STRUCTURAL ANALYSIS AND GEOMETRIC OPTIMIZATION OF A WEIGHT-STACK LAT PULLDOWN MACHINE

THESIS

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Introduction

Since early 2000 exercises have become a vital part of human life compared to 90s where exercises were most performed by athletes. Their contributions to enhance physical fitness, strengthening body muscles and person overall well-being have not only become the motivation for many people to engage in exercises but have also become the big factor for good performance and endurance in different kinds of sports. Recently train resistance has taken over in various sports because of their efficiency in strengthening different muscles in human body and because they make it possible to target very specific muscle of the body. Lat pull down exercise one kind of the resistance training has emerged as a standout exercise for dealing with back muscles. The lat pulldown machine give users the flexibility to perform controlled pulling exercises by using different hand grip position and the primary muscles targeted are latissimus dorsi, rhomboids, trapezius muscles and biceps brachii. Exercise efficiency and user safety depend on various reasons such as biomechanical and mechanical design, and awareness of the user on how to use machine. Despite various designs of different sizes, most of lat pulldown machine designs are designed empirically without considering structural stress distribution and geometry of the machine. Excessive weight and mechanical failure because of repetitive loading have been common setbacks because of these shortcomings.

A well designed lat pulldown machine ensures safety of the user, ergonomic comfort and smooth operation to user of different size and weight. The frame of the machine must have optimal weight and be capable of withstanding the repetitive maximum load without deflection or yielding and all joints should be strong enough to be structurally reliable for long-term use. To avoid cracking and structural instability, stress concentration must be reduced at all corners of the frame and in all locations with joints. For smooth operation of the machine misalignment of the cable path must be avoided because it leads to imbalance of the forces in the machine. To achieve structurally efficient and geometrically optimized machine, finite element analysis (FEA) is integrated during design and analysis stages.

In this thesis the focus will be structural analysis of the lat pulldown machine by using simulation tool (ANSYS Workbench) to evaluate the machine response to static and dynamic loading and on the other hand the focus will be on geometrical optimization to reduce the weight of the machine, increase its performance and improving the safety. The goal of the thesis is to minimize the weight of the machine, cutting off the cost of the material while improving the safety and performance of the machine

In modern technology geometric optimization approach combines modelling, design parameterization and numerical algorithms to find the most stable mechanical structural arrangement of the components by finding its lowest possible energy configuration. Topology optimization and response surface methodology (RSM) are some of the optimization techniques that have been used in recent years to improve structural efficiency in various industries such as automotive and manufacturing industries. Bringing these approaches to gym equipment offers a better way to enhance their performance. Structural optimization of the lat pulldown machine will not only reduce the weight of the machine but to some degree it will increase stiffness and reliability of the machine.

Most of the research conducted in recent years has shown the importance of simulation-based design in engineering. Finite element analysis has been used to study leg press and bench press inorder to predict deformation and failure under load. Research and studies on lat pull down machine have mainly focused on biomechanics and there are only empirical approaches without detailed stress analysis. This thesis will focus on that area to contribute to existing knowledge about lat pulldown by applying finite element analysis (FEA) on study structure of the machine and optimize the design. The resulting design will have information on material behaviour, stress distribution and the influence of the geometry on machine performance.

1 Literature review

1.1 Lat pulldown exercise

Human physical and psychological well-being depend on exercises as regular exercises boost our strength while reducing the chance of getting diseases associated with heart, liver and other sensitive organs, diabetes, obesity and hypertension are other cases which can be completely avoided by regular exercises [1]. Resistance training exercises have become a target for recent researchers in recent years as they have seemed to be effective in strengthening the targeted muscles. Lat pull down is one of the weight/ resistance training exercises that involve several joints that lead to complex shoulder movement such as glenohumeral joint, scapulothoracic joint and hand elbow and it can be performed by various types of equipment such as plate-loaded, resistance equipment, pneumatic resistance machine and adjustable cable columns [2].

Weight-stack lat pulldown machines are part of the resistance training machine used in gyms to strengthen the back muscles. Back muscles training plays a significant role for both athletic performance and rehabilitation as they help to build strength and prevent musculoskeletal injuries. As one of the trainings exercises that strengthen the back muscles, lat pull down exercises stand as one of the most versatile offering various hand grip positions, ability to change the amount of load [3]. The primary back muscles targeted during pull down exercises are latissimus dorsi, posterior deltoid, trapezius, teres major, rhomboids, biceps brachii, levator scapulae, triceps brachii, rotator cuff muscles and brachioradialis [2]. But being a 2-joint exercise that involves an adduction in the shoulder and a flexion in the elbow, the lat pull down exercise involves several back muscles while it is primarily designed to train latissimus dorsi muscles (Andersen et al., n.d.). There have been various designs of the machine to improve its performance and to meet user expectations but most of the existing designs have heavy steel frames and geometries that may not be optimal or for a wide range of user anthropometries.

The lat pull-down has been significantly important to athletes such as gymnasts, basketball players (pulling down rebound), swimmers (swimming freestyle (crawl), breakstroke and butterfly) and wrestlers (executing specific holds and takedown) whose upper-body strength and endurance are very important for their performance [4], [5]. Other advantages of the lat pull-down far from increasing upper-body back muscles capacity, it helps to strengthen the musculature of the glenohumeral joint as well as the primary mover (latissimus dorsi) [6]. Other evidence indicates the contribution of lat pull-down exercises to increase the maneuvering of the glenohumeral joints [7].

Figure 1. Assembly of lat puldownn machine [8]

1.2 Effect of lat pulldown exercise on back muscles

Most researchers have focused on studying the effects of lat pull down exercises on users by checking electromyography (EMG) response of the muscles involved during the exercise. [4] worked on a comparative electromyographical investigation by altering grip width, (Sperandei et al., n.d.) performed electromyographic analysis by changing the type of bar during lat pull down exercise, [5] investigated the effect of the grid width and [9] use three different types of lat pull down machine. From results obtained from various research, it has been concluded that different techniques and different equipment used during lat pull down exercises bring different results (electromyography responses) [10].

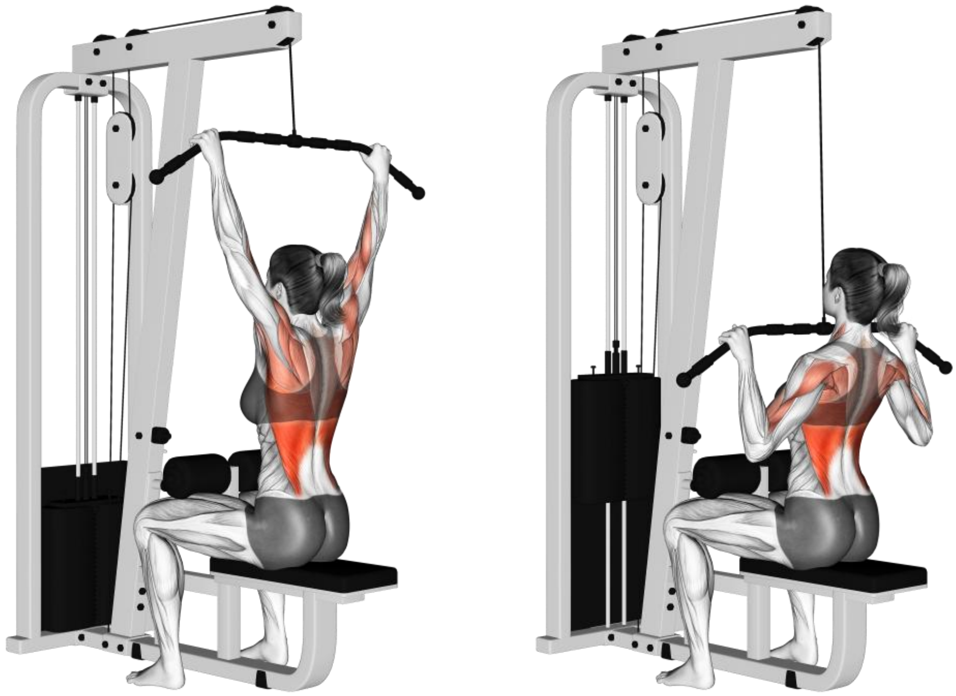


Figure 2.1: Lat Pulldown Machine Exercises [11]

1.2.1 Biomechanics of lat pull-down machine

Biomechanical analysis is an approach used to study motion, muscles activation and the force involved during resistance training exercises. The analysis helps the user of the lat pull down machine to understand the complexity of the joint kinematics, external forces from the machine and muscular activity. By using results from this analysis, creators and users of the machine can improve machine design, optimize technique and reduce the risk of getting injury during exercise. During biomechanical analysis electromyography is used for recording muscle activated and motion capture system is used to analyze the joint movements. These methods provide all information about the effects of hand grip variations, bar positions and exercise effectiveness.

Biomechanical analysis has identified the latissimus dorsi, biceps brachii, pectoralis muscles and posterior deltoid as the primary muscles that are strengthened by the lat pull-down exercises [12]. The focus of these analyses was to understand the muscles activation pattern, joint movements and how body posture and load distribution affect the performance of the exercise and injury risk. While designed to strengthen the upper-body back muscles such as latissimus dorsi, middle and lower trapezius. Lat pull-down exercises lead to number of joint actions during both concentric phases (pulling bar towards the chest) and the eccentric phase (returning the bar to the original position). The primary joint actions that take place during both phases are shoulder adduction and abduction, shoulder horizontal adduction and abduction, elbow flexion and extension, scapulae downward and upward rotation, scapulae retraction and protraction [13]. These multi-joint movements help in increasing the ability to transfer power between the lower and upper part of the body.

Latissimus dorsi muscles play a huge part to shoulder adduction, internal rotation and extension. It also connects the back upper part of the body and the trunk [14]. Considering its importance to athletes, body builders and other people, a lot of research have been conducted to find out the best possible exercises to strengthen latissimus dorsi and other nearest muscles connected to it. Lat pull down exercise has emerged as one that contribute most to latissimus dorsi muscle activation by changing hand grip position and forearm orientation. [4] concluded that a wide grip position is more efficient on activating latissimus dorsi muscles compared to other positions. Even though these muscles can be activated by several types of exercise and workouts but pull down in stand position and body lifting in the seated position have been more coefficient compared to others [14].

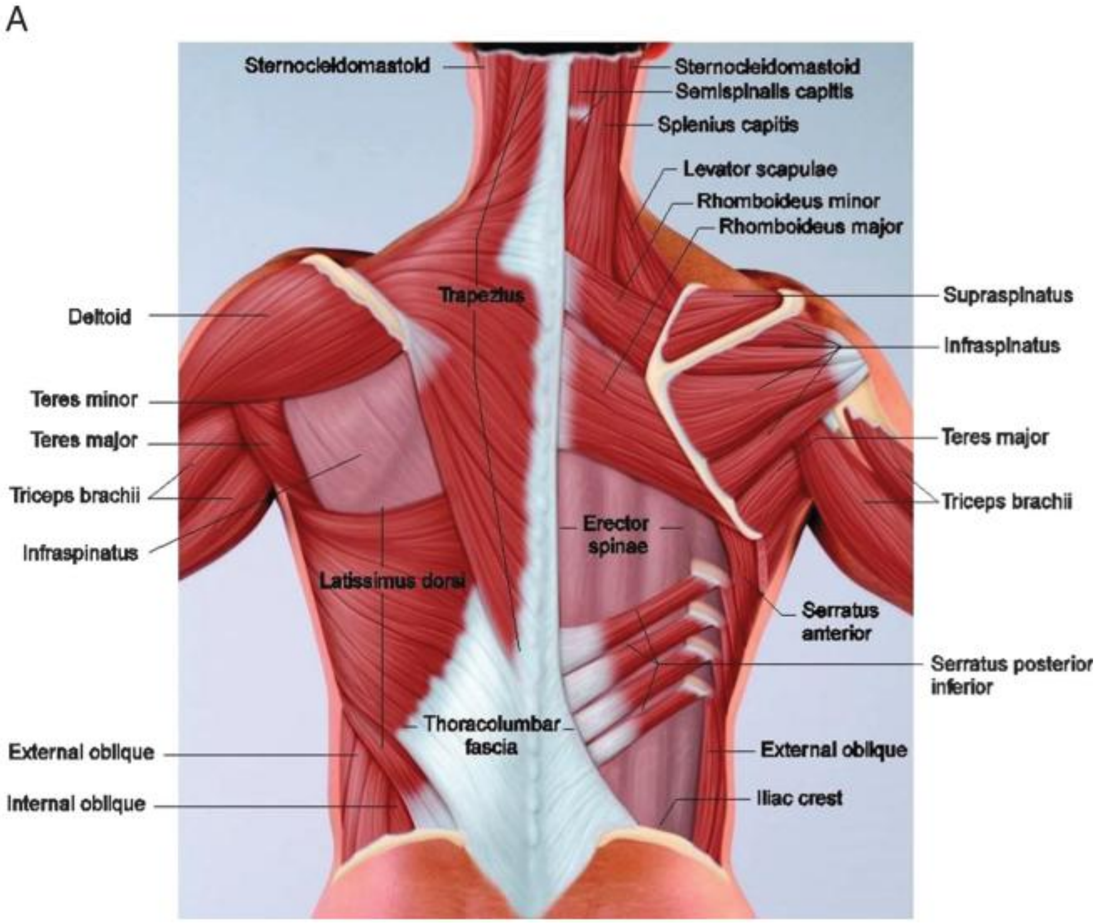


Figure 3: A- Primary muscles activated during the lat pulldown exercise [2]

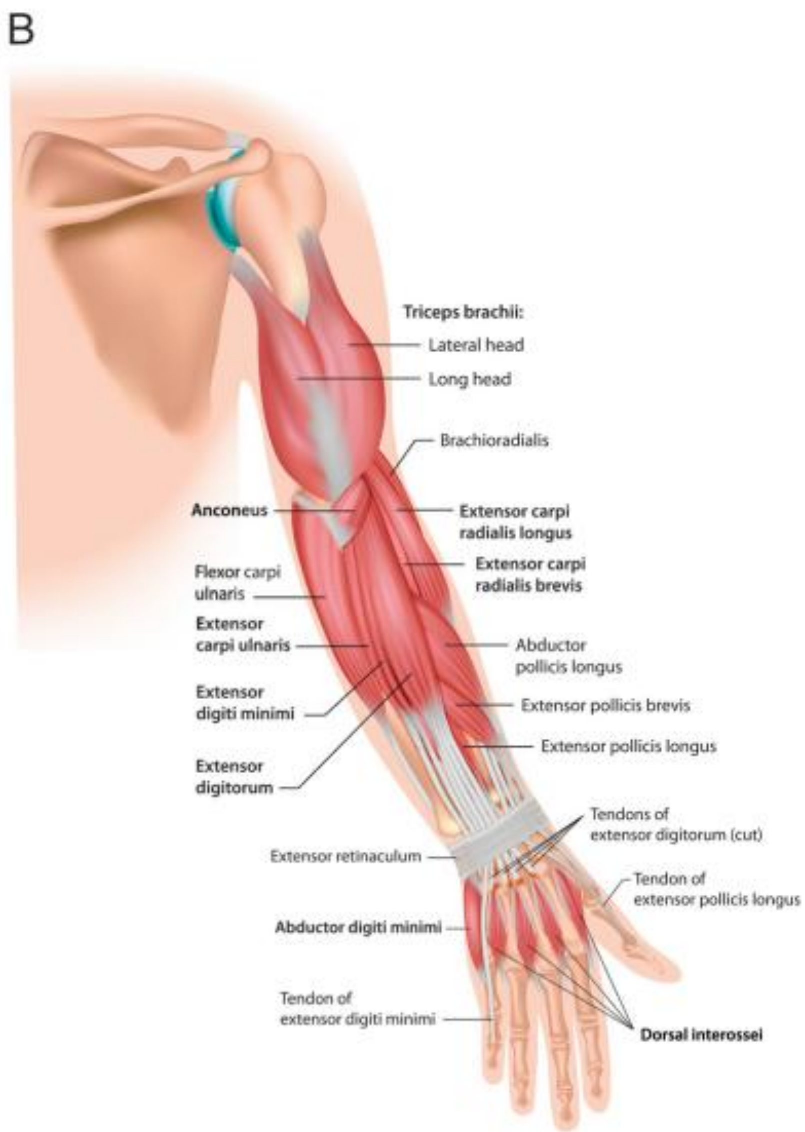


Figure 4: B- Secondary muscles activated during the lat pulldown exercise [2]

1.2.2 Electromyographic (EMG) Analysis

Different hand positions show different effects while performing lat pull-down exercises on the electromyographic activity of the shoulder muscles. According to the experiment performed by the department of exercise and sport science, university of Miami on the effect of various hand positions during the lat pull down, a comparative electromyographic analysis conducted revealed that the changes in handgrip position affect the activities of the specific muscles during the exercise [4]. The four variations used during the exercise were wide grip anterior (WGA), Supinated grip (SG), close grip (CG) and wide grip posterior (WGP) [15]. This brought to light the fact that a person can now target an extremely specific exercise by choosing the correct hand position while performing lat pull-down exercise [6].

