ENGINEER 1C03 - Engineering Design & Graphics Cornerstone Design Project
Instructor: Dr. Doyle
Milestone 3
Team #31-L11

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As a future member of the engineering profession, the student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by Ahmed Nazir, 400188027.

Ahmed

Signature

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Signature

Table of Contents

1.0 Introduction

This team was tasked to create a proof of concept mechanism of a pinching apparatus after being hired by BME Devices. The apparatus is a simple prosthetic of a human right hand, and involves the use of gears to translate the rotation of a motor into the rotation of the thumb and index finger in opposite directions, in order to emulate a pinching movement.

The design must satisfy three functional and spatial requirements. Firstly, the mechanism must incorporate a given rotational input speed of a motor and reduce it to a specific rotational output speed of the finger and thumb. Specifically, the input motor will rotate at 110.05 RPM and thumb and index finger must rotate at 7.5 RPM. Secondly, the thumb and index finger must contact each other in a given volume space. To achieve this, however, either appendage must rotate in opposite direction. Lastly, the entire gearing mechanism must reside in a custom mounting bracket which in turn, must meet spatial constraints of the given right hand prosthesis frame.

1.1 Problem Statement

The team is challenged to design, validate, and construct a gearing mechanism that translates rotational motion of an input motor with a specific speed into rotational motion of a thumb and index finger which must contact in a given volume at a given speed. The mechanism must be designed to meet any spatial constraints.

1.2 Research

Existing prosthetic hand mechanisms attempt to emulate the components and physical workings of a biological hand through various methods. One common method is the use of wires or strings to imitate flexion and extension motions of the hand. Wires are placed on either side of the prosthesis and when force is applied to the wires under the palm, flexion is achieved. On the other hand, when force is applied to the wires on top of the hand, extension is achieved [1].

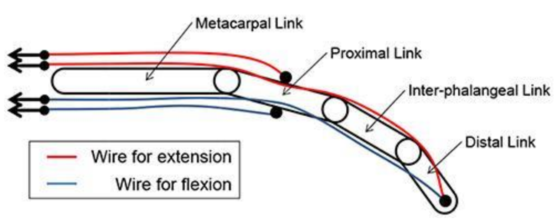
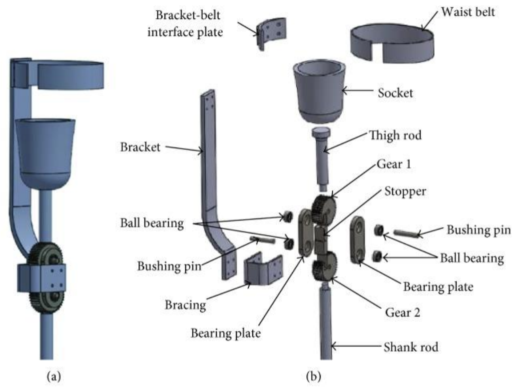


Figure 1. Wire mechanism for functional hand prosthetic.

Another existing mechanism used in prosthetics are gear trains and gear systems. This type of mechanism will be applied in the following design project. Gears are used to allow for the transfer of motion from one area to another in a relatively efficient manner. For above-knee amputees some artificial limbs use gears in place of a knee joint in lower-limb prosthetics, to allow for the flexion and extension of the legs [2]. Furthermore, gears create rotational motion which is very similar to a 2-dimensional motion of the thumb and index finger on a human hand to performing a pinching motion. In order for this motion to be achieved however, the two fingers must rotate in opposite directions. Specifically, the thumb must rotate in a clockwise direction and the index finger must rotate in a counter clockwise direction.



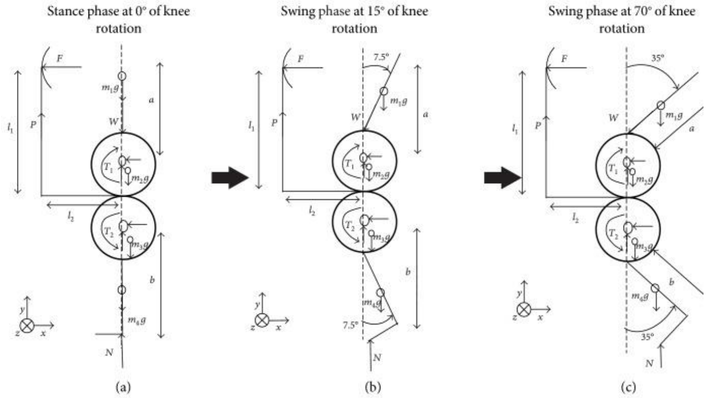


Figure 2. Isometric and exploded view of lower-limb prosthesis using a gearing mechanism
Figure 3. Free body diagram of knee joint prosthesis in various stages.

