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Senior Design Project Report

Designing and Manufacturing of Lower Limb Prosthetic

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team 16

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Abstract:

The area of wearable technology for replacement organs (e.g., prosthetic limbs) is rapidly developing. Prosthetics are defined as an artificial device designed to replace a missing body part (e.g., arms and feet) that may be lost by a condition present at birth, disease, or trauma. Therefore, prostheses are designated to restore the functions of the missing body organ usually. The major issues related to prosthetic practices and technologies contained poor prosthetic comfort and durability. This project aims to design a prosthesis for people who experience a missing lower limb. This project includes the design and manufacture of a lower limb prosthesis by adopting local materials (to enhance the product's affordability). The project is targeted to help people who need a prosthesis to live everyday life, considering the durability of the materials to avoid a premature failure of prosthetic feet, the comfort for the beneficiary by considering the prosthetic socket fit and alignment. This project aims to enhance the quality of life for people who lost their lower limbs by creating an affordable, comfortable, and durable Saudi prosthetic. The designed prosthesis contains the knee, knee shaft, height tube, leg case, foot, hydraulic connecter, hydraulic shaft, and hydraulic system.

Acknowledgments:

We are highly obliged to Dr. Megdi Eltayeb, who is part of the Mechanical engineering department faculty, for his guidance and help as that enabled us to complete the research work. We are also very thankful to everyone who gave us his quality time and showed us support during the entire time of this research.

List of Acronyms (Symbols) Used in The Report:

Symbol	Definition
m	Mass
A	Area
d	Diameter
a	Acceleration
T	Temperature
F	Force
σ	Sigma (Normal Stress)
τ	Tau (Shear Stress)

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Chapter 1: Introduction

A prosthetic lower limb is a non-natural lower limb that substitutes the natural biological lower limb, which may have been gone due to an accident or birth. For example, if an individual lost his lower limb due to a particular mishap, he or she would not be able to move naturally. It would require a walking cane to drive or use a wheelchair to move to places. However, using a wheelchair or a walking cane would not help the individual to move independently. It would require help or aid from another individual. To overcome this situation, prosthetic legs were introduced. With a prosthetic leg, the individual would not need to depend on another person to move independently with freedom. Many designs were introduced of prosthetic legs by numerous companies. Among these designs, various prosthetic legs were designed with different purposes, some configurations are for running or exercising specifically, and some were designed for daily usage and walking. Each design offers its user the movement they desire accordingly, and the configuration provided can handle each situation specified by the manufacturer. According to a survey in 2012 in the United States of America, a population of 1.90 million Americans was using prosthetic limbs to get rid of the aid of other individuals and keep themselves moving with freedom without help. This paper will discuss the prosthetic lower limbs and calculate the engineering design with constraints and manufacturing of the prosthetic and find the economics behind this project.

1.1 Project Definition

This project is planned to design and manufacture a lower limb prosthetic. The purpose of this prosthetic is to be used by individuals who lost a natural lower limb and use this prosthetic without any aid from others. The prosthetic should be strong, durable, light, and attractive to the eye. This project is vital as it can restore some freedom to a specific group of humans that lost a lower limb. Furthermore, it should not cost as much as competitors that design and manufacture prosthetic limbs without lowering the quality as this would not be economical and attractive.

1.2 Project Objectives

1. Localization of the Saudi industry, including adopting local materials.
2. Design an affordable lower limb prosthetic.
3. Design a low weighted, facilitated usable, and comfortable prosthetic.
4. Ensure the durability and corrosion resistance of the prosthetic.

1.3 Project Specifications

Leg's height from foot to knee: 46.5 cm

Max bodyweight: 125 kg

The overall weight of prosthetic: 2.1 kg

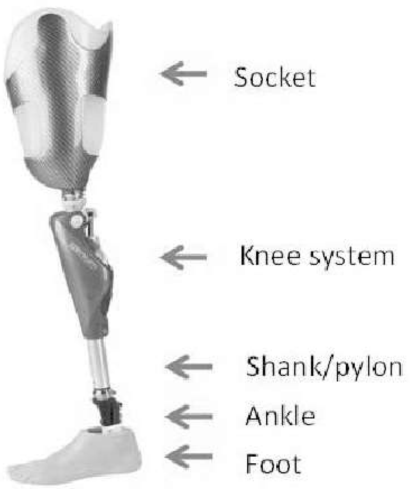

Figure 1.1: Lower limb Prosthetic's Basic Parts [9]

Figure 1.2: Lower limb Prosthetic Used in Real Life [10]

1.4 Applications

Following are the primary applications of the lower limb prosthetic we are ready to design:

- To aid the people whose lower limb has been lost due to an illness.
- To support a person whose lower limb is lost during an accident.
- To help an individual whose lower leg was not fit naturally.

Chapter 2: Literature Review

2.1 Project background

Prosthetic manufacturing is essential in many cases. For example, somebody who has been deprived of his leg below the knee now in this condition would have no choice to move autonomously. He would ask for assistance from an individual who would help him move or use a wheelchair to move on. To get rid of this situation, with the aid of a prosthetic leg, he might gain independence from a wheelchair and the extra help of another individual. There are several designs of lower limb prostheses among those designs running specific or the traditional technique for simple walking purpose. Each of these designs offers its operator the movement he desires, and the design could tangibly handle the situation. In this report, the designing and manufacturing a medical device, a lower limb, are discussed, and prosthetic manufacturing technique has been used. The suggested method is concentrated on the modeling of the patient's lower limb.

2.2 Previous Work

When going back in years and studying the history of prosthetic manufacturing, we come to know that archaeologists exhumed a 3000-year-old mummified body. Though, there was somewhat very exceptional about this finding. With that mummy, the archaeologists found a buried prosthetic toe that was made of wooden. This unique form of a prosthetic was prepared with fastenings to attach to the foot of the body and the leg of the body while the toe was unfluctuating made to move with the feet, which they found pretty strange when one thinks about the period in which it was made. However, this mummified body was the first ancient object to be revealed, sporting a prosthetic limb of classes. In 1910, the Capua Leg was uncovered in the north of Naples back to 300 BC. This European-made prosthetic was shaped from wooden material with an external coating of bronze material. The upper part of the prosthetic was excavated out with filling at the foot to provide housing for the owner. In addition to this antique prosthetic was fortified with tinny rods and strips that protected the limb in a good place. With the evidence that diversities of prosthetics in the years back to the B.C. ages, it is lovely to see the development of prosthetic limbs. Thanks to incredible advancements in engineering, the growth, and design of prosthetics have significantly developed.

2.3 Comparative Study

Many other companies that manufacture prosthetic lower limbs offer prosthetics with advanced technologies that utilize phones, batteries, and sophisticated materials. Some prosthetics are made out of carbon fiber, which is exceptionally light and strong. Such material is costly to produce, which will increase the price of the prosthetic. Moreover, they add batteries that are chargeable to allow many features on the prosthetic to be utilized. Some of these features will enable the user to connect to the prosthetic leg's computer and choose different modes. Some of these mods are running, walking, and exercising. Furthermore, the batteries and the app on the phone make the prosthetic's computer adjust the leg's damping and kick motion. These advanced features and materials made such prosthetics complex and refined, ultimately increasing the product's price significantly. However, our prosthetic is much simpler with not much less quality. We offer a purely mechanical prosthetic without the batteries, this would allow us to reduce the price, and that is our argument and a point that would make interest in our product.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

- Geometrical Constraints:

Regarding the geometrical constraints, since this prosthetic leg should replace a human's organ, then the width should be close to the human leg's width, keeping in mind that the more width added, the less mobility would result and more material will be used, so it is advised to reduce the width to the possible minimum. Regarding the length, it must be adjustable so it can balance the human's other leg, so it should have an adjustable length of 420 mm and can be decreased down to 390 mm (from the knee joint to ankle joint).

- Sustainability:

The prosthetic leg would be daily used and for a lifetime. In addition, it will be exposed to different types of environments. Therefore, the material used to build the prosthetic leg should have high fatigue strength and corrosion resistance. The leading choice of material that meets our requirements is aluminum. In addition, aluminum has an outstanding property, and that is, if the surface were scratched, it reveals a new character; aluminum will produce a new passive layer. Therefore, it will stand corrosion even if the surface gets damaged.

- Environmental

Our choice of material is environmentally friendly. Aluminum is easily recyclable. However, the process of acquiring such materials plays a vital role in the environmental effects that may occur, such as melting iron ores using coal to produce that high temperature that would make iron ores melt thus, harming the environment with the burning of coal instead of gaining that energy from renewable sources is a vast environment factor, which is not in our complete control.

- Social

The purpose of our prosthetic is to make the patient feel confident when wearing the prosthetic with an exciting and high-tech design. Usually, with such patients, they feel shy around others due to their disability that they are not like other human beings. Our prosthetic should be attractive to make the patient happy while using it and receive compliments about its design from other individuals.

- Economic

Economically, we found two ways to reduce the cost, first by the price of materials and second to deliver it from outside the kingdom. When someone needs it, the prosthetic leg would order it overseas, which will cost a lot. We are thinking about it, and we find ways to reduce the cost of it. The first way to manufacture it in Saudi Arabia is to use our local materials to reduce its cost. Moreover, they do not need to order it from outside and save the charge of the delivery.

- Manufacturability

Initially, manufacturability was not thought of as an issue; however, once we visited some factories and workshops, things became clear. It is difficult and expensive to manufacture the case from fiberglass without a permanent mold. It was easier and cheaper to manufacture it from aluminum using sand casting. Furthermore, things got complicated as the issue is not a regular shape which made manufacturability a constraint.

- Safety

Our prosthetic leg design is purely mechanical, which means it does not contain any electrical parts. Electrical parts require batteries, and batteries require special storage for contact with certain metals and heat. Batteries are fire hazards that we avoided. Furthermore, we focused on the mechanical parts in our design to give them a high safety factor to withstand stresses and impacts that could result in the fracture of the leg and an injury to the patient.

- Ethical

Our project is very ethical and humane. The prosthetic would help incapable humans to restore their everyday lives once again, at least to some extent. Moreover, we would use aluminum for the case and knee, which increases the safety margin. In addition, a hydraulic system would be fitted to absorb impacts on joints. With these features added, the patient using our prosthetic would be able to use it comfortably without any future problems in the spine or hipbones.

- Risk Analysis

Multiple risks could happen in our prosthetic if not designed well. First, corrosion might occur if the materials selected are not corrosion-resistant. That is why we chose aluminum as materials for the prosthetic's case and knee because of its corrosion resistance properties. Secondly, stress failures may occur in some areas that have high-stress concentration, that is the reason why we used SOLIDWORKS to analyze factors of safety with the corresponding materials with different components of the prosthetic, and we made sure our calculations are correct, so the leg does not fail by various forces applied, and fatigue stresses that occur in the movement of the portion.

3.2 Engineering Design Standards

Table 3.1: Engineering Standards

Component	Engineering Standards	Details
Screw	DIN 916	M8-1.25 x 20mm, Alloy Steel Metric Class 14.9-45H, Hex Socket
Barrel Nut	DIN	M6-1 x 45mm, T countersunk head female barrel nut, stainless steel, Rivet hex socket
Cap Bolts	DIN	M6-1 x 25mm, countersunk hex socket cap bolts, stainless steel
Material	BS EN 573	Aluminum Alloy 1050-H24

3.3 Theory and Theoretical Applications

3.3.1 Static Study

We assume the mass of the human body to be (125 kg), then we have to calculate the force (F) that will act on the whole leg with ($g=9.81\ m/s^2$), and we apply these values in this equation:

$$1.\quad F=mg$$

Knowing that the inner and outer diameter of the joint tube is respectively ($d_{j1}=0.013$ m, $d_{j2}=0.018$ m), the cross-sectional area of the joint tube (A_j) will be calculated using this formula:

$$2.\quad A_j = \left(\pi \frac{d_{j2}^2}{4}\right) - \left(\pi \frac{d_{j1}^2}{4}\right)$$

Since A_j will give us the least cross-sectional area, then it will have the most stress. Using the calculated variables from equations (1 and 2), we get ($F=1226.25$ N and $A_j= 1.21737\text{x}10^{-4}\ m^2$), then plug these variables in the following formula to get shear stress (τ) acting on the joint tube:

$$3.\quad \tau = \frac{F}{A_j}$$

From here, we get ($\tau=10.07294$ MPa) as the maximum stress that our components would get if it carried a human weight of (125 kg).

Table 3.2: Summary of The Results of The Static Study

Description	Symbol	Value	Unit
Joint tube inner diameter	d_{j1}	0.013	m
Joint tube outer diameter	d_{j2}	0.018	m
Force	F	1226.25	N
Joint tube cross-section area	A_j	$1.21737\text{x}10^{-4}$	m^2
Shear stress	τ	10.07294	MPa

3.3.2 Dynamic Study

In the dynamic part of the study, calculations were simplified in the best possible way due to their complexity. The calculated dynamic analysis was according to Newton's 2nd law and the human gait cycle angles of knee flexion at different angles where the foot is on the ground. The focus was on the knee because the knee is an integral part of our design, specifically the knee joint, a critical component. The assumption of a (125 kg) human body weight is still the same. However, the presumption of an acceleration of the human with a prosthetic is (0.5 m/s^2) during walking is added, which is the application of the designed prosthetic.