Normalized root means square of the EMG (NrmsEMG) of all targeted back muscles was recorded using surface electrodes and normalized using maximum voluntary contractions. Upper back muscles involved during the study were latissimus dorsi (LT), right posterior deltoid (PD), pectoralis major (PM), long head of the triceps (TLH), and teres major (TM). For different hand grip positions, each muscle shows different NrmsEMG during both concentric and eccentric phase. The result of the experiment leads to a conclusion that there is a direct relationship between the position of the handgrip and specific muscles activation [4]. But according to another experiment, it was concluded that the position of handgrips may not have a significant effect on latissimus dorsi, but they can only show a significant difference in the posterior deltoid when the exercise is performed by wide-pronated grip with a 30° trunk inclination [3].

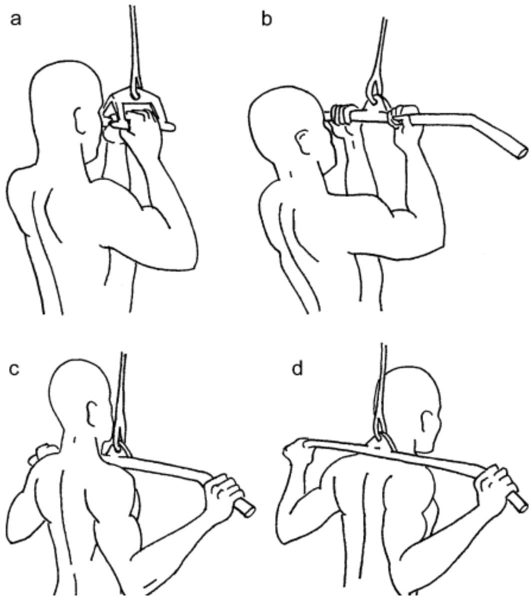


Figure 2:2: Hand positions examined during the lat pull-down: (a) close grip, (b) supinated grip, (c) wide grip anterior, and (d) wide grip posterior [4].

According to Raizada et al in his pull up experiment using different hand orientation/ position, the comparative electromyographical investigation was done between latissimus dorsi and biceps brachii, results (maximum voluntary contraction) were recorded by using biography infinity software used for electromyographical analysis while muscle electrical activity that happened while muscles contract was recorded by using surface electromyography. Latissimus dorsi muscles are more activated by prone wide hand grip while biceps brachii muscles are more activated by supine narrow grip compared to other hand position [12]. During lat pull down exercise, different hand grip positions affect the degree of external/internal rotation, abduction/ adduction of the glenohumeral joint which affects significantly the muscles involved during the exercise.

Table 1: Descriptive Statistics and Test of Normality

	Supine Narrow Grip Pull Ups		**Supine Shoulder Width Grip Pull Ups**		**Prone Narrow Grip Pull Ups**		**Prone Shoulder Width Grip Pull Ups**		**Prone wide Grip Pull Ups**		**Prone Extreme Wide Grip Pull Ups**	
	LD	BB	LD	BB	LD	BB	LD	BB	LD	BB	LD	BB
Mean	893.51	1435.9	991.4	1278	911.9	726.40	962.1	920.10	1042	881.90	1034	1110.7
Std. Error of Mean	63.67	40.00	75.19	53.85	57.04	57.36	30.12	68.41	49.45	71.87	49.40	65.01
Std. Deviation	201.35	126.48	237.78	170.3	180.4	181.40	95.26	216.32	156.4	227.29	156.2	205.59
Skewness	-0.18	-0.50	-0.09	-0.57	1.04	0.45	-1.30	-0.29	0.11	0.54	0.82	-0.20
Std. Error of Skewness	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Kurtosis	-0.94	-1.08	-1.50	-1.39	0.70	-1.49	1.99	-0.31	-0.40	-1.39	0.09	-1.66
Std. Error of Kurtosis	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Shapiro – Wilk (p-value)	.426	.426	.257	.057	.218	.417	.157	.740	.530	.573	.273	.641

Figure 3.1: latissimus dorsi and biceps brachii comparison [12].

1.3 Design of resistance training machine

Ergonomic evaluation, finite element analysis (FEA), kinematic analysis (MATLAB/ SIMSCAPE) and computer aided design (CAD) have been continuously used to improve the performance of the lat pull-down machine while enhancing the safety of user. With the help of this software, the cost of the machine has been minimized, the frame weight has been reduced, and the ergonomics have massively been improved.

The key structural distinctions exist between the lat pulldown and other machines. The lat pulldown uses a weight stack and cable mechanism to facilitate vertical pull, often coupled with adjustable seat height and thigh support for user stability. Other machines (such as leverage or pneumatic systems) may use alternative force delivery systems, and horizontal rows or presses direct resistance through different movement patterns [16].

Biomechanically, the lat pulldown is categorized as an open-chain exercise, where the hands move against the bar's resistance. Studies show open-chain exercises may activate fewer motor units compared to closed-chain movements (e.g., pull-ups), but still effectively recruit primary and synergistic muscles in the back, shoulders, and arms. Grip variation (pronated, supinated, wide/narrow) and trunk position can modify muscle recruitment during lat pulldown, with implications for training specificity and rehabilitation [3].

In terms of user experience, machine-based designs—including the lat pulldown—tend to improve accessibility through adjustable features, safety guards, and smooth resistance changes. Fixed-path machines promote ease of use and injury prevention, while machines with more dynamic motion options or free-weight alternatives can better mirror natural movement and functional strength adaptations.

1.4 Lat pull down equipment kinematics

Although previous techniques of the LP consisted of pulling the bar behind the neck, a more modern and safer way to perform the exercise uses a pull in front of the body. Pulling the bar behind-the-head puts the glenohumeral joint in a comprised position (i.e., externally rotated, abducted, horizontally abducted) increasing the risk of shoulder injury Chronic use of the behind-the-head LP increases the likelihood of developing anterior instability (AI) in the shoulder joint. Anterior instability in the shoulder joint is often associated with a variety of other soft tissue injuries such as supporting rotator cuff musculature, ligamentous, and cartilaginous damage [17]. With a transfer to an anterior pull (i.e., in front of the body), the LP becomes a more functional movement and reduces the prevalence of injury.

One study was conducted in this area to find out the correlation between the kinematics of the machine used for lat pulldown machine with one, two or three degrees of freedom and the timing and amount of electromyographic activity during the lat pulldown exercise performed on machines. Three different machines were used during the study, type 1 (movement is restricted to a frontal plane), type 2 (additional of forearm supination-pronation) and type 3 (more additional of horizontal extension-flexion about shoulder) [9]. With the same exercise as beginning movement load which involve lifting light load with relaxation-lengthening-shortening sequence of muscle activation, all machines give different results.

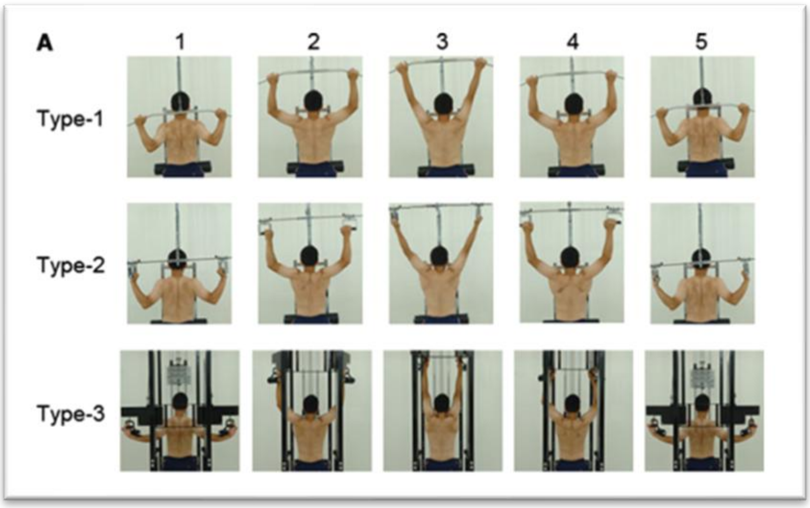


Figure 5: Video images of positions throughout the range of motion for the lat pull-down exercise performed by one subject on the three machines [9]

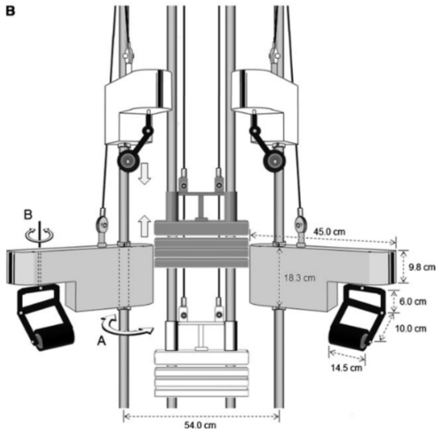


Figure 6:The degrees of freedom of the Type-3 machine [9]

Another study conducted by dona focused on the way to compare kinematics and the muscle activity between lat pull down and chi-ups exercises. The kinematics of back, shoulder and seventh cervical vertebrae were studied during chin-ups and lat pull down exercises in both phases of the exercises, eccentric and concentric phase. These exercises seem similar in terms of movements patterns of the upper extremity in case grip width and forearm orientation are equivalent between exercises [4], [18] [10]. During lat pull down exercise the load (bar) is pulled towards the chest while the lower part of the bord is held down by using knee restraints making it possible for open kinetic chain maneuver [10]. For chin-ups exercise the bar remains stagnant and the lower part of the body moves in a vertical or horizontal plane suggesting a closed kinematic chain. The purpose of the study was to determine if the EMG responses of the muscles during exercise were influenced by the kinematics of the exercise.

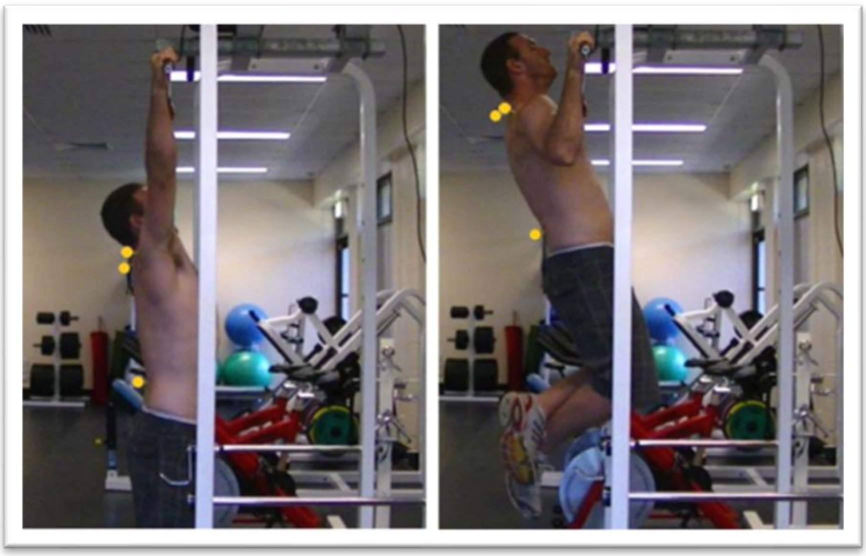


Figure 7:The starting and end positions of the chin-ups exercise with the bar attached to the power rack [10]

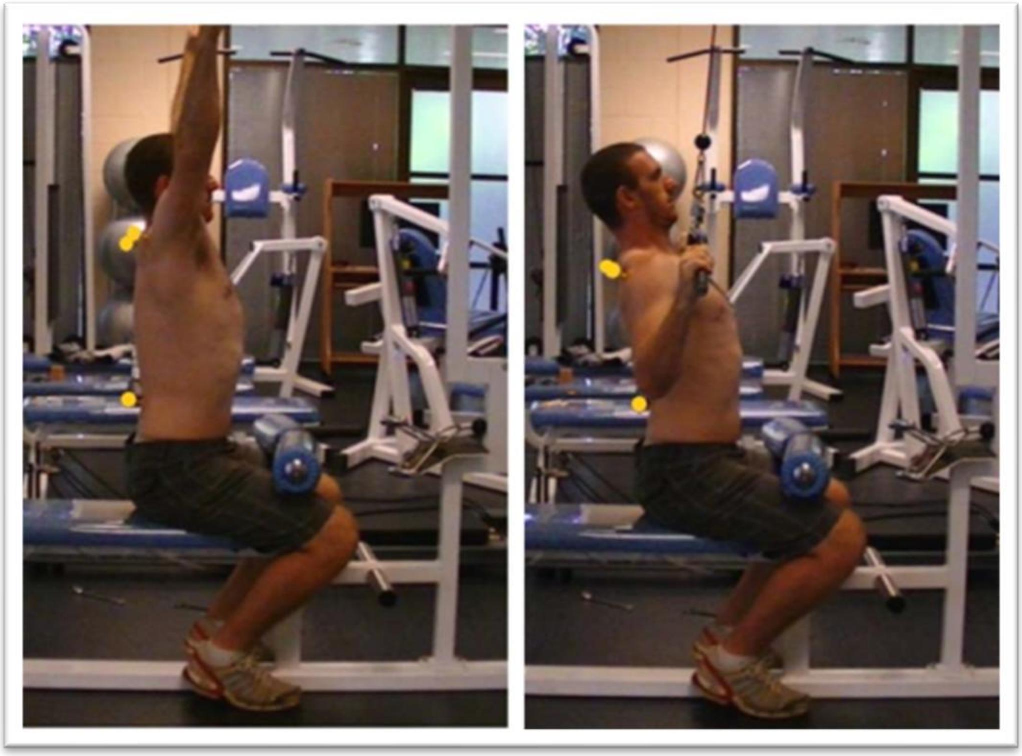


Figure 8: The starting and end positions of the lat-pull down exercise with the bar used identical to that during chin-ups [10]

The results of the study confirmed that the chin-ups were greater compared to lat pull down exercise for the horizontal displacement of the shoulder and seventh cervical vertebrae during the concentric phase. Which gives us a conclusion that the kinematic of the machine and exercises itself has effect on the muscles and should be considered during design phase of the machine.

1.5 Types of lat pull down machine

1. Plate loaded lat pulldown machine: this is specifically designed to target latissimus dorsi muscles which contribute too shoulder and back strength. Main features of the machine are sear for a person to sit, location to load weight plates that provide resistance during exercise, and it has padded bar connected to a cable system overhead. It is biomechanically and ergonomically design well to allow correct range of motion for the best contraction [19].

Figure 9:Plate loaded lat pulldown machine [19]

2. Leverage lat pulldown machine uses weight plate as resistance rather than a fixed weight stack. They deliver consistency resistance throughout the workout which increase muscular engagement. More safe and efficient for back strengthening activities compared to other types [19].

Figure 10: TKO Strength 703LPD Plate Loaded Lat Pull Down Machine [19]

3. Lat pulldown machine with weight stacks: some of the features of this machine is preloaded weights, weight adjustability using selector pin, have a seat with thigh support pad, there is a pulley system and bar connect to a cable overhead. The machine is suitable for both home uses and gym [19].

Figure 11: York Barbell STS Lat Pulldown Machine [19]

4. Lat pulldown mid row: versatile fitness equipment that combines the future of lat pulldowns and seated rows to provide an effective upper -body workout. Most of the back muscles such as rhomboids, latissimus dorsi, biceps and trapezius are all strengthened by the workout from this machine. Because of the dual functionality of this machine a person can perform vertical pulling workouts (lat pulldowns) for upper back and width and it also a person can perform seated rows for mid and lower back thickness [19].

