation is instantaneous and would cause a jerk while the user is trying to actuate it. Hence, a locomotive mechanism was adopted for smoother operation.

A Scotch Yoke Mechanism was selected for sliding the base along the bed but was replaced by Rack and Pinion mechanism. Scotch Yoke mechanism required a larger diameter crank for displacing the required linear distance of the slider and that would consume a lot of space. Rack and Pinion was opted for its compactness and ease of accessibility.

The seat tilting mechanism used in cars, involving a constant torque spring was initially chosen for tilting the head rest seat/upper member. However, the mechanism was complex and involved lot of components, thus reducing its reliability, and increasing its probability to failure. Just like the lower member, we opted for a locomotive mechanism in upper member tilt.

The understandings that we gained as a part of brainstorming and concept selection process was implemented and a 3D CAD model of the detailed design was designed in SolidWorks.

3.2 Final Design

The final design was conceptualized, and its 3D CAD model was designed primarily in SolidWorks (by Dassault Systemes), with some accessory parts designed in Autodesk Fusion 360.

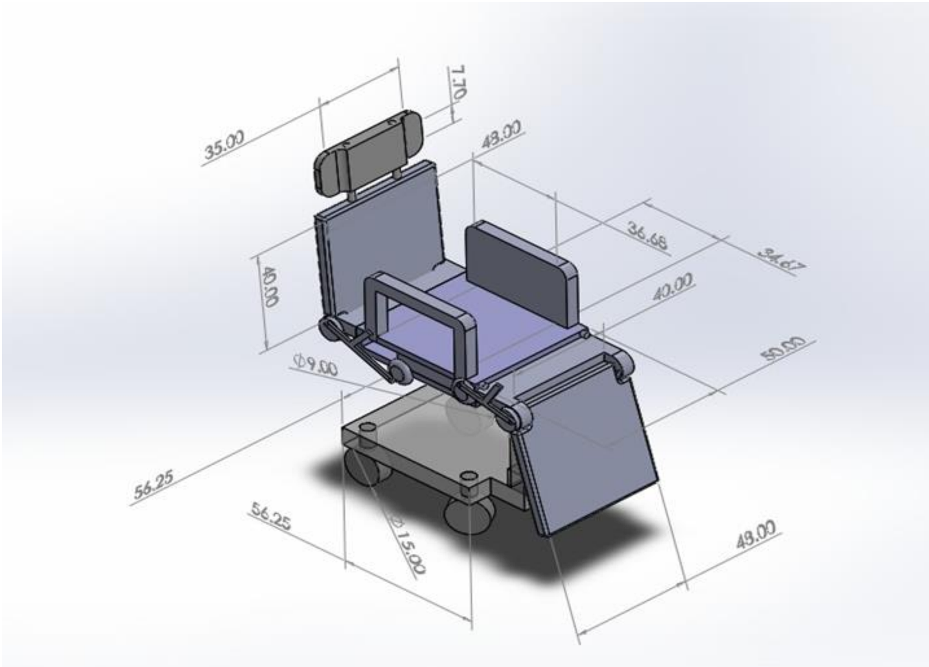


Figure 3.2 Isometric View of Final Design (With Key Dimensions)

Locomotive mechanism was selected and designed for both lower member tilt and upper member tilt. A revolute joint was designed for armrest tilt and a rack and pinion mechanism was modelled for base slider.

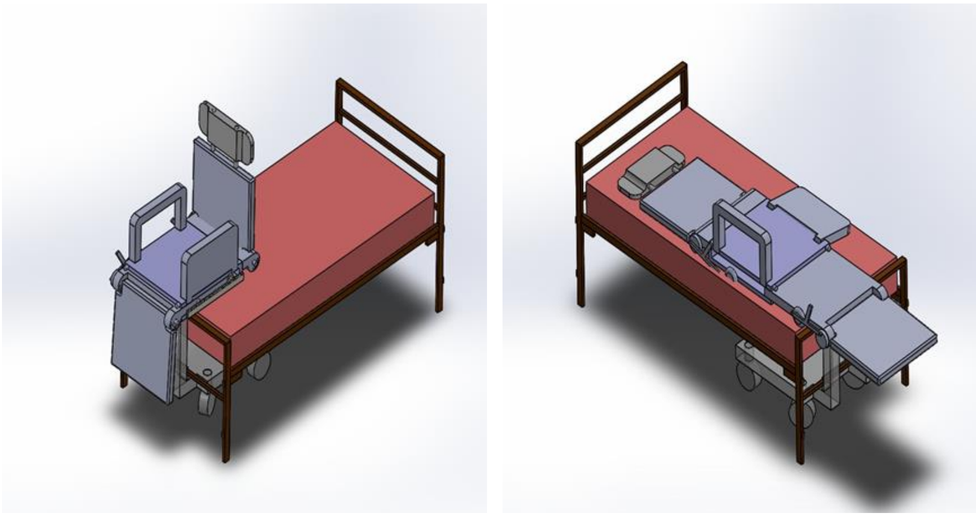


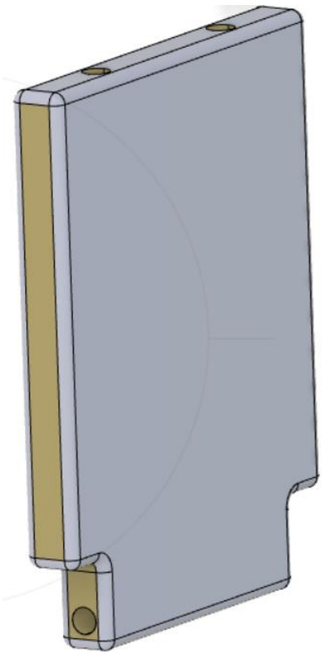
Figure 3.3 (A) Initial Orientation of the Chair and Bed
(B) Final Orientation of the Chair and Bed

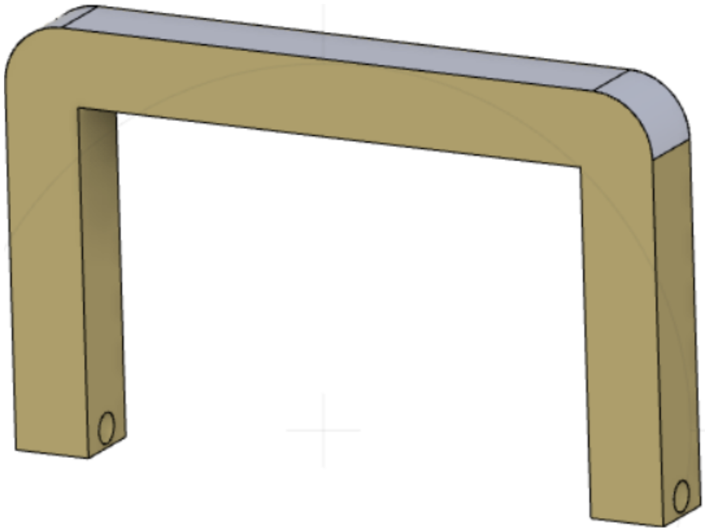
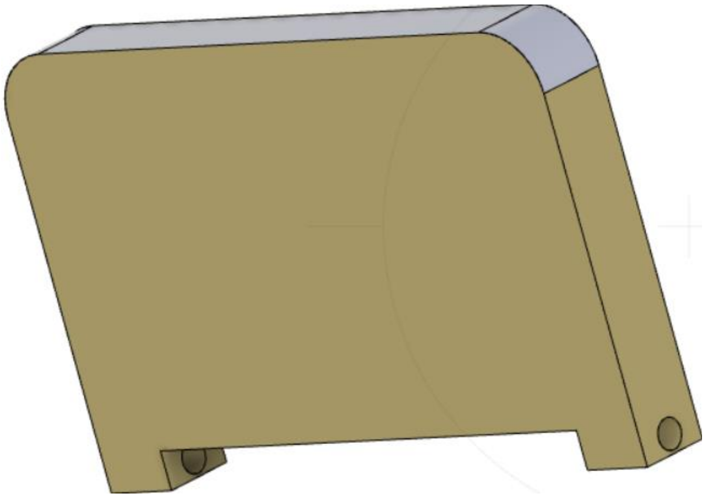
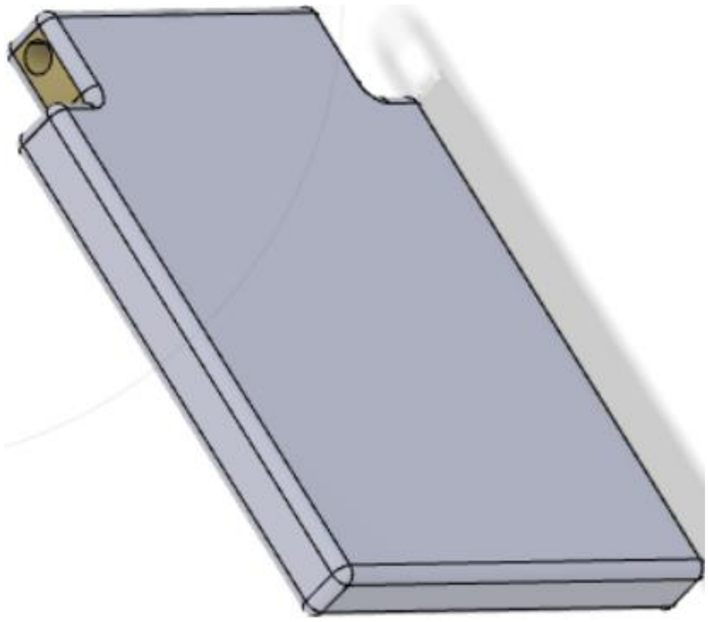
SolidWorks software was exploited for motion analysis and toolbox feature to add standardized parts, such as gears. During the initial orientation, the base of chair fits just above the chair. During the final orientation, the device will be fully inclined over the bed.

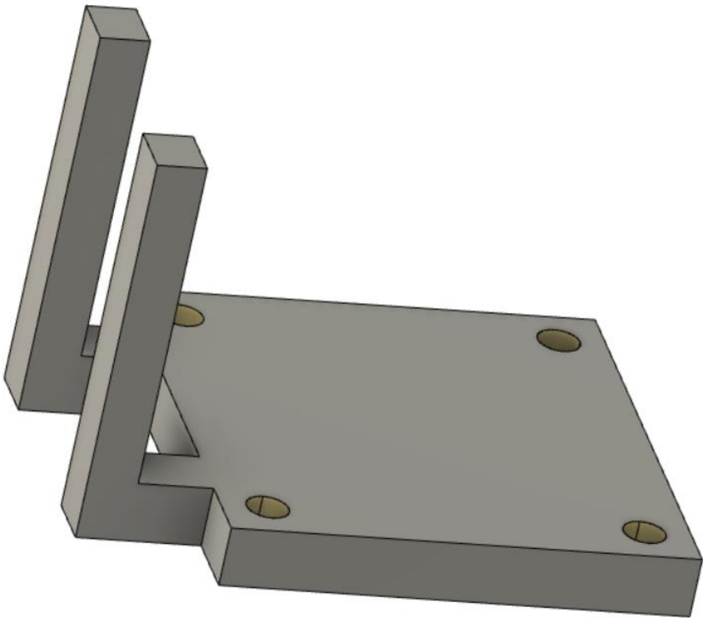
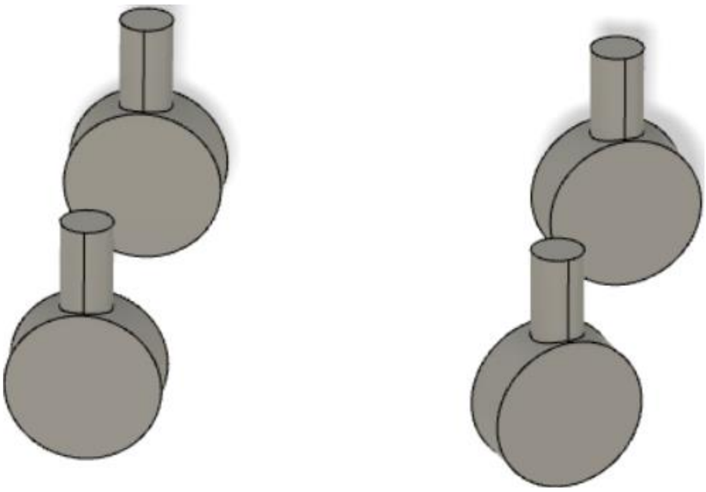
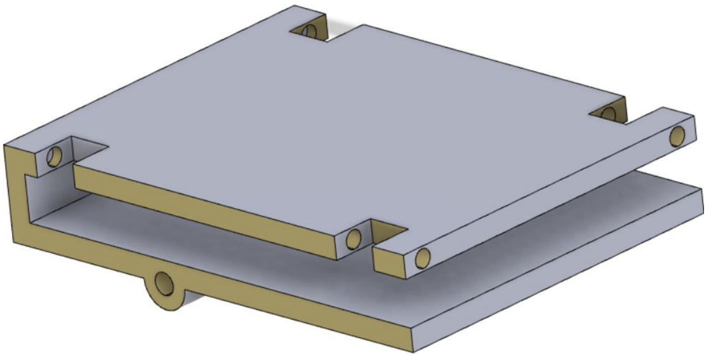
3.3 List of Components

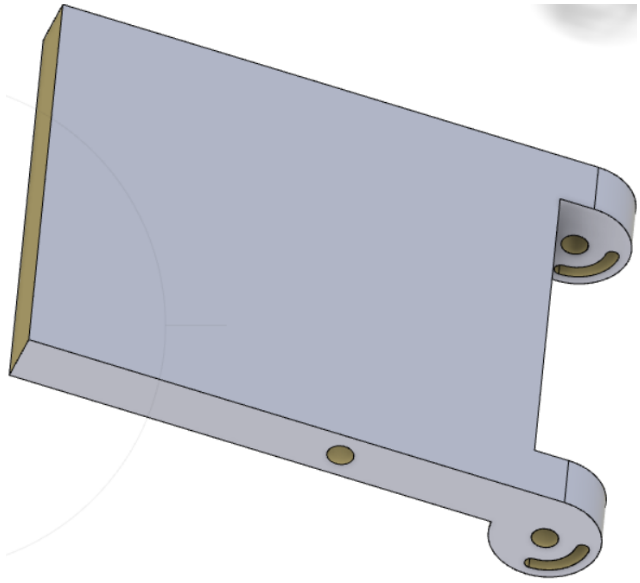
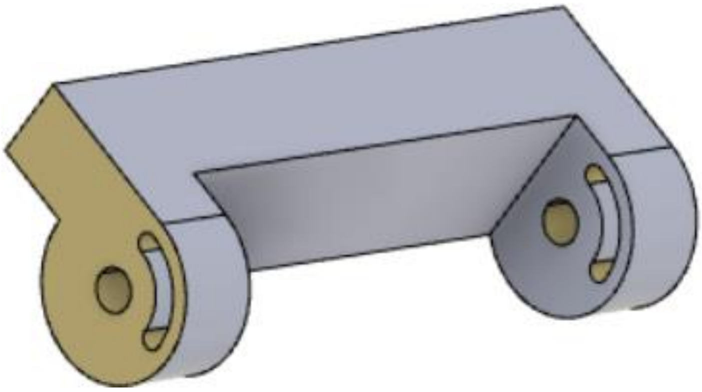
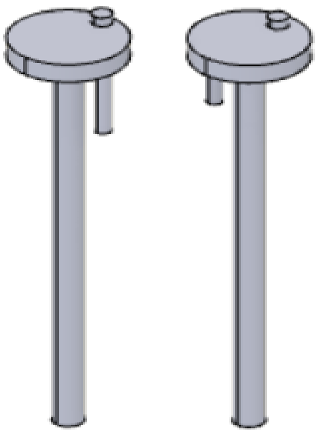
A total of 32 components were designed for the concept of convertible wheelchair with assist-free bed transfer support.