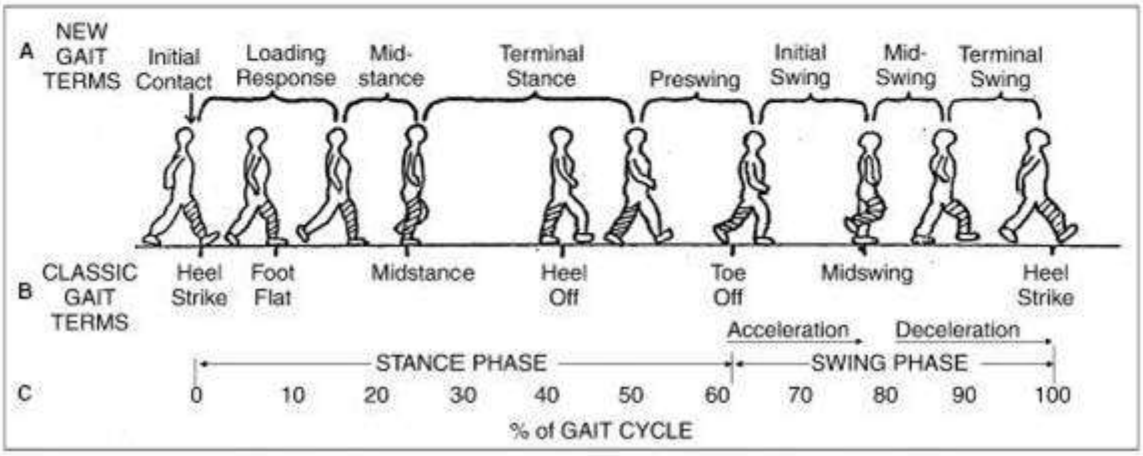

Figure 3.1: Human Gait Cycle [11]

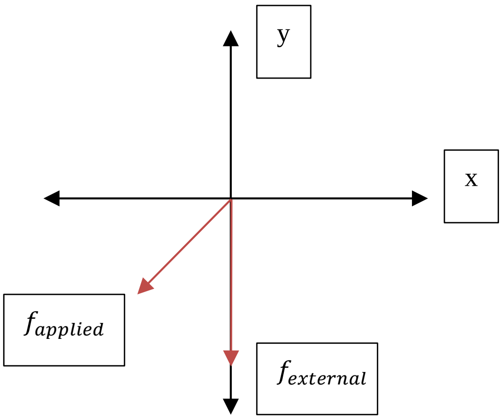

Figure 3.2: Forces on The Knee at Varying Angles from Y-Axis

The calculations went in reverse. First, it started by considering the knee joint to be a point to make it simple. Moreover, forces on the knee were simplified in figure (3.2). In addition, the resultant magnitude force was calculated using this formula:

1. $F_R = \sum F_X + \sum F_Y$

Next, the sum of forces will be calculated using this formula:

2. $\sum F = f_{external} + f_{applied}$

Moreover, the sum of forces will be different according to which axes are being calculated. "g" is (g=9.81 m/s^2), "a" (0.5 m/s^2), m_b is (125 kg), m_l is (2.1 kg), which is the weight of the prosthetic leg, and “∅” is a varying angle of knee flexion. These are the formulas used in each axis:

3. $\sum F_X = (m_b \times g \times \sin\emptyset) + (m_l \times a \times \sin\emptyset)$
4. $\sum F_Y = (m_b \times g \times \cos\emptyset) + (m_l \times a \times \cos\emptyset)$

According to [11], in the human gait cycle during the "heel strike," the knee would flex at an angle of (5°). This defines the angle so that the calculation can be continued with this angle at this specific step.

Table 3.3: Dynamic Study at 5° Knee Flexion

Description	Symbol	Value	Unit
Sum of forces in the x-axis	$\sum F_X$	1.01	N
Sum of forces in the y-axis	$\sum F_Y$	1226.55	N
Resultant force	F_R	1227.56	N
Joint tube cross-section area	A_j	1.21737×10^{-4}	m^2
Shear stress	τ	10.08371	MPa

In the "foot flat" phase, the knee flexion is between 15° and 20° according to [11]. An average angle between them was used, which is 17.5°, then the forces were calculated again using the same equations:

Table 3.4: Dynamic Study at 17.5° Knee Flexion

Description	Symbol	Value	Unit
Sum of forces in the x-axis	$\sum F_X$	1.02	N
Sum of forces in the y-axis	$\sum F_Y$	1226.48	N
Resultant force	F_R	1227.5	N
Joint tube cross-section area	A_j	1.21737×10^{-4}	m^2
Shear stress	τ	10.08321	MPa

In the "toe-off" phase, the knee flexion is between 35° and 40° according to [11]. Yet again, an average angle between them was considered, which is 37.5°, then the forces calculated are given using the same equations:

Table 3.5: Dynamic Study at 37.5° Knee Flexion

Description	Symbol	Value	Unit
Sum of forces in the x-axis	$\sum F_X$	0.21	N
Sum of forces in the y-axis	$\sum F_Y$	1227.28	N
Resultant force	F_R	1227.49	N
Joint tube cross-section area	A_j	1.21737×10^{-4}	m^2
Shear stress	τ	10.08313	MPa

These results are logical. When the person is walking (dynamic study), an applied force is added to the external force already applied due to gravity and the body's weight. The applied force was not much due to the slow acceleration of a human with a prosthetic. The stresses due to the dynamic study for such application will not significantly higher than the static study because the higher force is being the external force that is already calculated during the static analysis.

3.4 Product Subsystems and Selection of Components

The primary part of the prosthetic is the leg case. It has two holes, one for a shaft and the other is for a long bolt. The shaft is inserted into the hole to fit a knee bearing on top to rotate and give the knee motion. The hole which has the long bolt is used to insert the hydraulic system inside the leg case, which is held by the long bolt and tightened from both sides, and a shaft fits the other end of the hydraulic system to the knee to give the damping feeling and absorption of the impacts. A length tube is used to adjust the height of the leg to match the other patient's leg. This tube is inserted into the bottom of the leg case and tightened with two small screws at the end of the case. Finally, the foot is connected to the long tube from the bottom of it using an inverted pyramid connector that goes under the length tube's spherical hole and is held by four screws.

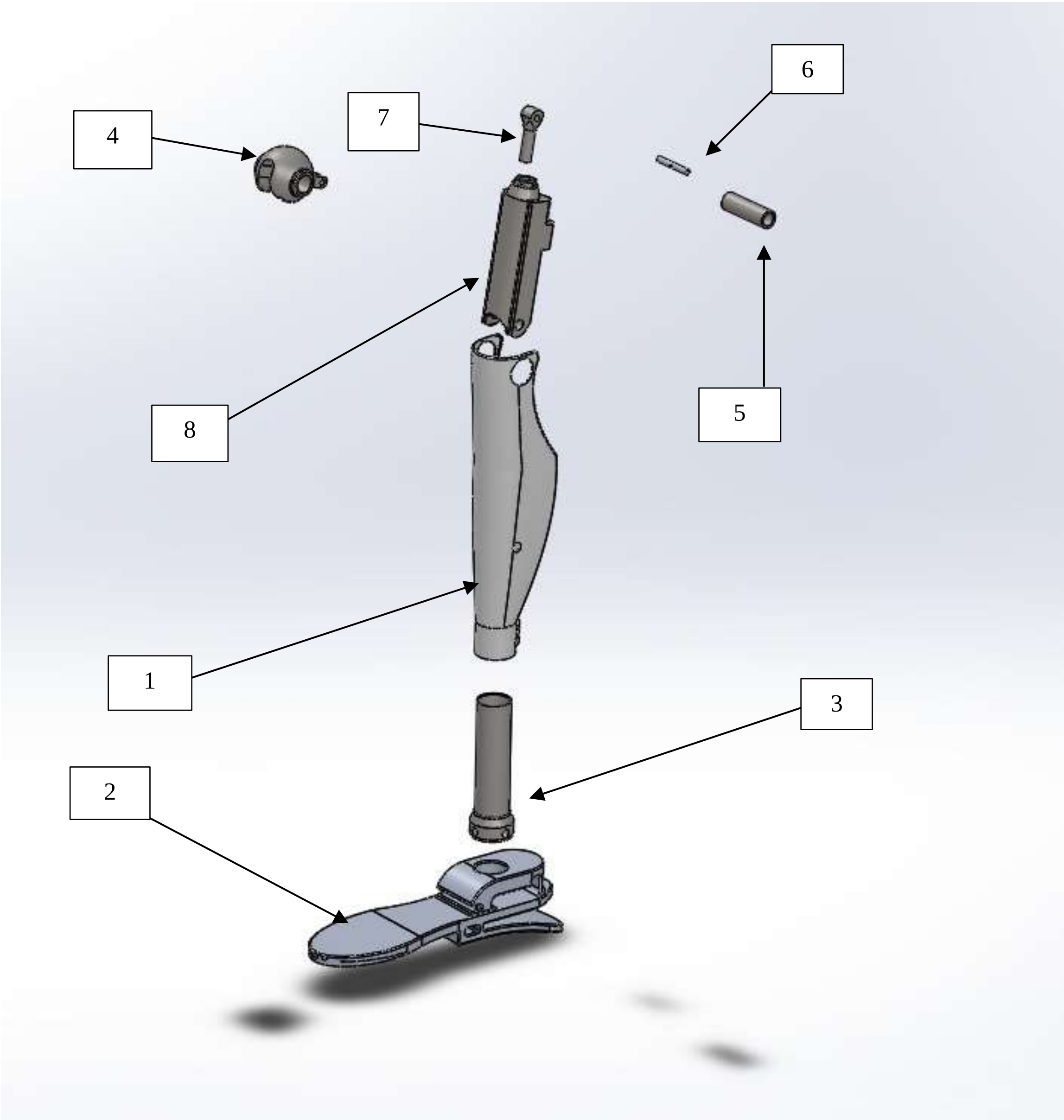

Figure 3.3: Exploded View of The Assembly

Table 3.6: Parts of The Designed Prosthetic

Item number	Part Number	QTY.
1	Leg Case	1
2	Foot	1
3	Height tube	1
4	Knee	1
5	Knee shaft	1
6	Hydraulic connecter	1
7	Hydraulic shaft	1
8	Hydraulic system	1

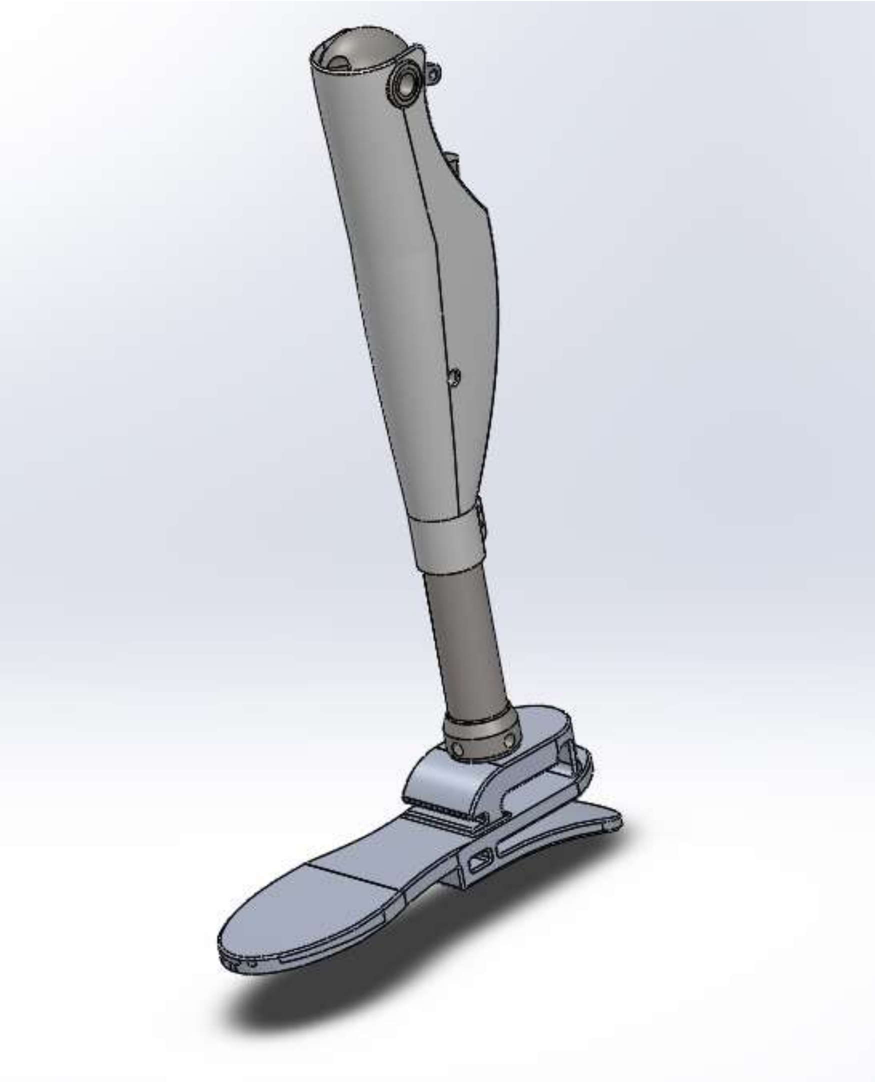

Figure 3.4: Collapsed View of The Assembly

3.5 Manufacturing and Assembly (Implementation)

The leg case was initially planned to be made out of fiberglass. Fiberglass is light, corrosion-resistant, and has good properties regarding stresses and forces. Furthermore, it is easily made using a mold that does not cost much and straightforwardly manufacturable. However, when we visited many factories, the mold was expensive for a prototype. Instead, we used sand-casted aluminum alloy. Aluminum alloy gave the case the protective strength required. Plus, aluminum is corrosion-resistant because it creates a passive layer that heals itself, and it gave the necessary strength-to-weight ratio for our design. In addition, the knee and the knee joint were all made using the same aluminum alloy. Stainless steel was considered but, it would cost more than the aluminum alloy used, and it is heavier.

3.6 Economic Evaluation of The Project

- Capital cost
  - Equipment: CNC milling machine (375,035.00 SAR), CNC lathe machine (29,177.72 SAR), saw machine (771.00 SAR), toolbox (620.00
  - SAR).
  - Construction: there will be no construction because the workshop will be rented so that it will be transferred to the variable cost.
- Operation cost
  - Energy: we will not use any other energy source other than electricity to be neglected.
  - Electricity: it will be the estimated electrical bill supplied from the SCECO. So it will be (14,294.02 SAR/year) for the first four years and will increase to (21,491.71 SAR/year) from the 4^{th} year till the 10^{th} year.
  - Labor: at first, we will assign five technicians to the production line, which will cost an average of (3000 SAR/Labor). Then we will set a manager to take over, a human resources department made of one employee, and a marketing department made of one employee, which will cost an average of (5000 SAR/Labor).
  - Insurance: this will be the sum of the company insurance (10,000 SAR/year) plus the employees' health insurance (1,000 SAR/Labor/year).
  - Taxes: the taxes will be 2.5% subtracted from revenue.
- Revenue

  The total legs we sell (35 prosthetics for the first four years, 65 legs from 4^{th}-10^{th} year) multiply by the price of one leg (5000 SAR).