Figure 12: Lat pulldown mid row [19]

5. Lat pulldown low row machine has 4-position adjustable foam rollers, interchangeable seat from low row to lat pull down and it has lat bar and low pull handle. Combine lat pull down and low row movement which target back muscles (latissimus dorsi) and it can also be used to strengthen the biceps and shoulders. Lat pulldowns target back muscles while the low row focus the middle and lower backs. Is the most convenient for home uses [19].

Figure 13:Body Solid GLM85B Lat Pulldown and Low Row Machine[19]

2 Design the assembly process of the machine

2.1 Tool and hardware list required for assembly

1. Wrenches/ open spanner
2. Adjustable wrench
3. Nuts

Exploded view of the lat pull downn machine

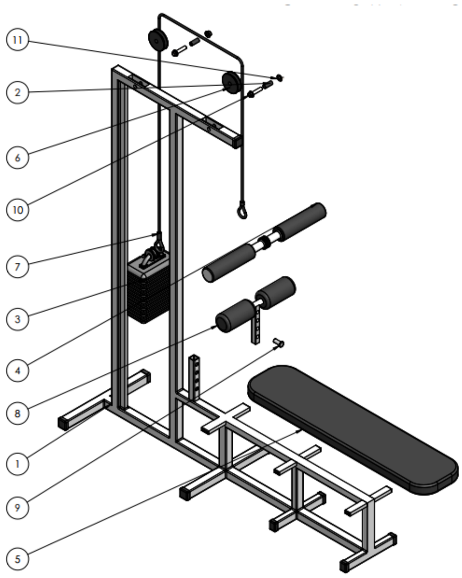


Figure 14: Exploded view of lat pulldown machine

2.2 Assembly process of lat pull down machine

Figure 15: Lat pull down machine

1. Step 1
   Preparation of the main frame of the machine ready for assembly of the other parts. The frame is made up from mild steel and is fixed to the ground

Figure 16: Frame of the machine

2. Step 2
   Attach the seat at the respective place (don eby fitting)

Figure 17: Fixation of seat

3. Step 3
   Assemble the pulley part number 6 at the respective place and make sure both pulleys are aligned with respect to the seat. The front and rear pulley must be aligned for the better operation of the machine. The pulley assembly must align well with the seat.

Figure 18: Assembling of pulley

4. Step 4
   Put the rope on the pulley

Figure 19: Assembling of the wire rope

5. Step 5
   Install block (weight) part number 3 to the assembly

Figure 20:Fixing of brick (stacked weight)

6. Step 6
   Final step is the assembling of the handle to the other part of the rope

Figure 21: Attachment of handle

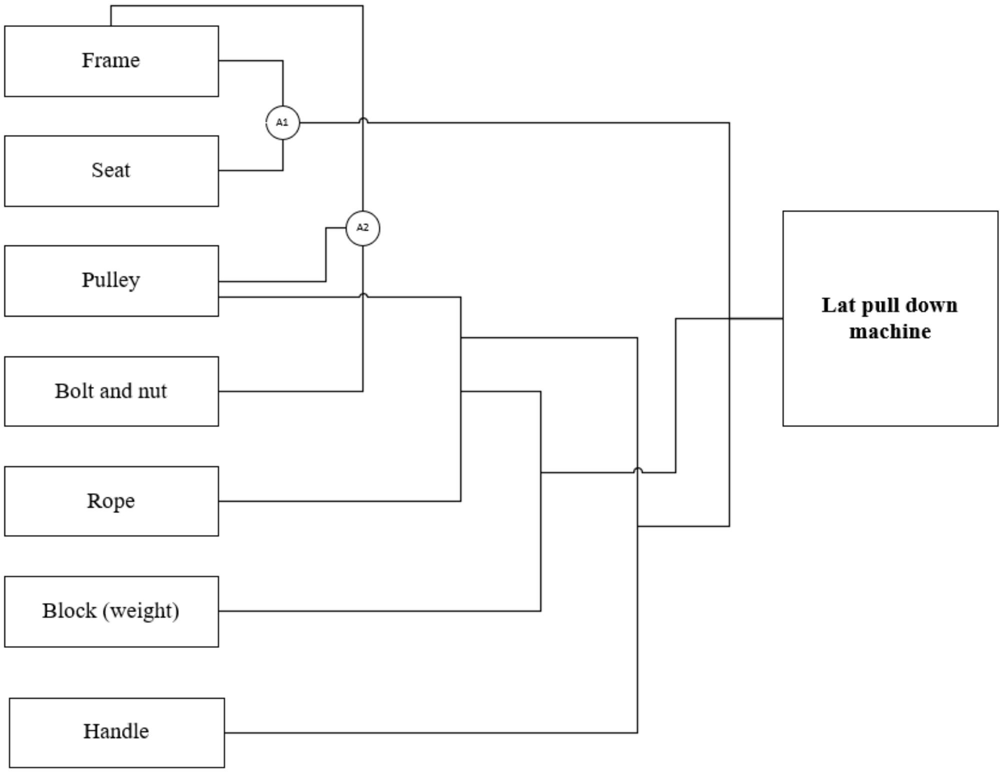


Figure 22: Figure 22: Assembly tree of the lat pull down machine

The figure above illustrate how the assembly of the machine is being done with frame being the main components. The rest of the components is attached to the frame. The assembly is done by fixing the seat first and then attch the pulley system to the main frame by using pins. Alignment of the pulley is performed to make sure they are in the right position and laigned well with the seat.

When three main sub assemblies are well fixed, wire rope in introduced onto pulley system as in the designed followed by attching weight stack and handle at each end of the wire rope.

Bolt and nut are fasteners used to fix the seat and restraint pad to the main frame of the machine, while pins are used for pulleys. Other parts of the frame are mainly welded during fabrication of the frame.

After being assembled completely. The machine installation can be done in many ways, the emphasize during installationis for the whole frame to be completely at rest before, during and after the exercise has been performed.

3 FEM analysis for the load capacity

The finite elemet analysis of this Lat pull down machine has been done by using ANSYS software and the following aspects has been examined

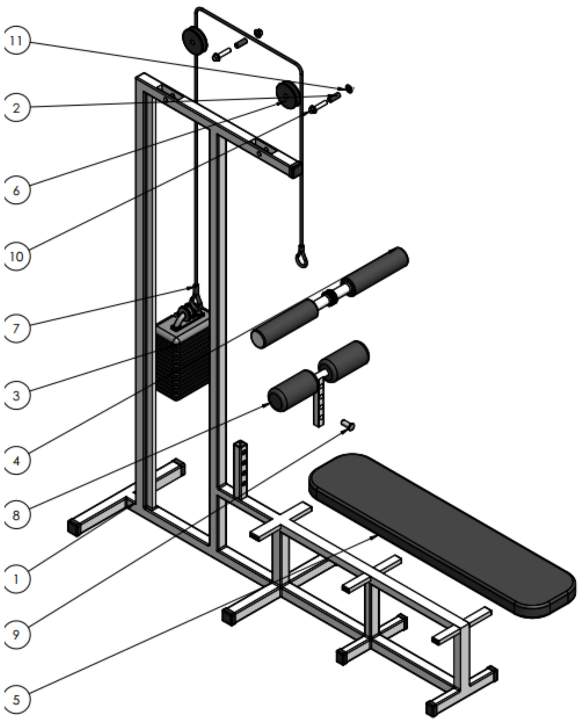
i. The structure is safe
ii. Area with maximum stress
iii. Factor of safety

3.1 Engineering data and assumption for the FEM

Assumptions made during finite element analysis

1. Bush rubbers, small fillets and pulley geometry were ignored
2. Material properties of the main frame is the same throughout
3. Factor of safety for the calculation is 2
4. Main frame of the machin eis welded and fixed to the ground

Engineering data/ information



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
11	ISO - 4161 - M16 - N		2
10	ISO 4162 - M16 x 70 x 38-N		2
9	KEY	MILD STEEL	1
8	LEG RESTRAINT PAD	STEEL TUBE	1
7	ROPE	HARD RUBBER	1
6	PULLEY	MILD STEEL	2
5	SEAT	LEATHER	1
4	HANDLE	STEEL TUBE	1
3	BLOCK	CAST IRON	1
2	BUSH RUBBER	RUBBER	2
1	MAIN FRAME	MILD STEEL	1

Figure 23: exploded view of the original design

Material for the main frame (Mild Steel)

Important properties of the material.

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
12	Strain-Life Parameters		
20	S-N Curve	Tabular	
24	Tensile Yield Strength	2.5E+08	Pa
25	Compressive Yield Strength	2.5E+08	Pa
26	Tensile Ultimate Strength	4.6E+08	Pa
27	Compressive Ultimate Strength	0	Pa

Figure 24: Engineering data of structural steel

3.2 Model (geometry) and meshing of the model

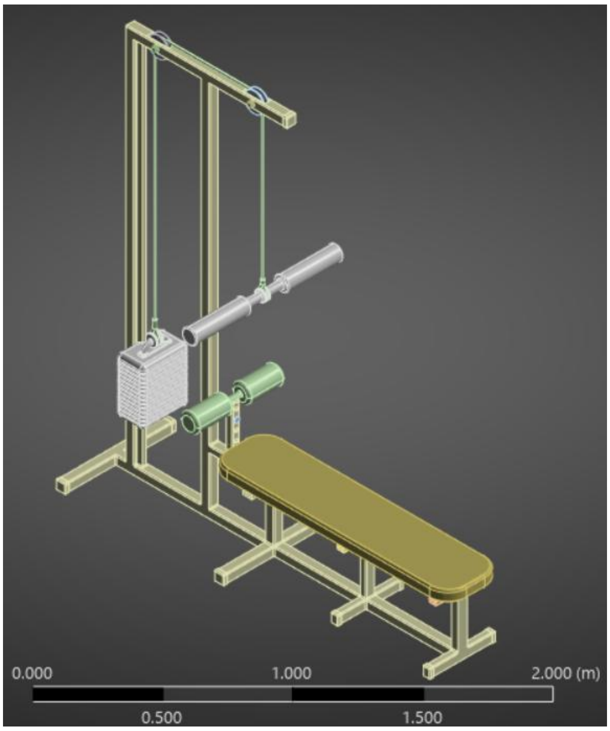


Figure 25: model of the original design in workbench

Geometry preparation in ANSYS (SpaceClaim)

i. Cleaning the mode; by removing holes, rounds and chamfers.
ii. Merge the bodies that are welded (contact bonded)

Figure 26: Structural frame of the original design

Meshing of the frame

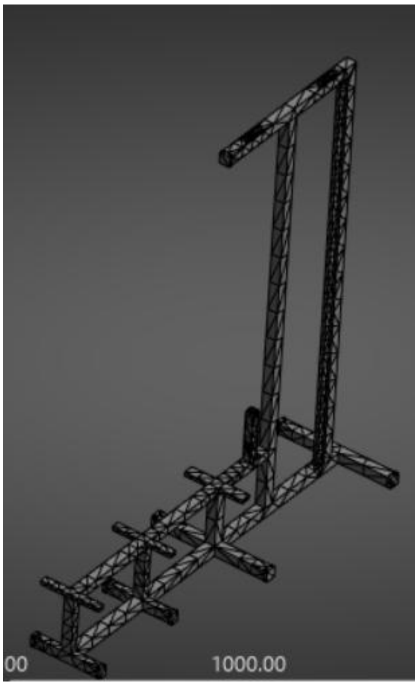


Figure 27: meshing of the model

3.3 Boundary conditions and loading

Load location and analysis settings

Main frame is bolted to the ground; **Fixed support** was used in the analysis settings.

Loading

Suppose maximum stack is 100 kg

$$Design\ load = 2 \times 9.81 \times 100 = 1962\ N \approx 2000\ N$$

At the pulley; Force applied along cable direction.

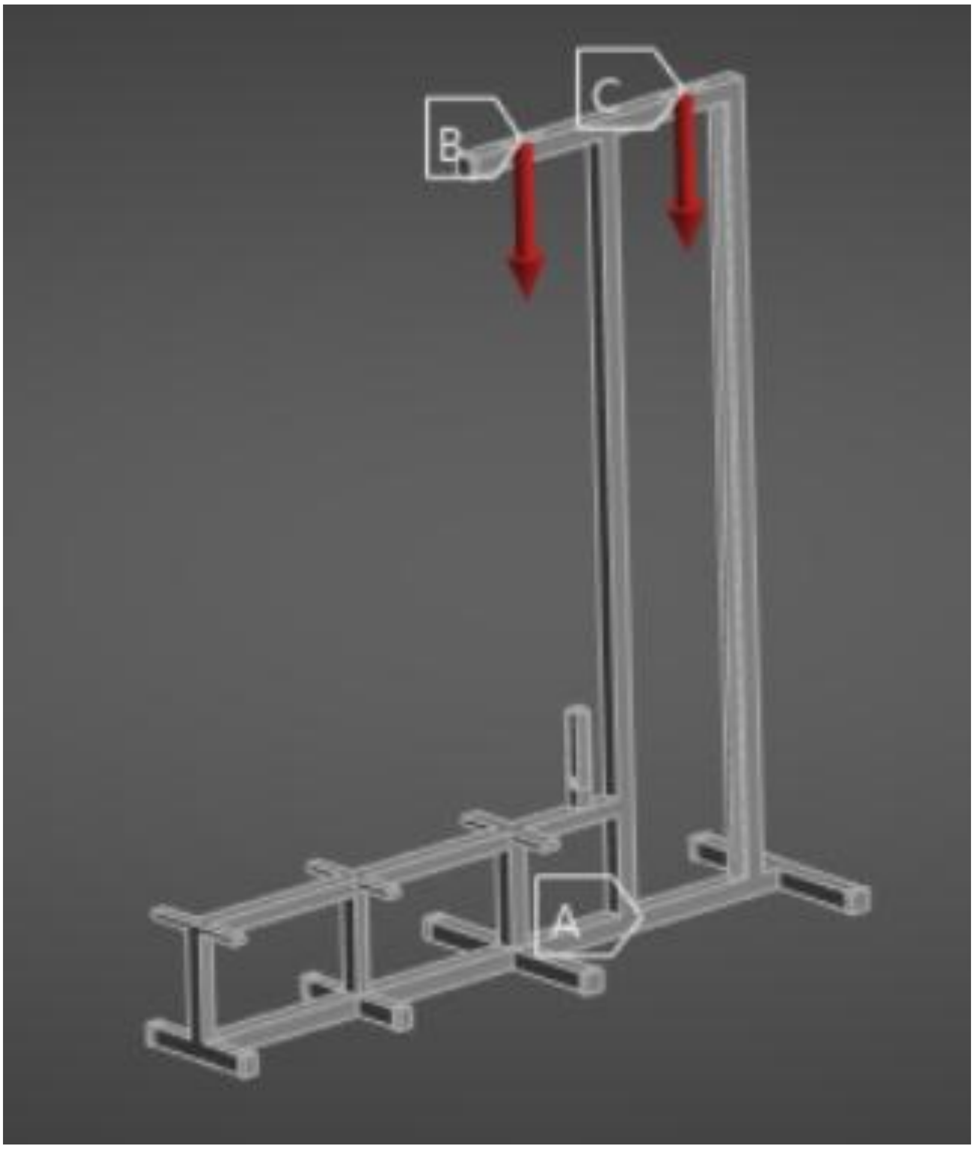


Figure 28: force at the pulley; Force applied along cable direction

3.4 Results of the finite element analysis of the original design

1. Total Deformation

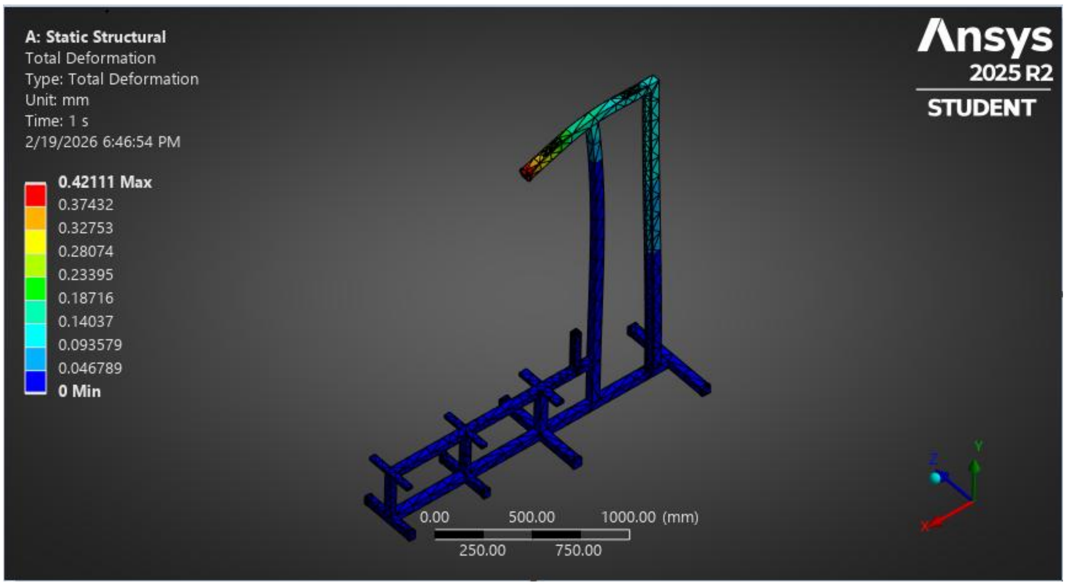


Figure 29: total deformation analysis result

Near zero deformation for the lower part of the frame and supports are effective.there is gradual increase of deformation towards the free end (cantilever) which indicate no sudden deformation jumps (model is stable). And since the maximum defrmation is very small (0.421 mm), this give assurance that the strructure has good strength and stiffness and more load can be applied. Colour contour shows a deep blue colour for the majority of the lower part which suggest that the lower part of the frame is well fixed and no deformation is happening in that region. At the top of the frame, there is significant deformation taking place with a maximum deformation of 0.421 mm. The maximu deformation is at the farthest part from the fixed support and most susceptible to deflection. The results from the analysis with a deformation of less than 1 mm suggest that the design is robust and safe. Continous colour gradient across structure shows that there is no stress concentration or irregular deformation patterns. The region with a red colour remains the most critical region of the frame structure.