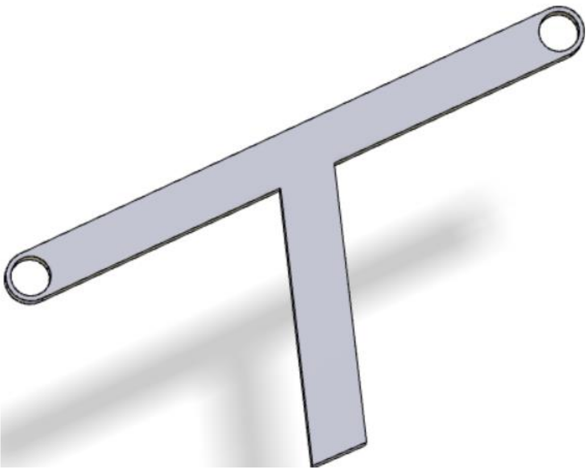
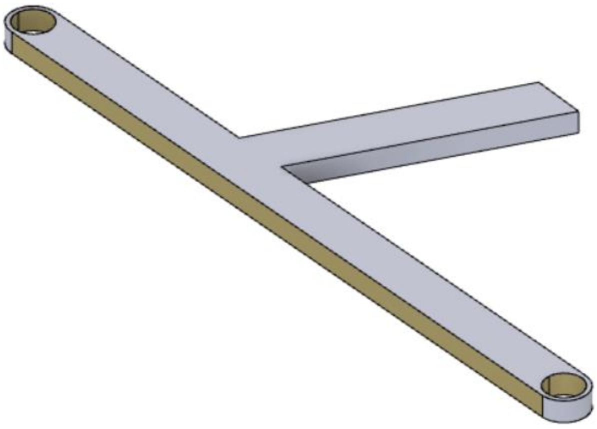
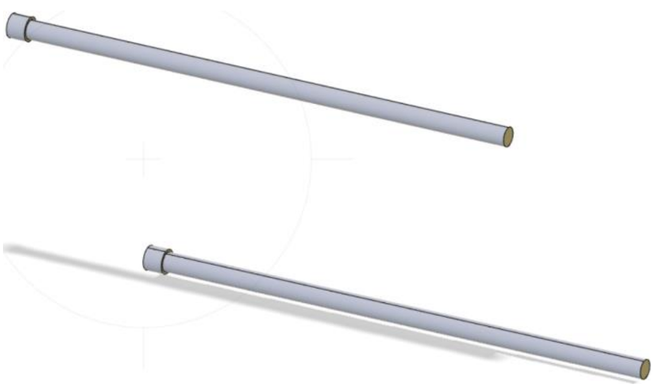
Table 3.1 List of Components with their Dimensions and Sample Diagram

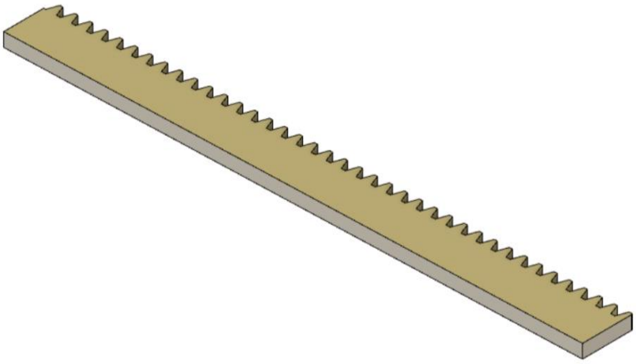
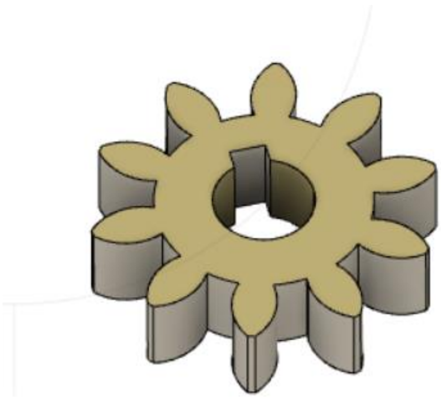
Component	Dimension	Sample Diagram
Headrest	450mmx177mmx 50mm	
Circular Support Rod (x2)	25mm diameter x 330mm	
Back Rest	500mmx400mmx50 mm	

Handle Rest	447mmx275mmx50 mm	
Supporting Bed Plate for Transfer	447mmx275mmx50 mm	
Leg Rest	500mmx400mmx50 mm	

Base Plate	562mm x 562mm x 75 mm 51mm diameter (4 holes) 500mmx75mmx75 mm (extension rods x 2)	
Wheels (x4)	150 mm diameter Extension Rod 51mm diameter x85mm length	
Sliding Extension	530mmx400mmx100mm	

Fixed Seat	550mm x 400mm x 50	
Extension Joint	400mm x 140mm x 50mm	
Pin 1&2	90 mm diameter x 20 mm Extension Rod (long) 24 mm diameter x 420mm Extension Rod (short) 12 mm diameter x 70mm	

Pin 3&4	100 mm outer diameter 60 mm inner diameter Extension Rod (long) 24 mm diameter x 400mm	
Link1	240mmx130mmx10 mm (holes diameter 16mm x2)	
Link 2	310mm x 130mm x 10mm (holes diameter 16mm x2)	
Revolute Joint Rod 1&2	550mm x Outer Diameter 25 mm x Inner Diameter 20mm	

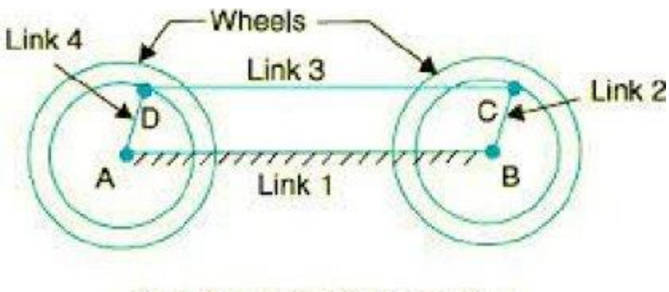
Rack Spur Rectangular	485mm x 40mm x 12mm	
Spur Gear	Pressure Angle 20 No. of teeth 10 Face width 12mm Nominal Shaft Diameter 14 mm	

3.4 Working Mechanisms

3.4.1 Locomotive Mechanism for Lower Member and Upper Member Tilt

The parallelogram mechanism is an inversion of the four-bar mechanism where linkages of equal lengths are positioned opposite to each other. Here, the sum of the largest and smallest links is equal to the sum of adjacent links, giving a double crank motion. The locomotive mechanism is a type of parallelogram mechanism where the largest link is grounded.

The locomotive mechanism is used to turn leg-rest and head-rest seats by 90 degrees to achieve conversion of the seat to the horizontal platform. The locomotive mechanism is situated at the joints of the middle seat and leg/head-rest seats.



3.4 Kinematic Diagram of Locomotive Mechanism

With the base of chair acting as the frame or grounded link relative to the mechanism, left side disc and right-side disc are the crank and rocker of the mechanism respectively. The connecting rod of the mechanism will be the lever connecting both the discs.

The length of crank and rocker is the radius of their respective discs. The distance between the centres of the disc will be the length of grounded link and the largest tangent meeting both the disc will be the length of connecting rod.

Locomotive mechanism will be deployed for upper member and lower member tilt. Locomotive mechanism will be operated through a lever extruded from the connecting rod.

3.4.2 Rack and Pinion Mechanism for Sliding

The rack and pinion mechanism is a gear mechanism that converts rotary motion into translation. It consists of gear with a small pitch radius, called pinion, and a linear gear, with an infinite pitch radius. The rack and pinion mechanism are deployed for sliding the bed along the length of the bed. The rack and pinion are situated at the middle seat.

3.5 Rack and Pinion Mechanism

Rack gear will be present in the fixed seat and the pinion gear will be fixed at the sliding seat. The purpose of rack and pinion mechanism is to facilitate sliding of patient along the bed.

3.4.3 Assembling of Mechanisms Together

Various mechanisms were assembled by keeping in mind of the intended motion of each and every component of the device. The locomotive mechanism deployed for lower member lilt and the rack and pinion mechanism share a common link, which is the fixed seat.

The fixed seat member acts as a frame in case of locomotive mechanism, whereas it acts as component carrying the pinion in case of the rock and pinion mechanism. The slider member which encloses the fixed seat initially serves as a frame for the locomotive mechanism which was used to tilt the upper member.

Furthermore, the slider also acts a base for the tilting armrest and serves as a housing for the revolute joint.

Important Assembly Connections:

1) Armrest and the slider are connected with the help of a rod, which runs through the circular extruded cut provision at the end of armrest and the edge of the slider. Concentric mates were used to achieve that.
2) Fixed seat and the slider were aligned horizontally along their width such that the slider encloses the fixed seat completely. Coincidence mates were used to achieve that.
3) A slot of 90 degree was made on the profile of both the slider and the fixed seats at one of their ends, such that it guides the pin to swivel around the fixed base, in case of leg rise or

the slider, in case of upper member tilt by 90 degrees to lift the leg member or tilt the upper member. Slot mates and coincidence mates were used to realize this assembly.

4) A freely rotating disc is attached to the fixed base and the slider to complete the four-bar mechanism deployed in both the locomotive mechanisms. Using concentric mate, this locomotive mechanism was realized

Table 3.2 Mechanisms and the Components Involved in their Construction

SI.No.	Mechanisms	Involved Components
1	Locomotive Mechanism for Lower Member	Lever 1, Discs (2), fixed seat
2	Rack and Pinion Mechanism	Rack (Attached to the slider) Pinion (Attached to the fixed seat)
3	Locomotive Mechanism for the Upper Member Tilt	Lever 2, Discs (2), fixed seat
4	Arm Rest Tilt	Slider, Revolute Joint Housing with the Pivoting Rod, Armrest

3.5 Steps of Operation

The proposed solution aids with patients to make themselves lie down in a bed from their wheelchair without any external assistance from others. The approach requires minimal effort from the wheelchair user – the user needs to lie along the seat/platform and initiate the mechanism required for the transfer.

The approach of self-transferring the patient from chair to bed and vice versa is enabled by four steps or four simple motions:

STEP 0: (Preliminary Step)

The patient needs to align the wheelchair in such a way that the base of the wheelchair aligns with the mattress of the bed, as well as the length of the base, is made parallel to that of bed's length. In other words, it needs to be aligned sidewise to the bed, along the width of bed.

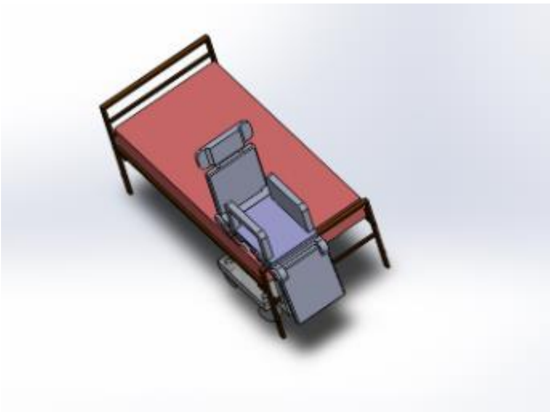


Figure 3.6 Initial Position of Wheelchair with respect to Bed

STEP 1: (Leg rise)

The patient should then lift the lever on the right side of the base, situated near to his knees. He pulls it up through the locomotive mechanism, which was inverted from the basic four-bar mechanism, excepting the crank link, and the rocker link being a rotating disc. Once he pulls up, the leg seat tilts by 90 degrees in anticlockwise direction and becomes horizontal to the middle seat

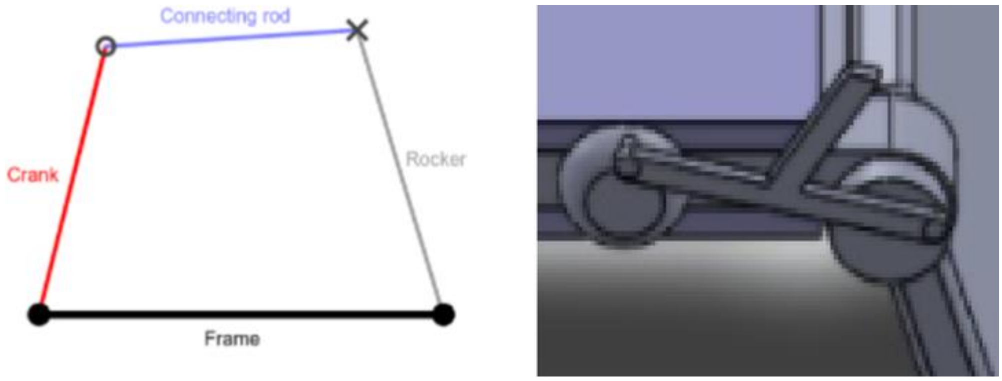


Figure 3.7 (A) Four Bar Mechanism Terminology (on the left)
(B) Mechanism Incorporated for Leg Rise (on the right)

Table 3.5: Mechanism Terminology and their Respective Elements in Locomotive Mechanism

Mechanism Terminology	**Respective Elements**
Frame	Fixed Base of Chair
Crank	Left Side Disc
Connecting Rod	Lever
Rocker	Right Side Disc

The connecting rod is pulled up with the help of an extruded portion in the rod. The extruded rod is accessible to the wheelchair user and hence is easy to operate as well.

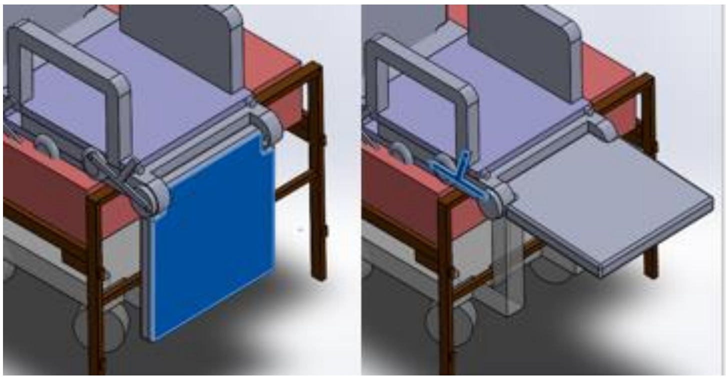


Figure 3.8 (A) Initial Position of the Leg Member (on the left)
(B) Final Position of the Leg Member (on the right)

<u>STEP 2: (Base Slide)</u>

The patient must crank the pinion gear on the left side of the base. This will propel him to move further into the bed. Rack and pinion mechanism was deployed for this action. The rack is attached with the slider, which is fitted into the base. The pinion is the gear that is mounted on an axis normal to the sidewalls of the base.

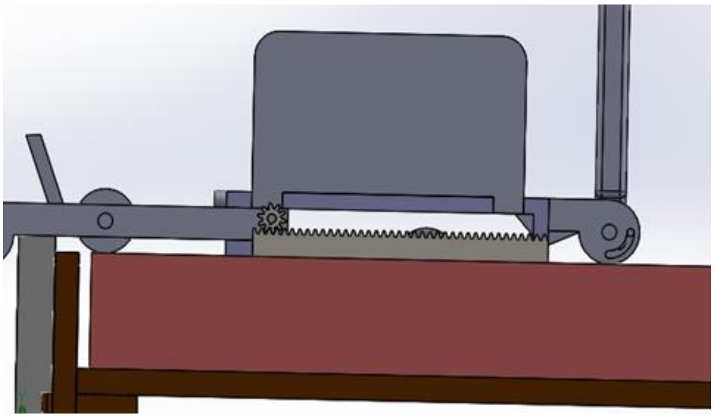


Figure 3.9 Rack and Pinion Mechanism in Assembly

Rack is attached to the rear end of the slider and pinion is coaxially affixed with the bottom of the fixed base.

STEP 3: (Upper Member Tilt)

The patient must perform the same activity as described in Step 1, but this time he/she should lift the lever closer to the upper member. This will tilt his upper body down. The locomotive mechanism was deployed, as described in Step 1, to achieve this action. At the end of this step, his whole body gets aligned horizontally with the bed.

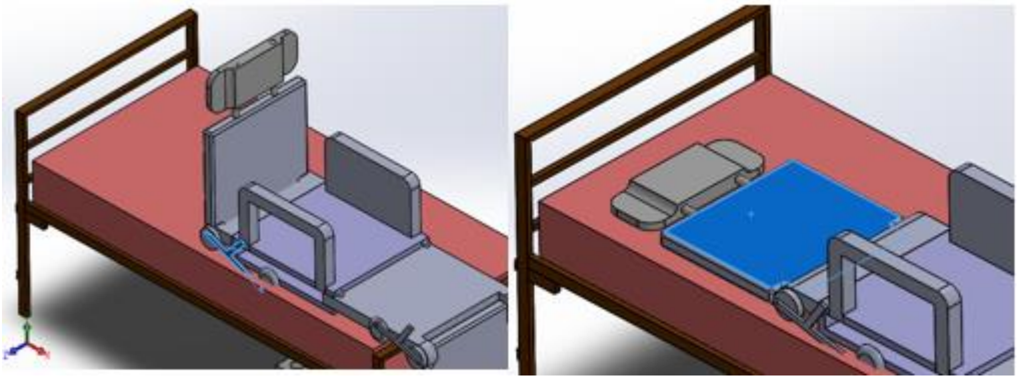


Figure 3.10 (A) Initial Position of the Upper Member (on the left)
(B) Final Position of the Upper Member (on the right)

STEP 4: (Armrest Tilt)

Finally, the patient should push his left arm/hand rest downwards such that the revolute joint between the base and the armrest tilts the armrest towards the bed. Once, it has been fully tilted, it establishes a connection between chair and bed such that the patient can move towards the bed.

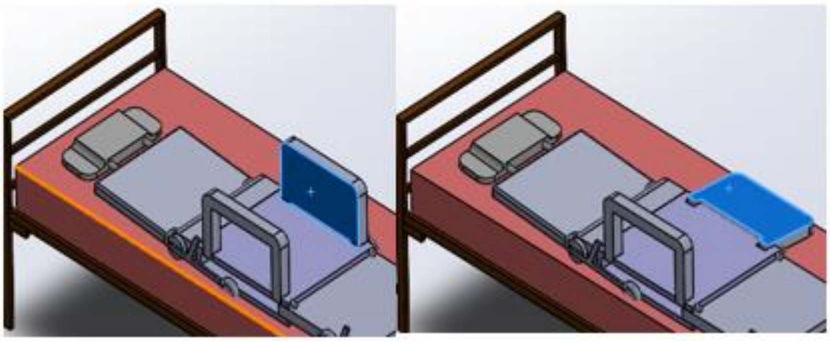


Figure 3.11 (A) Initial Position of the Armrest
(B) Final Position of the Armrest

REVERSE TRANSFER: From Bed to Chair

For transfer from bed to chair, the same steps (as described above) are to follow but in the reverse order.