Table 3.7: Excel Sheet Calculations

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs											
Equiprment	300603.72	0	0	0	0	300603.72	0	0	0	0	0
Construction	0	0	0	0	0	0	0	0	0	0	0
Total	300603.72	0	0	0	0	300603.72	0	0	0	0	0
Operating Cost											
Energy	0	0	0	0	0	0	0	0	0	0	0
Electrcitiy	14294.016	14294.016	14294.016	14294.016	14294.016	21491.712	21491.712	21491.712	21491.712	21491.712	21491.712
Number of Employee	6	6	6	6	6	8	8	8	8	8	8
Labour	18000	18000	18000	18000	18000	40000	24000	24000	24000	24000	24000
Insurance	16000	16000	16000	16000	16000	18000	18000	18000	18000	18000	18000
Workshop rent	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Total	88294.016	88294.016	88294.016	88294.016	88294.016	119491.712	103491.712	103491.712	103491.712	103491.712	103491.712
Total cost	388897.736	88294.016	88294.016	88294.016	88294.016	420095.432	103491.712	103491.712	103491.712	103491.712	103491.712
Revenues											
number of Product sold	35	35	35	35	35	65	65	65	65	65	65
sum of product revenues	175000	175000	175000	175000	175000	325000	325000	325000	325000	325000	325000
taxes	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Total revenues after tax	170625	170625	170625	170625	170625	316875	316875	316875	316875	316875	316875
yearly profit	-218272.736	82330.984	82330.984	82330.984	82330.984	-103220.43	213383.288	213383.288	213383.288	213383.288	213383.288
Cumulative Profits	-218272.736	-135941.752	-53610.768	28720.216	111051.2	7830.768	221214.056	434597.344	647980.632	861363.92	1074747.21

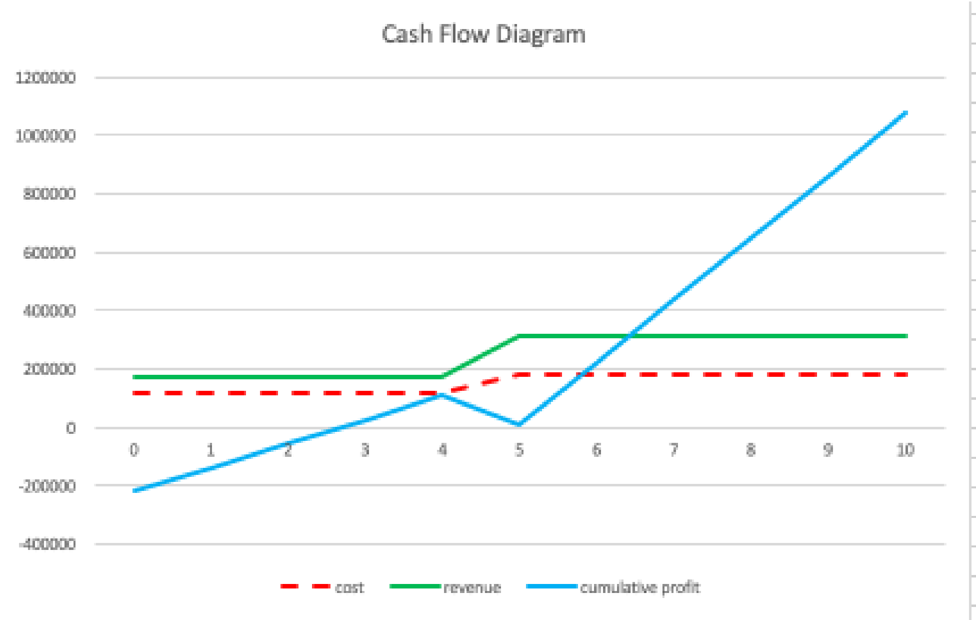

Figure 3.5: Cash Flow Diagram

- Payback period: The period needed to get back your Capital Cost, which means the break-even point shown in Figure 3.5 will be around 2.5 years.

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors, and data acquisition system

With the help of SOLIDWORKS, we were able to apply the force on the joint tube. The joint tube is a part that is critical in our calculations, and for simplicity reasons, we chose to analyze it independently without the complications of other components. Our approach was by finding out where the forces will be distributed while the person is standing still (Static analysis). We chose aluminum 1050-H24 alloy for the joint tube because of the corrosion resistance properties of aluminum. Furthermore, we took into consideration stainless steel. However, it is more expensive than aluminum. Moreover, stainless steel has better mechanical properties but, our choice for aluminum 1050-H24 alloy gave a suitable factor of safety (FOS) which means we have a margin safety available. Stress and the factor of safety calculated in SOLIDWORKS are both according to von Mises's theories.

4.1.1 Joint Tube

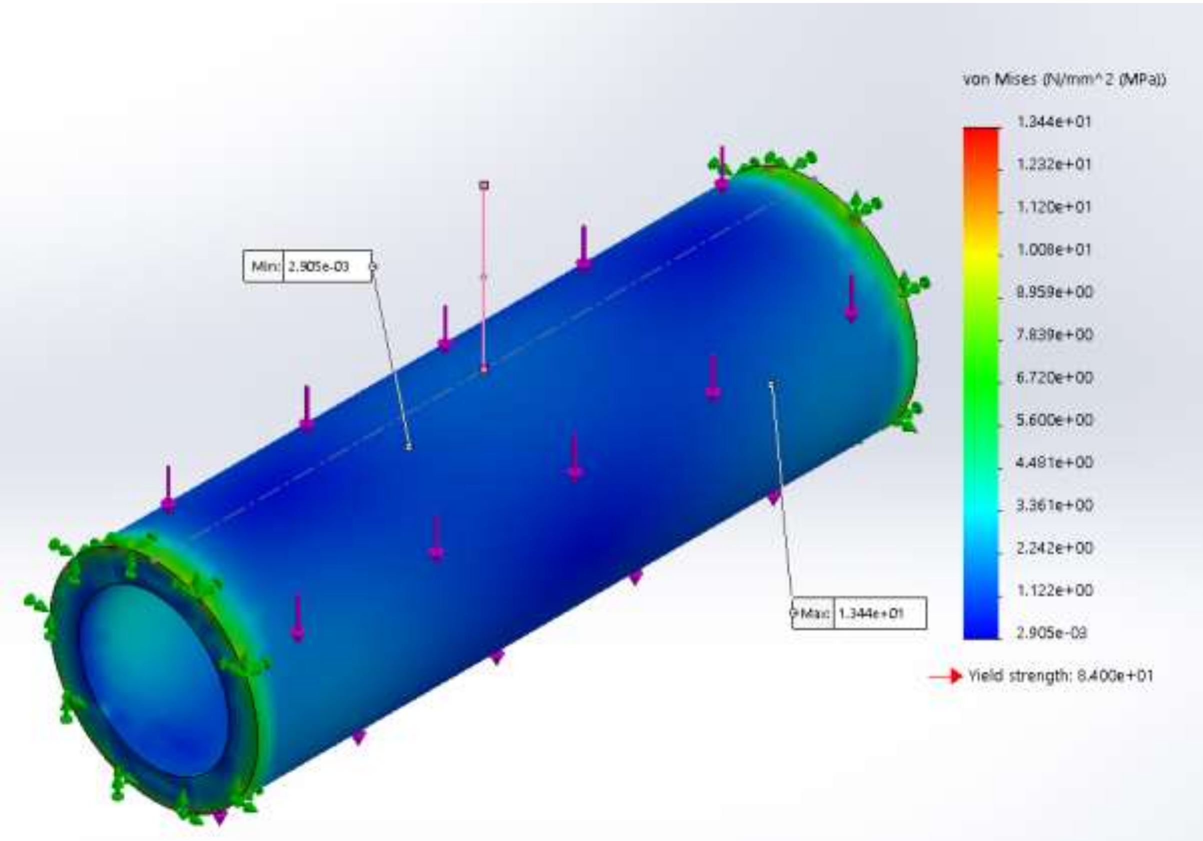

Figure 4.1: Joint Tube Stress

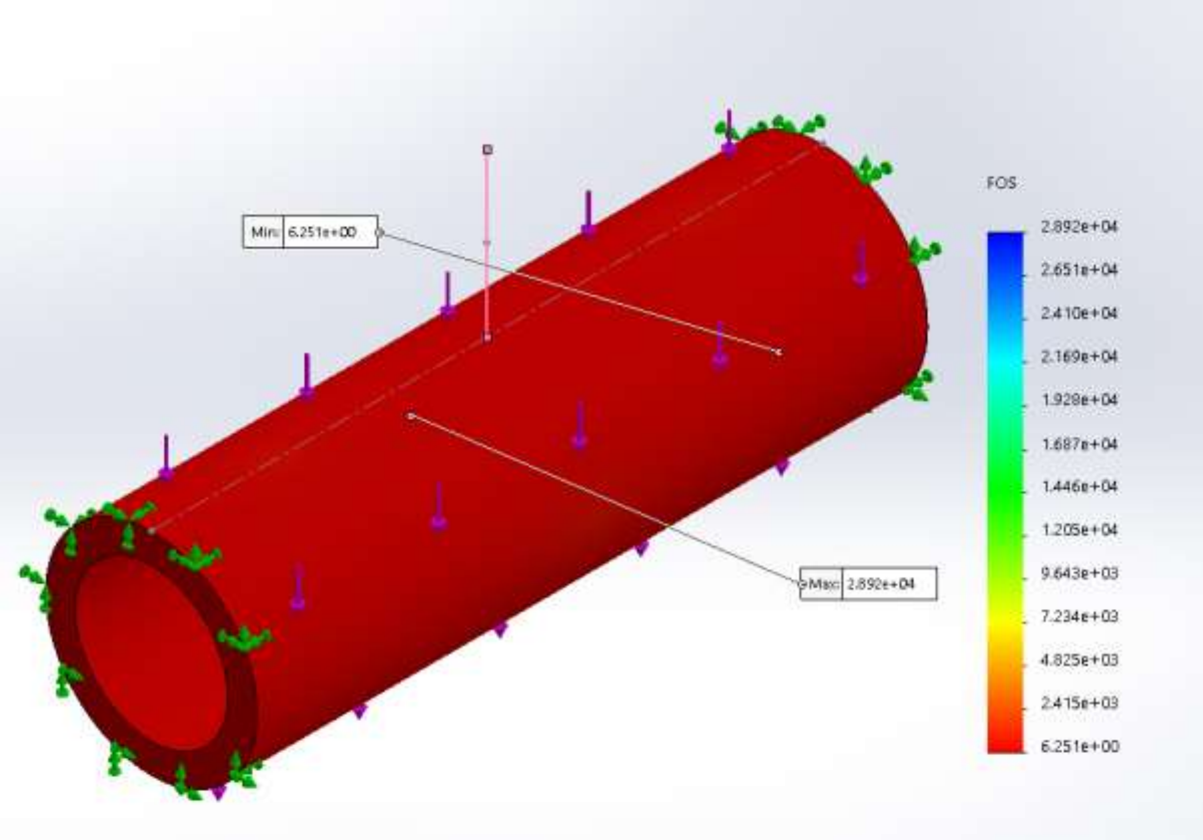

Figure 4.2: Joint Tube (FOS)

4.2 Results, Analysis, and Discussion

Table 4.1: SOLIDWORKS Results Summary

Name	Type	Min Value	Max Value	Unit
Stress	VON: von Mises Stress	2.905e-03	1.344e+01	MPa
Displacement	URES: Resultant Displacement	0	1.605e-03	N.A
Strain	ESTRN: Equivalent Strain	6.183e-07	8.361e-05	N.A.
Factor of Safety	Max von Mises Stress	6.251e+00	2.892e+04	N.A

In the table above, a static study was conducted using SOLIDWORKS with the specified material and specific boundary conditions, which are:

- Max bodyweight: 125 kg
- Operating temperature: 298 K

The values achieved from using SOLIDWORKS were different than the theoretical static study by (3 MPa). This could be due to rounding issues. However, even with the higher stress value calculated in SOLIDWORKS, the knee joint can still withstand six times the force applied with the conditions stated above. This is due to the high factor of safety which is an essential part of any design. Furthermore, the displacement and strain on the piece are considered low for such application.

Chapter 5: Project Management

5.1 Project Plan

The planning of this project was conducted by cooperation between all the members of the team. Each member was assigned an objective to finish within a certain amount of time. Moreover, some tasks were done with the cooperation of two or more members. The tasks with their durations are listed in table (5.1).

Table 5.1: Tasks and Their Durations

Objectives		Start	End	Duration (days)
1	Chapter 1: Introduction	6/2/2021	20/2/2021	14
2	Chapter 2: Literature Review	6/2/2021	20/2/2021	14
3	Chapter 3: System Design	20/2/2021	25/3/2021	34
4	Chapter 4: System Testing & Analysis	25/3/2021	31/3/2021	6
5	Chapter 5: Project Management	3/4/2021	11/4/2021	8
6	Chapter 6: Project Analysis	12/4/2021	18/4/2021	6
7	Chapter 7: Conclusion & Recommendation	22/4/2021	26/4/2021	4
8	Design of Prototype	3/3/2021	23/3/2021	20
9	Parts Purchase	25/3/2021	4/4/2021	10
10	Manufacturing	25/3/2021	29/4/2021	35
11	Testing	29/4/2021	4/5/2021	5

5.2 Contribution of Team Members

The tasks assigned to each member were based on the availability of each member and their preferences. Several studies necessitated the collaboration of all team members. Table (5.2) shows the tasks assigned to each member.