Many products used in everyday lives operate through gear trains. For example, quartz watches use gears to to allow for the rotation of the seconds, minutes, and hours hands. The gears are battery powered and are weighted with a quartz crystal to regulate the speed of rotation of the hands. More complicated mechanisms, such as pendulum clocks, also use gears however their speed is regulated by a swinging pendulum [3]. To fit many gears and get an accurate gear ratio watches use lots of axial connections and stack gears on top of each other, the proposed design uses a similar concept but using multiple axial connections horizontally, instead of vertically.

2.0 Preliminary Design

The goal of the project is to have a motor on one side of the bracket providing an input speed of 110.05 RPM and to use a calculated gear train to reduce the output speed of the thumb and index finger to 7.5 RPM. The total ratio of the gear train should be $14.67\underline{3}$ as shown in the calculations section.

The way that the team plans to create the mechanism is by meshing various size spur gears. The decision of creating a gear train consisting solely of spur gears was made due to the fact that they would be easier to print than worms and also that worm gears and their corresponding worm lie perpendicularly, thus, occupying more space in the relatively small bracket.

3.0 Calculations

3.1 Required Gear Ratio Calculation:

$$\omega_i = (3.55\,rpm)(31) = 110.05\,rpm$$

$$\omega_o = 0.125\ \frac{r}{s} \cdot \frac{60s}{min} = 7.5\ rpm$$

$$GR_t = \frac{\omega_i}{\omega_o}$$

$$= \frac{(31)(3.55\ rpm)}{7.5\ rpm}$$

$$= \frac{2201}{150} = 14.67\underline{3}$$

Table 1: Gear Specifications

Gear Name	Type of gear	Connection to Preceding Gear (Type)	Connection to Preceding Gear (Name)	Pitch Diameter (mm), D	Module (mm/tooth), m	Number of Teeth, z
G1	Spur	N/A	N/A	15	1	15
G2	Spur	Mesh	G1	29	1	29
G3	Spur	Axial	G2	15	1	15
G4	Spur	Mesh	G3	23	1	23
G5	Spur	Axial	G4	15	1	15
G6	Spur	Mesh	G5	22	1	22
G7	Spur	Axial	G6	12	1	12
G8	Spur	Mesh	G7	18	1	18
G9	Spur	Axial	G8	12	1	12
G10	Spur	Mesh	G9	18	1	18
G11	Spur	Axial	G10	15	1.25	12
G12	Spur	Mesh	G11	15	1.25	12
G13	Spur	Mesh	G12	15	1.25	12
G14	Spur	Mesh	G13	22.5	1.25	18
G15	Spur	Mesh	G12	15	1.25	12
G16	Spur	Mesh	G15	15	1.25	12
G17	Spur	Mesh	G16	22.5	1.25	18

3.2 Proposed Gear Mechanism Ratio and Output Speed

$$GR_t = \frac{29}{15} \cdot \frac{23}{15} \cdot \frac{22}{15} \cdot \frac{18}{12} \cdot \frac{18}{12} \cdot \frac{12}{12} \cdot \frac{12}{12} \cdot \frac{18}{12}$$