3.6 Design Improvements

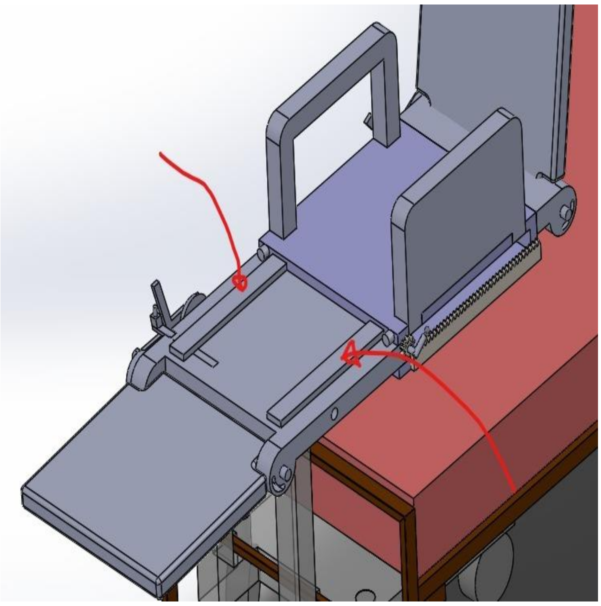
Shelling

3.12 (A) Illustration of Hollow Structures in Real Life
(B) Shelling of Wheelchair Seats

Shelling is done to make thin-walled, hollow structures in CAD. Thin-walled components not only reduces the weight of the component but also increases the manufacturing feasibility due to availability and capability to be made from metal sheets. As inferred from the figure 3.6.1(B), in order to reduce the weight of the wheelchair and to utilize the productivity of extra space, shelling has been performed on the base.

Another vital reason for shelling is to reduce the cost of material associated with the weight of material. The material chosen for our design is Chromoly steel, which is predominantly used for such thin-walled, hollow structures. Hence, hollow structures also help bring down the cost of the device.

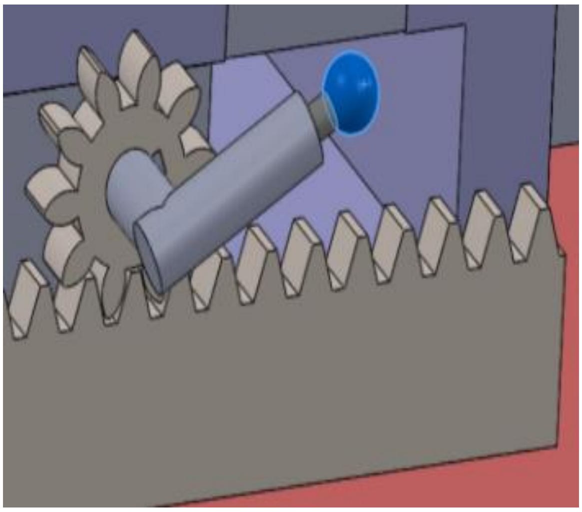
Redesigning the Slider:



3.13 Sliders in middle seat

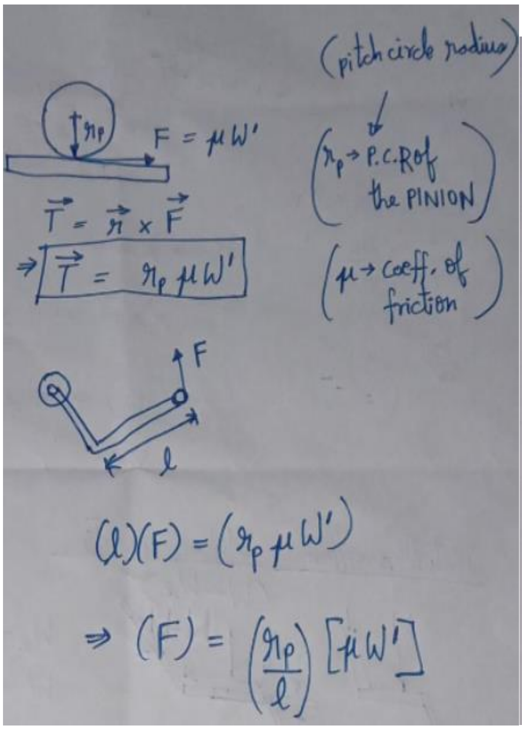
Slider is re-designed to properly fit the fixed seat. Two extrusions on the fixed seat are made and similarly two rectangular cavities are made to restrict the degrees of freedom (D.O.F.) along lateral direction. Restricting the movement of lateral direction during sliding, along the longitudinal direction, is essential to prevent the seat and the patient from slipping to the sides of the bed. This modification makes the design error-proof.

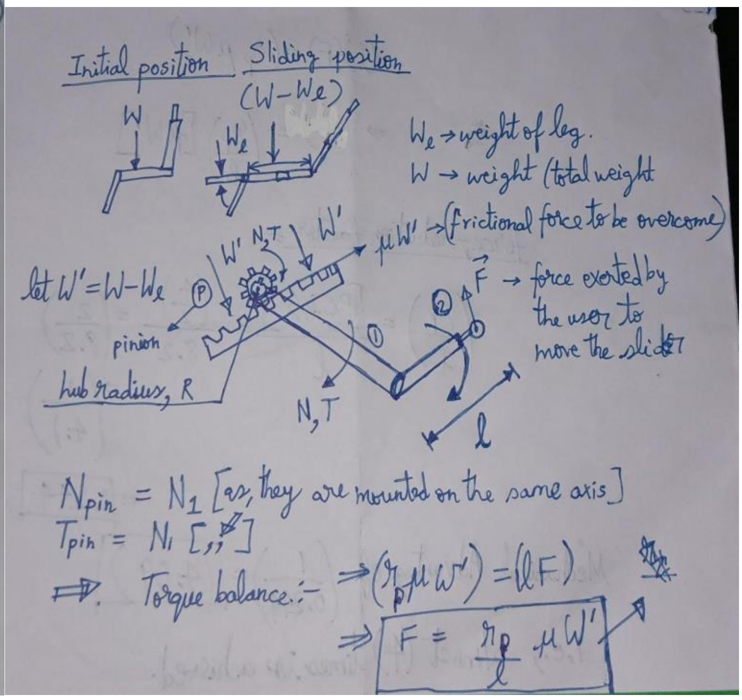
Redesigning Crank Lever Incorporating Mechanical Advantage:

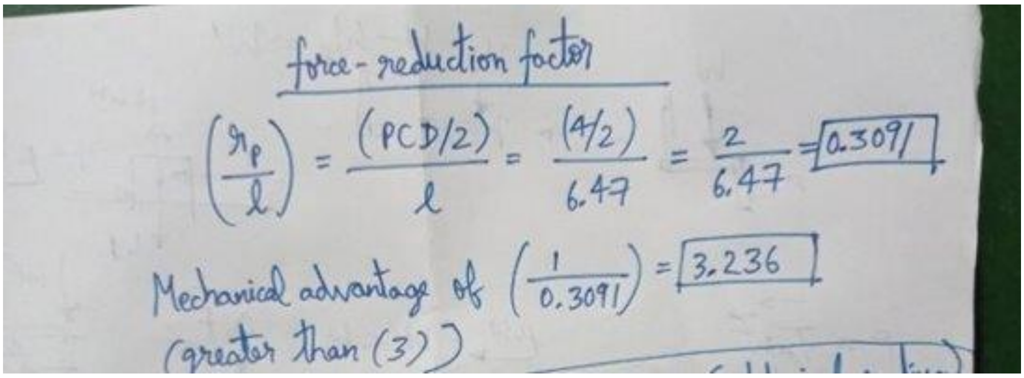


3.14 Stepped Crank Lever in Rack and Pinion Mechanism

Mechanical advantage is a measure of the force amplification achieved by using a tool, mechanical device, or machine system. An extra feature was added into the rack and pinion mechanism for sliding which enables the user to operate the pinion with greater ease of access. We added a stepped bar with length along the axis and perpendicular to the axis of the gear. It acts as a wrench that we use to tighten or loosen the screws in case of changing tires while puncture.







3.15 Calculations Performed to find Mechanical Advantage

The detailed force and force reduction could be deduced in figure 3.14. From the figure, it was observed a force reduction of up to 0.3091. Hence, a mechanical advantage of 3.236 or around 3 is observed.

3.7 Design Modifications after Analysis

Stopper:

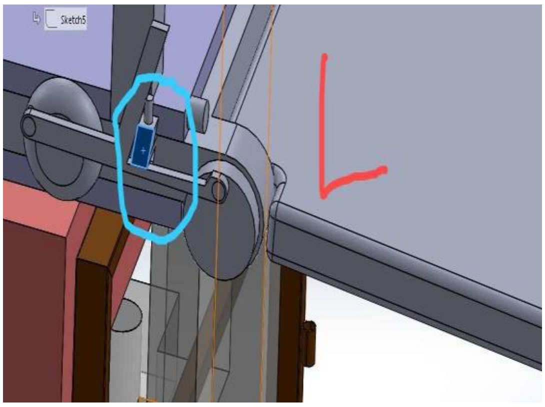
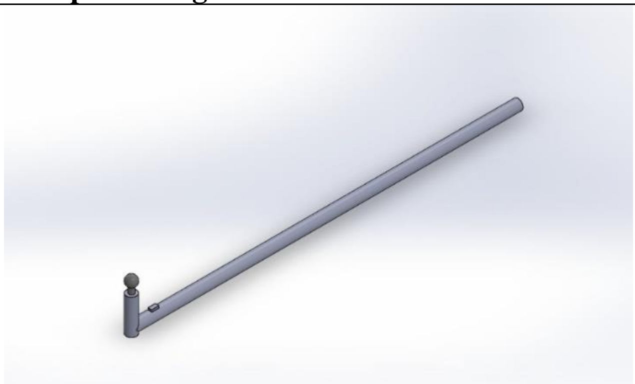
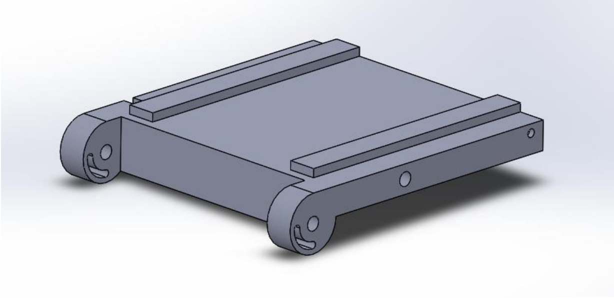


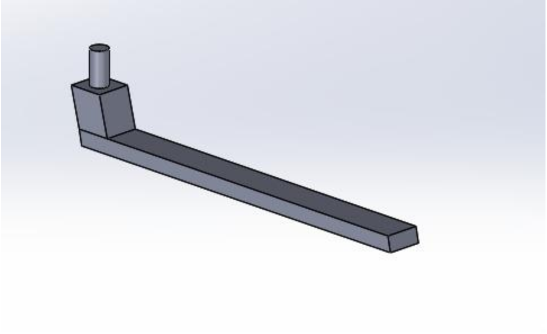
Figure 3.16 Stopper

During our structural analysis (Refer section 4.1.1), the maximum stress value is obtained at the interface between the joins of the leg member and the fixed seat. This might be due to the entire leg and foot load acting on the pivoted end of the leg member. Hence to reduce this, as part of design modification we incorporated a stopper which will take up the stress. The 'L' denotes the leg member in figure 3.16

NEW COMPONENTS AFTER DESIGN MODIFICATION

Table 3.6 New Components and their Component Figures

SI.No.	Component name	Component figure
1	Modified Fixed Base	
2	Slider Crank	

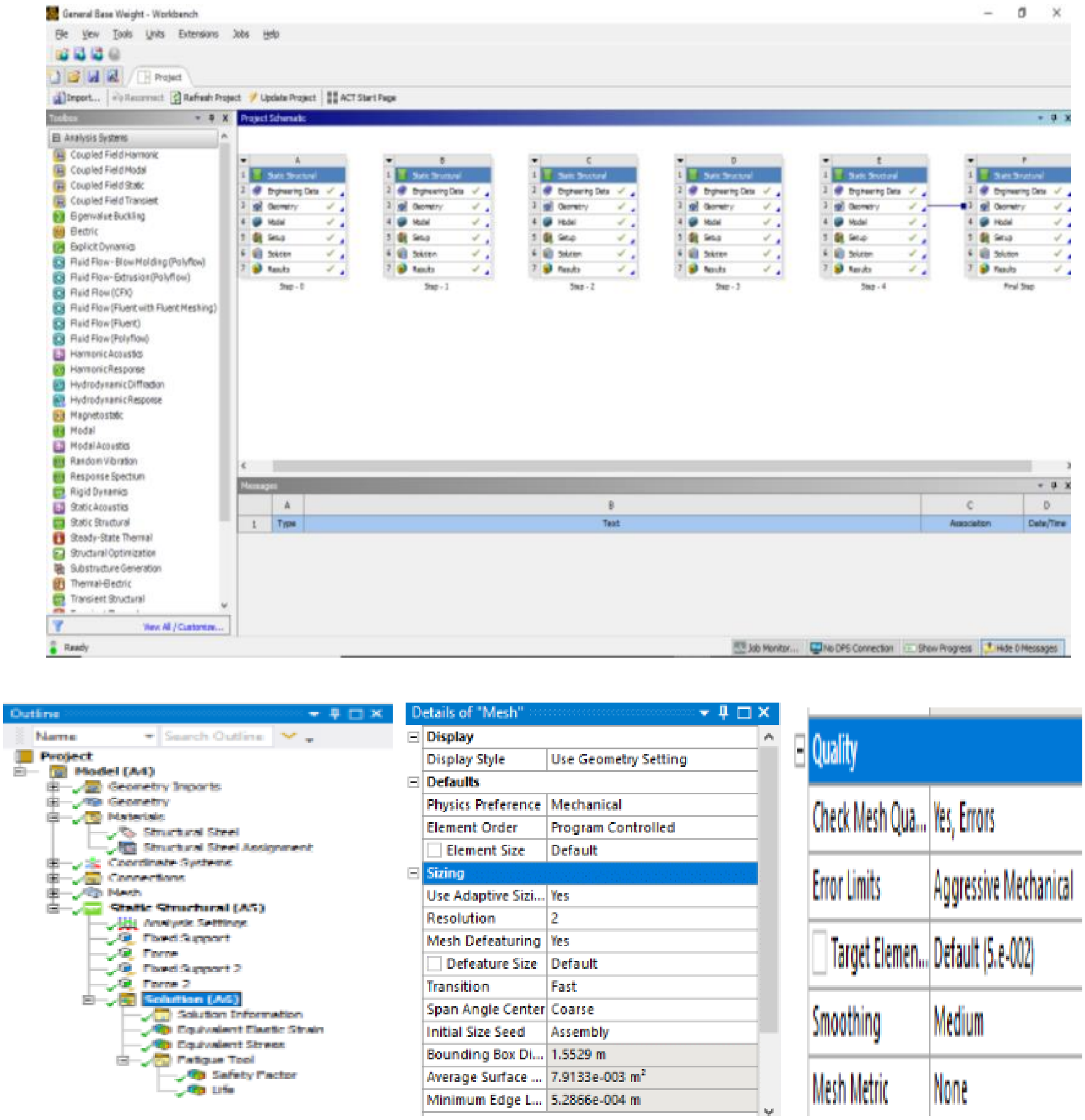
3	Stopper	

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Observations and Interpretations

The structural analysis was performed using Static Structural module of ANSYS Workbench as followed in Woo Suk Chung et al. [10].



4.1 ANSYS Workbench Static Structural module

The material chosen for fabrication was Chromoly steel. However, due to its unavailability in ANSYS material database, we opted for Structural steel for the structural analysis. The various steps of 3D CAD model, which was designed in SolidWorks, was exported separately as IGES, and were analyzed for its structural integrity.

Boundary Conditions:

(i) Fixed supports were assigned to the components which lie directly above the mattress.

(ii) Loading: Loading for different steps were obtained with the help of the data extracted from Melvin Adolphe et al. [9].