Table 5.2: Tasks and Assigned Members

Objectives		Assigned to
1	Chapter 1: Introduction	All
2	Chapter 2: Literature Review	Ali Alabdrabbuh
		Majed Alarfaj
		Feras Alotaibi
3	Chapter 3: System Design	All
4	Chapter 4: System Testing & Analysis	All
5	Chapter 5: Project Management	Musaed Alotaibi
		Abdulrahaman Alnaim
		Majed Alarfaj
6	Chapter 6: Project Analysis	Ali Alabdrabbuh
		Majed Alarfaj
		Abdulrahaman Alnaim
7	Chapter 7: Conclusion & Recommendation	Feras Alotaibi
		Musaed Alotaibi
		Abdulrahaman Alnaim
8	Design of Prototype	Ali Alabdrabbuh
		Musaed Alotaibi
9	Parts Purchase	All
10	Manufacturing	Ali Alabdrabbuh
		Majed Alarfaj
11	Testing	All

5.3 Project Execution Monitoring

To ensure our project runs smoothly with a high-quality outcome, we had to make a meeting schedule to ensure that each group member is aware of the updates and receives different opinions while planning. With the pandemic out there, the group members had to test for Covid-19 repeatedly. These meetings and activities were listed in the table (5.3)

Table 5.3: Dates of Activities and Events

Time/Date	**Activities/meetings**
WhatsApp group participation	All most daily
Weekly	Meeting with group members
Biweekly	Meeting with the advisor and co-advisor
2 Feb 2021	First Meeting
7 Feb 2021	Second meeting (planning and execution)
3 Apr 2021	Mid-term meeting and practice
16 Apr 2021	Finishing final prototype
19 Apr 2021	Test the system
8 May 2021	Final Submission of the report
20 May 2021	Final presentation

5.4 Challenges and Decision Making

There were many obstacles that we faced during this project. Thankfully, as a group, we thought of alternatives and solutions. These are most of the challenges:

1) Time struggle
2) Lack of Manufacturer
3) Design problems

5.4.1 Time Struggle

One of the most annoying things while doing this project was time management. The deadlines kept on changing, and there were things that we did not expect to happen. But as a group, we worked to adjust fast to any changes that might occur suddenly through our WhatsApp group. The team took full responsibility for their tasks, and if they had an emergency, they always give us a heads up so other group members will cover for them.

5.4.2 Lack of Manufacturer

A huge problem that we faced was the lack of a manufacturer. As a group, we split into smaller groups and head to search for a manufacturer. Unfortunately, we did not find a factory or a workshop that could reach our requirements. The manufacturers were either too expensive, take a long time to finish, or not available in the local market. Therefore, we had to change our design for the prototype to manufacture it here in KSA.

5.4.3 Design Problems

We faced a problem while drawing in SOLIDWORKS because of the complexity of our design having multiple components and running the simulation with the whole assembly. The group members kept finding solutions repeatedly by searching on YouTube or going to the CAD instructor to help us out. This solution did cost us time. Yet, we got great drawings.

5.5 Project Bill of Materials and Budget

Table 5.4: Bill of Materials

Part/service description	Cost (SAR)
Foot	508.20
Length Tube	150.00
Hydraulic System	800.00
Manufacturing	2,702.50
Total	4,160.70

Chapter 6: Project Analysis

6.1 Life-long Learning

This project has positive influences on the team member by gaining and extending skills and knowledge, which would benefit the team member in personal and career life. The considerable skills that have been acquired from this project can be summarized as software skills, hardware skills, time management, and project management. This part will present these skills in detail.

6.1.1 Software Skills

The software skills gained from this project are noticeable. For instance, Microsoft Word has been efficiently used to write the report. At the same time, SOLIDWORKS was used to design the prosthetic leg while following engineering standards in design. This software has shown an improvement in the patience, precision, writing, and designing of each member.

6.1.2 Teamwork

Throughout our project, members communicated with each other to make sure tasks were completed before deadlines. The leader signs tasks to a member or a group of members, and they communicate with each other to achieve them professionally. These communications between group members made us appreciate teamwork skills. Without such skills in each member, completing tasks professionally and ethically would not be achieved. We believe this skill would benefit us throughout our career life and personal life too.

6.1.3 Time Management Skills

Through the project creating process, the members have gained one of the essential skills: time management. During the project's stages (from project initiation phase to project closure phase), the members managed their time between studying, working on the project, and spending some personal time. In depths and within the project scope, dividing the project into small tasks was helpful in where each member knows their mission and based on it, they were able to perfectly manage their time to submit their duties within the agreed date. Moreover, submitting a report to the advisor was beneficial in where the advisor was allowed to follow up with our work and assist us at the right time.

6.1.4 Project Management

In this project, the leader had divided the project into small tasks and assigned each member their job. The division was as follows: some members were assigned to conduct the scientific research, whereas the others were assigned to find materials. Then members have been meeting eventually to ensure the project is ongoing and assist the faltering member. In the end, the leader conducted a meeting to assemble the tasks, manufacturing the leg, and writing the report as a team.

6.2 Impact of Engineering Solutions

This project influences the economy and society. In this part of the report, the impact of the economy and society will be discussed.

6.2.1 Economy

This project impacts the economy positively. Individuals who require a prosthetic in the region will not be able to get one designed locally. Products from overseas would be used. However, a prosthetic created locally would benefit these individuals in terms of cost. This prosthetic would be significantly cheaper than alternatives overseas.

6.2.2 Society

Creating a project on a prosthetic leg is an influence on society. This project would help individuals who require a prosthetic lower limb to regain some of the lost freedom due to losing the original lower limb. Furthermore, society would appreciate such work since it is serving humanity directly.

6.3 Contemporary Issues Addressed

There were multiple issues encountered during this project. One of them was that the knowledge on prosthetics, in general, is very minimal in Saudi Arabia. This was a difficulty in explaining various problems in design to other engineers in workshops and factories. In addition, the limited knowledge in factories and workshops in Saudi Arabia rose another issue that we encountered: the manufacturing of the prosthetic lower limb. The majority of manufacturers were surprised when the drawings were given and said it was complex.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

While brainstorming the project, we wanted to work on a project that might impact our community positively. Due to the scarcity in manufacturing prosthetics in Saudi Arabia, the idea of producing a lower limb prosthetic intrigued us. In this project, we applied what we learned from previous courses. The project involved numerous engineering disciplines such as statics, dynamics, material science, and engineering economy. Revisiting these subjects helped us to strengthen our problem-solving skills. Furthermore, we relied heavily on our communication skills in the time of this COVID pandemic. In addition, our teamwork skills were improved significantly due to the difficulty of working individually on such a project. This skill was utilized by organizing tasks between members and helping each other with much harder duties. Moreover, designing a prosthetic leg challenged us in many ways. One of these challenges is envisioning the design of the prosthetic leg. And how it can be adaptable to many people. Another challenge was prototyping. We had to choose a suitable manufacturing method to produce the prototype. The results of this project were excellent. Our design can withstand six times the stress in our theoretical calculations.

7.2 Future Recommendations

Any design can be improved. Further, our design is not an exception. One of the ways to improve our design is to use carbon fiber instead of aluminum 1050-H24. In this instance, carbon fiber provides excellent strength to weight ratio. Another way to improve our design is to use an advanced hydraulic system. Moreover, the software can be developed to mitigate the inconvenience of adjusting the height of the prosthetic limb or aiding in changing the process of the foot attachments. Furthermore, a customizable casing can be added to the prosthetic for aesthetic use.

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Appendix A: Progress Reports

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering Prince Mohammad bin Fahd University

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2020/2021**
PROJECT TITLE	**Designing and Manufacturing of Lower Limb Prosthetic**		
SUPERVISORS	**Dr. Megdi Eltayeb**		

Month 1: February

ID Number	Member Name
201702210	Ali Alabdrabbuh
201800470	Feras Alotaibi
201700073	Musaed Alotaibi
201601591	Abdulrahman Alnaim
201600963	Majed Alarfaj

List the tasks conducted this month and the team member assigned to conduct these tasks.

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	**Writing Milestone 3**	All	100%	
2	**SOLIDWORKS Drawings & Assembly**	Ali & Musaed	100%	
3	**Finding a Suitable Manufacturer**	Majed & Abdulrahman	70%	
4	**Calculations of The Prototype**	Ali, Feras, & Musaed	100%	

List the tasks planned for the month of February and the team member/s assigned to conduct these tasks.

#	Task description	Team member/s assigned
1	**Writing Milestone 3**	All
2	**SOLIDWORKS Drawings & Assembly**	Ali & Musaed
3	**Finding a Suitable Manufacturer**	Majed & Abdulrahman
4	**Calculations of The Prototype**	Ali, Feras, & Musaed
5	**Preparation of The Midterm Presentation**	All

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in the global, economic, environmental, and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their effects on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their effects on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their effects on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their effects on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop teamwork plans and allocate resources and tasks	Fails to develop teamwork plans and allocate resources and tasks	Shows limited and less than adequate ability to develop teamwork plans and allocate resources and tasks	Demonstrates satisfactory ability to develop teamwork plans and allocate resources and tasks	Properly and efficiently makes teamwork plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in teamwork projects to meet objectives	Fails to participate and function effectively in teamwork projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in teamwork projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in teamwork projects to meet objectives	Function effectively in teamwork projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	**Ali Alabdrabbuh**	3	3	3	3
2	**Feras Alotaibi**	3	3	3	3
3	**Musaed Alotaibi**	3	3	3	3
4	**Abdulrahman Alnaim**	3	3	3	3
5	**Majed Alarfaj**	3	3	3	3

Comments on individual members

Name	Comments
Ali Alabdrabbuh	Trying to fast-track all the task that is possible execute in parallel.
Feras Alotaibi	Trying to fast-track all the task that is possible execute in parallel.
Musaed Alotaibi	Trying to fast-track all the task that is possible execute in parallel.
Abdulrahman Alnaim	Trying to fast-track all the task that is possible execute in parallel.
Majed Alarfaj	Trying to fast-track all the task that is possible execute in parallel.

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2020/2021**
PROJECT TITLE	**Designing and Manufacturing of Lower Limb Prosthetic**		
SUPERVISORS	**Dr. Megdi Eltayeb**		

Month: March

ID Number	Member Name
201702210	Ali Alabdrabbuh
201800470	Feras Alotaibi
201700073	Musaed Alotaibi
201601591	Abdulrahman Alnaim
201600963	Majed Alarfaj

List the tasks conducted this month and the team member assigned to conduct these tasks.

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	**Presenting the Midterm**	All	100%	
2	**Manufacturing and Taking a video of the Prototype**	Ali, Majed, & Abdulrahman	100%	
3	**Taking a Video of the Prototype**	Ali	100%	
4	**Writing Milestones 4,5, and 6**	All	40%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks.

#	Task description	Team member/s assigned
1	**Presenting the Midterm**	All
2	**Manufacturing and Taking a video of the prototype**	Ali, Majed, & Abdulrahman
3	**Taking a Video of the Prototype**	Ali
4	**Writing Milestones 4,5, and 6**	All
5	**Making the Brochure and Banner**	NYA

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in the global, economic, environmental, and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop teamwork plans and allocate resources and tasks	Fails to develop teamwork plans and allocate resources and tasks	Shows limited and less than adequate ability to develop teamwork plans and allocate resources and tasks	Demonstrates satisfactory ability to develop teamwork plans and allocate resources and tasks	Properly and efficiently makes teamwork plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in teamwork projects to meet objectives	Fails to participate and function effectively in teamwork projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in teamwork projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in teamwork projects to meet objectives	Function effectively in teamwork projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	**Ali Alabdrabbuh**	3	3	3	3
2	**Feras Alotaibi**	3	3	3	3
3	**Musaed Alotaibi**	3	3	3	3
4	**Abdulrahman Alnaim**	3	3	3	3

Comments on individual members

Name	Comments
Ali Alabdrabbuh	Understand the impact of engineering solutions in a global/societal context, properly and efficiently make teamwork plans and allocate resources and tasks, function effectively in teamwork projects to meet objectives, and communicates properly and effectively with team members.
Feras Alotaibi	Understand the impact of engineering solutions in a global/societal context, properly and efficiently make teamwork plans and allocate resources and tasks, function effectively in teamwork projects to meet objectives, and communicates properly and effectively with team members.
Musaed Alotaibi	Understand the impact of engineering solutions in a global/societal context, properly and efficiently make teamwork plans and allocate resources and tasks, function effectively in teamwork projects to meet objectives, and communicates properly and effectively with team members.
Abdulrahman Alnaim	Understand the impact of engineering solutions in a global/societal context, properly and efficiently make teamwork plans and allocate resources and tasks, function effectively in teamwork projects to meet objectives, and communicates properly and effectively with team members.

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2020/2021
PROJECT TITLE	Designing and Manufacturing of Lower Limb Prosthetic		
SUPERVISORS	Dr. Megdi Eltayeb		

Month: April

ID Number	Member Name
201702210	Ali Alabdrabbuh
201800470	Feras Alotaibi
201700073	Musaed Alotaibi
201601591	Abdulrahman Alnaim
201600963	Majed Alarfaj

List the tasks conducted this month and the team member assigned to conduct these tasks.

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Finalizing the Report	All	90%	
2	Preparation for the Final Presentation	All	80%	
3	Completing the Brochure, Banner, and Cover for the Report	Ali & Feras	90%	
4	Utilizing Grammarly for the Report	Abdulrahman & Majed	90%	

List the tasks planned for the month of May and the team member/s assigned to conduct these tasks.