GR_t =14.674

$$\omega_o = \frac{\omega_i}{GR_T}$$

$$\omega_o = \frac{110.05\, rpm}{14.674} = 7.499\, rpm$$

3.3 Output Speed Tolerance

Required output speed: 7.5 RPM; Calculated output speed: 7.499 RPM

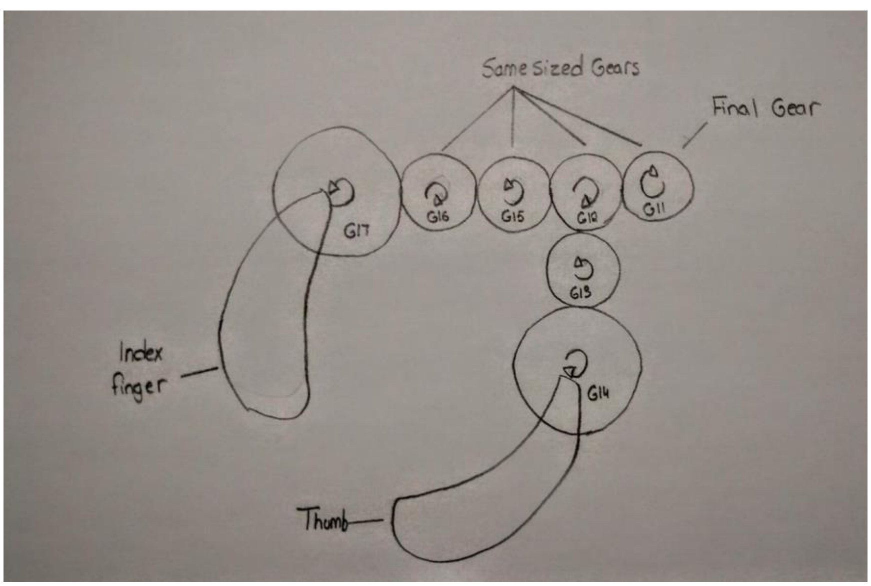
$$\%\, Error = \frac{|Actual\ speed - Theoretical\ Speed|}{Theoretical\ speed} \times 100$$

$$\%\, Error = \frac{|7.499\ RPM - 7.5\ RPM|}{7.5\ RPM} \times 100 = 0.01\%$$

The output speed of the designed gear mechanism is within the acceptable tolerance of 5% and is almost negligible taking error into account.

4.0 Conceptual Design

To create a functional prosthetic pincher, it is necessary to have the thumb and the finger move in opposite directions, and per requirements of the project, they must rotate with the same speed. Figure 1 shows how the team plans to achieve this. By having G12 fork to two individual gear trains, the required gear ratio for either finger will be maintained. In addition, G12 will rotate in a clockwise direction, thus, the thumb gear (G14) will also rotate in a clockwise direction as there is one gear between G12 and G14; and the index finger gear (G17) will rotate in a counterclockwise direction since there are two gears between G12 and G17. To achieve a clockwise rotation of the thumb and a counterclockwise rotation of the index finger the input gear (G1) should rotate in a clockwise direction.



Sketch 1: Index and Thumb Gear Trains (Side View).

Furthermore, one of the constraints and requirements of the design is that the gear train and custom mounting bracket should fit in the provided hand frame, also that the gear train must allow the index finger and thumb to rotate at their specific locations with respect to the provided hand frame (landmark 2 and landmark 3 indicated in figure 4). To satisfy this constraint, the module of gears 12-17 were designated at 1.25 mm/tooth. Thus, increasing the pitch diameter of each individual gear and allowing the train to reach the landmarks.

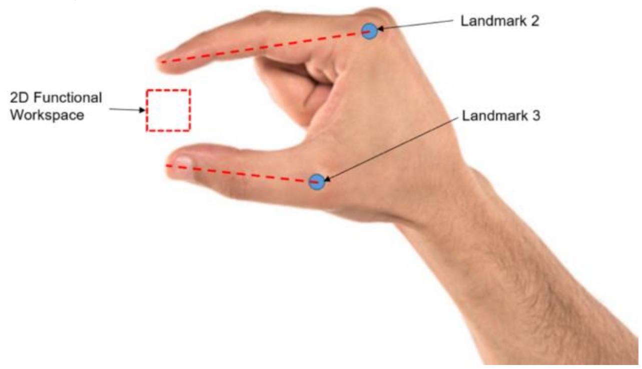
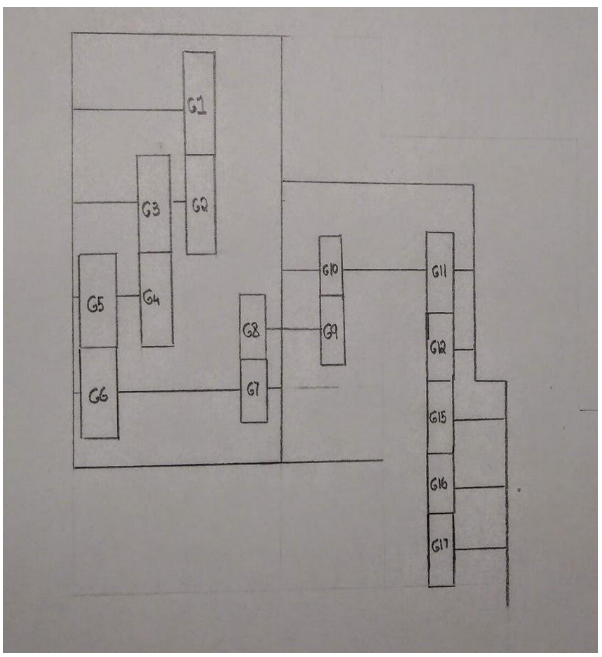