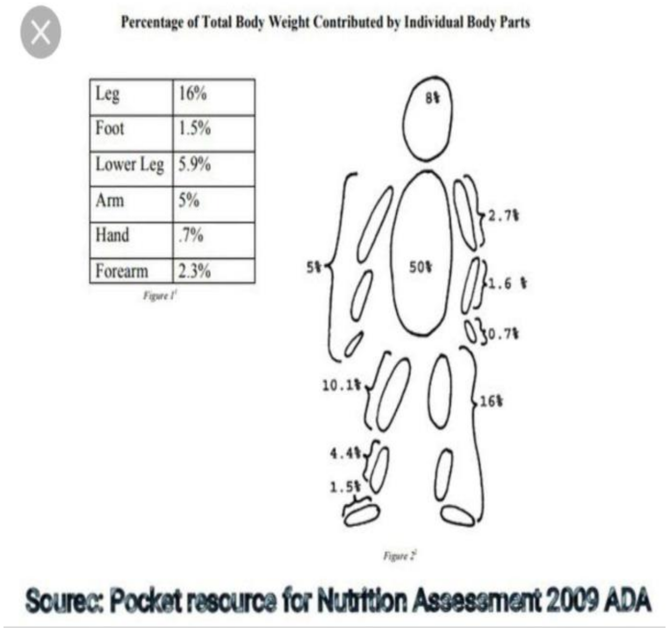
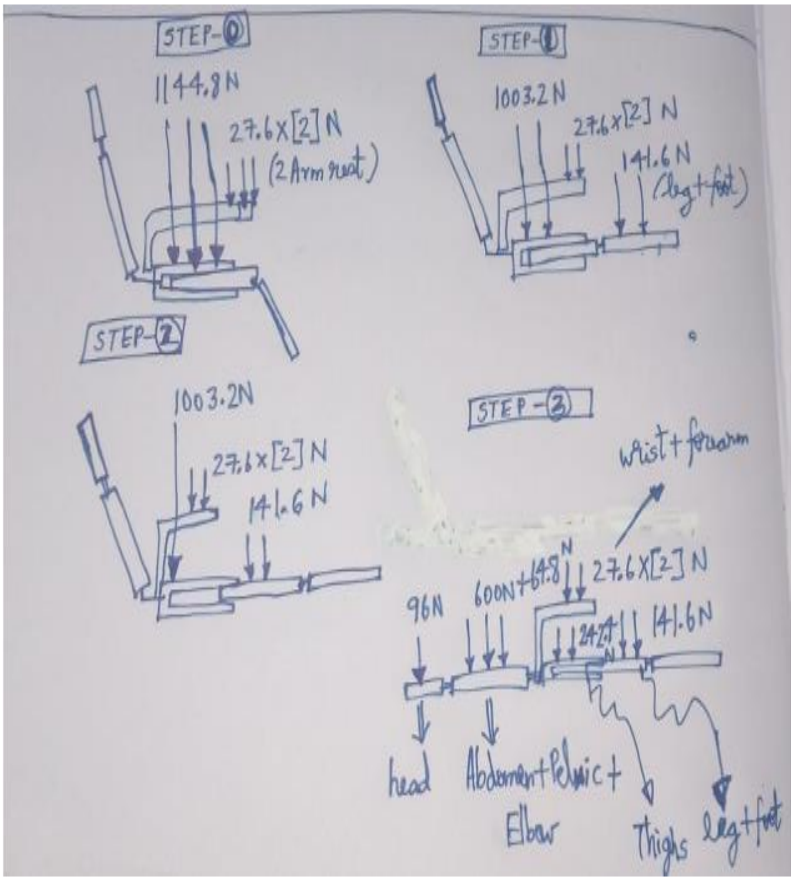


Figure 4.2 Different Body Parts and their Weight Constituents in Whole Body Weight



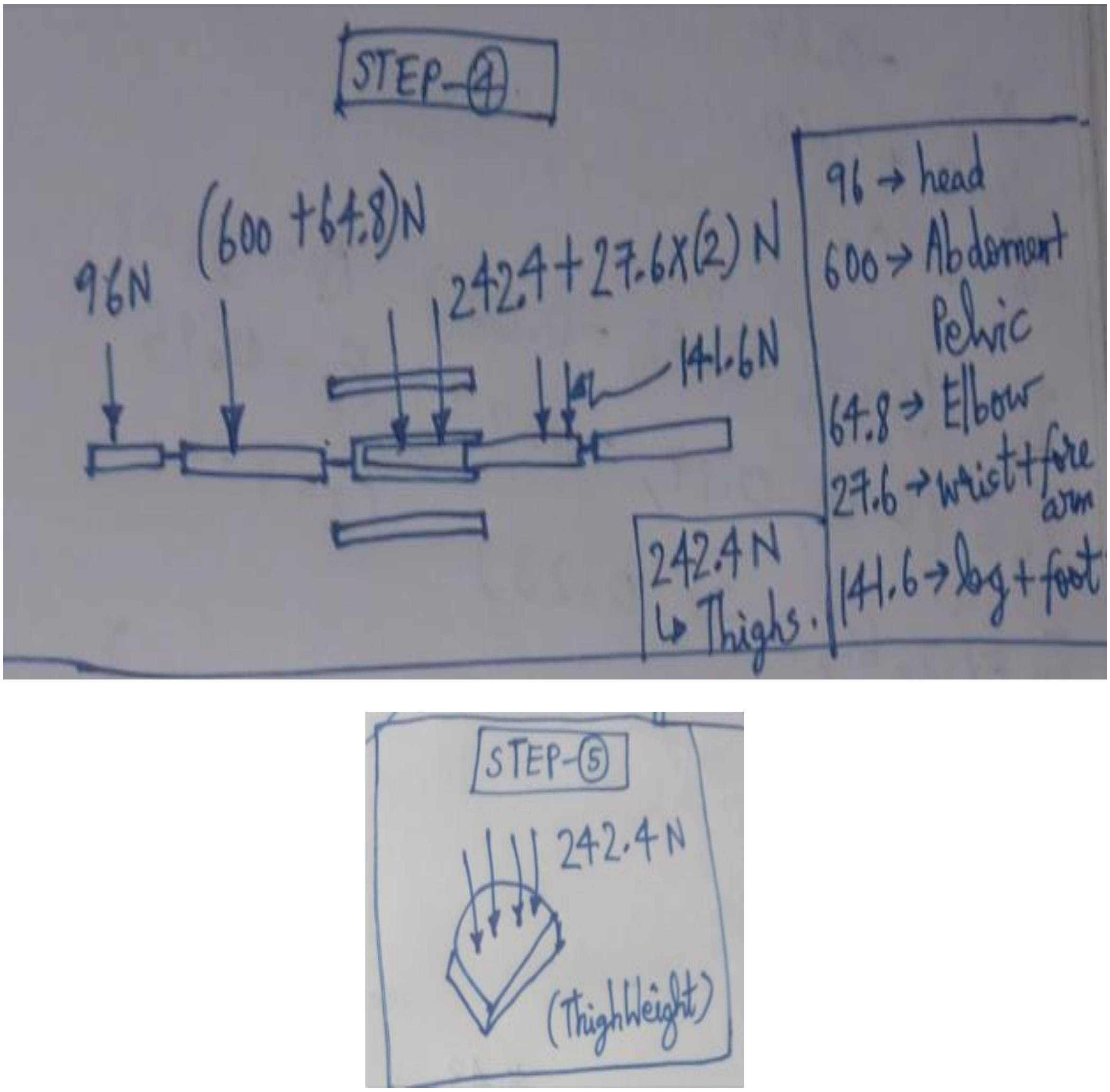


Figure 4.3 Calculations for Finding Weight on Each Part

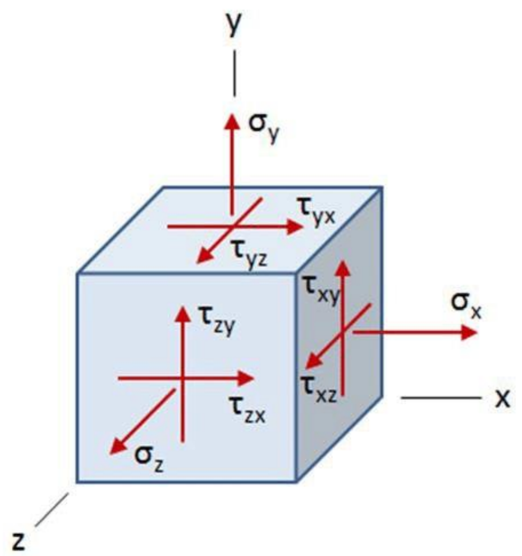
Table 4.1. Individual Body Parts and their Constituent in Whole Body Weight (in %)

S.No.	Body Parts	Percentage (%)	Weight (120*(%))
(1)	Hand Wrist	0.7*2 = 1.4	16.8
(1)	Forearm	1.6*2 = 3.2	38.4
(1)	Elbow	2.7*2 = 5.4	64.8
(1)	Thighs	10.1*2 = 20.2	242.4
(1)	Abdomen + Pelvic	50	600
(1)	Leg + Foot	(4.4+1.5) *2 = 11.8	141.6
(1)	Head	8	96

For meshing, a resolution of 2 is used, which is the maximum resolution available for student version of ANSYS Workbench,

Solutions Extracted:

Through structural simulation, equivalent stress (Von Mises) and equivalent strain (Von Mises) were obtained.



$$\sigma_{vm} = \sqrt{0.5\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + (\sigma_z - \sigma_x)^2\right] + 3({\tau_{xy}}^2 + {\tau_{yz}}^2 + {\tau_{zx}}^2)}$$

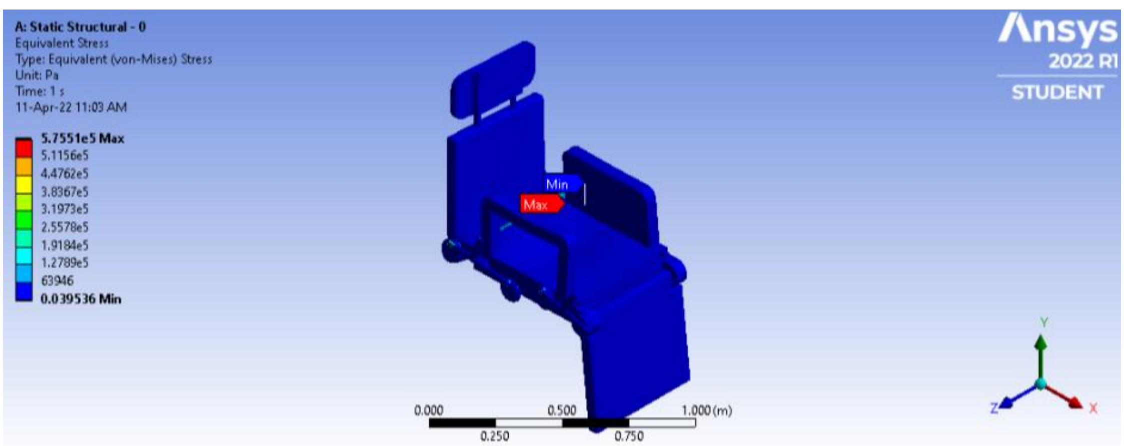
Figure 4.4 Equivalent Stress (Von Mises)

Fatigue Analysis was performed, assuming that a fully reversed cyclic loading has a scale factor of 1. Scale Factor = P_{min}/P_{max}, where $\boldsymbol{P_{max}}$ and $\boldsymbol{P_{min}}$ are the maximum and minimum cyclic loading. From fatigue analysis, life, and factor of safety of the device was calculated.

4.1.1 Structural and fatigue analysis

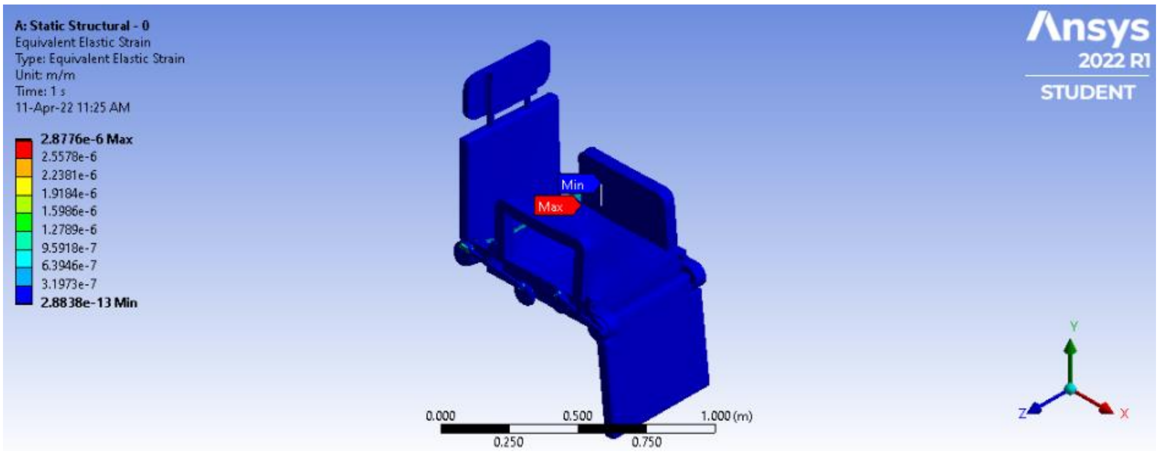
During the structural analysis, equivalent stress, equivalent strain, life and safety factor were assessed for each step.

Step 0:



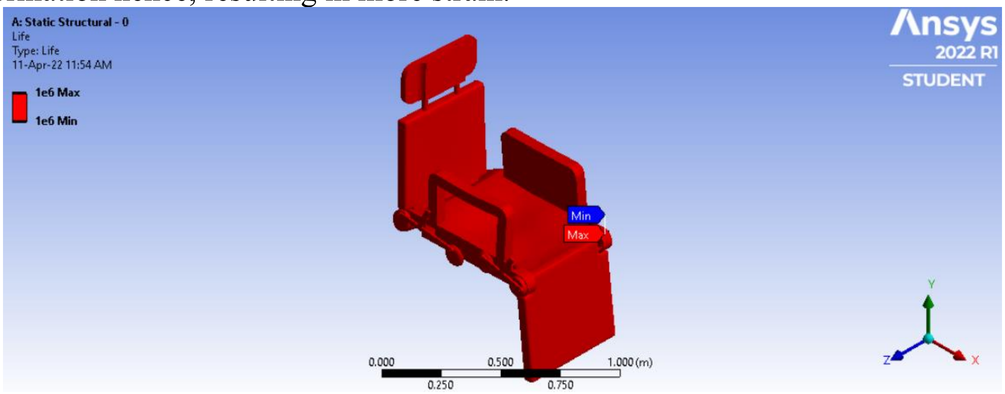
4.5(A) Equivalent Stress during Step 0

The maximum stress value is obtained at the right back corner of the sliding seat. This might be due to the entire central load acting on the back of the chair more as we move towards the upper member.



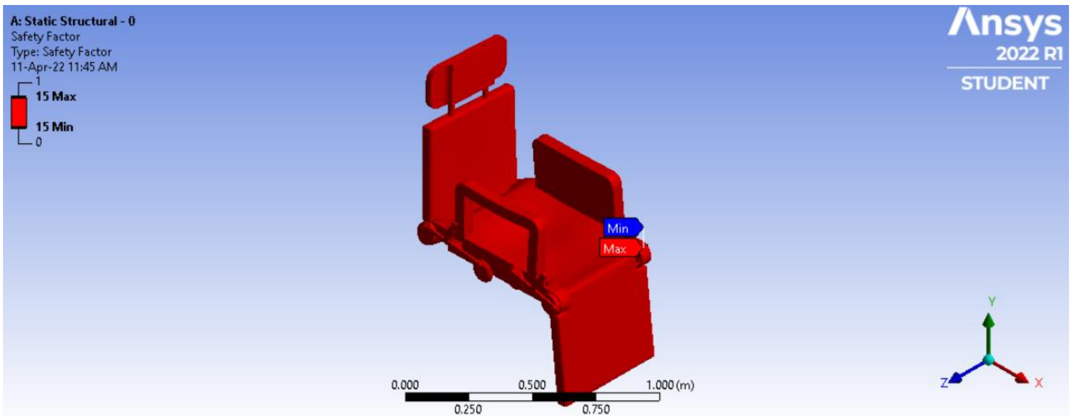
4.5(B) Equivalent Strain during Step 0

The maximum strain value is obtained at the right back corner of the sliding seat. This might be due to the entire central load acting on the back of the chair, and this concentrated load creates more deformation hence, resulting in more strain.



4.5(C) Life during Step 0

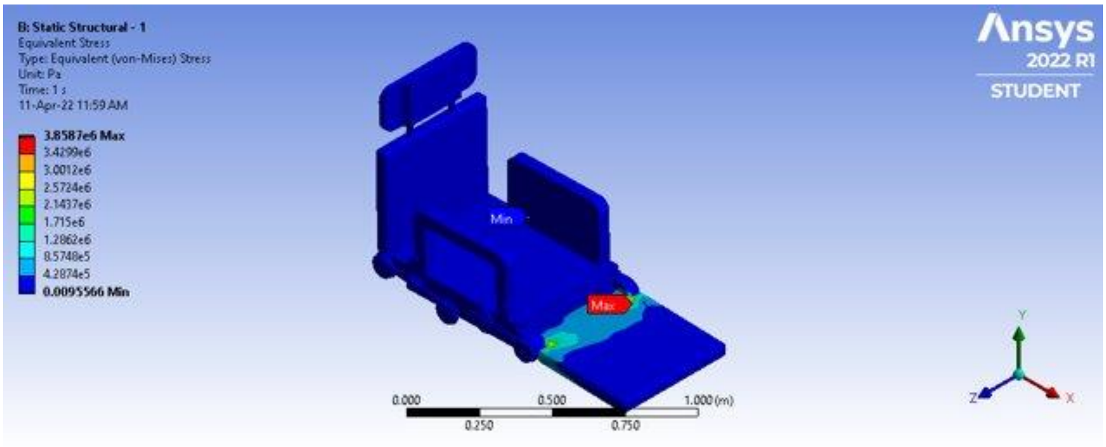
As the obtained equivalent stress is lesser than the yield strength, the life is 10^6 which is infinite life cycle.



4.5(D) Factor of Safety (FoS) during Step 0

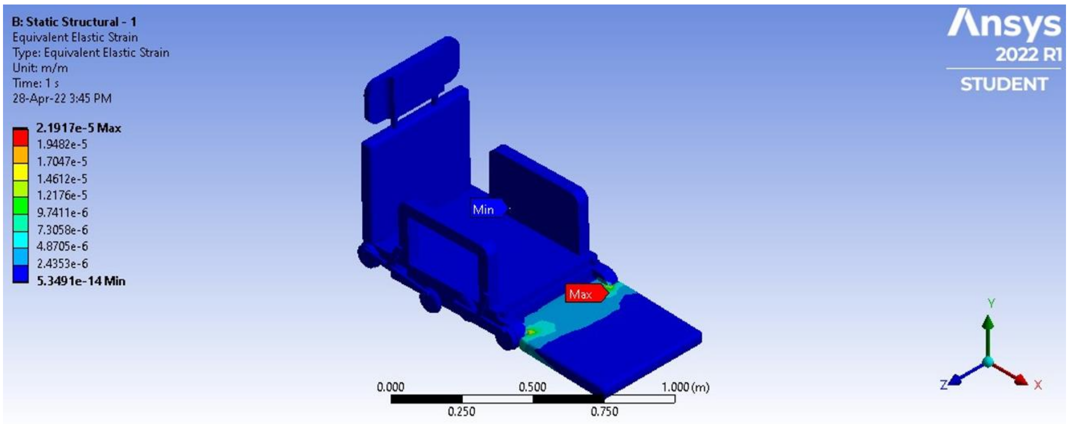
Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS.