#	Task description	Team member/s assigned
1	Finalizing the Report	All
2	Preparation for the Final Presentation	All
3	Completing the Brochure and Banner	Ali & Feras
4	Utilizing Grammarly for the Report	Abdulrahman & Majed
5	Conducting the Final Presentation	All

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in the global, economic, environmental, and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop teamwork plans and allocate resources and tasks	Fails to develop teamwork plans and allocate resources and tasks	Shows limited and less than adequate ability to develop teamwork plans and allocate resources and tasks	Demonstrates satisfactory ability to develop teamwork plans and allocate resources and tasks	Properly and efficiently makes teamwork plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in teamwork projects to meet objectives	Fails to participate and function effectively in teamwork projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in teamwork projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in teamwork projects to meet objectives	Function effectively in teamwork projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

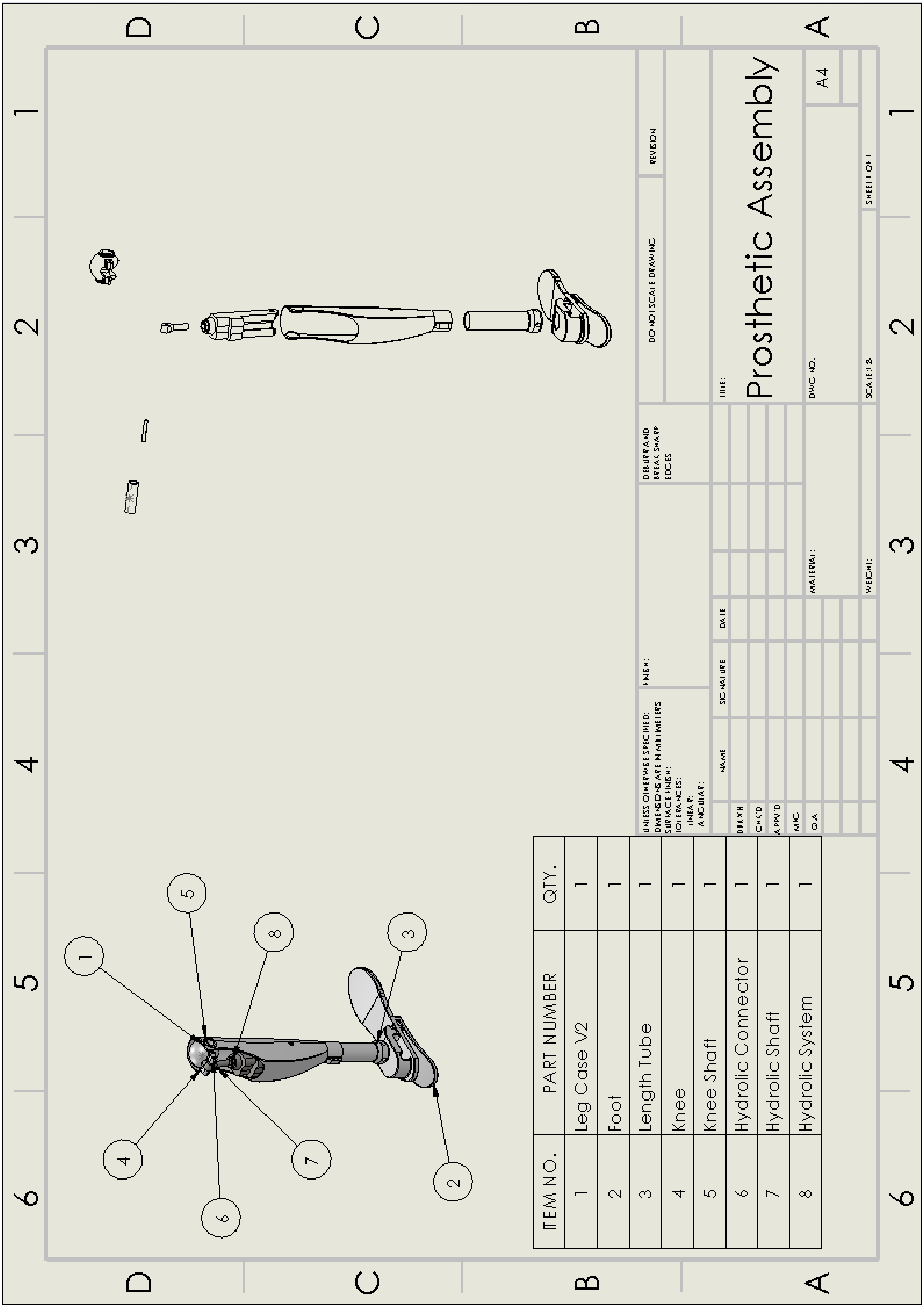
Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	**Ali Alabdrabbuh**	4	4	4	4
2	**Feras Alotaibi**	4	4	4	4
3	**Musaed Alotaibi**	4	4	4	4
4	**Abdulrahman Alnaim**	4	4	4	4

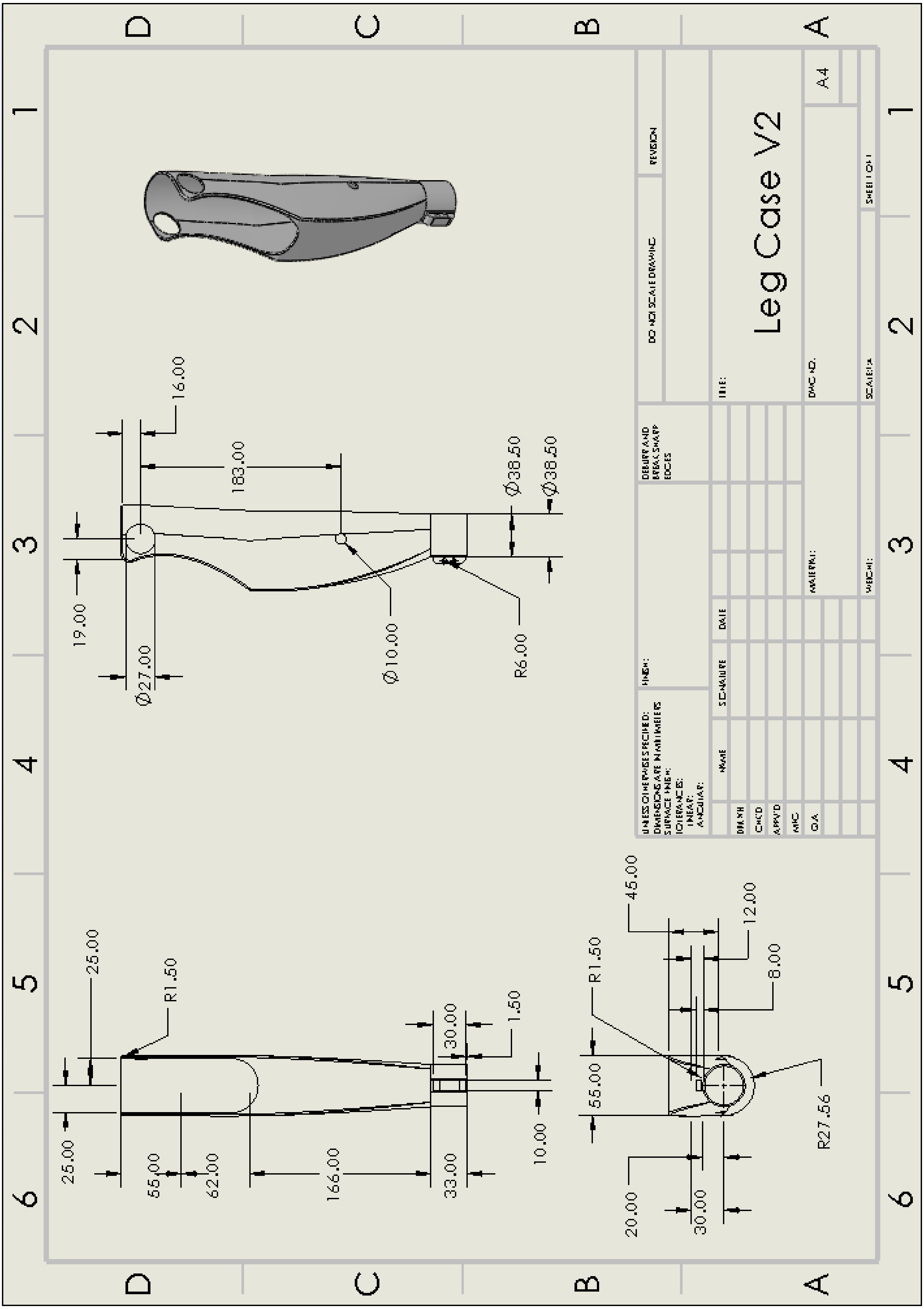
Appendix B: Engineering Standards (Local and International)

Component	Engineering Standards	Details
Screw	DIN 916	M8-1.25 x 20mm, Alloy Steel Metric Class 14.9-45H, Hex Socket
Barrel Nut	DIN	M6-1 x 45mm, T countersunk head female barrel nut, stainless steel, Rivet hex socket
Cap Bolts	DIN	M6-1 x 25mm, countersunk hex socket cap bolts, stainless steel
Material	BS EN 573	Aluminum Alloy 1050-H24

Appendix C: CAD Drawings and Bill of Materials



ITEM NO.	PART NUMBER	QTY.
1	Leg Case V2	1
2	Foot	1
3	Length Tube	1
4	Knee	1
5	Knee Shaft	1
6	Hydrolic Connector	1
7	Hydrolic Shaft	1
8	Hydrolic System	1