Figure 4: Location of landmarks on an actual human hand.

To fabricate a functioning gear train, the team planned to design a custom mounting bracket consisting of compartments that can hold gears as shown in sketch #2. By separating the two compartments by a wall, this allows for easier installation of axial connections to get from one end of the mounting bracket to the index finger and the thumb.



Sketch 2: Proposed gear train in custom mounting bracket

5.0 Final Design

Ultimately, the gear train had to perform two main functions: firstly, Slowing down the speed of rotation of the motor to the thumb and index finger; and secondly, allowing the index finger and thumb to rotate in opposite directions. To slow down the speed from input to output, the size of the gears must generally increase, thus increasing total gear ratio, and in turn decreasing the output speed. This is because $\omega_o = \frac{\omega_i}{GR_T}$, therefore as GR_Tincreases, $\omega_o$decreases. Furthermore, meshing spur gears spin in opposite direction and axially connected spur gears spin in the same direction.

The translation of motion of the gear train is summarized in Table 2. One noticeable feature of the gear train is that G12 is connected to two gears in a non-consecutive order. G12 forks into two individual gear trains for the thumb and index finger respectively. Between G12 and the thumb is only 1 gear, therefore, if G12 rotates CW, the thumb should also rotate clockwise. And there are two gears between G12 and the index finger, thus the index finger rotates CCW, creating a pinching/closing motion.

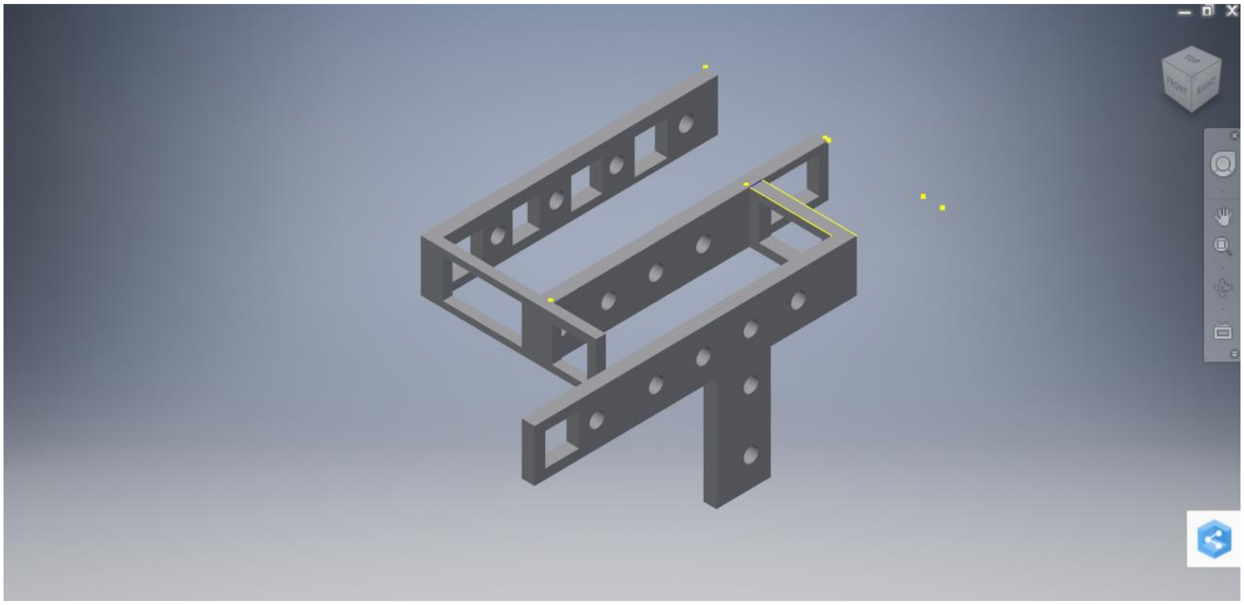
Moreover, to ensure that the index finger and thumb rotate at the same angular speed, the gears axially connected to either finger were made to have the same number of teeth. And the preceding gear train also all had the same number of teeth. G11, G12, G13, G15, and G16 all had 12 teeth, while G14 and G17, the thumb and index finger gears had 18 teeth. This maintains the gear ratio to wither finger and as a result allows rotation with equal magnitude of speed of 7.5 RPM.