<u>Step 1:</u>



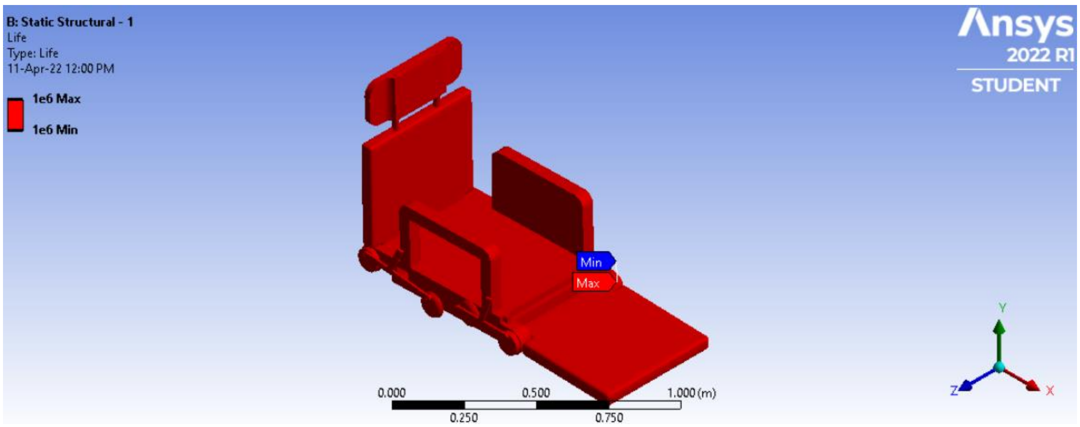
4.6(A) Equivalent Stress during Step 1

The maximum stress value is obtained at the interface between the joins of the leg member and the fixed seat. This might be due to the entire leg and foot load acting on the pivoted end of the leg member. This can be reduced by a stopper that we had incorporated as a design modification.



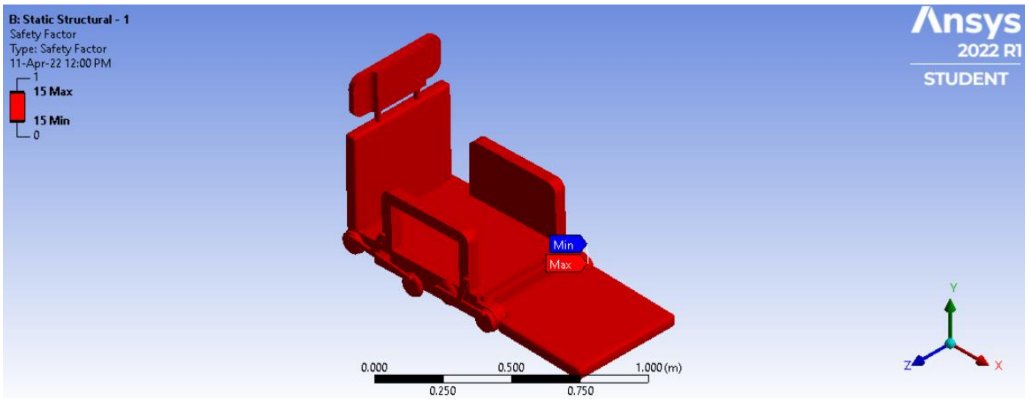
4.6(B) Equivalent Strain during Step 1

The maximum strain value is obtained at the interface between the joins of the leg member and the fixed seat. This might be due to the entire leg and foot load acting on the pivoted end of the leg member which increases the deformation at that location hence the increased strain.



4.6 (C) Life during Step 1

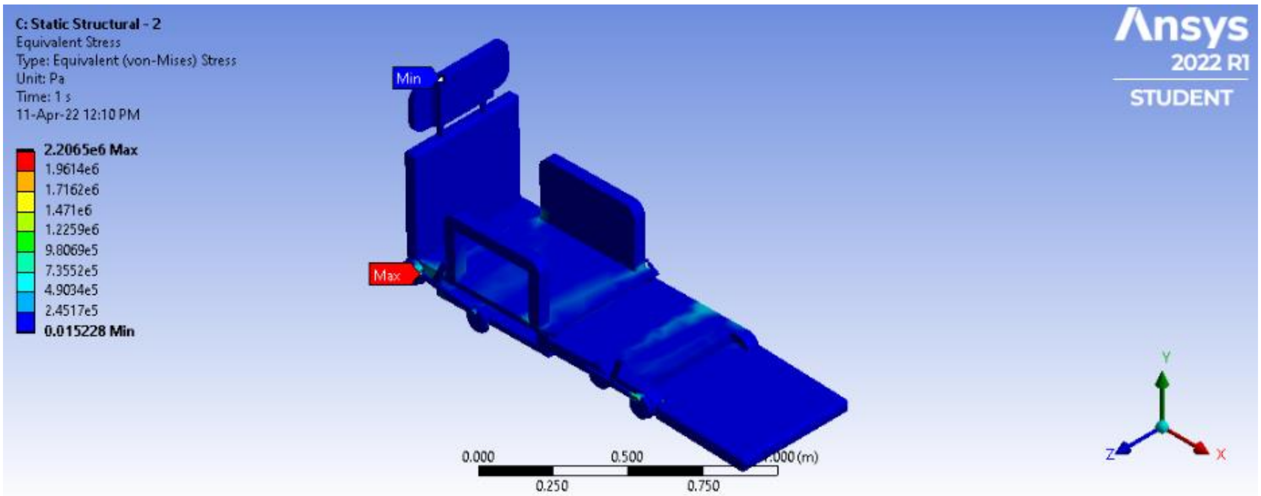
As the obtained equivalent stress is lesser than the yield strength, the life is 10^6 which indicates infinite life cycle.

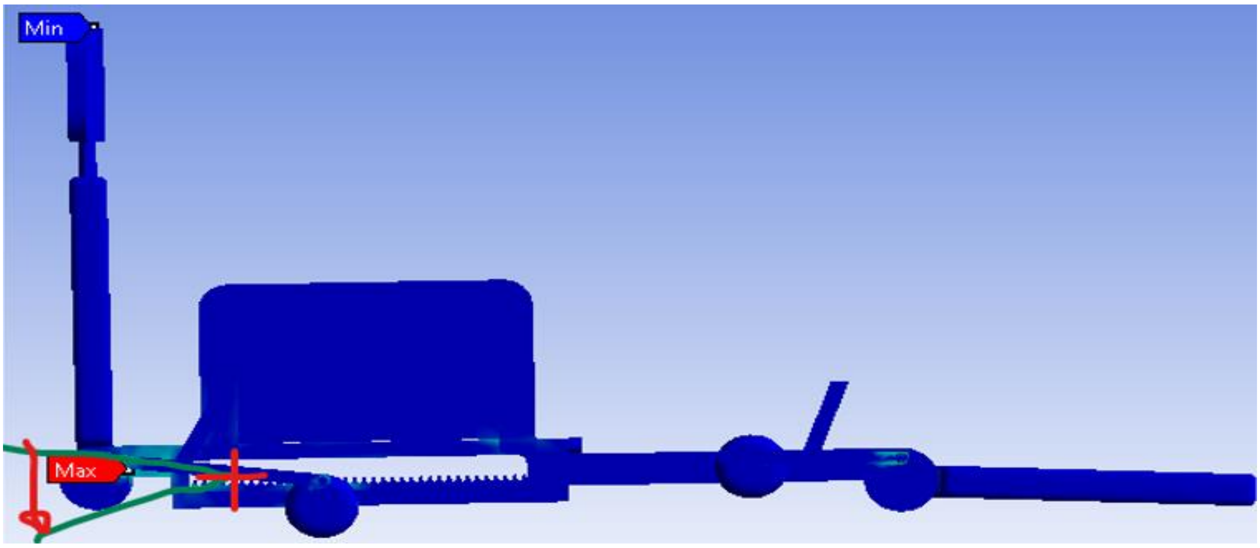


4.6 (D) Factor of Safety (FoS) during Step 1

Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS.

Step 2:





4.7 (A) Equivalent Stress during Step 2
(B) Maximum and Minimum Von Mises Stress and their Positions

The maximum stress value is obtained at the interface between the joins of the leg member and the fixed seat. This might be due to the majority fraction of the load acting on the chair acts on the left extreme of the chair and the connection joint between the upper member and the slider is hinged above the mattress by a slight distance. Hence, it acts as a cantilever beam with a fixed end at the right end. Another reason for this observation not noticed in the previous cases were due to the hollow slider member enclosing the fixed base which gave the structural support, but here as it slights away from the fixed base, it loses its strength.

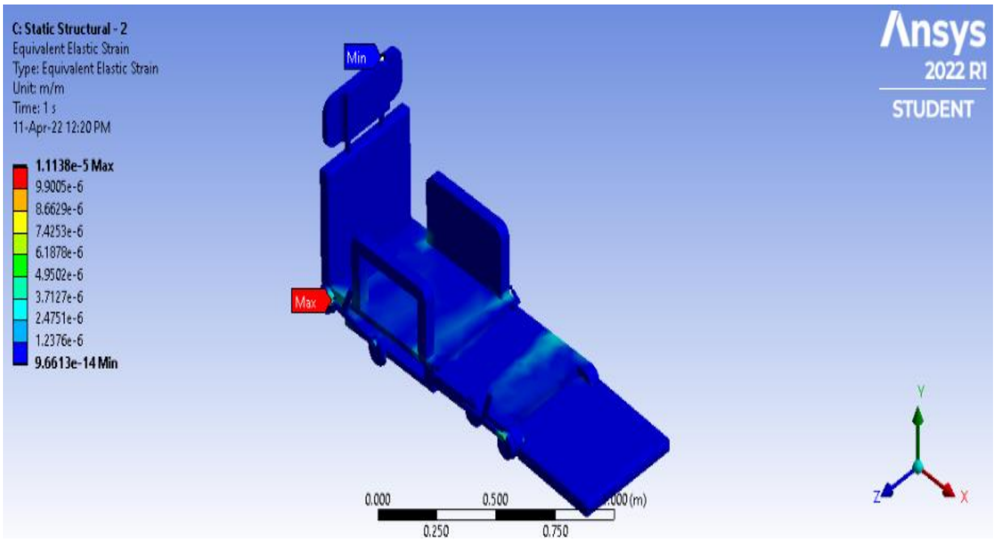


Figure 4.7 (C) Equivalent Strain at Step 2

The maximum strain value is obtained at the interface between the joins of the leg member and the fixed seat. This might be due to the majority fraction of the load acting on the chair acts on the left extreme of the chair and the connection joint between the upper member and the slider is hinged above the mattress by a slight distance. Hence, it acts as a cantilever beam with a fixed end at the right end. Another reason for this observation wasn't felt in the previous cases were due to the hollow slider member enclosing the fixed base which gave the structural support, but here as it slights away from the fixed base, it loses its strength. Hence, due to majority of the force acting on the left extreme of the connection joint, deformation and strain is higher in that region.

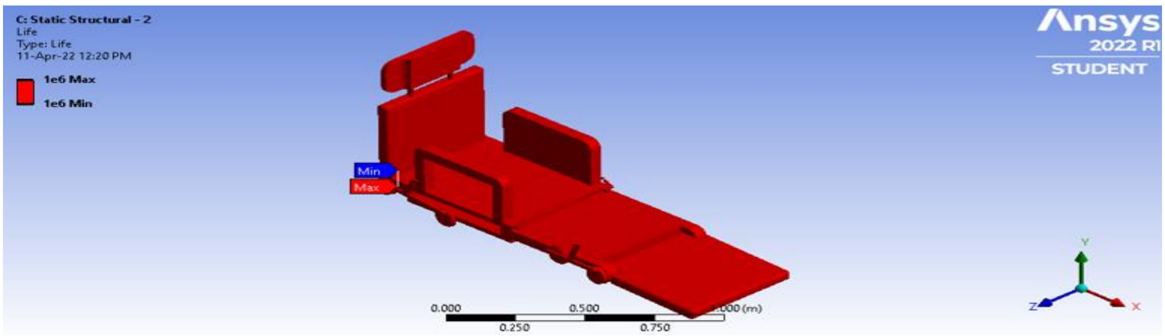


Figure 4.7 (D) Life at Step 2

As, the obtained equivalent stress is lesser than the yield strength. The life is 10^{6}, which is infinite life cycle.

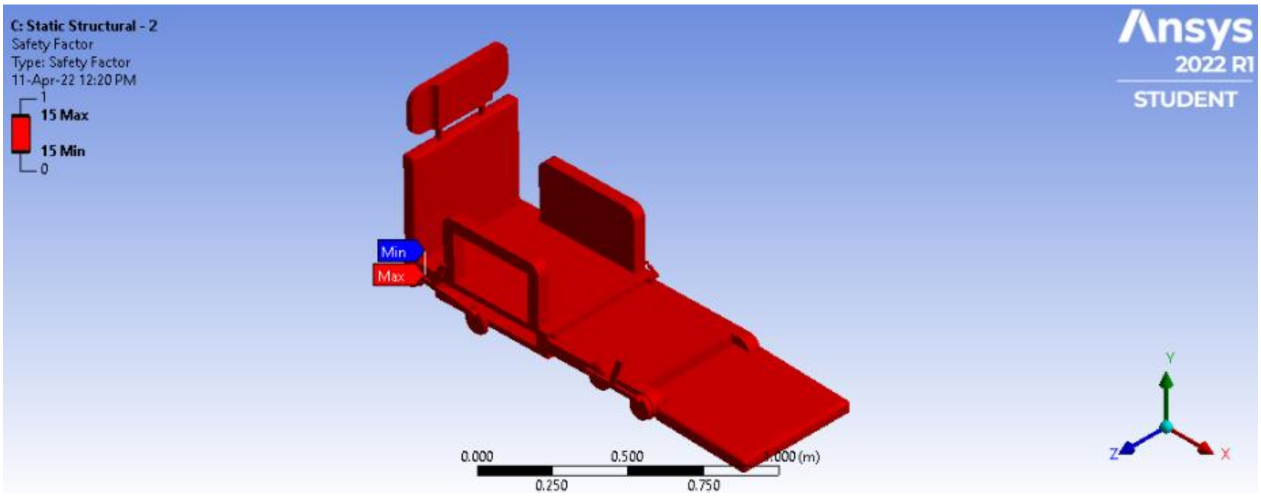
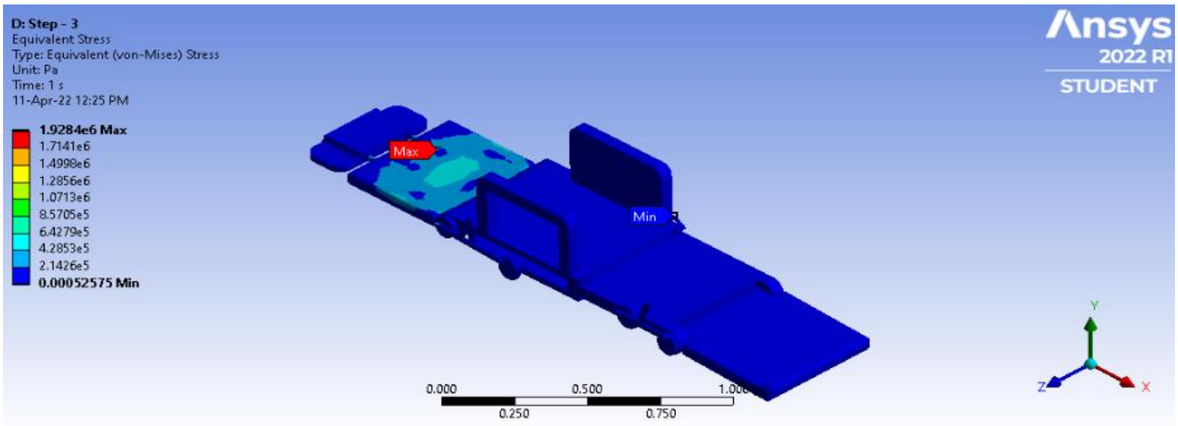


Figure 4.7 (D) Factor of Safety (FoS) at Step 2

Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS.

<u>Step 3:</u>



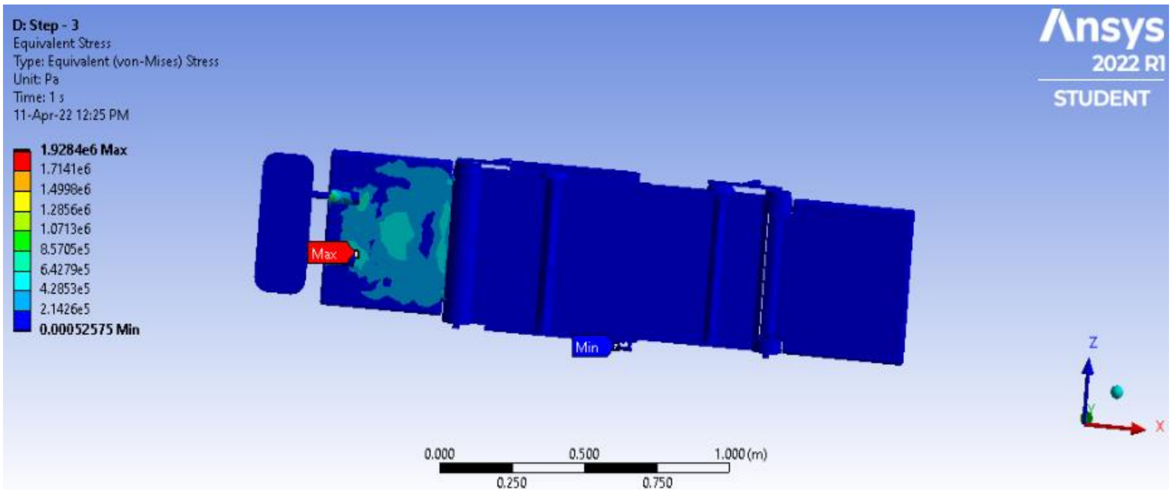


Figure 4.8(A) Equivalent Stress at Step 3
(B) Maximum and Minimum Equivalent Stress at Step 3

The maximum stress value is obtained near the rod housing of the handle in the upper member. This might be since Nearly 50% of the weight acts on the upper member and particularly at the housing end of the rod due to local stress concentration.