Leg Case V2
A4
REVISION
DO NOT SCALE DRAWING
DEBURR AND BREAK SHARP EDGES
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
DWG NO.
MATERIAL:
WEIGHT:
SCALE:1:1
SHEET 1 OF 1
16.00
183.00
19.00
Ø27.00
Ø10.00
R6.00
Ø38.50
Ø38.50
25.00
R1.50
25.00
55.00
62.00
166.00
33.00
30.00
1.50
10.00
45.00
12.00
8.00
R1.50
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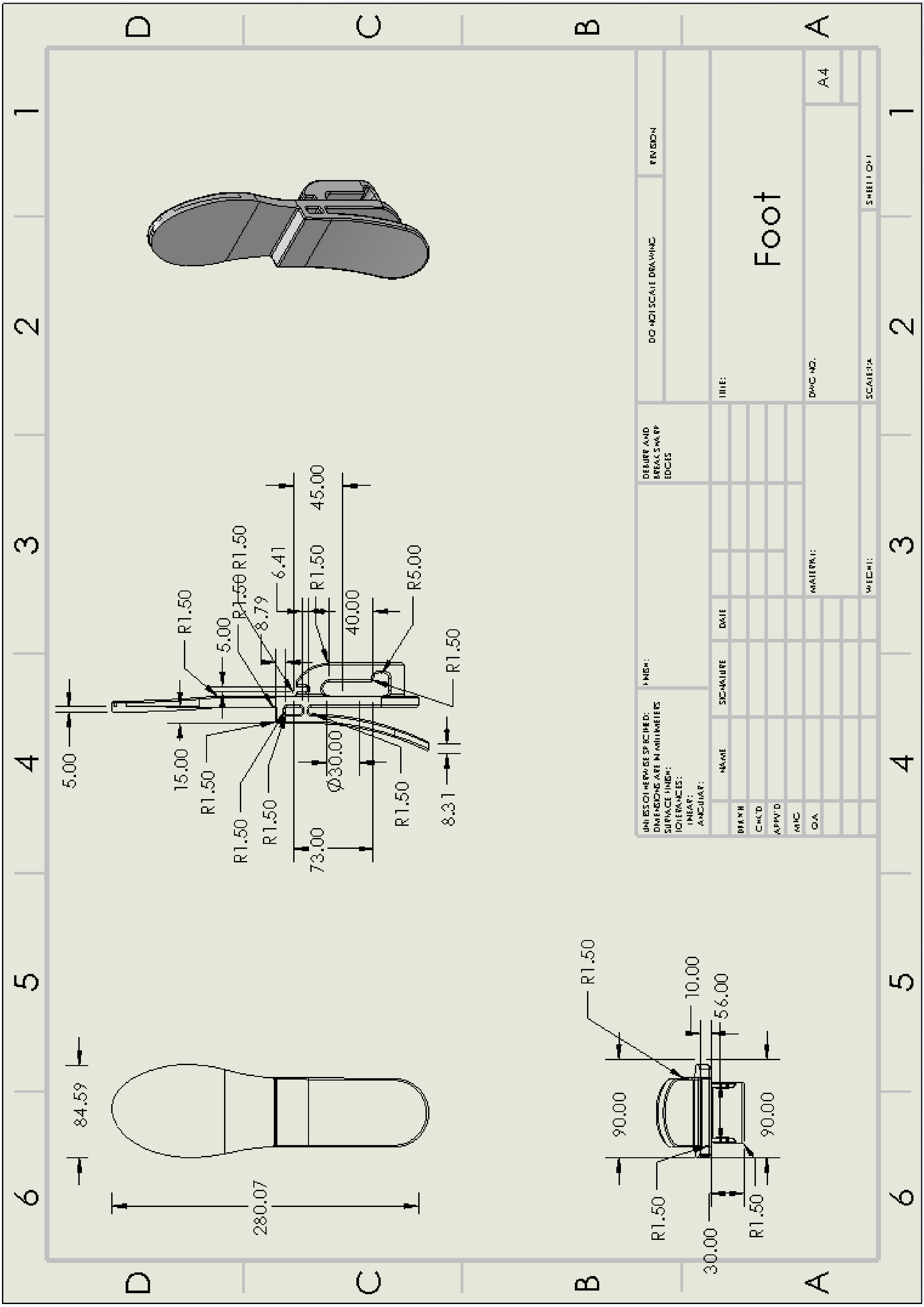
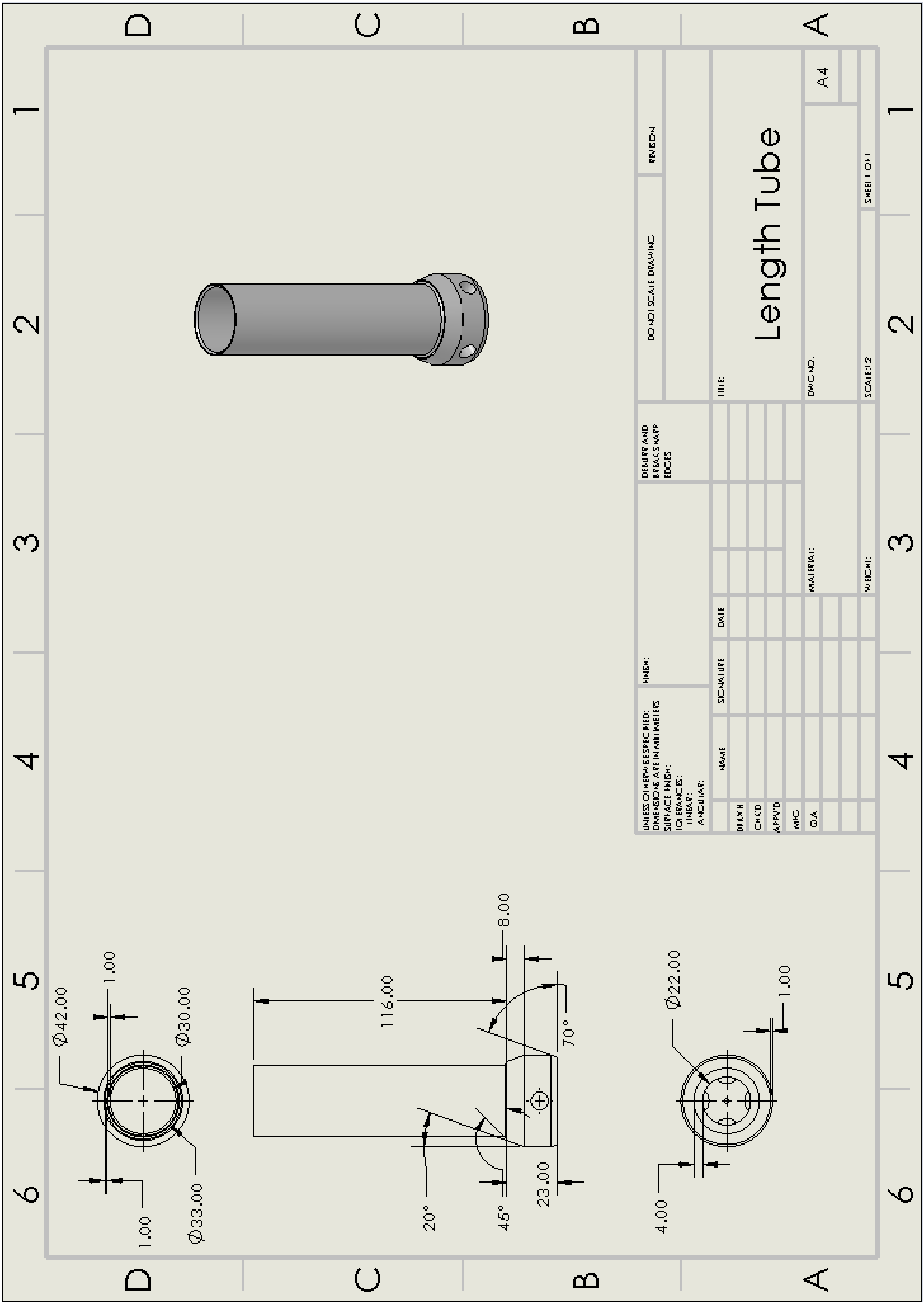
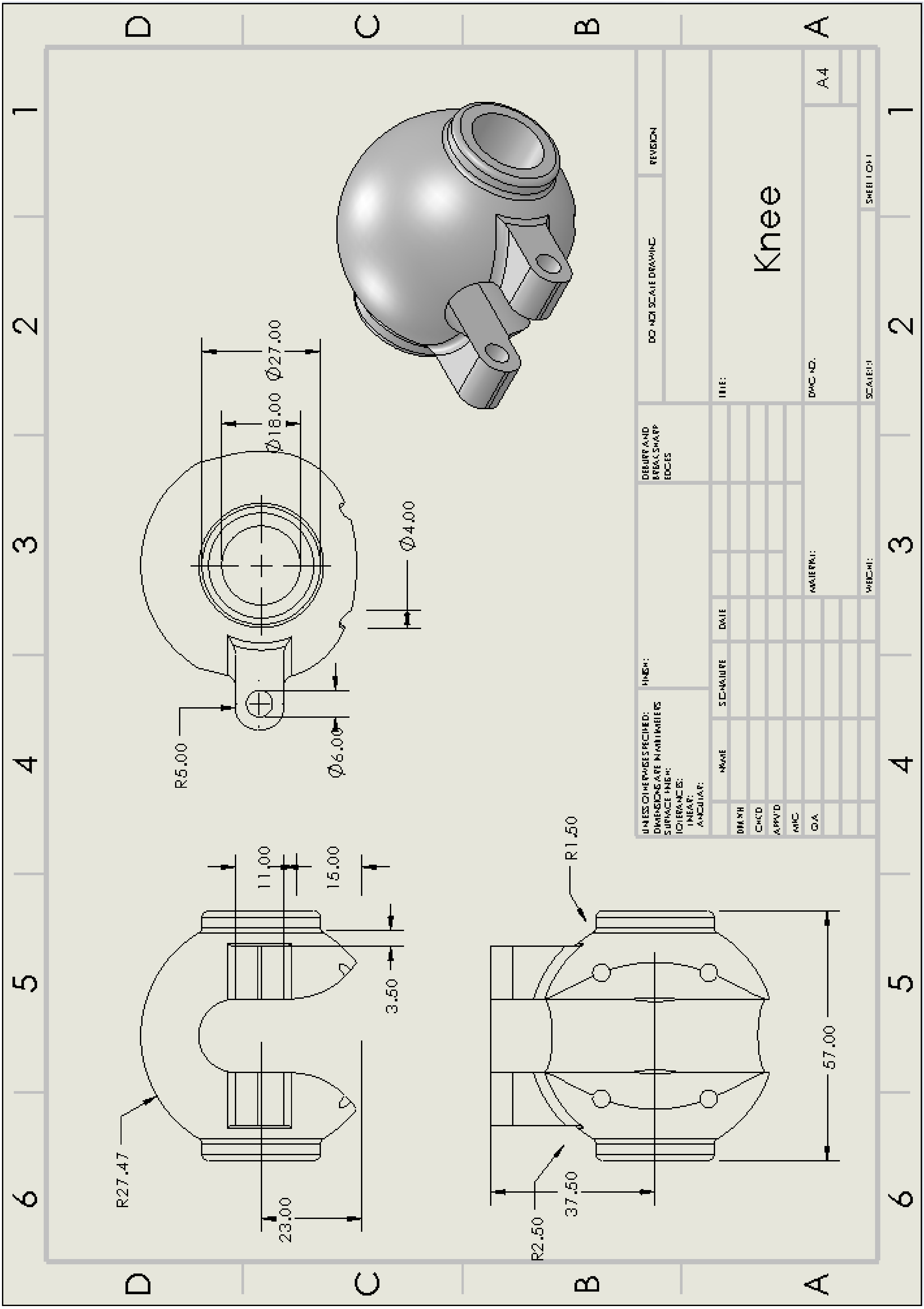
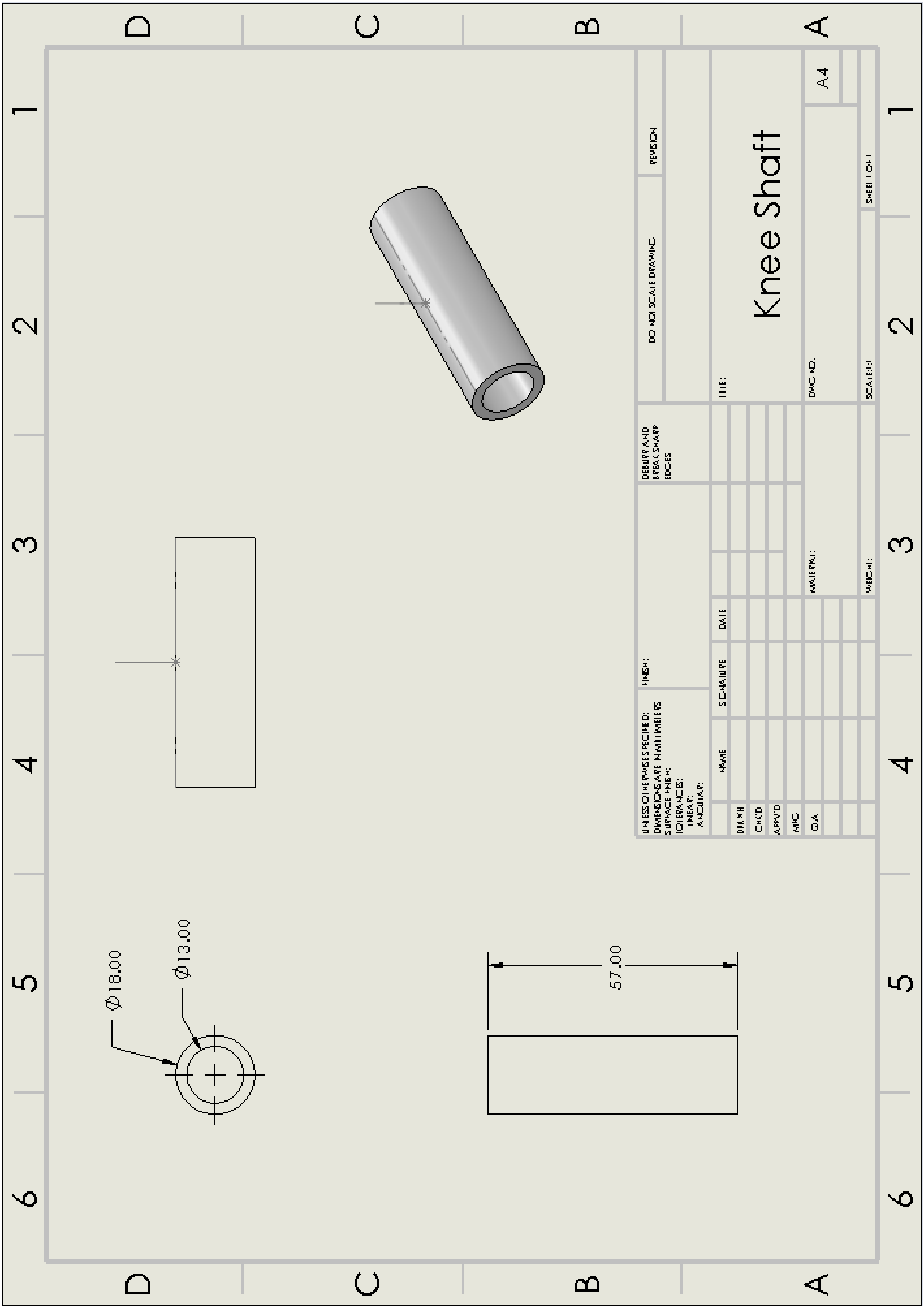
R27.56
20.00
30.00



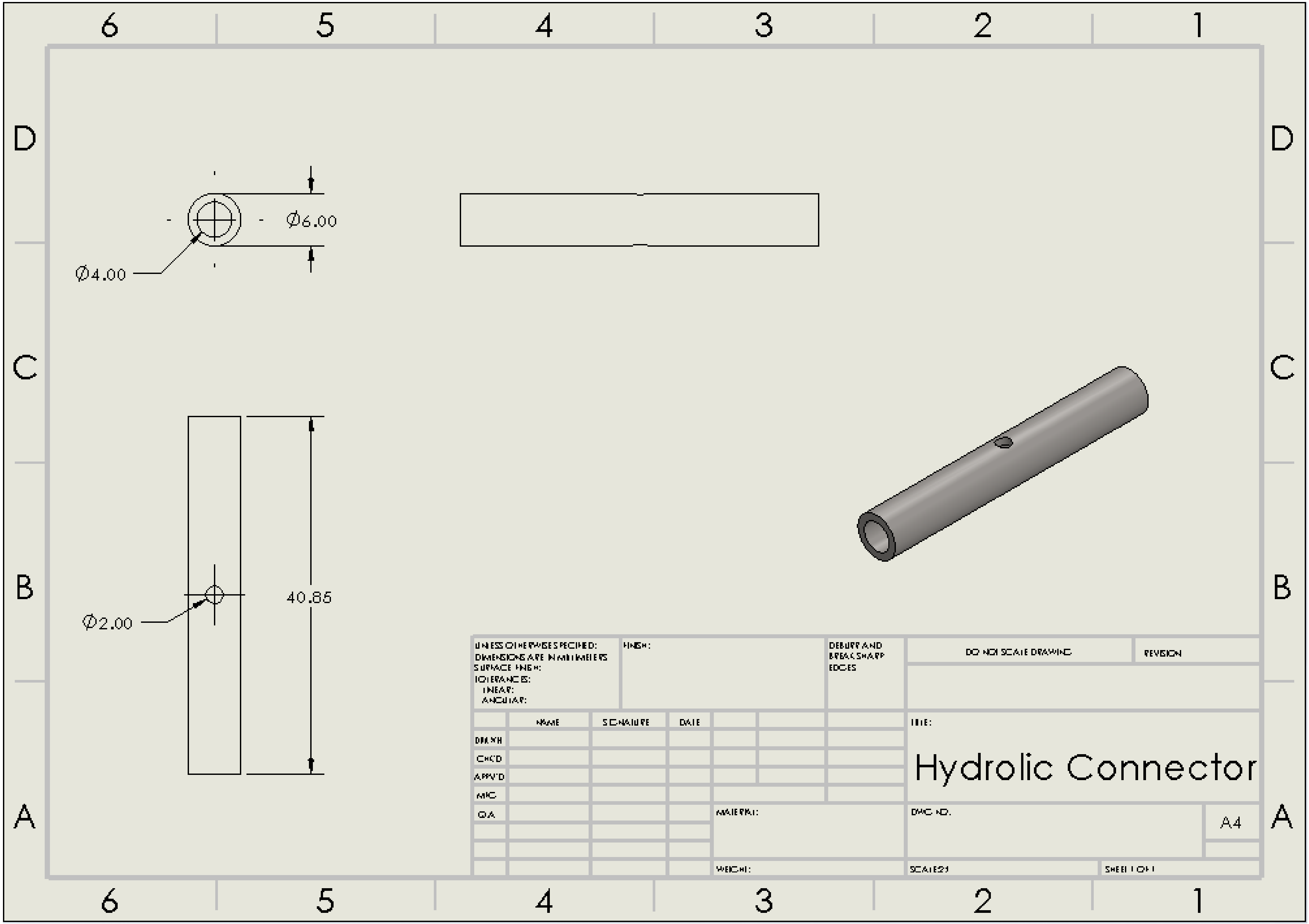
Foot
DO NOT SCALE DRAWING
REVISION
DEBURR AND BREAK SHARP EDGES
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
WEIGHT:
SCALE:1:5
SHEET 1 OF 1
A4
84.59
280.07
5.00
15.00
R1.50
R5.00
8.79
6.41
45.00
40.00
73.00
Ø30.00
8.31
10.00
56.00
90.00
30.00