2. Equivalent Stress

The von-Mises stress analysis done on the original frame shows a mimimum stress on the frame of 2.1543e-6 Mpa and maximum stress of 22.977 Mpa. Almost the whole frame is covered with deep blue colour from base frame, lower legs, and vertical comuns. This proves that the majority part of the frame are operating within safe operating limits. Highets stress is displayed by yellow-green colour at the top of the frame. Comparing the maximu stress and the yield stress of the mild steel of 250 Mpa, shows that the structure operates at less than 10% of the material’s yield capacity. The smooth and gradual stress gradient suggests that there is sharp stress concentration that can cause premature failure of the machine.

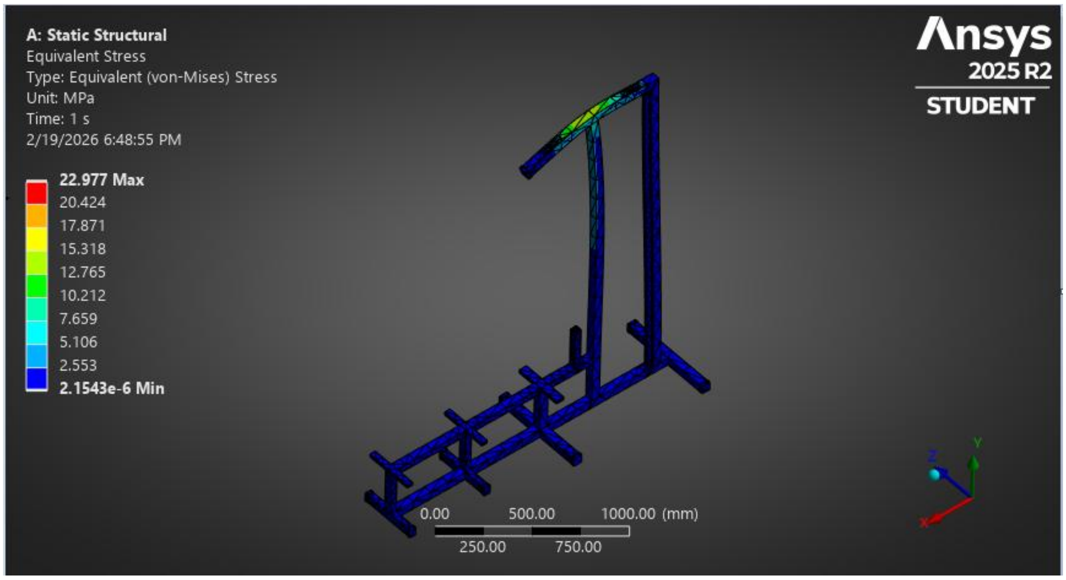


Figure 30: equivalent Stress analysis result

3. Maximum Principal Stress

Figure 31: maximum Principal Stress analysis result

With a maximum principal stress of 15.525 MPa, this indicate that the design is safe the yield strength of the material used on frame is far too large, 250 Mpa (mild steel), which assure safety with a factor of safety of more 16. therefore no yielding risk and critical region identified at the top of a joint. The point of loading exhibit maximu stress compared to other regions of the frane structure.

4. Normal Stress

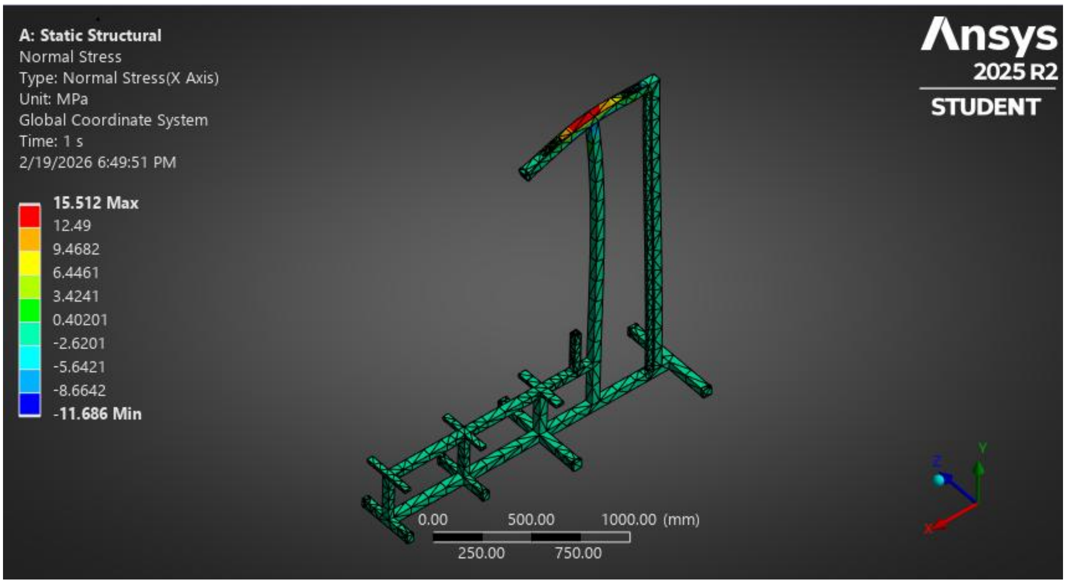


Figure 32: normal stress analysis result

5. Factor of safety

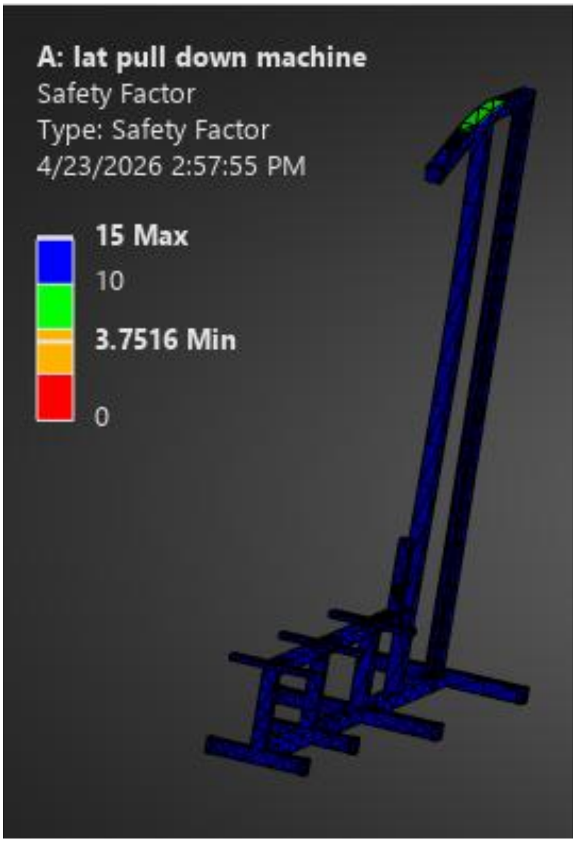


Figure 33: Factor of safety of the original design

The factor of safety range from 3.75 to 15 with majority part of the frame having the value between 10 to 15 due to unloading on those areas.

The higher value of factor of safety shows that the frame of the machine is overdesigned compared to load which is being applied to the machine. This simply give room for two options.

Case number one is to increase the amount of loading but because the equipment is for fitness and exercises, the option seems impossible as people have limited amount of weight they can lift.

Case number two is by using another kind of material that will be to carry the planned amount of load and still offer a reasonable amount of factor of safety which range between 2 to 5.

But for this design, nothing will be adjusted consider that the main frame is being designed to use rectangular hollow section of plain mild steel as a primary material. The price of the material is low, the weight of material is also small which make it the most favourable material for the manufacturing of the frame for thsi machine.

The decision has come since various people will be using the same machine and apply different forces and as it was seen on the comparison table , with various loading there are various factor of safety which goes to 0.97 which is not acceptable in engineering practices.

On future more adustment can be done to lower fcator of safety and improve the overall design of the machine that it can have reasonable factor of safety, afforadble price while ensuring a long life span of individual components and the whole machine as whole.

4 Redesign of the machine geometry and the assemblage

From the results, material used for the frame structure (mild steel) show a good performance with an acceptable value of factor of safety. Thus, the modification of the machine focus more on improving the usability of the machine in case of operation by adding number of operation (exercises) instead of having a single operation (lat pulldown exercise)

From the original design of lat pull down machine, another operation has been added to improve the effectiveness of the machine on strengthening more back muscles. The machine has been designed by using solidWorks software. To accomodate the operation of another exercise pulley assembly has been modified. Another modification has been done for the weight stack, instead of using a single solid block, in the new design various plate of different weight which can be added or removed to meet the needed weight will be used.

Figure 34: Redesigned model of the machine

The lat pulldown machine is divide into several sub-assemblies such as the main frame, handle and linkages, seat and pads, weight stack and pulleys system assembly. Each sub-assembly has two or more parts and play a crual role into the overall functionality of the machine.

Frame assembly

The structural frame is the main part of the lat pulldown machine because all other components of the machine are attached to it. The frame is made up by using plain mild steel because of ots strength and reasonable cost. The hollow section are used to made the frame in order to avoid unnecessary weight of the machine. The main process used during the fabrication of the frame are cutting of the hollow section by using shearing machine which is followed by the welding (MIG weldong) of the components following the design. Due to nature of the machine, frame is the main part which carry the weight of themachine and is also subjected to stress during the operation of the lat pulldown maachine. Even for the matter of the addition operation that will also contribute more to strengthen the buck muscles, frame will still be the main part of the machine that will be subjected to more stress compared to other part. All other parts of the machine are attached to the main frame.

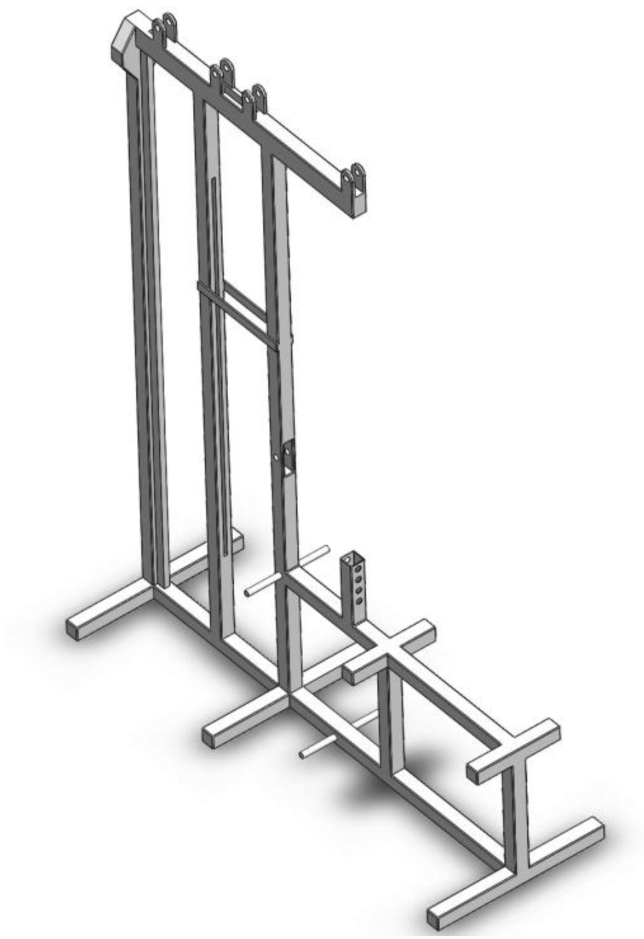


Figure 35: Structural frame of the designed model

The frame of this machine is a welded structure made of steel and is divided into three main parts, base supports, vertical colums and the top beam that carry most of the load from the weight stack.

The whole frame assembly act as one single entity with no relative motion between any two joints. In the SpaceClaim during analysis, all the joints will be treated as bonded joints to ensure they mimics the nature of the welded joints.

Pulley assembly & Weight stack assembly & handle and linkage assembly

The pulley assembly includes rope, top and middle pulleys. For this modified design pulley systems has been designed to support two different operations that enhance the functionality of the machine. Pins are used to connect pulley to the frame

Weight stack and handle are coonected at each end of the wire rope. With two different operations in the machine there are two different handles, one for a tradional lat pull down exercise while the other one is for the second operation that has been added to the machine. Weight stack has been assembled to the machine in such a way that it move up and down along the vertical beam.

Figure 36: pulley assembly & weight stack and handle assembly

All seven pulleys in the machine for lat pulldown operation and low row operation are well aligned both vertically and horizontally to avoid any miaslignement which will lead to inbalance of forces that may affect the perforamance of other components such as wire rope and the whole operation of the machine. Alignment of the pulleys is the critical part duirng the assembling process of the machine. Failure of the machine depends mostly on the opertaion of the pulleys and the wire rope.