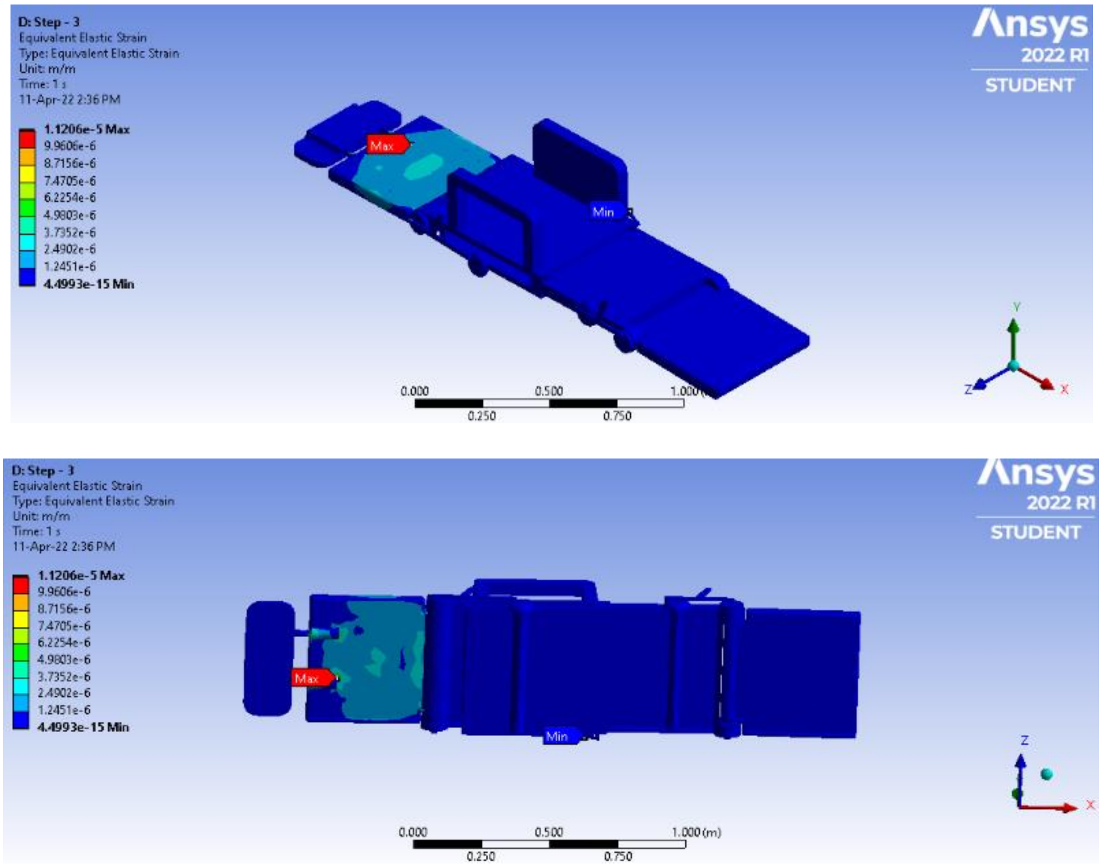


Figure 4.8 (C) Equivalent Strain at Step 3
(D) Maximum and Minimum equivalent strain at Step 3

The maximum strain value is obtained at a similar location as that of the maximum stress. This might be due to the 50% of the weight contributed by the abdomen and pelvic weight. Hence, due to this more force, deformation tends to be more and thereby greater strain value in that region.

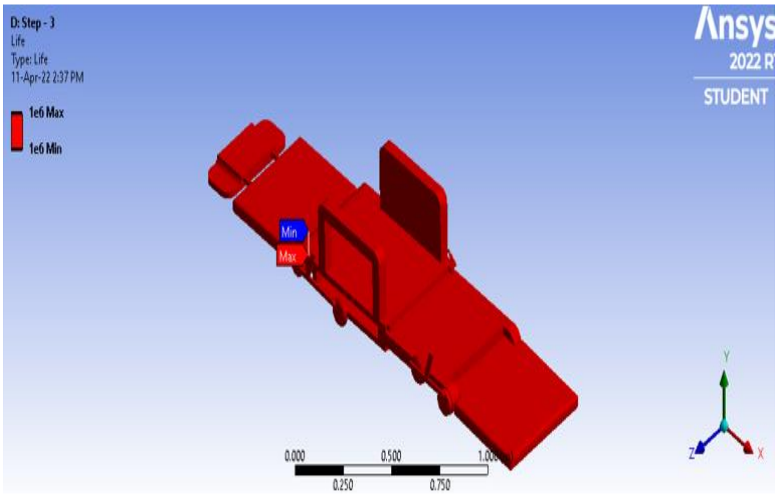


Figure 4.8 (D) Life at Step 3

As the obtained equivalent stress is lesser than the yield strength. The life is 10^6 which is infinite life cycle.

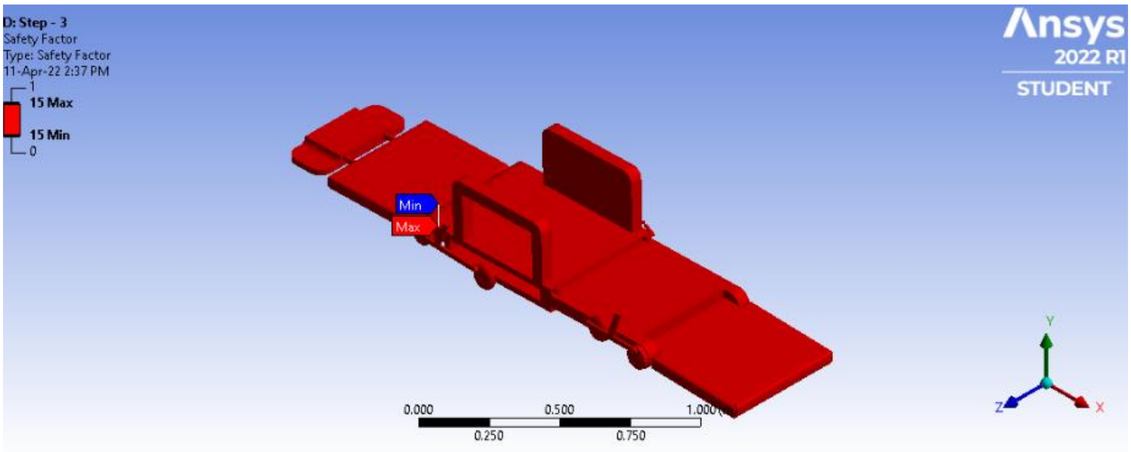
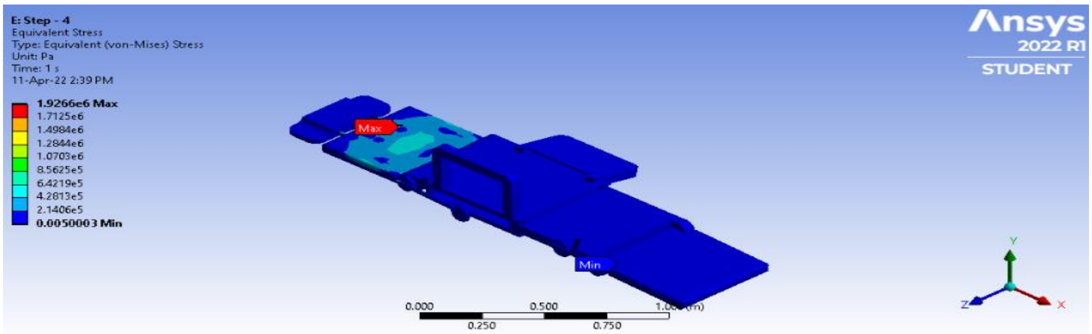


Figure 4.8 (E) Factor of Safety (FoS) at Step 3

Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS

Step 4:



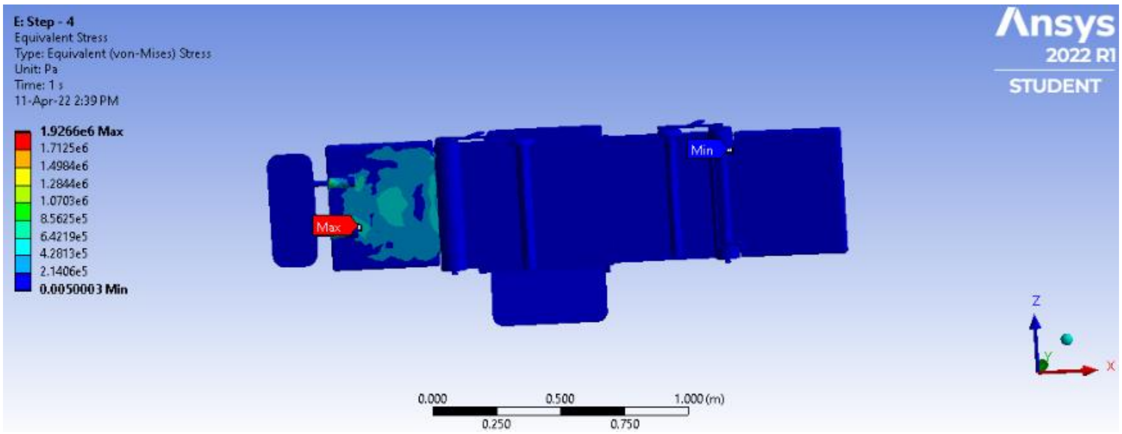


Figure 4.9 (A) Equivalent Stress at Step 4
(B) Maximum and Minimum Equivalent Stress at Step 4

This case is pretty much the same as compared to that of the previous step. Here just the arm and elbow weight get added on the sliding member, which contributes about only 5.4% of the total weight. The maximum stress value is obtained near the rod housing of the handle in the upper member. This might be since most of the load. Nearly 50% of the weight acts on the upper member and particularly at the housing end of the rod due to local stress concentration.

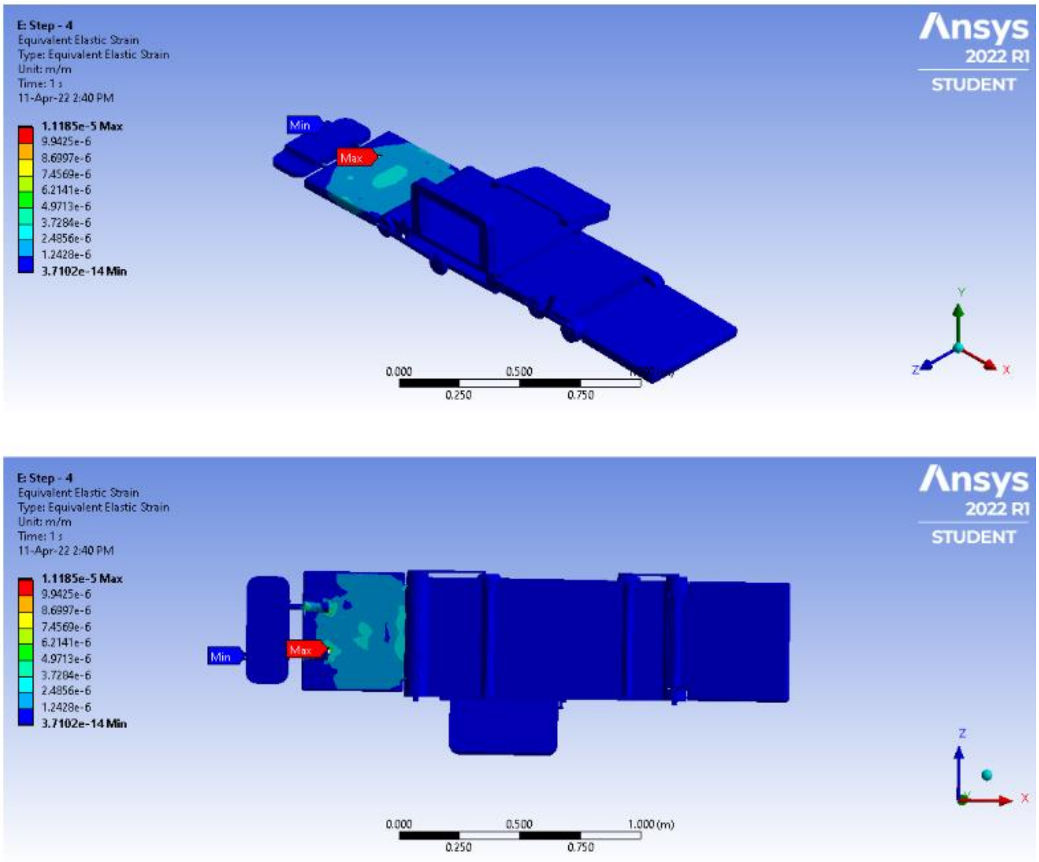


Figure 4.9 (C) Equivalent Strain at Step 4
(D) Maximum and Minimum Equivalent Strain at Step 4

The maximum strain value is obtained at a similar location as that of the maximum stress. This case is pretty much the same as compared to that of the previous step. Here just the arm and elbow weight get added on the sliding member, which contributes about only 5.4% of the total weight. This might be due to the 50% of the weight contributed by the abdomen and pelvic weight. Hence, due to this more force, deformation tends to be more and thereby greater strain value in that region.

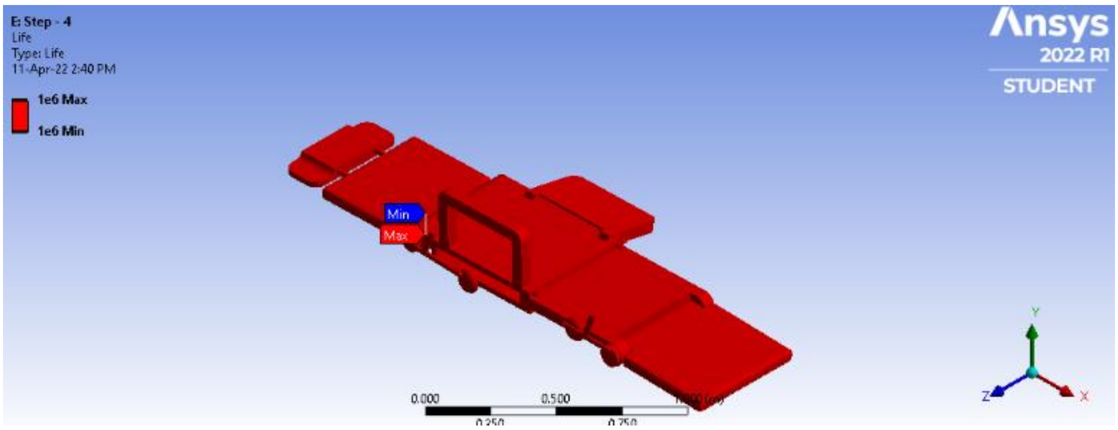


Figure 4.9 (E) Life at Step 4

As the obtained equivalent stress is lesser than the yield strength. The life is 10^6 which is infinite life cycle.

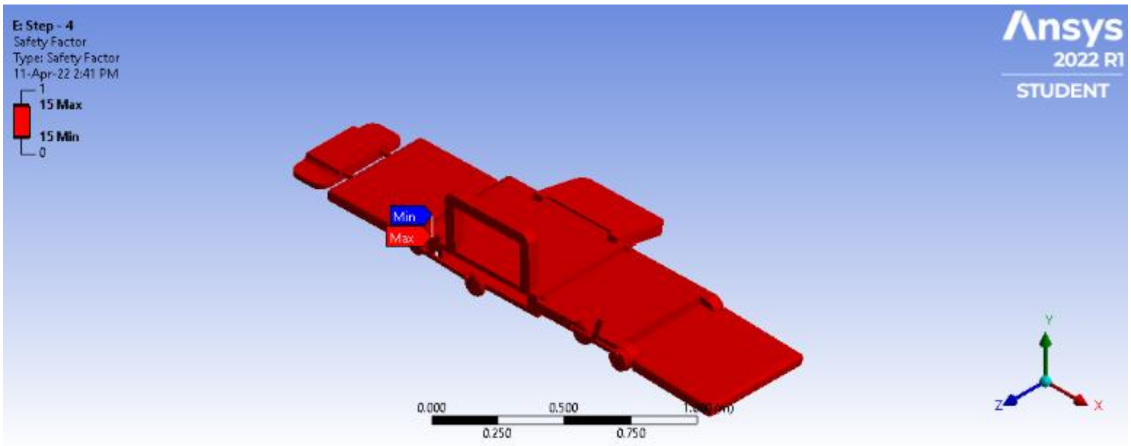


Figure 4.9 (F) Factor of Safety (FoS) at Step 4

Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS.