Gears	**Connection**	**Direction**	**Gears**	**Connection**	**Direction**
G1, G2	Mesh	CW, CCW	G9, G10	Mesh	CW, CCW
G2, G3	Axial	CCW, CCW	G10, G11	Axial	CCW, CCW
G3, G4	Mesh	CCW, CW	G11, G12	Mesh	CCW, CW
G4, G5	Axial	CW, CW	G12, G13	Mesh	CW, CCW
G5, G6	Mesh	CW, CCW	G13, G14 (Thumb)	Mesh	CCW, CW
G6, G7	Axial	CCW, CCW	G12, G15	Mesh	CW, CCW
G7, G8	Mesh	CCW, CW	G15, G16	Mesh	CCW, CW
G8, G9	Axial	CW, CW	G16, G17 (Index Finger)	Mesh	CW, CCW

Table 2: Connection and Direction of Rotation of Gears during pinching motion.

5.1 Custom Mounting Bracket

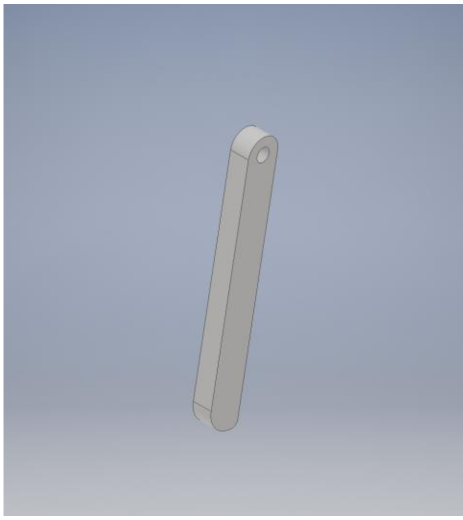
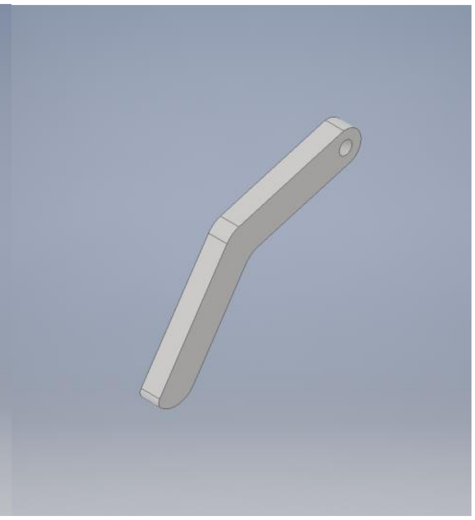
The mounting bracket was designed to follow a skeletal model. Using a skeletal model with various gaps and empty spaces would not only save on material but also save on printing time. Despite the advantages of designing the mounting bracket like this, there were also multiple drawbacks. The design consisted of a lot of holes to reduce print time and material but it came at the cost of the strength of the bracket. The bracket would often flex when too much force is applied to the crank and when gears bind. In addition, 3D printing error was not accounted for during the design phase, as a result some axials misaligned with their holes until they were sanded.



CAD 1: Final design of the custom mounting bracket assembly.