Length Tube
Ø42.00
Ø30.00
Ø33.00
1.00
1.00
116.00
8.00
70°
20°
45°
23.00
Ø22.00
1.00
4.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
DWG NO.
SCALE:1:2
SHEET 1 OF 1
A4


Knee
Ø27.00
Ø18.00
Ø4.00
R5.00
Ø6.00
11.00
15.00
3.50
R27.47
23.00
R1.50
57.00
37.50
R2.50
DO NOT SCALE DRAWING
REVISION
TITLE:
DWG NO.
A4
SCALE:1:1
SHEET 1 OF 1
WEIGHT:
MATERIAL:
DEBURR AND BREAK SHARP EDGES
FINISH:
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A



Knee Shaft
Ø18.00
Ø13.00
57.00
A4
DO NOT SCALE DRAWING
REVISION
DEBURR AND BREAK SHARP EDGES


Ø6.00
Ø4.00
Ø2.00
40.85
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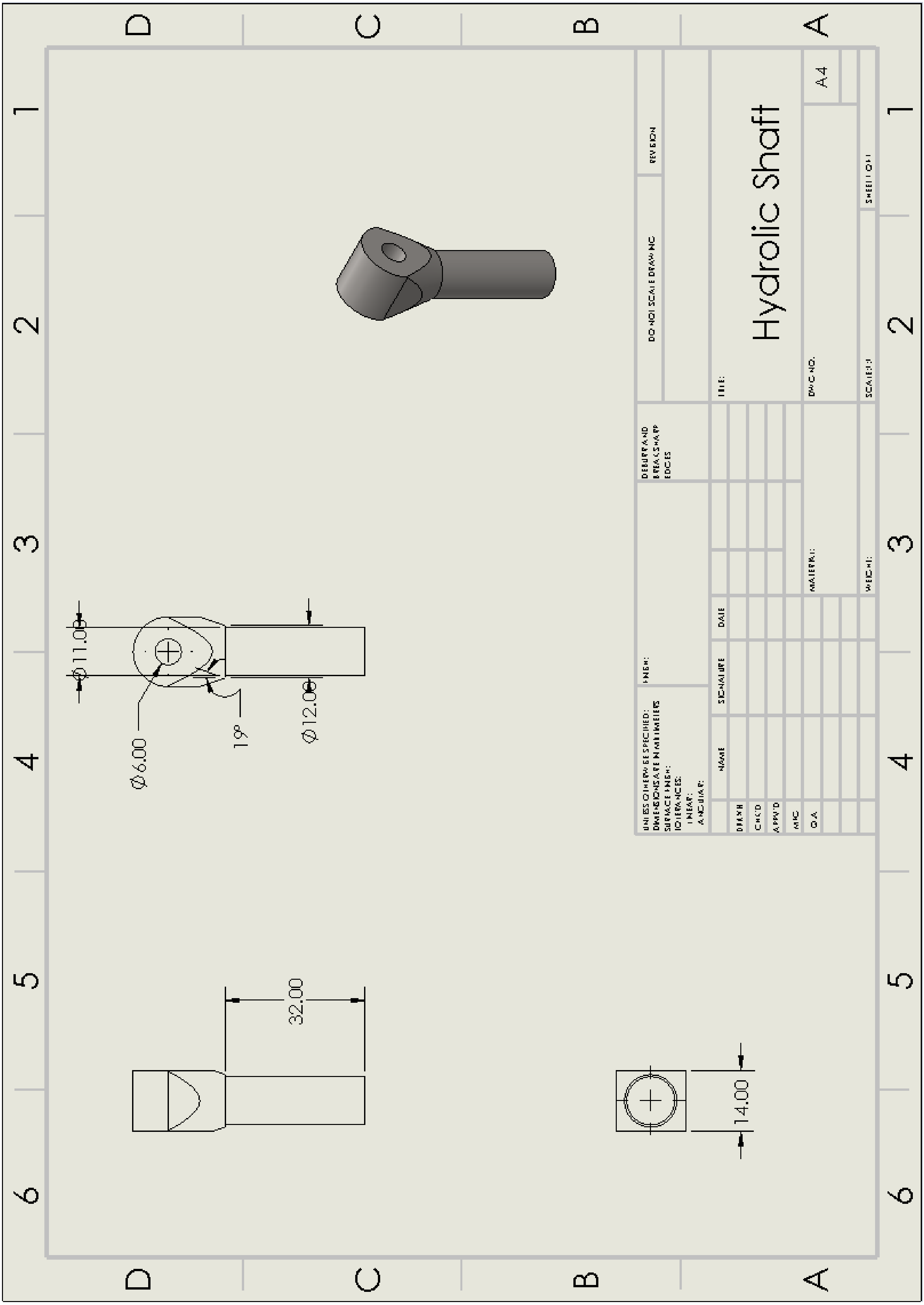
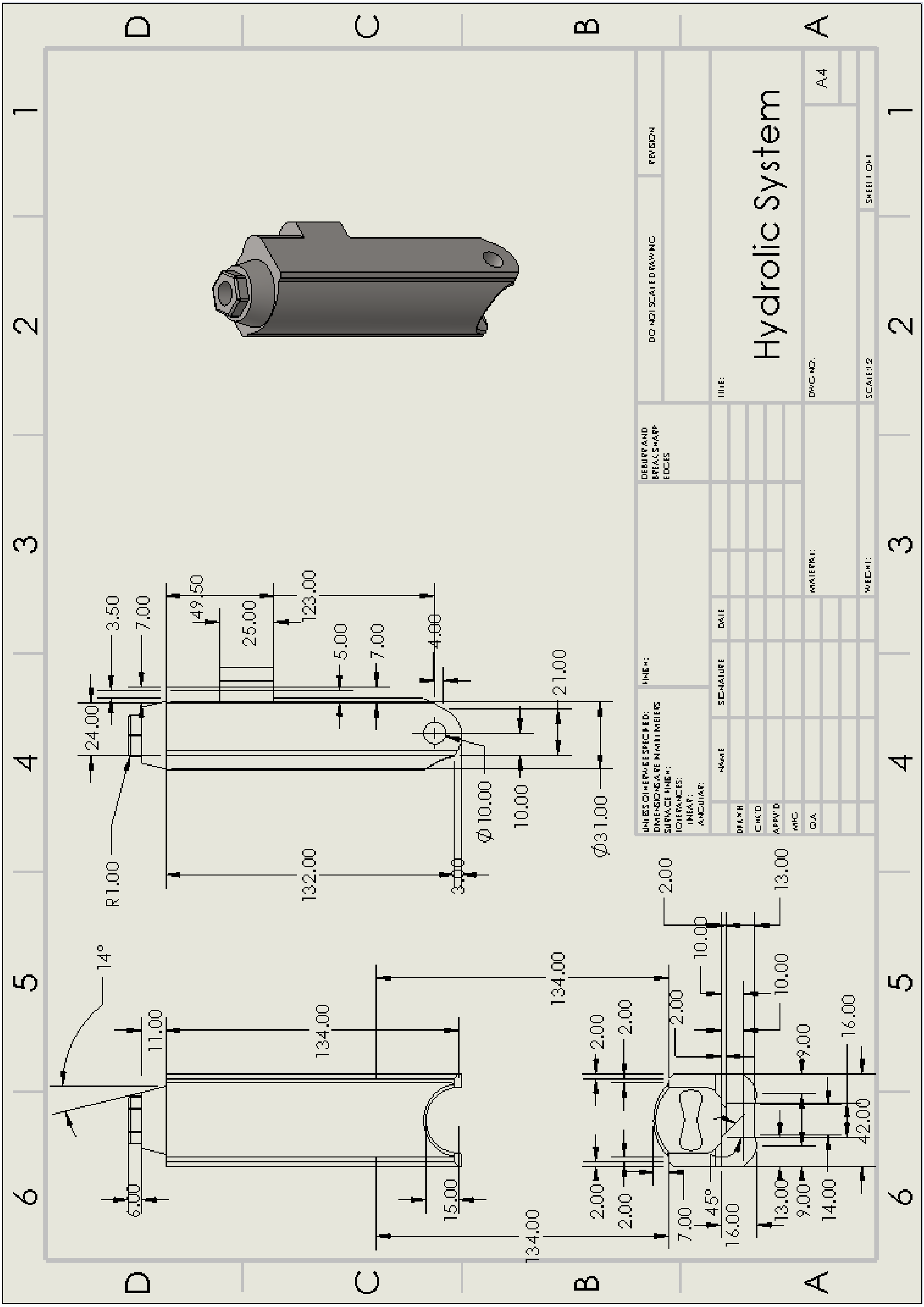
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Hydrolic Connector
DWG NO.
A4
SCALE:2:1
SHEET 1 OF 1


Ø11.00
Ø6.00
19°
Ø12.00
32.00
14.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Hydrolic Shaft
DWG NO.
A4
SCALE:1:1
SHEET 1 OF 1

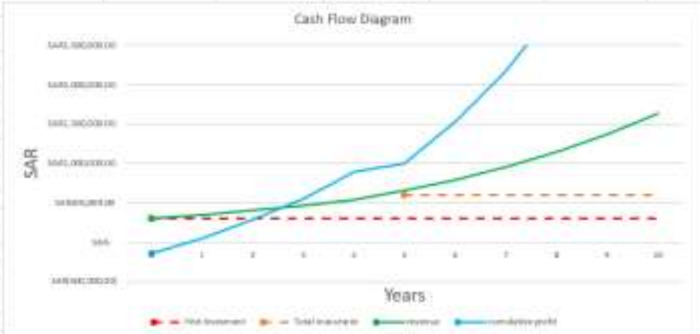

Hydrolic System
TITLE:
DWG NO.
A4
SCALE:1:2
SHEET 1 OF 1
WEIGHT:
MATERIAL:
DO NOT SCALE DRAWING
REVISION
DEBURR AND BREAK SHARP EDGES
FINISH:
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
R1.00
14°
Ø10.00
Ø31.00
134.00
132.00
123.00
25.00
24.00
21.00
16.00
15.00
14.00
13.00
11.00
10.00
9.00
7.00
6.00
5.00
4.00
3.50
3.00
2.00
42.00
49.50
45°

Appendix D: Economic Analysis Data Sheet

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs											
Equipment	300603.72	0	0	0	0	300603.72	0	0	0	0	0
Construction	0	0	0	0	0	0	0	0	0	0	0
Total	300603.72	0	0	0	0	300603.72	0	0	0	0	0
Operating Cost											
Energy	0	0	0	0	0	0	0	0	0	0	0
Electricity	14294.016	14294.016	14294.016	14294.016	14294.016	21491.712	21491.712	21491.712	21491.712	21491.712	21491.712
Number of Employee	6	6	6	6	6	8	8	8	8	8	8
Labour	18000	18000	18000	18000	18000	40000	24000	24000	24000	24000	24000
Insurance	16000	16000	16000	16000	16000	18000	18000	18000	18000	18000	18000
Workshop rent	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Material cost	63000	72000	82800	95400	109800	135000	162000	194400	234000	280800	336600
Total	151294.016	160294.016	171094.016	183694.016	198094.016	254491.712	265491.712	297891.712	337491.712	384291.712	440091.712
Total cost	451897.736	160294.016	171094.016	183694.016	198094.016	555095.432	265491.712	297891.712	337491.712	384291.712	440091.712
Revenues											
number of Product sold	35	40	46	53	61	75	90	108	130	156	187
sum of product revenues	315000	360000	414000	477000	549000	675000	810000	972000	1170000	1404000	1683000
taxes	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Total revenues after tax	307125	351000	403650	465075	535275	658125	789750	947700	1140750	1368900	1640925
yearly profit	-144772.736	190705.984	232555.984	281380.984	337180.984	103029.568	524258.288	649808.288	803258.288	984608.288	1200833.288
Cumulative Profits	-144772.736	45933.248	278489.232	559870.216	897051.2	1000080.768	1524339.056	2174147.344	2977405.632	3962013.92	5162847.208

	first perio	second period
electricity c	28.2	42.4
working hou	2816	2816
kW-h	79411.2	119398.4
avg salary	3000	5000
number of product sold		

year	First investment	Total investment	revenue	cumulative profit	total investment
0	SAR 300,603.72		SAR 307,125.00	SAR (144,772.74)	
1	SAR 300,603.72		SAR 351,000.00	SAR 45,933.25	
2	SAR 300,603.72		SAR 403,650.00	SAR 278,489.23	
3	SAR 300,603.72		SAR 465,075.00	SAR 559,870.22	
4	SAR 300,603.72		SAR 535,275.00	SAR 897,051.20	
5	SAR 300,603.72	SAR 601,207.44	SAR 658,125.00	SAR 1,000,080.77	
6	SAR 300,603.72	SAR 601,207.44	SAR 789,750.00	SAR 1,524,339.06	
7	SAR 300,603.72	SAR 601,207.44	SAR 947,700.00	SAR 2,174,147.34	
8	SAR 300,603.72	SAR 601,207.44	SAR 1,140,750.00	SAR 2,977,405.63	
9	SAR 300,603.72	SAR 601,207.44	SAR 1,368,900.00	SAR 3,962,013.92	
10	SAR 300,603.72	SAR 601,207.44	SAR 1,640,925.00	SAR 5,162,847.21	