Assembling of the modified machine

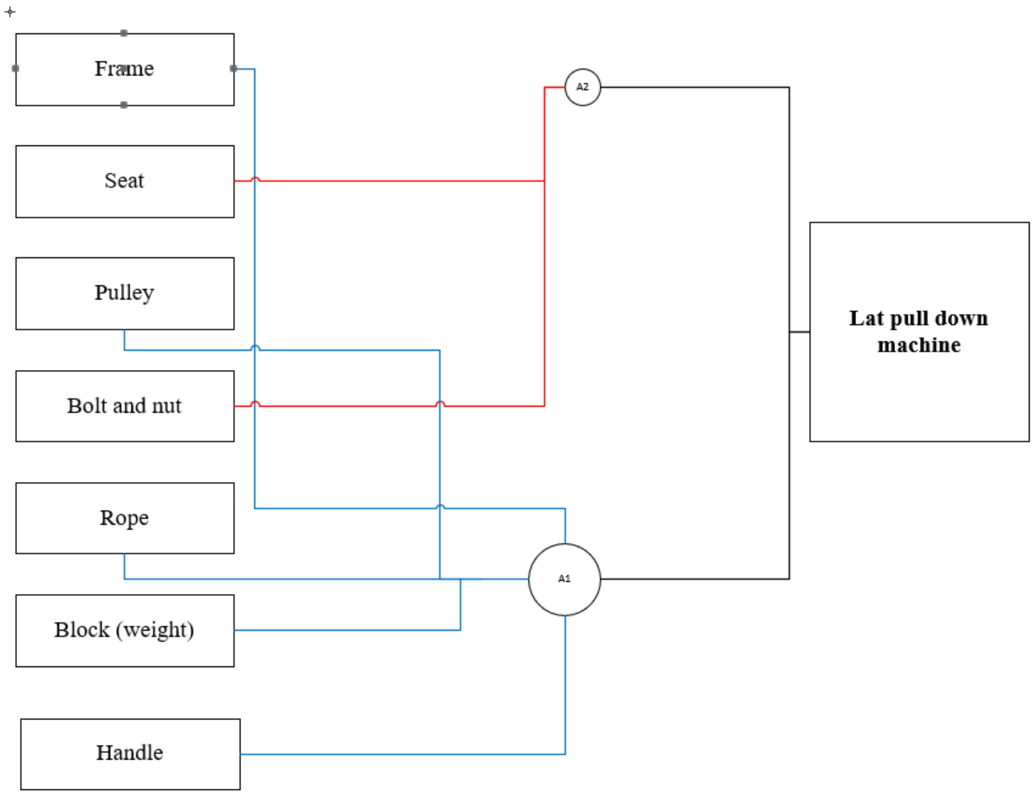


Figure 37: assembly process of the modified design

5 Do FEM analysis for the redesigned geometry and compare the results

The finite elemet analysis of this Lat pull down machine has been done by using ANSYS software and the following aspects has been examined

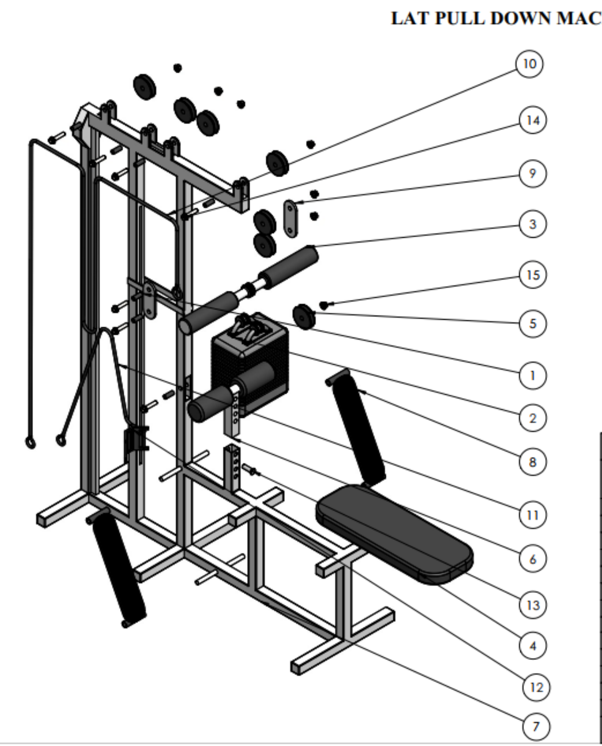
i. The structure is safe
ii. Area with maximum stress
iii. Factor of safety

5.1 Engineering data and assumption for the FEM

Assumptions made during finite element analysis

1. Bush rubbers, small fillets and pulley geometry were ignored
2. Material properties of the main frame is the same throughout
3. Factor of safety for the calculation is 2
4. Main frame of the machin eis welded and fixed to the ground

Engineering data/ information



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
15	ISO - 4161 - M16 - N		7
14	ISO 4162 - M16 x 70 x 38-N		7
13	KEY	MILD STEEL	1
12	PULLER	MILD STEEL	1
11	ROPE 2	STEEL WIRE	1
10	ROPE 1	STEEL WIRE	1
9	BRACKET	MILD STEEL	2
8	FOOT PLATE	STEEL PLATE	2
7	MAIN FRAME	MILD STEEL	1
6	LEG RESTRAINT PAD	MILD STEEL	1
5	PULLEY	CAST IRON	7
4	SEAT	STEEL FRAME +PU FOAM	1
3	HANDLE	MILD STEEL	1
2	BLOCK	MILD STEEL	1
1	BUSH RUBBER	HARD RUBBER	7

Figure 38: exploded view of the modified design

Material for the main frame (Mild Steel)

Material chosen for fabricating the frame is mild steel, factors like mechanical propersties, availability and cost has been considered during the selection processs. In the ansys software the material assigned is structural steel.

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
12	Strain-Life Parameters		
20	S-N Curve	Tabular	
24	Tensile Yield Strength	2.5E+08	Pa
25	Compressive Yield Strength	2.5E+08	Pa
26	Tensile Ultimate Strength	4.6E+08	Pa
27	Compressive Ultimate Strength	0	Pa

5.2 Model (geometry) and meshing of the model

The model of this machine (lat pull down machine) has been designed by using solidWork software and imported to the ansys workbench for the analysis.

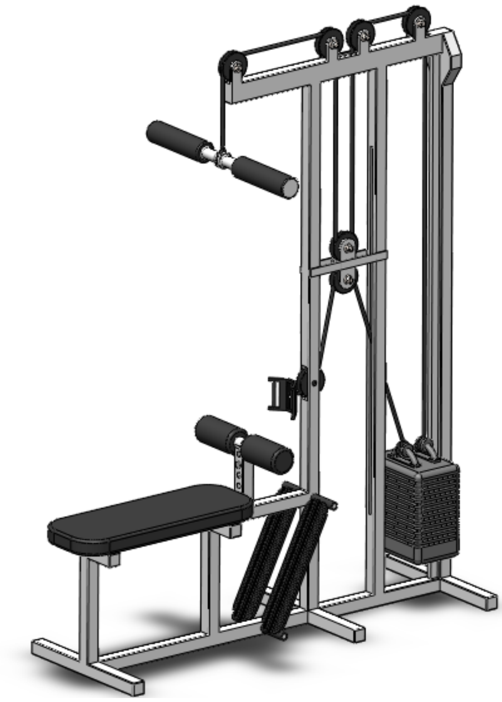
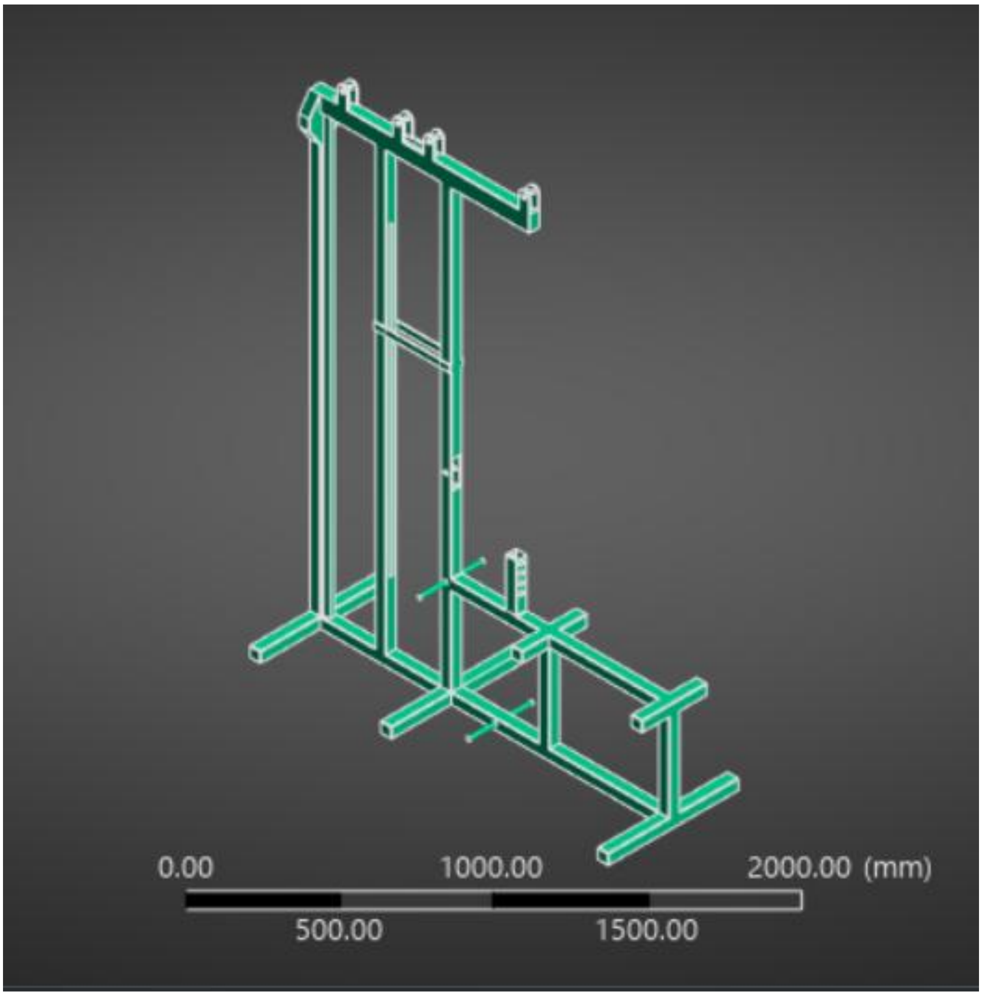


Figure 39: model of the modified design in workbench

Geometry preparation in ANSYS (SpaceClaim)

After the model imported into the ansys workbench, inorder to reduce number of errors, features that are not important in determinining the strength like holes, rounds and chamfers were all removed and cleaned by using spaceClaim. And since almost all parts of the frame are welded together, thus the whole frame was merged together and treated as contact bonded.



Meshing of the frame

No specific method has been assigned to mesh the model, the mesh is automatic generated. The element size used is 50 mm due to the size of the frame structure. The total number of nodes of 67692 and total number of elements is 34419.

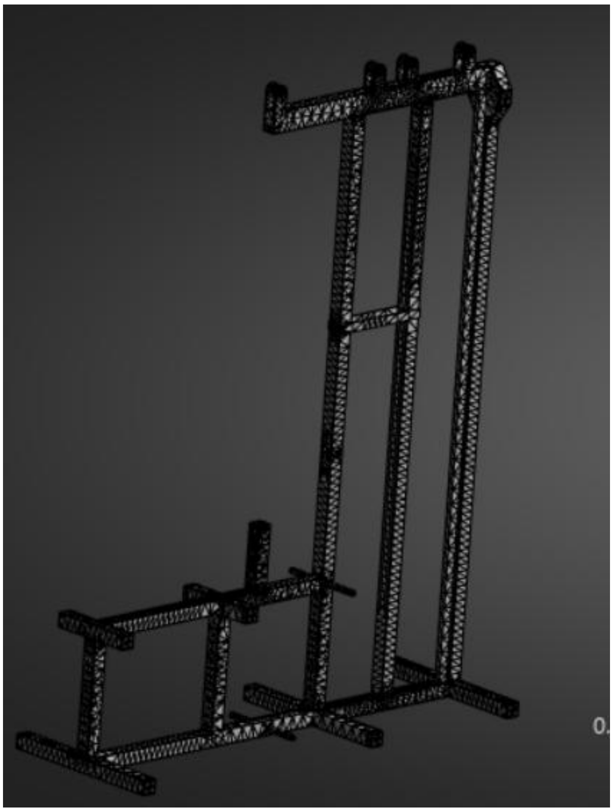


Figure 40: Meshing of the model

5.3 Boundary conditions and loading

Main frame is bolted to the ground; **Fixed support** was used

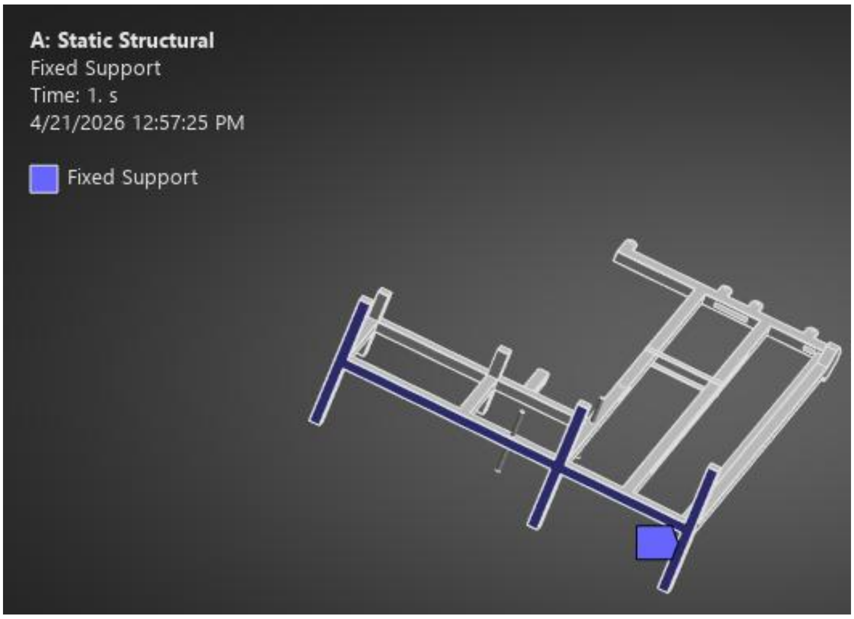


Figure 41: Frame fixed at the bottom part of the frame

Loading

Suppose maximum stack is 100 kg

$$Design\ load = factor\ of\ safety\ \times weight\ of\ the\ stack$$

For the typical fitness equipment, the optimal factor of safety range from 2 to 4,

$$Design\ load = 2\ \times 9.81 \times 100 = 1962\ N\ \approx 2000\ N$$

$$Design\ load = 1962\ N\ \approx 2000\ N$$

Load location and analysis settings

For the new additional operation (low row bench operation) the pulling force is applied horizonally parallel to the bench which cause tension to the vertical column. For the lat pulldown operation the loading will be the same as in the original design, thus no more additional analysis will be done on that area and results of the analysis of the original design will be taken into account as both the original design and modified design use the same.