Step 5:

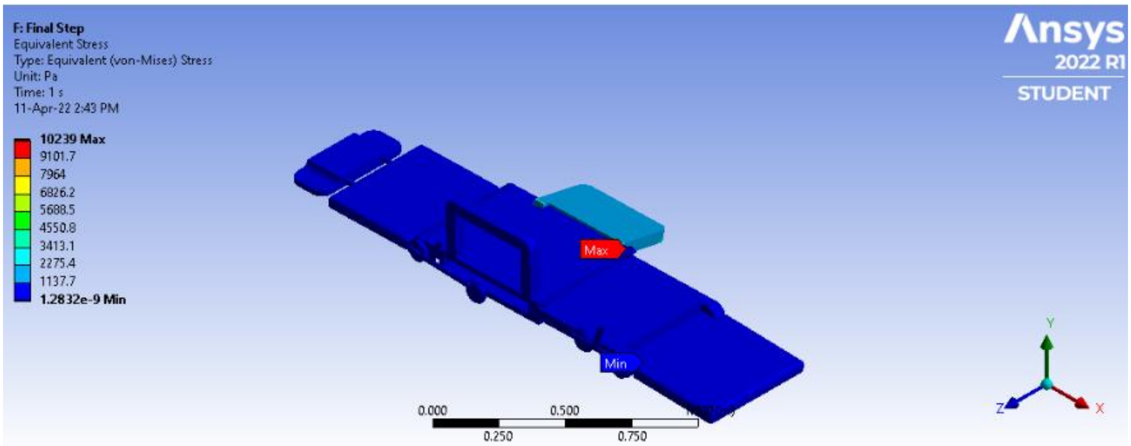


Figure 4.10 (A) Equivalent Stress at Step 5

Here, the load is applied only on the armrest to check on the structural stability of the armrest when the patient / user rolls over the armrest on to the bed. Loading force is the weight of the thighs. Here, the Maximum stress is obtained at the revolute joint of the tilting armrest as the entire armrest acts as a cantilever beam, and the maximum stress occurs near the fixed end.

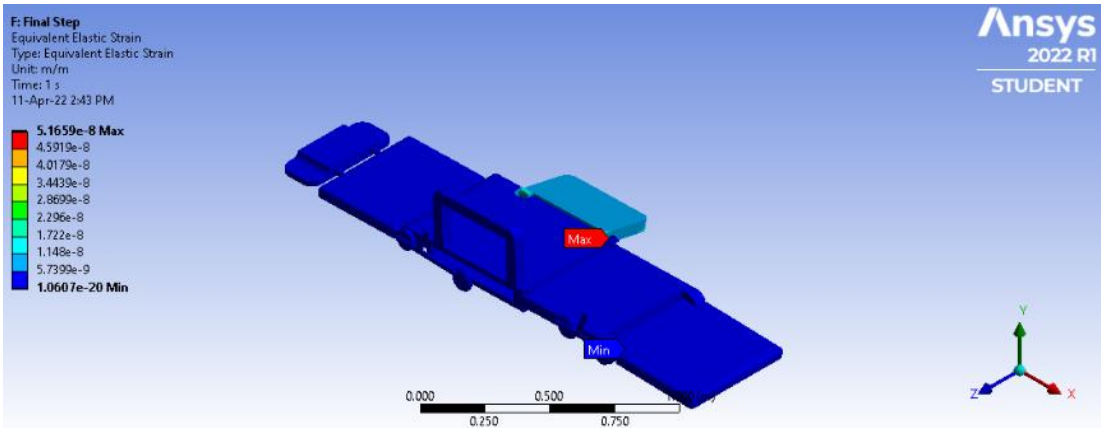


Figure 4.10 (B) Equivalent Strain at Step 5

Here, even though the load acts uniformly throughout the armrest, but still the right portion, or the portion which is in contact with the mattress experiences less deformation as compared to the left one and less strain to the contact / normal reaction at the corner. Hence, the maximum strain is observed near the revolute joint of the armrest.

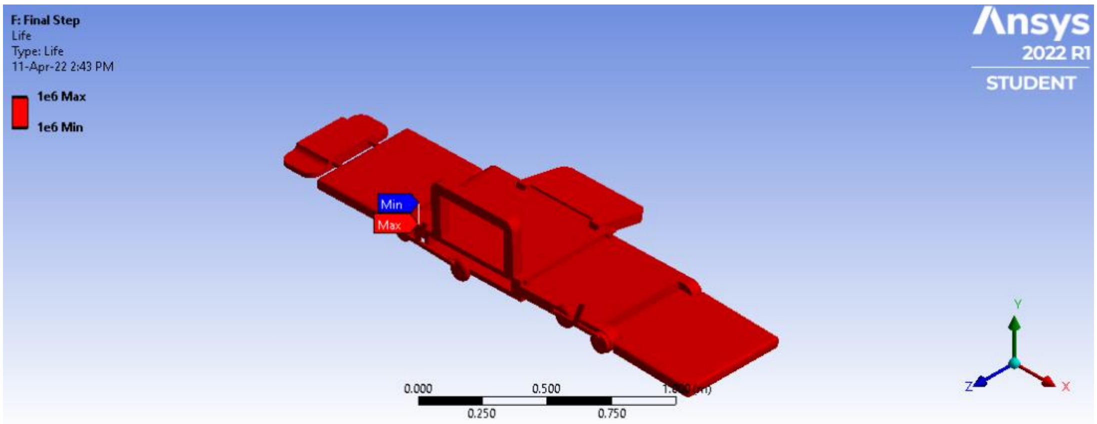


Figure 4.10 (C) Life at Step 5

As the obtained equivalent stress is lesser than the yield strength, the life is 10^6 which is infinite life cycle.

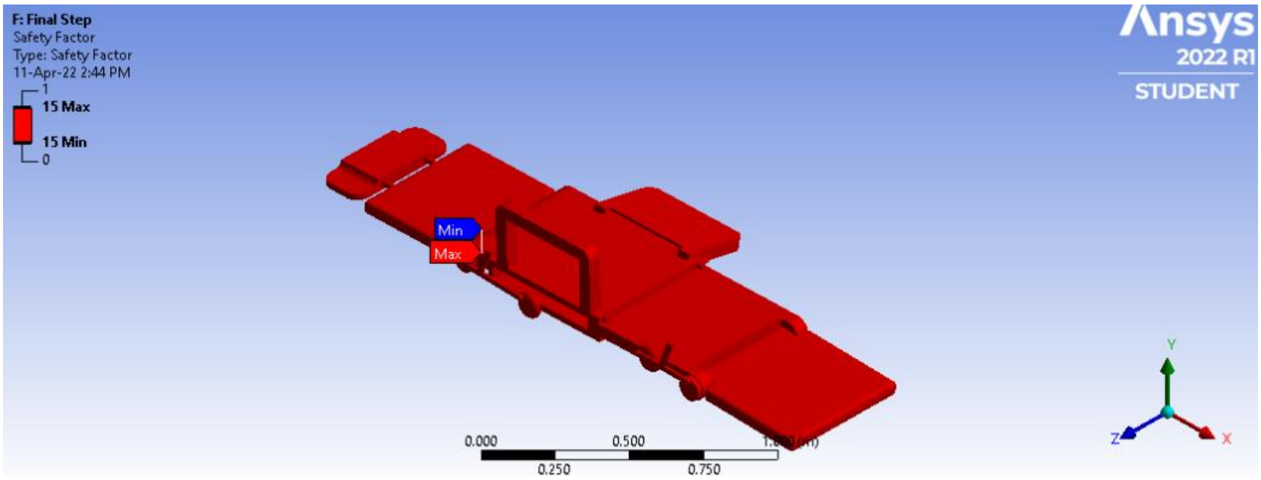


Figure 4.10 (D) Factor of Safety (FoS) at Step 5

Factor of safety is obtained to be 15, by assuming the user weight to be 120 KGS.

Table 4.2 Equivalent Stress, Equivalent Strain, Life, and Factor of Safety (FoS) for Each Step

STEPS	Eq. Strain (m)	Eq. Stress (Pa)	Life	Factor of Safety
Step 0 – Initial	Max: 2.8876e-6 Min:2.8838e-13	Max:5.7551e5 Min:0.039536	Max: 10^6 Min: 10^6	Max: 15 Min: 15
Step 1	Max: 2.1917e-5 Min: 5.3491e-14	Max:3.8587e6 Min:0.0095566	Max: 10^6 Min: 10^6	Max: 15 Min: 15
Step 2	Max:1.1138e-5 Min:9.6613e-14	Max:2.2065e6 Min: 0.015228	Max: 10^6 Min: 10^6	Max: 15 Min: 15
Step 3	Max: 1.1206e-5 Min:4.4993e-15	Max: 1.9284e6 Min:0.00052575	Max: 10^6 Min: 10^6	Max: 15 Min: 15
Step 4	Max:1.1185e-5 Min:3.7102e-14	Max:1.9266e6 Min:0.0050003	Max: 10^6 Min: 10^6	Max: 15 Min: 15
Step 5 – Final	Max: 5.1659e-8 Min:1.0602e-20	Max:10239 Min:1.2832e-9	Max: 10^6 Min: 10^6	Max: 15 Min: 15

Inference of Analysis with respect to Chromoly Steel:

Chromoly is a chrome alloy steel with a medium carbon content and 0.8% to 1.1% chromium, 0.15-0.25% Molybdenum for strength. In general, Chromoly steel is lightweight and possess high ductility but can withstand more load. It's commonly used in hospital beds. Yield Strength of Chromoly Steel is 460MPa or 460000000Pa. All the observed stress in the analysis is way lesser than the above-mentioned threshold. Hence, we can conclude that the product does not fail in any of the operating stages.

Figure 4.11 Chromoly Alloy Steel

Table 4.3 Equivalent Stress for Each Step

STEPS	Equivalent Stress
Step 0 (Initial)	5.7551x10^5
Step 1	3.8587x10^6
Step 2	2.2056x10^6
Step 3	1.9824x10^6
Step 4	1.9266x10^6
Step 5 (Final)	10239

4.1.2 Center of Mass (COM) Analysis

In physics, the center of mass of a distribution of mass in space sometimes referred to as the balance point) is the unique point where the weighted relative position of the distributed mass sums to zero. This is the point to which a force may be applied to cause a linear acceleration without an angular acceleration. Calculations in mechanics are often simplified when formulated with respect to the center of mass. It is a hypothetical point where the entire mass of an object may be assumed to be concentrated to visualize its motion. In other words, the center of mass is the particle equivalent of a given object for application of Newton's laws of motion.

In the case of a single rigid body, the center of mass is fixed in relation to the body, and if the body has uniform density, it will be located at the centroid. The center of mass may be located outside the physical body, as is sometimes the case for hollow or open-shaped objects, such as a horseshoe. COM Analysis was done in Solidworks by Dassault Systemes. Along with the center of mass we were able to obtain other vital data such as principal axes of inertia, principal moments of inertia and moments of inertia.

It is calculated by the formula below

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Step 0:

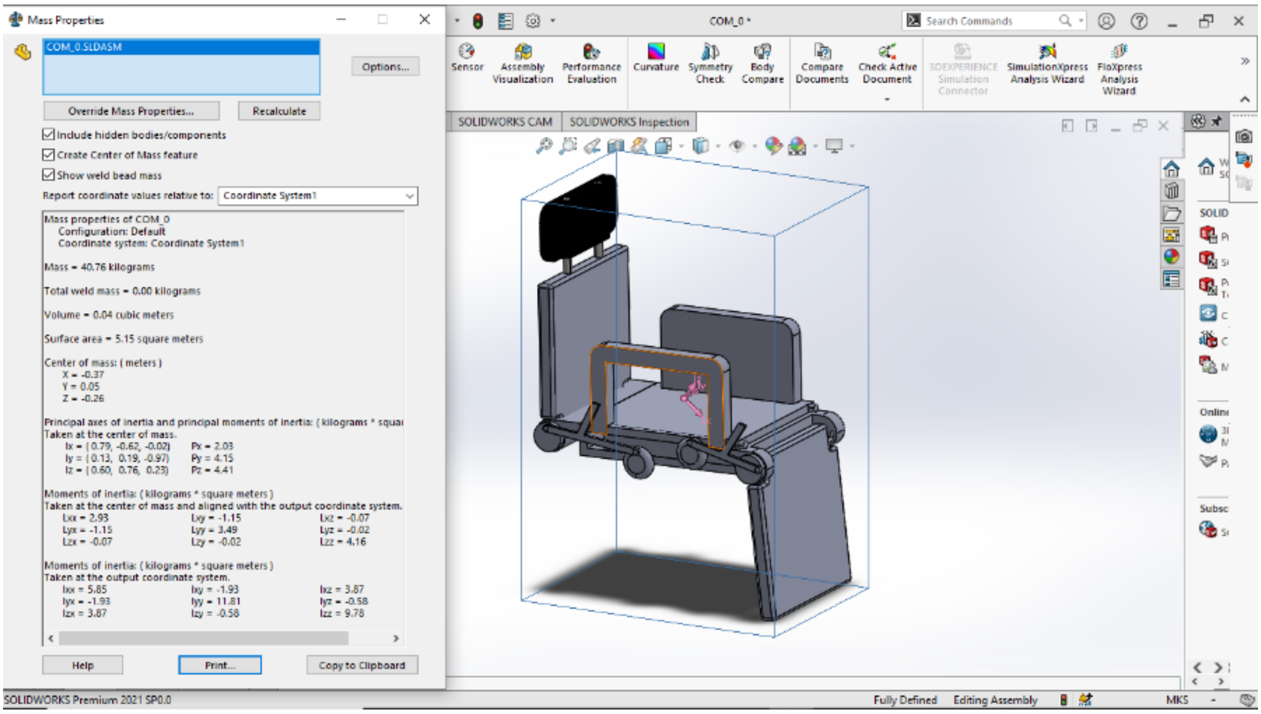


Figure 4.12 COM during Step 0

Origin (0,0,0) is fixed to be the right extreme of the fixed base. Coordinates of the COM would be (-0.37,0.05, -0.26). For COM at step 0 as pictured in figure, D = 0.207 m (20.7 cm).

Step 1:

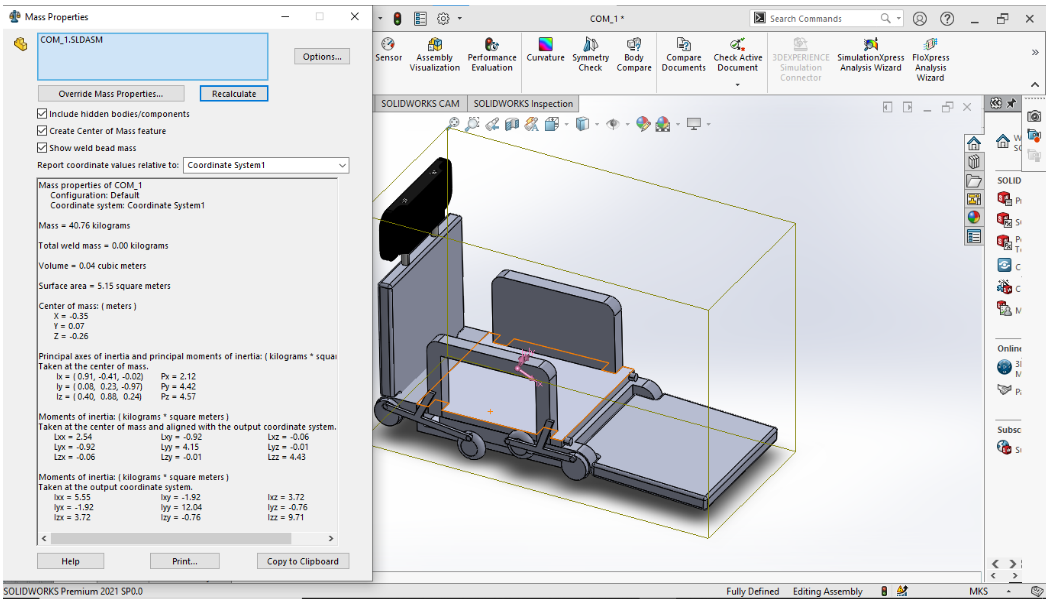


Figure 4.13 COM during Step 1

From here, we take (x2, x1), (y2, y1), (z2, z1) as relative to each other COM and origin 0,0,0 no longer comes into the picture. In this case D would be 0.028 m (2.8 cm) and COM coordinates would be (-0.35,0.07, -0.26).

Step 2:

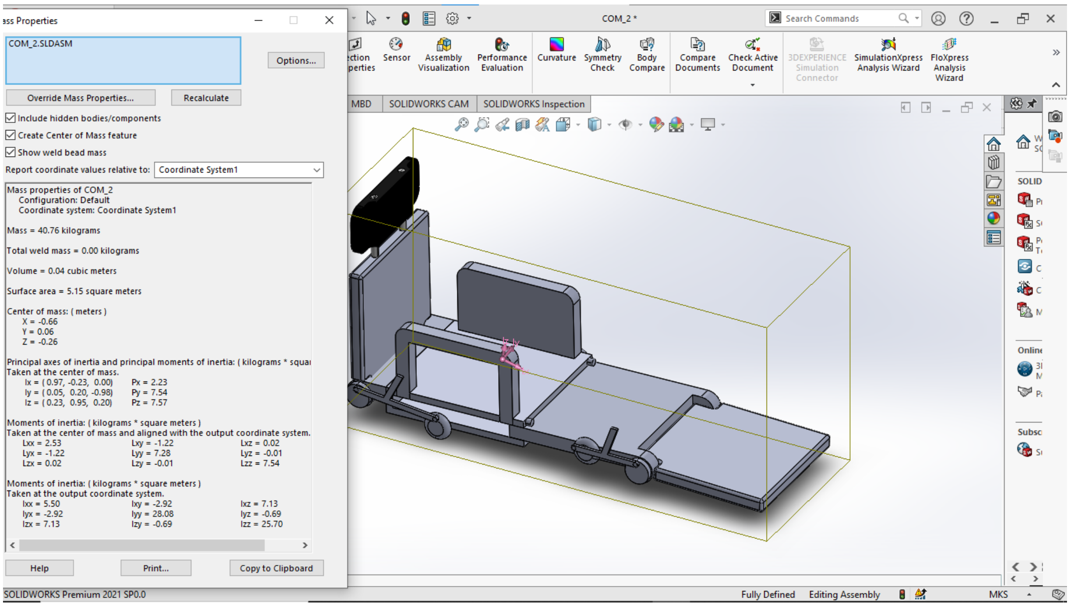


Figure 4.14 COM during Step 2

In this case, D would be 0.31m (31 cm). Coordinates of COM would be (-0.66,0.06, -0.26).