Appendix E: Operation Manual

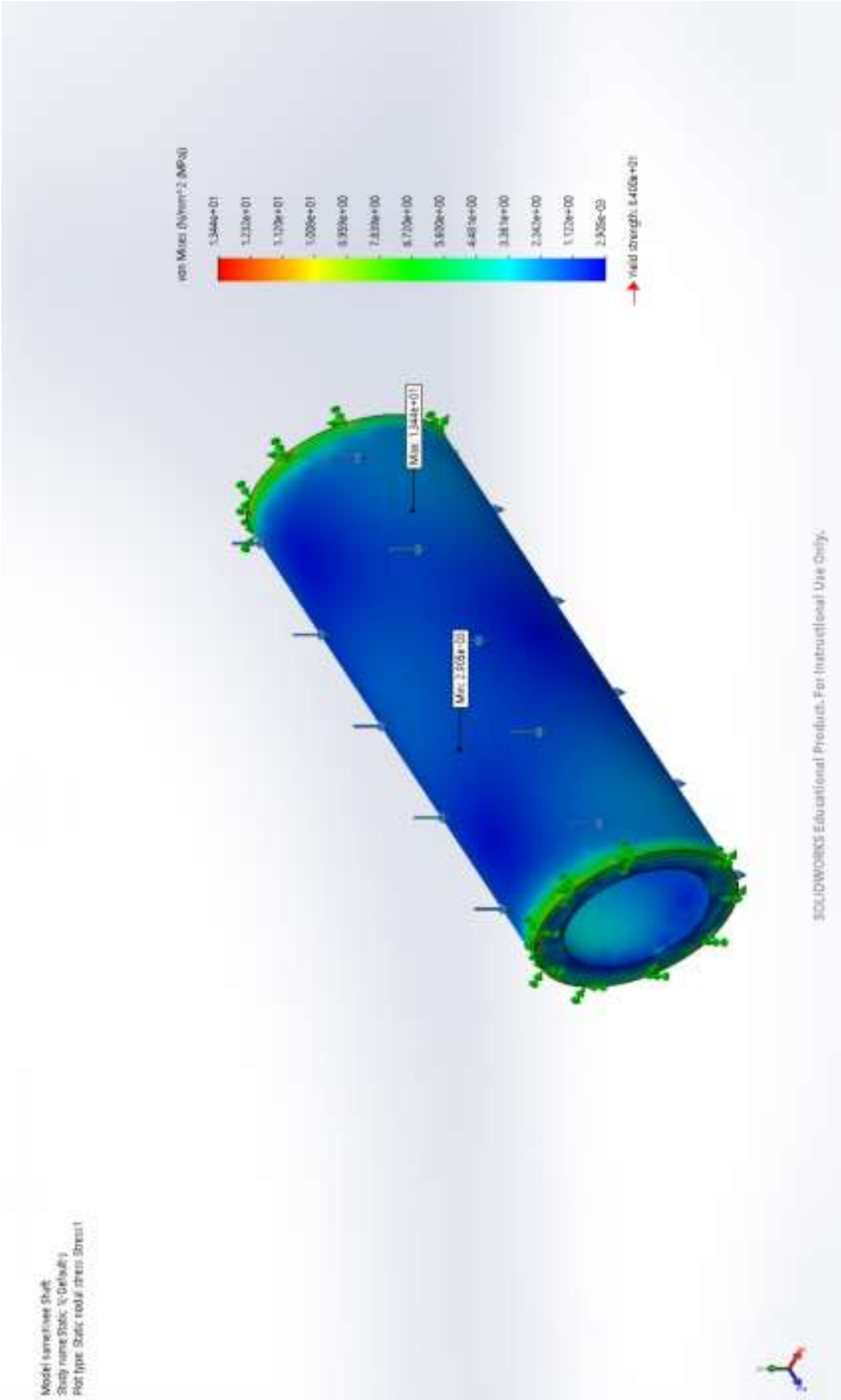
To run the prototype, please follow these steps:

- Insert the tube to the bottom of the case and adjust the height to the desired height.
- Fit the foot to the tube and tighten the four screws of the tube to the foot's pyramid thread
- Insert the tailored custom socket to the pyramid thread on the knee

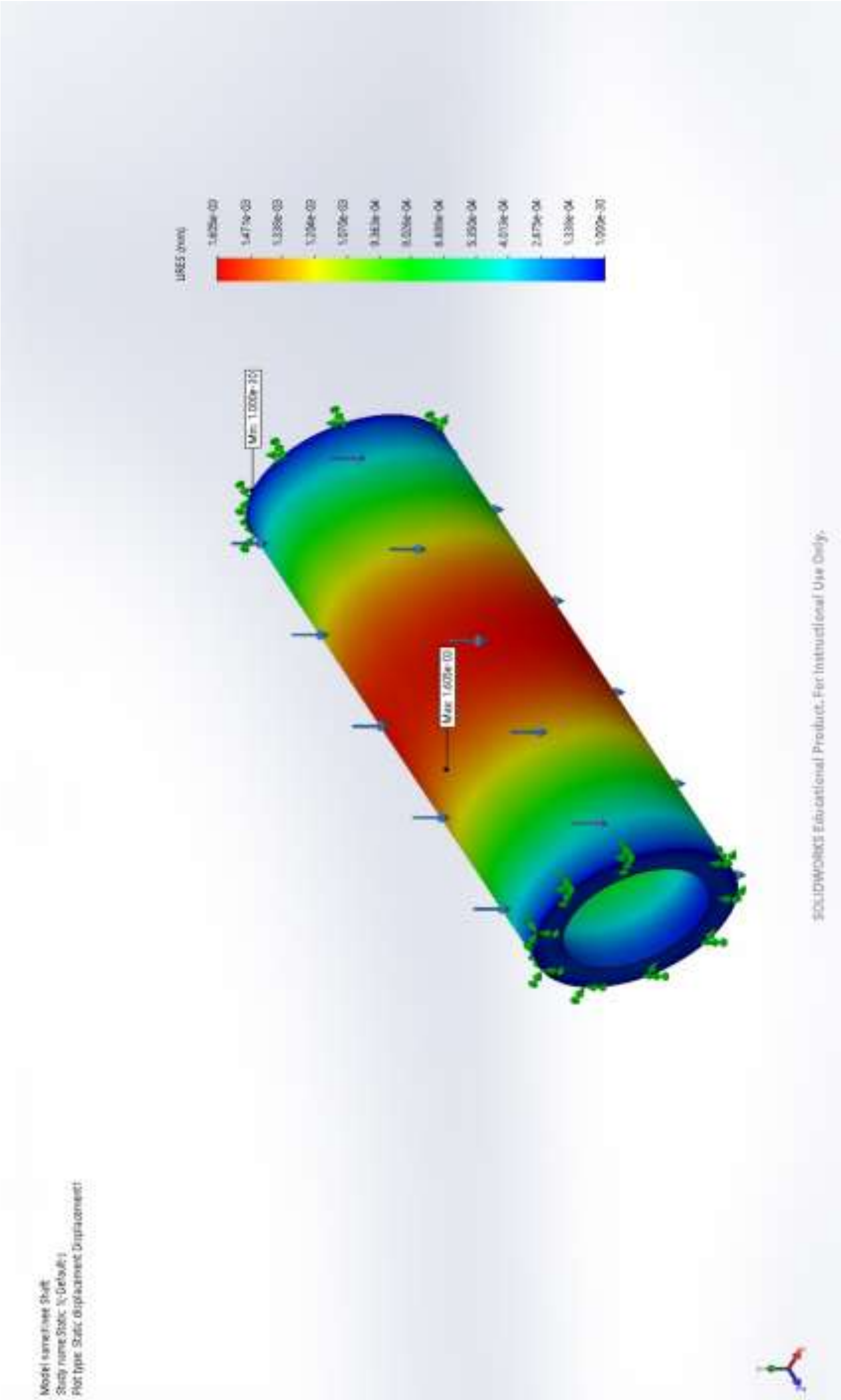
Appendix F: Gantt Chart

Milestone 1	**Start Date**	**Days to complete**
Group Formation	17/01/2021	2
Project Selection	19/01/2021	2
Developing a Gantt chart	19/01/2021	7
Milestone 2		
Collecting resources about the project	26/01/2021	5
Taking notes from resources	31/01/2021	2
Paraphrasing and developing drafts	03/02/2021	2
Developing the first draft of the project intro	05/02/2021	10
Reviewing the first draft	15/02/2021	3
Modifying and finalizing the project intro.	18/02/2021	3
Milestone 3		
Acquiring standards dimensions	21/02/2021	2
Drawing rough skitch	23/02/2021	1
Developing 3D parts and assembling them	24/02/2021	5
Extract the drawings from the 3D program	28/02/2021	1
Simulating and extracting calculation	1/03/2021	2
Milestone 4		
Powerpoint preparation	02/03/2021	3
Powerpoint first draft	05/03/2021	8
Reviewing and Editing	13/03/2021	2
Preparing and dividing slides on group member	15/03/2021	4
Milestone 5		
Checking workshop and comparing them	20/03/2021	3
Talking about the chosen shop and give the drawings	23/03/2021	1
Adjusting the prototype after it was finished	30/03/2021	1
Milestone 6		
Determine the ways of testing	10/04/2021	2
Testing them on machines	12/04/2021	3
Testing them on real-life consumers	14/04/2021	1
Gathering the feedback and results	15/04/2021	2
Project management and analysis	16/04/2021	5
Milestone 7		
Adding all files on a USB	24/04/2021	1
Creating brochures and posters	26/04/2021	5
Preparing final presentation	1/05/2021	5
Creating leather bound copies	6/05/2021	2
Presenting final project	10/05/2021	2
Final Presentation	20/05/2021	1

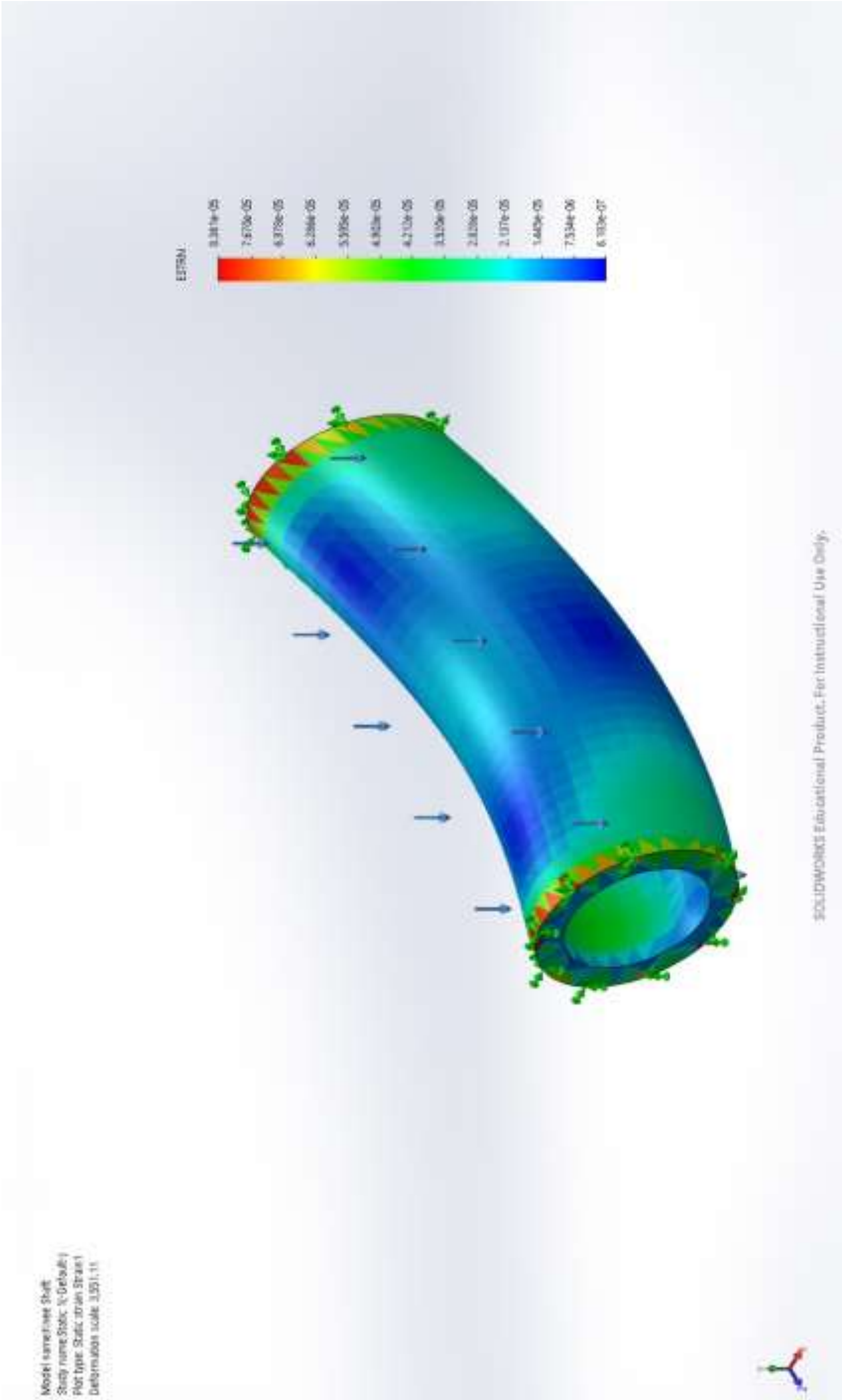
Appendix G: SOLIDWORKS (Stress Analysis)



Appendix H: SOLIDWORKS (Displacement Analysis)



Appendix I: SOLIDWORKS (Strain Analysis)



Appendix J: SOLIDWORKS (FOS Analysis)