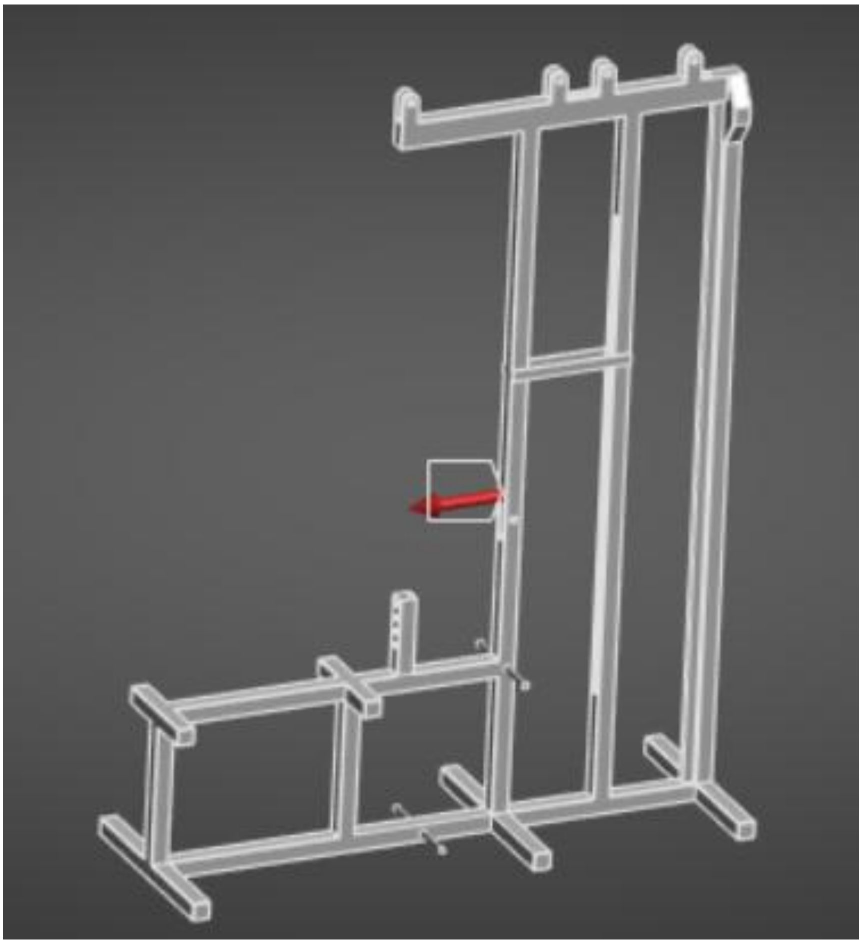


Figure 42: Force applied at the handle

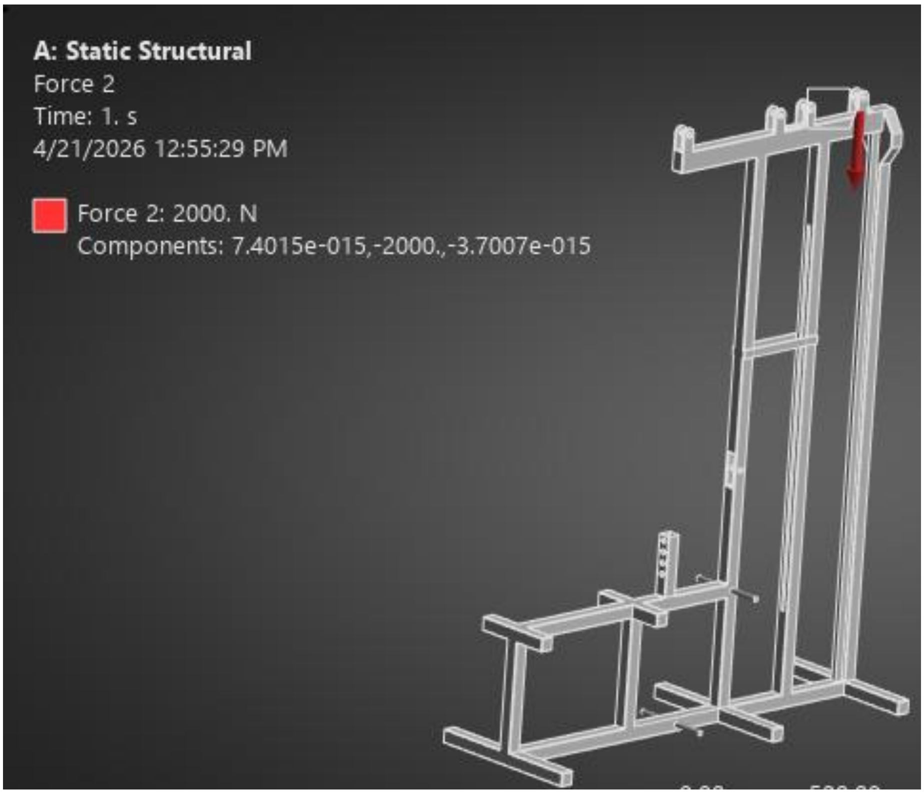


Figure 43: Force due to weight of the block

5.4 Results of the finite element analysis of the modified design

1. Total Deformation

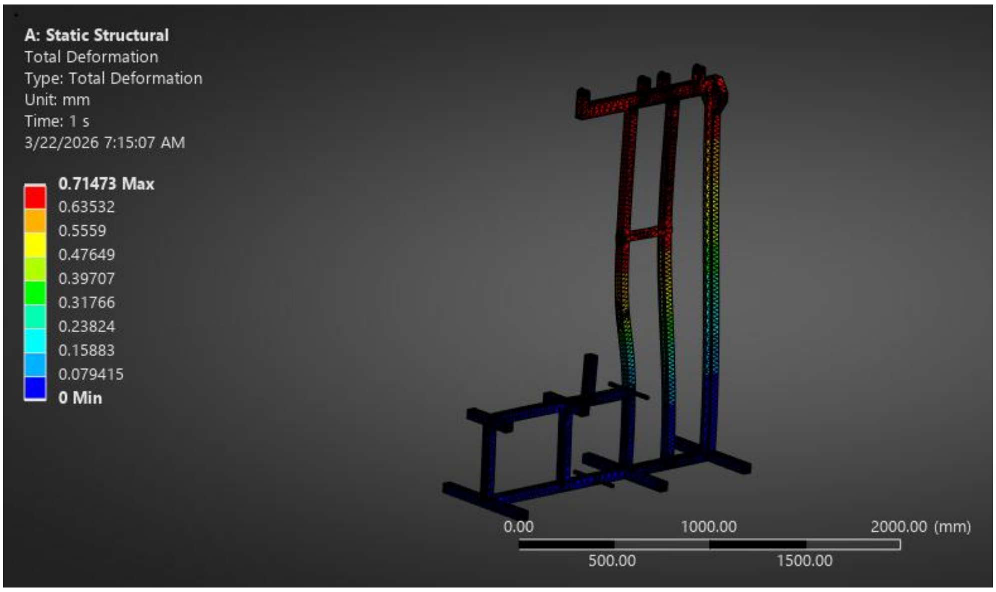


Figure 44: total deformation analysis result

The results from simulation shows that minimum deformation of the frame is 0 mm and it occur at the fixed end of the structure while the maximu deformation of the frame happenned to be 0.71473 mm. The deformation distribution as it has been highlighted by the colour contour increases gradually from the bottom part of the structure to the upper part with the maximum value of deformation being tat the upper part of the section specifically on the horizontal members. The minimum deformation at the lower part of the frame structure indicates that it well constrained and stable. The vertical members of the frame shoews a moderate gradient of deformation.the colour from blue to red gives the overall implication that the frame has good stiffness and the deformation magnitude is acceptable for engineering applications. This analysis has considered linear elastic material behaviour under static loading conditions and this can be well seen as there is no abrupt deformation discontinuties observed.

2. Equivalent Stress

As the von-mises stress didtribution is used to predict yielding stress on the structure made of ductile materials. The results from the analysis indicate that the maximum stress of 54.287 Mpa is only localized at small specific areas of the frame structure like joints and bolt/welding connection. On the other end the minimum stress on the frame structure is 1.461e-10 Mpa which cover the large part of the structure which shows that large portion of the frame structure is not experiencing any loading. As the colour distribution shows that blue colour has covered the large part of the frame and mostly the lower end of the stress spectrum indicating that the frame can operate safely. The analysis proves that the design is safe, robust and capable of withistanding optimal loading.

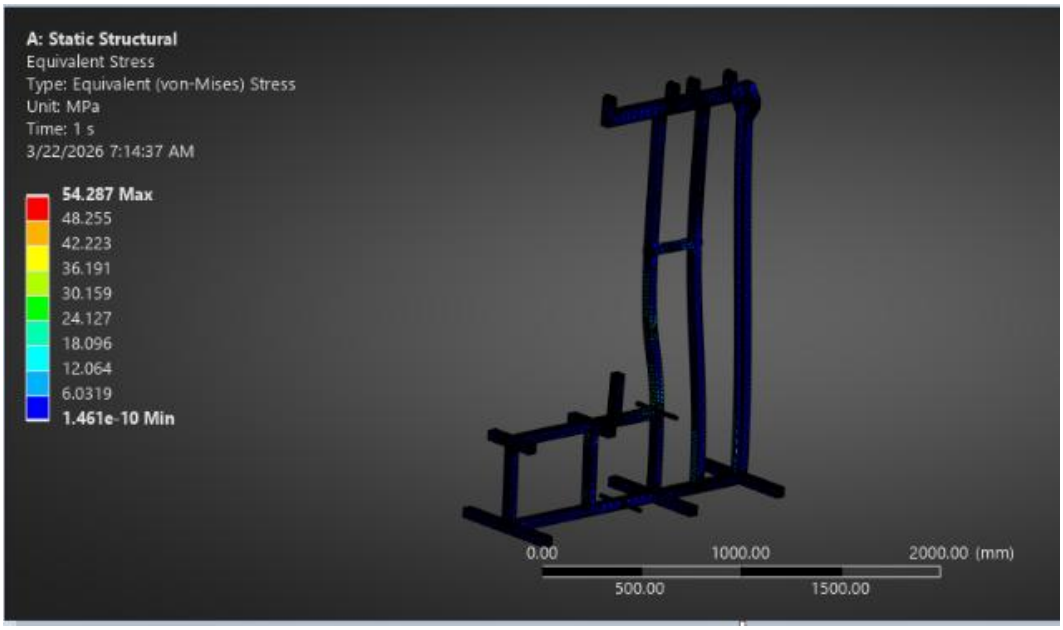


Figure 45: equivalent Stress analysis result

3. Maximum Principal Stress

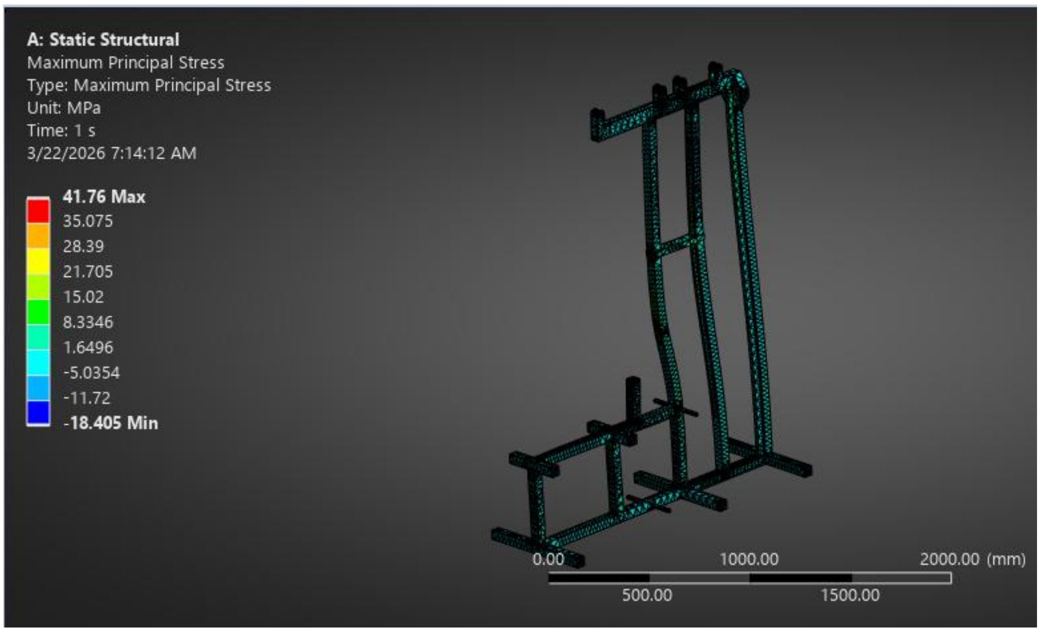


Figure 46: maximum Principal Stress analysis result

Evaluation of maximum principal stress on the frame shows that the maximum principal stress is around 41.76 Mpa and the minimum value is -18.41 Mpa, this shows the presense of both tensile stress and compressive stress. The maximu vale of stress (tensile stress) is located at the upper joints which shows that these are the areas where stress concentrations occurs and subjected to failure when stress excessed the safe limit. The analysis shows that the majority region of the frame structure are subjected to very low stress range as most regions are highlighted by green-blue colur distribution. The base of the frame structure experience very less stress compare to the upper section. The vertical member of the frame structure show gradual stress distribution. The is no stress discontinuities on the frame which indicate that the frame is well-designed and for the negative value of the stress signalize the compressive stress which are found mainly at the base and lower members of the frame. The overall stress is within range and are acceptable compared to yield strength of the material.

4. Directional deformation

The deformation of the frame gradualy increases from the fixed base (acting as a fixed support) at the bottom of the frame where is fixed to the free upward part (the cantilever behaviour). The minimum deformation is 0 mm while the maximum deformation is 1.421 mm. The fram estructure is bending in the x-direction. As for the other deformation and stress results, there is no sudden stiffness discontinuities which is vividly see on the results by smooth colour changes.

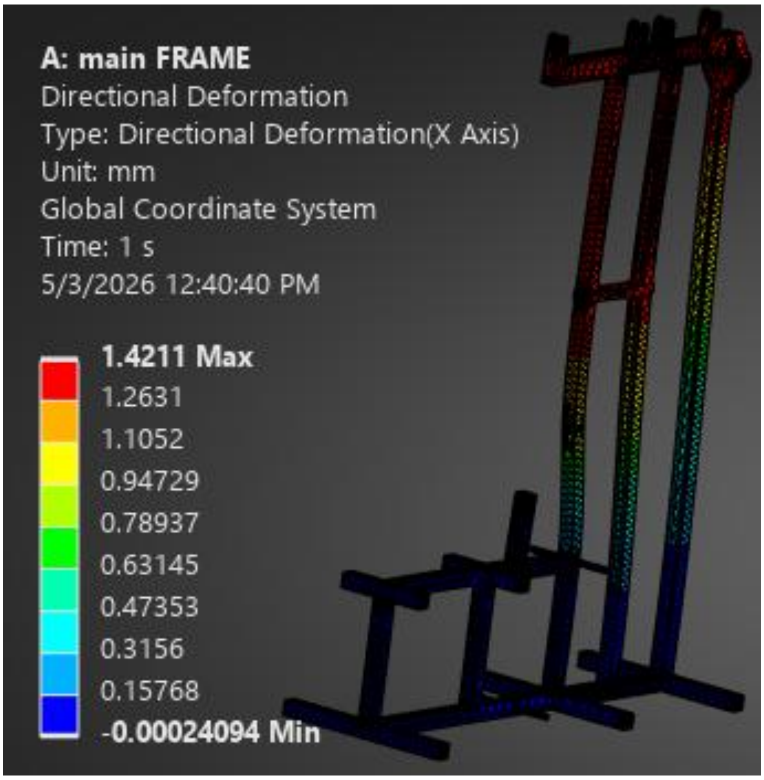


Figure 47: Directional deformation of the modified design

4. Factor of safety

Figure 48: Factor of safety for the modified diagram

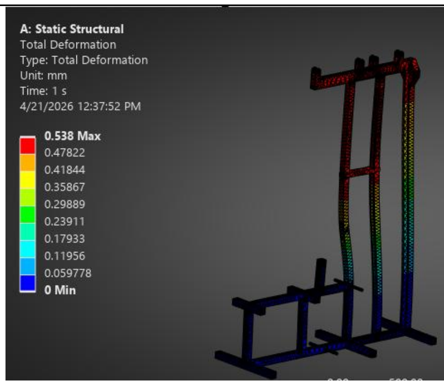
The dominant blue colour which indicate the safety of factor to be above 15, which indicates that large portion of the frame is far from failure due to the amount of the load applied during the operationof the lat pull down machine. The minimumfactor of safety which happens to be 1.5879 which is acceptable in structural engineering. There are few critical zones indicated by faint yellow as it seems at the connection of the lower vertical colum

Comparison of the analysis results of original and modified design

			Original design	Modified design
1	Total deformation (MPa)	Maximum	0.42111	0.71473
		Minimum	0	00
2	Maximum principal stress (MPa)	Maximum	15.525	41.76
		Minimum	-8.4213	-18.405
3	Equivalent stress (MPa)	Maximum	22.977	54.287
		Minimum	2.1543e-6	1.461e-10

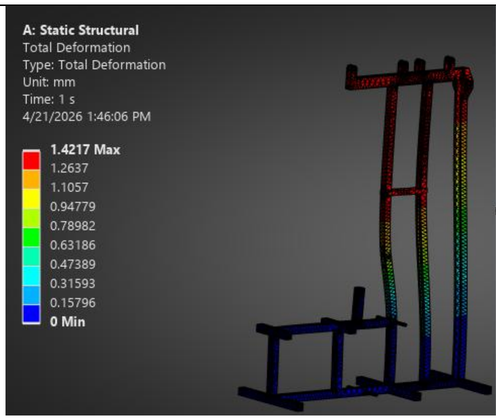
Total deformation

1000N



1500N

3000N



4000N

Figure 49: Total deformation results with differents loads

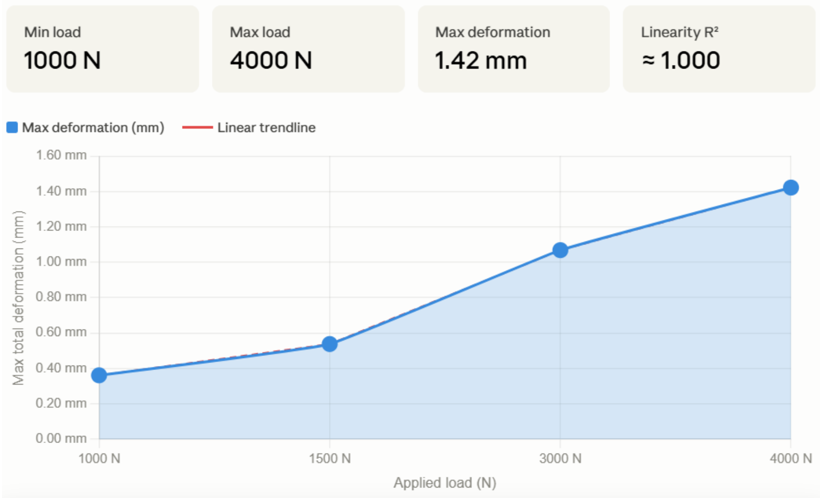


Figure 50: Graph of maximum total deformation against load applied

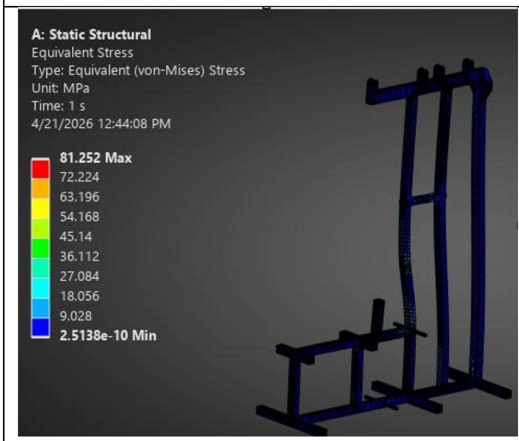
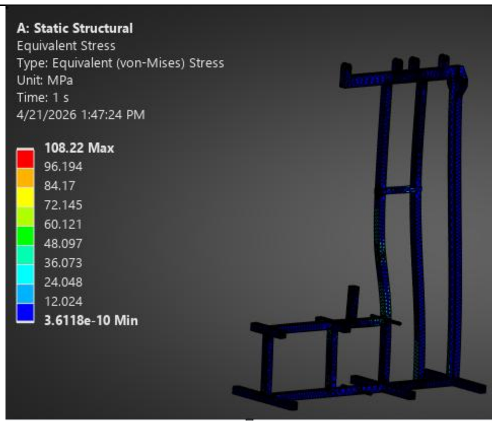
<table>
<tr><th colspan="2">Equivalent stress</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>1000N</td><td>1500N</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>3000N</td><td>4000N</td></tr>
</table>