Step 3:

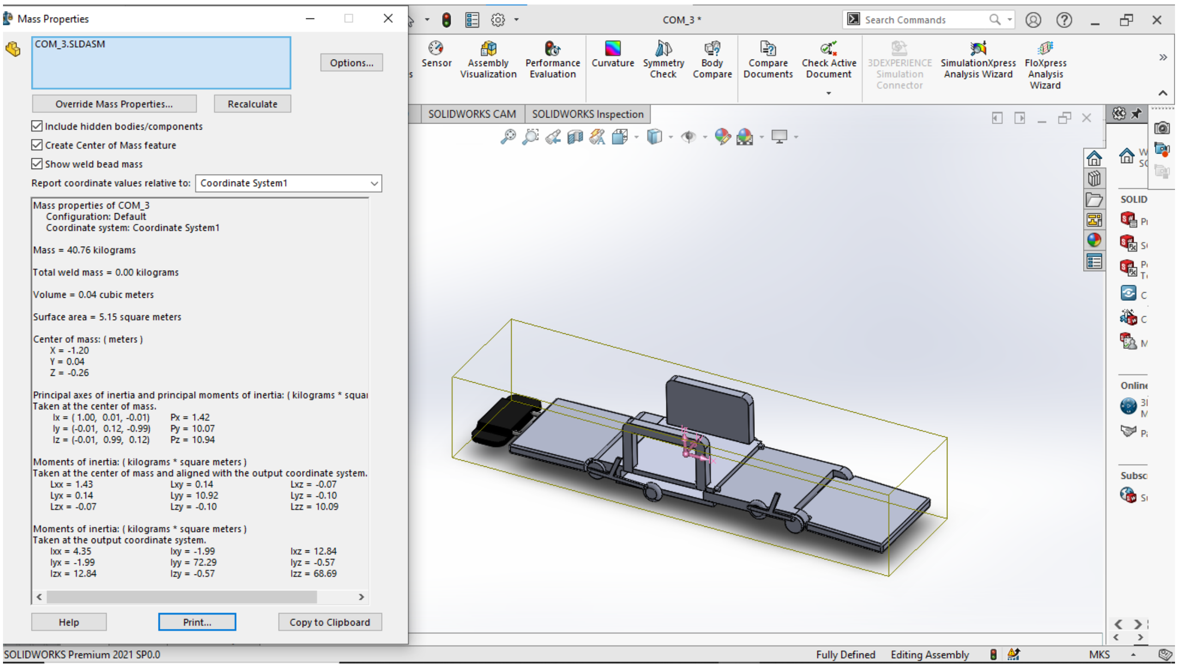


Figure 4.15 COM during Step 3

In this case D would be 0.54 m (54cm). Coordinates of the COM would be (-1.20,0.04, -0.26).

Step 4:

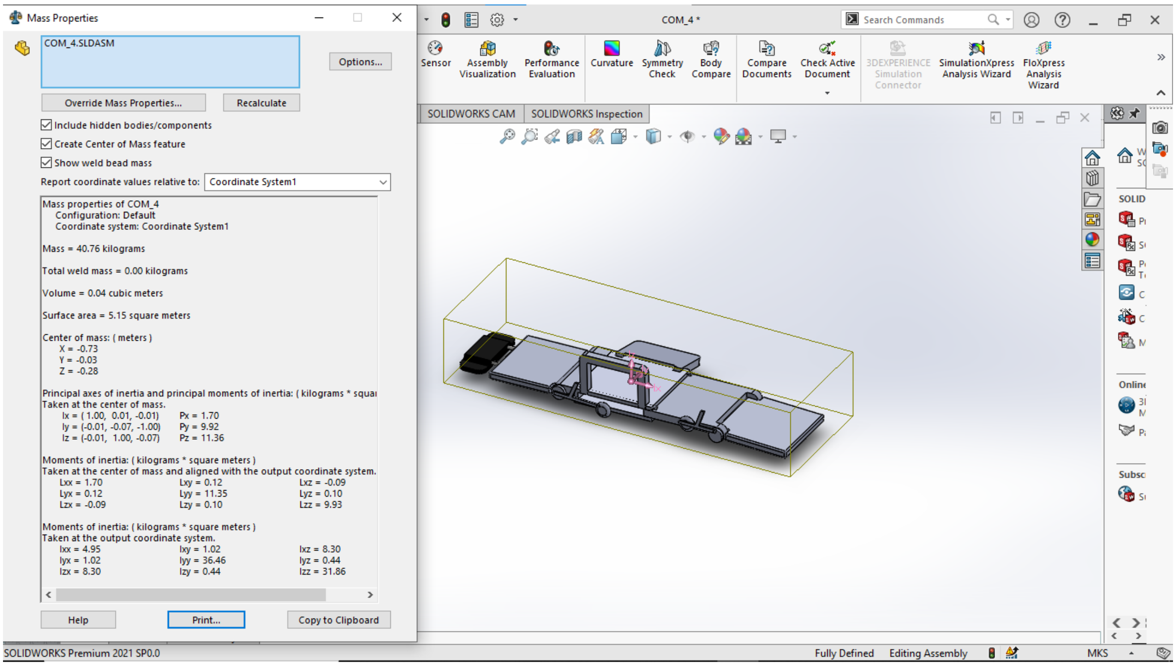


Figure 4.16 COM during Step 4

In this case D would be 0.47m (47 cm). Coordinates of the COM would (-0.73, -0.03, -0.28).

The Center of Mass (COM) of all the steps have been tabulated here.

Table 4.4 COM Coordinates and Distance for Each Step

STEPS	COM Coordinates	D Value
Step 0 – Initial	**(-0.37, 0.05, -0.26)**	**0.207 m (20.7 cm)**
Step 1	**(-0.35, 0.07, -0.26)**	**0.028 m (2.8 cm)**
Step 2	**(-0.66, 0.06, -0.26)**	**0.31m (31 cm)**
Step 3	**(-1.20, 0.04, -0.26)**	**0.54 m (54cm)**
Step 4	**(-0.73, -0.03, -0.28)**	**0.47m (47 cm)**

4.2 Meshing Analysis

All the above stepwise analysis solutions are obtained from ANSYS Student Version (Of resolution = 2). We exploited the OCTA Lab to access the actual version for mesh analysis. The analysis is conducted reiterated over and over by changing the resolution of the mesh size and the solutions are tabulated in Table.

The Standard deviation and the variance for Eq. Stress is observed to be 1.96 and 3.86 respectively. The Standard deviation and the variance for Eq. Strain is observed to be 9.892*10^-7 and 9.785*10^-13 respectively. As the Standard deviation and variance are small enough, the analysis is assumed to be converged to an extent.

Table 4.5 Meshing Analysis of Step 0 for Various Resolutions

	Step 0						
S.No.	Resolution	Nodes	Elements	Eq. Stress	Eq. Strain	Life	Safety Factor
1	2	87889	39552	5.76E+05	2.88E-06	1.00E+06	15
2	3	114013	54374	5.13E+05	2.57E-06	1.00E+06	15
3	4	192195	89316	6.65E+05	3.40E-06	1.00E+06	15
4	5	151107	70633	7.70E+05	3.85E-06	1.00E+06	15
5	6	450050	197457	1.06E+06	5.31E-06	1.00E+06	15
6	7	200414	101036	8.15E+05	4.16E-06	1.00E+06	15
	Standard Deviation			1.96E+00	9.892E-07	0	0
	Variance			3.86E+00	9.785E-13	0	0

4.3 Final Design at a Glance

Exploded view:

An exploded view drawing is a diagram, picture, schematic, or technical drawing of an object, that shows the relationship or order of assembly of various parts. It shows the components of an object slightly separated by distance or suspended in surrounding space in the case of a three-dimensional exploded diagram. An object is represented as if there had been a small, controlled explosion emanating from the middle of the object, causing the object's parts to be separated an equal distance away from their original locations.

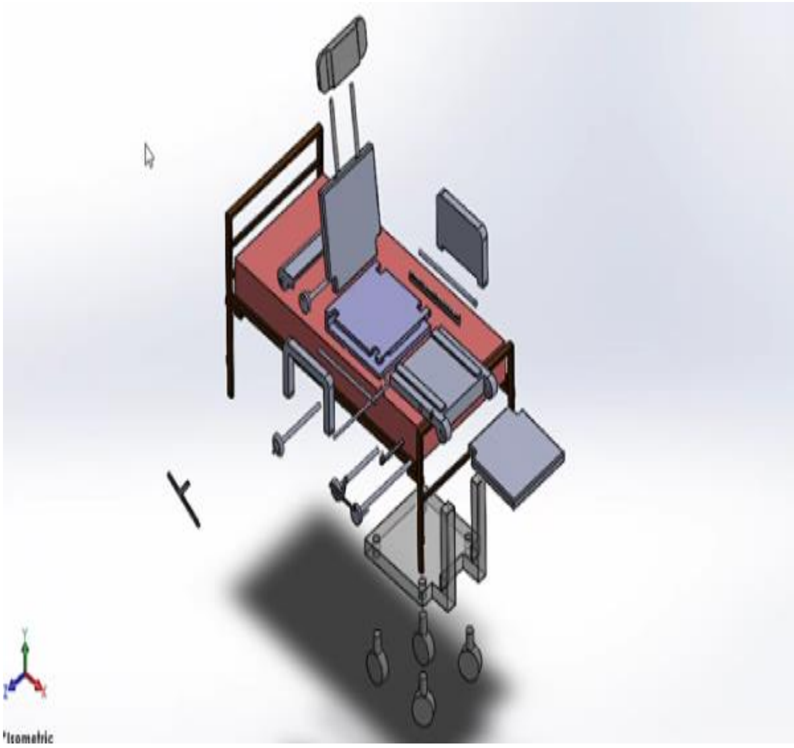


Figure 4.17 Exploded View of Product Design

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The importance of transferring patients with lower body disability was understood properly. The safety and comfort of the patient was kept in mind and ideated a possible design which could serve the intended purpose. Finally, the idea was extrapolated into a 3-Dimensional Computer Aided Design - CAD model with the help of Solidworks and analyzed with the help of a finite element methods (FEM) technique using ANSYS software. The extracted life of 10^6 cycles under cyclic loading proves that it's long lasting. Furthermore, the factor of safety of 15 in each of the stage of operation proves the structural stability of the device. At the same time, it is also designed in a manner to comfort the user.

5.2 Future Scope

As, the designing and analysis stage of our product is complete, we applied for Center for Entrepreneurship Development and Incubation (CEDI) - Siemens grant and have successfully cleared round 1 and round 2 along with the approval from mechanical department design team after vetting the project and requirement usage from a doctor which was requested by the committee.

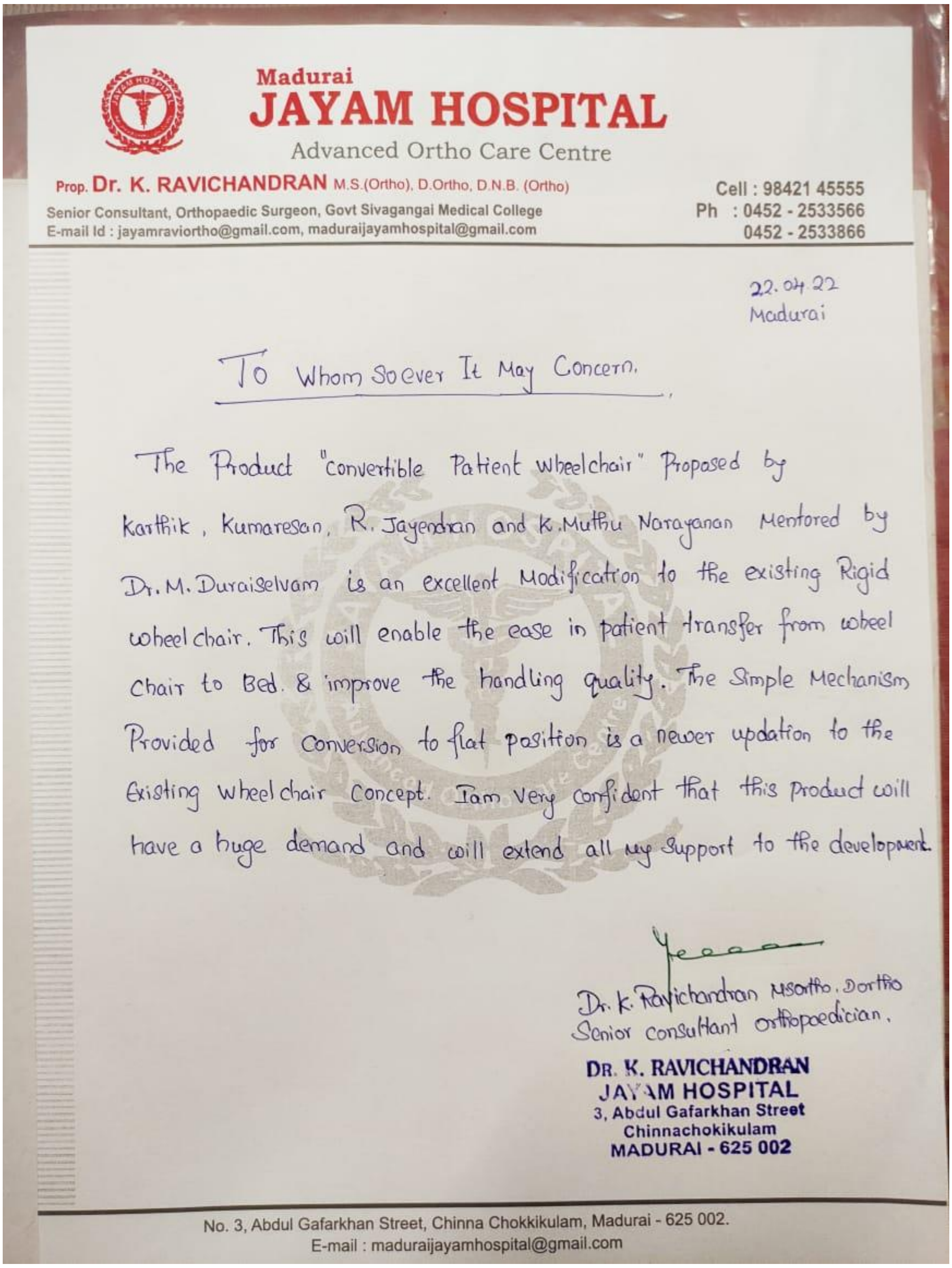
We are now waiting for the grant amount to be dispatched from CEDI and with the help of juniors under our supervision and the overall guidance of Dr. Ing. Duraiselvam sir, will be able to fabricate the device successfully.

As, our project is made up of simple hand operated mechanisms, it can be also extended to fully automated device, where just with a push of a button all the intended movements are made seamlessly. This can be attained with the help of motor, push buttons and sensors.

APPENDIX A

Appendix A.1

Testimonial for our product design was provided by Dr. K. Ravichandran, Senior Consultant and Orthopedic Surgeon, Government Sivagangai Medical College and Madurai Jayam Hospital for CEDI Level 2 Innovation Grant.



Madurai
JAYAM HOSPITAL
Advanced Ortho Care Centre

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Cell : 98421 45555
Ph : 0452 - 2533566
0452 - 2533866

22.04.22
Madurai

To Whom So ever It May Concern.

The Product "convertible Patient wheelchair" Proposed by Karthik, Kumaresan, R. Jayendran and K.Muthu Narayanan Mentored by Dr. M. Duraiselvam is an excellent Modification to the existing Rigid wheelchair. This will enable the ease in patient transfer from wheel Chair to Bed. & improve the handling quality. The Simple Mechanism Provided for Conversion to flat position is a newer updation to the Existing wheelchair concept. Iam Very confident that this product will have a huge demand and will extend all my Support to the development.

Dr. K. Ravichandran MS ortho, D ortho
Senior consultant orthopaedician.

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E-mail : maduraijayamhospital@gmail.com

Appendix A.2

The product design was technically vetted by Prof. Dr. A.R. Veerappan, Professor (H.O.D.), Department of Mechanical Engineering, NIT Trichy, Prof. Dr. K. Paneerselvam, Associate Professor, Department of Mechanical Engineering, (NIT Trichy), and Prof. Dr. Nivish George, Assistant Professor, Department of Mechanical Engineering, National Institute of Technology Tiruchirappalli (NIT Trichy) for CEDI Level 2 Innovation grant.

---------- Forwarded message ----------
From: hodmech@nitt.edu
To: durai@nitt.edu
Cc: hodmech <hodmech@nitt.edu>
Bcc:
Date: Tue, 26 Apr 2022 10:29:18 +0530
Subject: Re: SIEMENS Innovation Grant Selection Committee's Recommendation
Dear Prof. Duraiselvam,

The students under your mentorship made a detailed presentation on the proposed project on convertible wheel chair. I reviewed its design along with two of my faculty members. The students have also done a detailed analysis on the mechanisms involved.
I wish to state that the design is viable and may be processed for implementation.

Best Regards,
AR. Veerappan
Head, Mechanical Engineering department

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