Figure 51: Equivalent stress of various loads

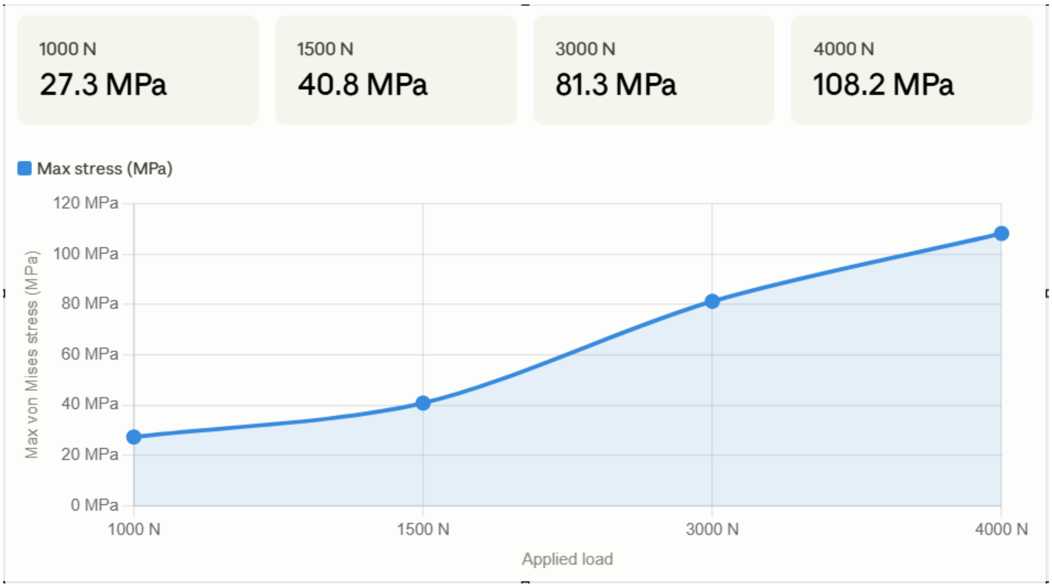


Figure 52: Graph of equivalent stress against load applied

As the amount of pulling force increases, also the equivalent stress on the frame of the machine also increases but the relationship is not directly proportional (as the line is not completely straight)

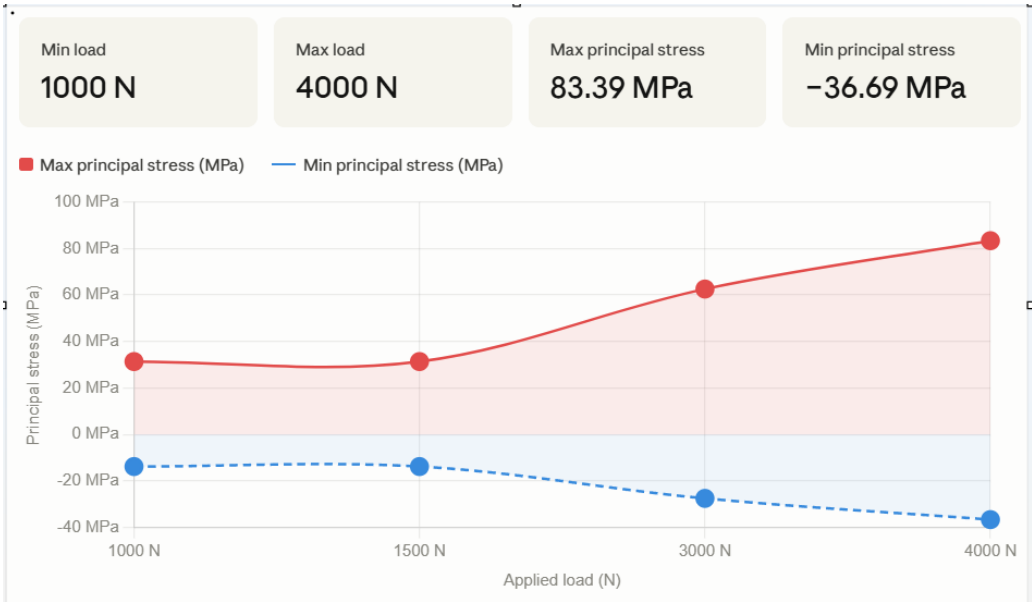
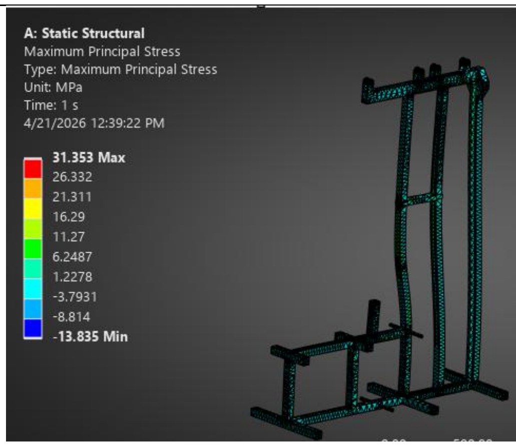


Figure 53: Graph of maximum principal stress against applied load

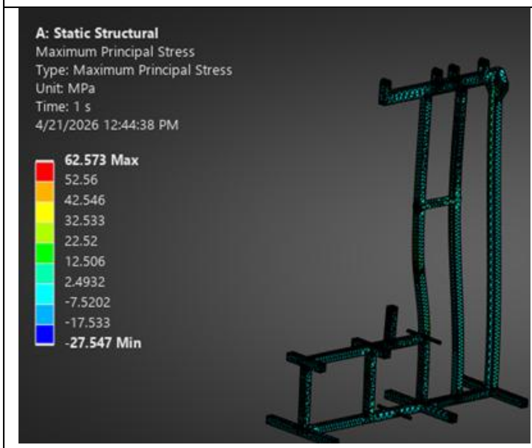
As the amount of pulling force increases, also the maximum principal stress on the frame of the machine also increases but the relationship is not directly proportional (as the line is not completely straight) but for this case both tensile and compressive stress are happening on the frame, the negative sign shown compresiive stress.

Maximum principal stress

1000N



1500N



3000N

4000N

Figure 54: Maximum principal stress of various loads

Factor of safety with various values of forces			
LF		PF	
2000 vs 2000		2000 vs 4000	
3000 vs 2000		3000 vs 4000	
4000 vs 2000		4000 vs 4000	

Figure 55: Factor of safety of the frame with various loading condition

Validation of the finite element analysis results

Factor of Safety

$$FoS = \frac{Material\ strength}{Actual\ stress\ in\ Machine} \quad (1)$$

For the factor of safety less than 1, the frame will fail while for the factor of safety of more than 5 means the frame was over designed. For exercise equipments, expected range for the fcator of safety is 2 – 4.

Maximum load on the frame

$$F_t = F_u + F_w + F_d \quad (2)$$

$F_t = total\ force$

F_u = pulling force (2000 N weight reaction)

F_w = weight stack 2000 N

F_d = dynamic factor, 1.5

Critical members of the main frame

i. Top horizonal beam: pulley is mounted, the forces are acting on it
ii. Vertical columns: bending take place on it due to compression
iii. Welded joints: stress concentrations happens in these areas

Bending moment for the horizontal beam

$$M = \frac{F \times L}{4} \quad (3)$$

F = Pulling force 2000 N

L = Beam length 600 mm

$$M = \frac{2000 \times 600}{4}$$

$$M = 300\ KNmm$$

Moment of inertia of a rectangular hollow section (50× 50 × 4)

$$I = \frac{b \times h^3}{12} - \frac{b \times {h_i}^3}{12} \quad (4)$$

$$I = \frac{50 \times 50^3}{12} - \frac{42 \times 42^3}{12}$$

$$I = 520833.33 - 259308$$

$$I = 2.62 \times 10^5$$

Distance fromneutral axis to outer fiber, c (mm)

$$c = \frac{h}{2} \quad 5$$

$$c = \frac{50\,mm}{2}$$

$$c = 25\,mm$$

Actual stress on the main frame of the machine

$$\sigma_{actual} = \frac{M \times c}{I} \quad 6$$

$$\sigma_{actual} = \frac{300000 \times 25}{2.62 \times 10^5}$$

$$\sigma_{actual} = 28.63\,MPa$$

Shear stress on the frame

$$\tau = \frac{F}{2 \times A} \quad 7$$

$$\tau = \frac{2000}{2 \times 50 \times 4}$$

$$\tau = 5\text{ MPa}$$

Combined stress (Von Mises)

$$\sigma_{VM} = \sqrt{(\sigma^2 + 3\tau^2)} \quad 8$$

$$\sigma_{VM} = \sqrt{(28.63^2 + 3(5^{\,2}))}$$

$$\sigma_{VM} = 29.9\,MPa$$

Factor of safety

Material structural steel

Compressive yield strength $\sigma_y = 250\,MPa$

Compressive ultimate strength $\sigma_u = 360\,MPa$

$$FoS_y = \frac{\sigma_y}{\sigma_{VM}} \quad 9$$

$$FoS_y = \frac{250}{29.9}$$

$$FoS_y = 8.36$$

The factor of safety is 8.4 which show the overdesign of the structure. For a mechanical structure specifically for fitness equipment the reasonable factor of safety was supposed to be 2 to 4. and in case of uncertain and fatigue it may go up to 5.

$$FoS_u = \frac{\sigma_u}{\sigma_{VM}} \quad (10)$$

$$FoS_u = \frac{360}{29.9}$$

$$FoS_u = 12$$

Comparing to the results from the analysis which range from 1.4582 to 15 with majority of the part covered with deep blue which shiws factor of safety from 10. the results of the simulation are correct and feasible.

Manufacturing technology of the machine (lat pulldown machine & Low row bench machine)

1. Structural frame manufacturing

Material used

Structural steel (mild steel) is used to build the main frame of the machine on which other compnents will be mounted. Rectangular hollow section has been used throughout the frame. The back vertical column and horizontal beam of the frame structure is made of rectangular hollow section.

Manufacturing process involved

i. Hollow section cutting: pricise length, is used for the purpose of reducing the whole wait of the machine.
ii. Welding: used to merged the hollow section together
iii. Surface finishing: surface grinding and painting are the operation performed to finalize the appearance of the frame.

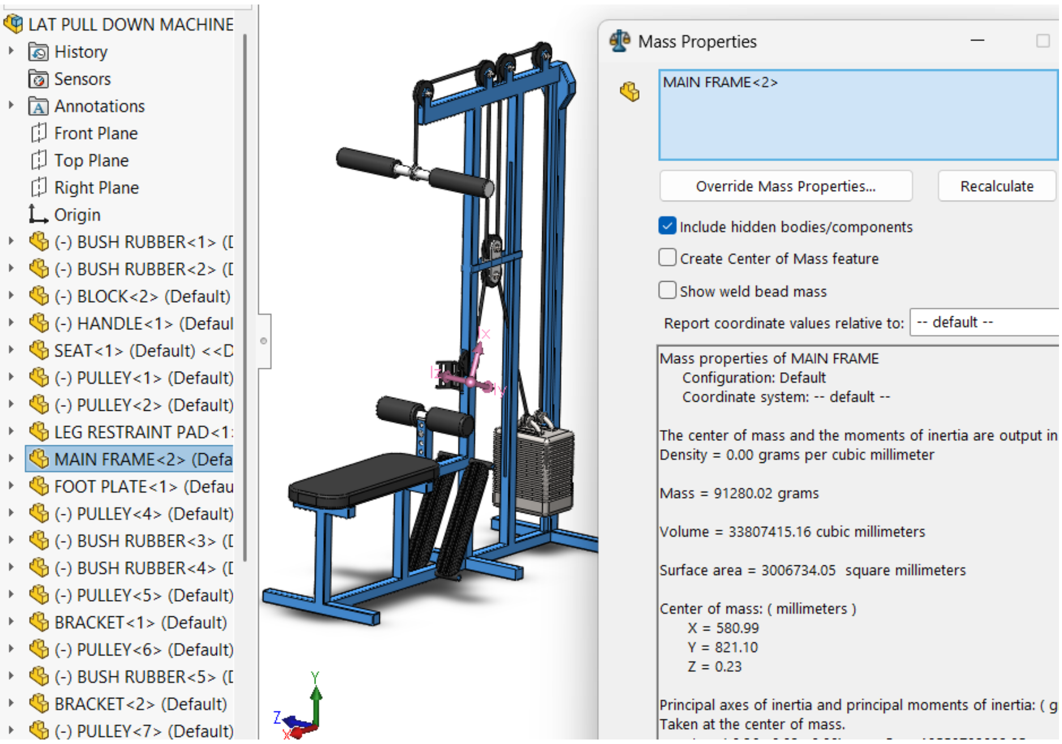


Figure 56: Mass of the frame

2. Pulley system manufacturing

Material used

Cast iron is the material used to manufacture the pulleys.

Manufacturinf process involved

Pulleys were made up by using casting process.

The pulley assembly consists of steel axle pins, brass bush and well aligned wire rop to make sure the machine operate as expected for both lat pulldown and low row exercises. Handle and stack weight are fixed at the end of each rope to complete the pulley system.

To make sure the the machine opertaes without any failure, all pulleys involved for both processes are well aligned

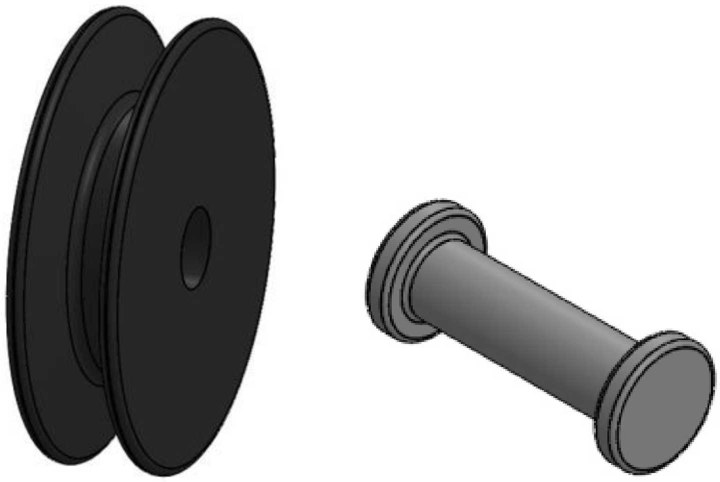


Figure 57: pulley and the axle pin

3. Weight stack manufacturing

The rectangular weight plates made of cast iron are stacked together and used as source of weight for the exercises in the machine. The weight stack is guided to move along the vertical beam while aligning well to the pulley system. The weight can be varied by adding or removing number of plate on the weight stack (act as asinggle block)

Figure 58: weight stack of the machine

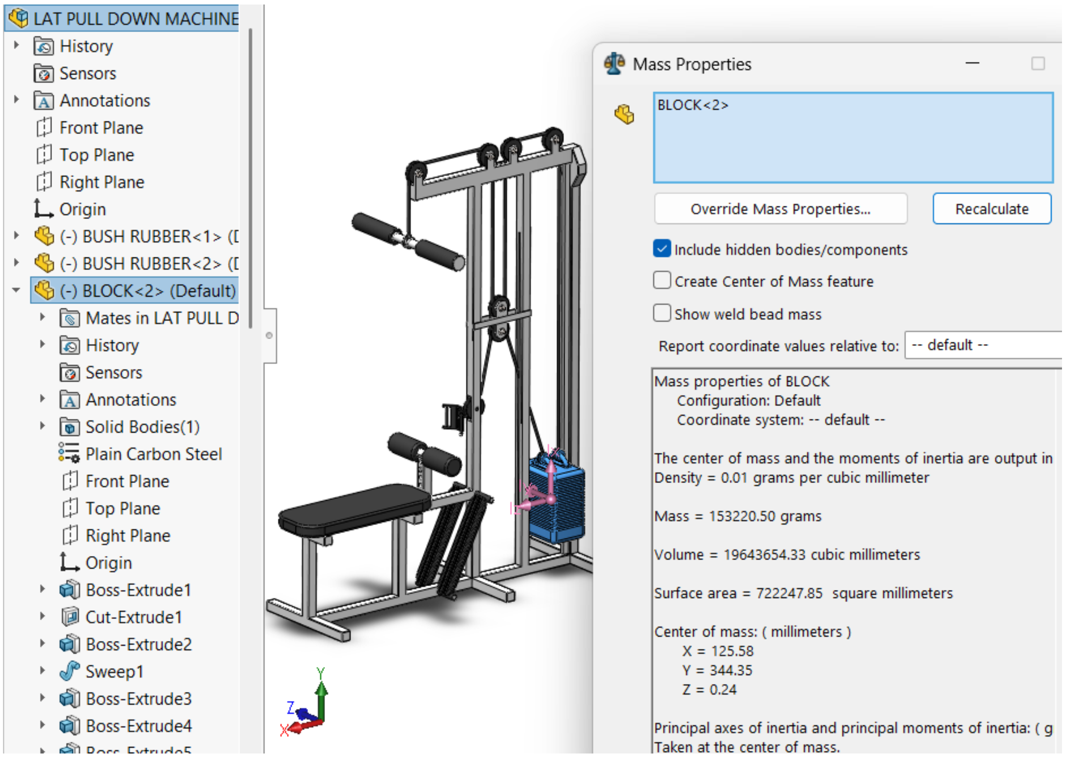


Figure 59: mass of the weight stack

4. Bench and knee pad manufacturing

Bench and kneed pad are all made up from mild steel and cover with rubber and platic (PVC) respectively to provide comfort to the user.

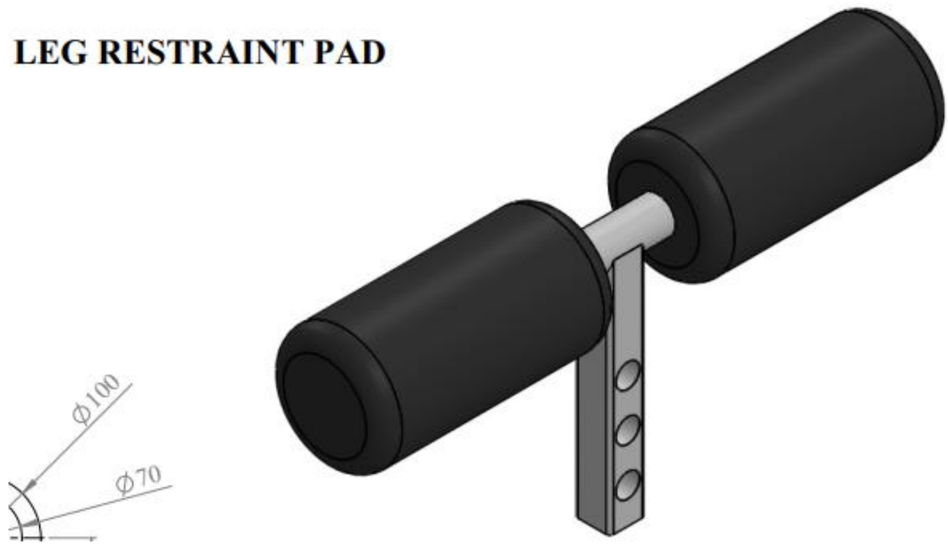


Figure 60: restraint knee pad

5. Assembly and finishing

Assembling of the whole machine has be performed by using parent-child method. With all other sub- assemblies being attached to the main frame. The method makes the assemblies easier and the alignment of all systems possible.

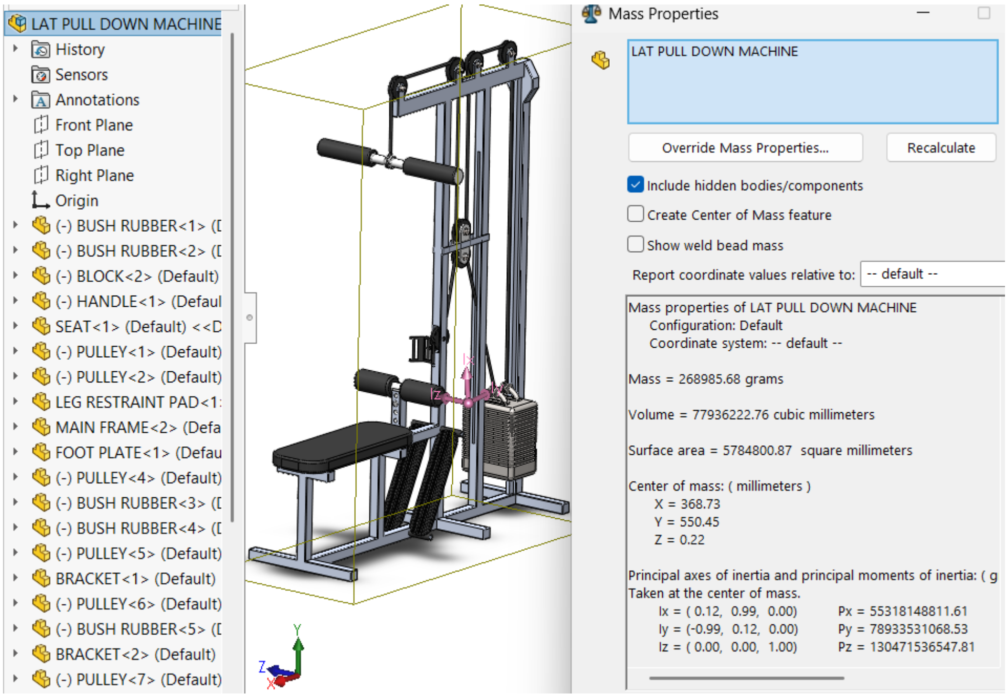


Figure 61: mass of the whole machine

The total mass of the machine is around 270kg which is acceptable for a normal gym/ fitness equipment. For normal fitness equipments, their weight range between 150 kg to 300 kg while for heavy duty equipments, the weight can go up to 500 kg. With this design there is a room to reduce the weight even more and make the equipment even more suitable to be installed at home.

Engineering principles applied during design and manufacturing of the machine

1) Mechanical advantage; many pulleys have been used to reduce wire rope strain which ensure long life for the wire rope.
2) Dynamic loading: impact factor has applied to ensure safety of the machine during impact loading.
3) Pulley mechanics: multiple pulleys have been used to change direction of the motion without affecting the magnitude of the force.
4) Static equilbrium: the main structural frame must be well fixed to ensure all forec are balanced at rest.
5) Friction losses: pulley system always lose the efficiency of the machine for about 2% to 5%.

Operation of the lat pulldown (& seated row) machine

The user of the machine whether is performing lat pulldown or seated row exercise must pull the handle inorder to lift the weight stack through a wire rope and pulley system, this whole system converts the user's effort into controlled resistance and this help to improve the strength of all involved muscles.

Main components in the machine and their roles

Component	**Function**
Weight stack	Provides resistance load
Flat bench	Seating position
Frame (both horizontal beam and vertical column)	Support for other components of the machine
Top pulley system (three pulleys at top)	Redirects cable force direction
Middle pulley	Intermediate link
Wire rope	Motion and force transmission
Restraint pad	Help to hold the user during exercise
Handle	Input force

Working principle of the machine (working procedures)

1. User sits on the bench, set the restraint pad and hold the handle

Maintain the body position and posture before pulling the handle down is very important for the exercise because it determines which muscles of the body will be affected more during exercise. Making sure the back is vertically and straight come first.

The restraint pad help to lock the suer from lifting up during the pulling action and it can be adjusted to fit any user of the machine. Therefore the user must lock him/ herself well in way that he will be comfortable to pull the handle slowly and release it inn the same way without affecting the thigh muscles.

The most important action is for the user to hold the handle with two while balancing him/herself well on the seat putting both feet flat on the floorwhile keeping his/ her back straight

The arm must be extended to make sure the gap between them fit the kind of exercise the user wants to do whether is wide grip lat pulldowns exercise or other kind of lat pulldowns.

Figure 62: User sitting on the bench and ready for the exercise [20]

2. Pulling down of the handle for lat pulldown (concentric phase) and pulling the handle horizontally for seated row exercise

The procedure one is practically a prelimarily/ preparatory procedure for the exercise.

When the user of the machine is comforatble and ready to use the machine, the first step is pulling the handle down which apply the downward pulling force which transmitted through the wire rope attached to the handle.

During this procedure the user can lean up for about 10° to 20° while pulling the handle slightly towards the chest while maintain the shoulder down position.

Pulling the handle brings different undesired results that is why the user is supposed to pull the handle slowly while maintain his postion and to make sure he release the handle slowly. Allowing the weight stack to fall down on itself wont help the user to build any muscles and that must be vaoided during exercise.

$$input\ pulling\ force = user\ musce\ force$$

$$input\ pulling\ force = weight\ stack$$

Figure 63: The user is pulling the handle towards the chest [20]

3. Weight stack rise up

Due to input pulling force from one end of the wire rope which is connected to the handle, the weight stack from the other end start rising up. The weight stack is lifted against gravity.

$$resistance\ force = mass\ of\ the\ weight\ stack\ \times g$$

4. Controlled eccentric return (upward movement)

This is the critical stage during exercises, on this procedure the user is supposed to control the speed of pulling the weight stack and releasing it so that the specific muscles are strengthened as inteded. So when the user is releasing the bar slowly, the weight stack goes down.

This is the eccentric phase (lengthening) of the muscle contarction. Targeted muscles during exercises are latissimus dorsi, biceps brachii, rear deltoid and rhomboids.

During this step, the user inhale while abducting the shoulderand extending the elbow as he/she release the handle to its original position.

5. Common mistake that must be avoided
   i. Pulling the handle behind the neck can bring different results, increase the chance of injury due to extreem stress on the shoulder joints and reduce lat activation.

Figure 64: behind the neck lat pulldown [21]

   ii. Using momentum is another challenge in lat pulldown since the user is supposed to use the muscles from the beginning to the end of the exercise.

Figure 65: momentum lat pulldown [21]

   iii. Another mistake to avoid is leaning too far back and using hand to pull instead of elbow.
   This turn the lat pulldown exercise into a seated row, thus diffrent muscles will be activated as the tenson on the shoulder will be reduced because the user end up performing the exercise by using momentum instead of muscles.

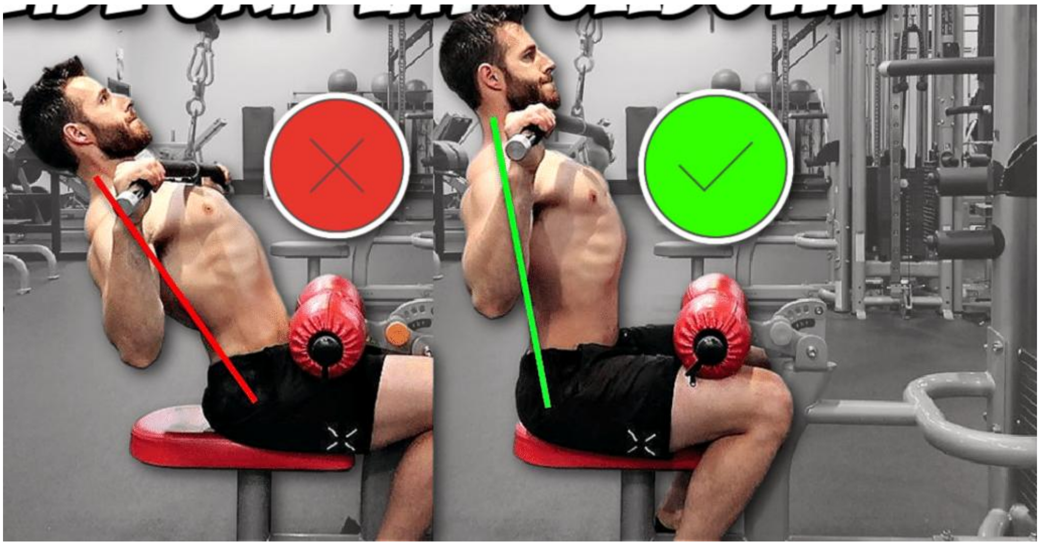


Figure 66: learning too far back [21]

iv. Doing eccentric and concentric phase in less than 2 seconds don't bring good results
v. Shrugging of the shoulders will lower the tension which is supposed to be avoided. Shoulders should always be depressed.
vi. Excessing backward lean.
vii. Taking spine and neck out of neutral position.

Lat pull down adaptation

	Direction of palms
Narrow grip	The bar is grabbed close to the center
Wide grip	The bar is grabbed at the ends which make the space between the palms wide
Supinated grip	Palms face away from user
Pronated grip	Palms face towards the user
Infront of the head	During the pulling face, the bar is Infront of the user, this is the recommended way.
Behind the head	The bar is behind the head, not recommended as it has different effects to the back muscles

Approximated budget (cost of the machine 270 kg)

S/N	Component (specifications)	Cost
1	Main frame Steel, 75% of total mass = 200 kg Cost of steel €1.5/kg	€300
2	Weight stack 150 kg of steel plates	€225
3	Pulley and wire rope system Multiple pulleys Wire rope	€200
4	Seat and restraint pad Plastic base pad	€100
5	Fasteners Bushing Pins Bolts and nuts	€125
6	Manufacturing and finishing Cutting Welding Painting	€300
7	Assembly and labour Assembly time Labour	€250
		€1500

The cos of the machine has been estimated with the help of AI, by breaking down the assembly into sub assemblies and activities and by taking the approximated average prices of the individual components. The cost of the machine may vary depending on the real price of the components and it can also be reduced by reducing the uses of steel which contribute more to the total cost of the machine. Compared to the marjet price of the machine with the same weight, this design seem to have the acceptable value of cost.

6 Conclusion and recommenadation

6.1 Conclusion

From the finite element analysis done on the ansys software and other features like mass properties checked by using solidwork software, the modified design of the machine with two operation lat pulldown exercise and seated rwo exercise stand out to be an upgrade to the original design. With the mass of around 270 kg, the machine is suitable for both gym environment and household environment. The only important care must be taken during installation to mke sure the frame is well fixed to the ground.

The results shows that design performed with the help of simulation, gives a systematic and effective way to enhance the structural performance of the lat pulldown machine and other gym equipment. This analysis establishes a methodological foundation for future optimization efforts, including material substitution strategies to further enhance performance, safety, and cprice-effectiveness.

6.2 Recommendation

The room for upgrading the design is still open, considering the weight is still high and it can be reduced to 150 kg. And since the factor of safety was ranging from 1.4 to 15 by analysis and ranging from 8 to 15 by calculation which signfies the overdesign. The change can be done form the nature of material and component used in the design and this can improve the overall design and improve other criteria like cost and life span of the machine.

I also recomment for other engineering materials with a better strength to weight ratio to be used to fabricate these gym equipments.

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I would like to express my heartfelt gratitude to Dr. Bodzás Sándor, my thesis supervisor for his guidance from the begining of this thesis to the end, his suggestion, feedbacks and continous supports have been helpful to me to complete this work, the time that he dedicated on this work was more than I could have asked, for that I am grateful. I would also like to extend my sincere thanks to Dr. Pálinkás Sándor as my external consultant for his inputs during the design part of my work.

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