5.2 Fingers and Crank Handle

The index finger and the thumb were created using Inventor by drawing a line between the joint of either finger and the center of the functional workspace. A coincident constraint was then added to the tips of each line at the center of the workspace to emulate the tips of the thumb and index finger touching each other. Using the length of each line, a simple outline was drawn and extruded for each finger. Finally, to add realism and aesthetic appeal, fillets were added to the tips of both fingers.

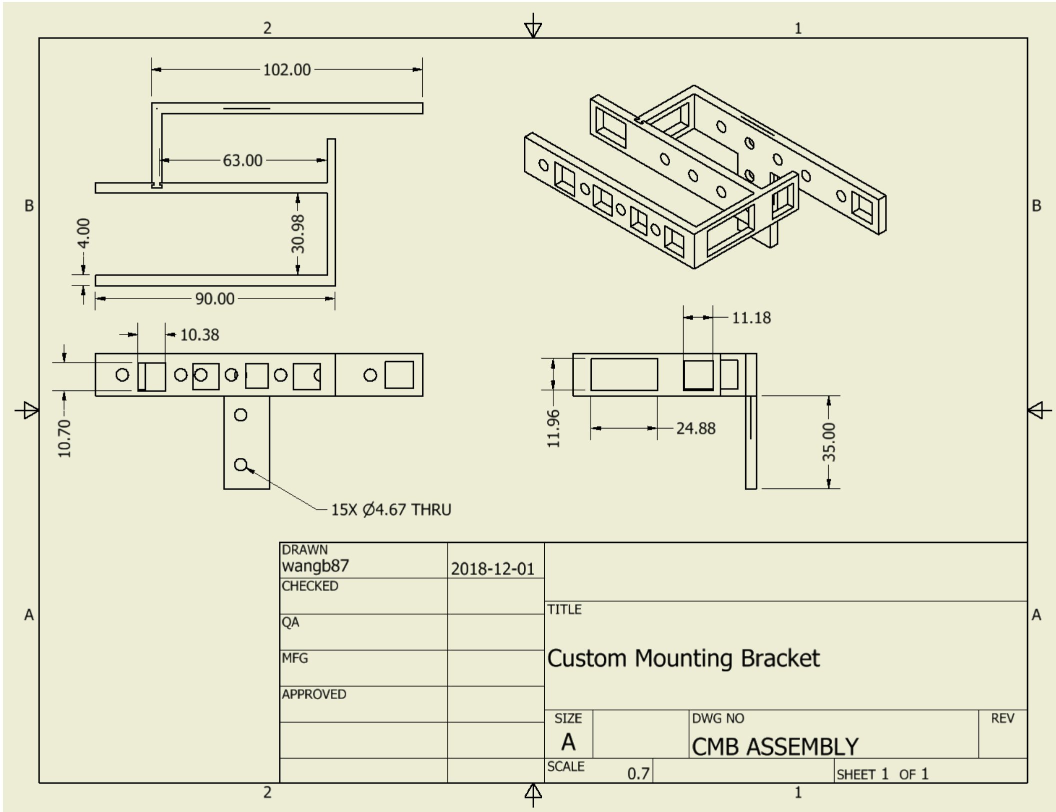
CAD 2: Thumb design on Inventor.
CAD 3: Index Finger design on Inventor

Finger Assembly Dimensions
Distance from Index finger joint to functional workspace: 70mm
Distance from Thumb Joint to functional workspace: 75mm
Angle between thumb and finger: 48 deg

The crank was designed to be simple and easy to print, due to time constraints during the project. A portion of the crank was left empty which decreased print time significantly. Also, the crank was designed to be small so it would fit into the final assembly without interfering with any rods.

6.0 Working Drawings

Drawing	Page Number	Drawing	Page Number	Drawing	Page Number
CMB	10	Gear 4	13	Gear 11	17
Crank	10	Gear 5	14	Gear 12	17
Thumb	11	Gear 6	14	Gear 13	18
Index Finger	11	Gear 7	15	Gear 14	18
Gear 1	12	Gear 8	15	Gear 15	19
Gear 2	12	Gear 9	16	Gear 16	19
Gear 3	13	Gear 10	16	Gear 17	20



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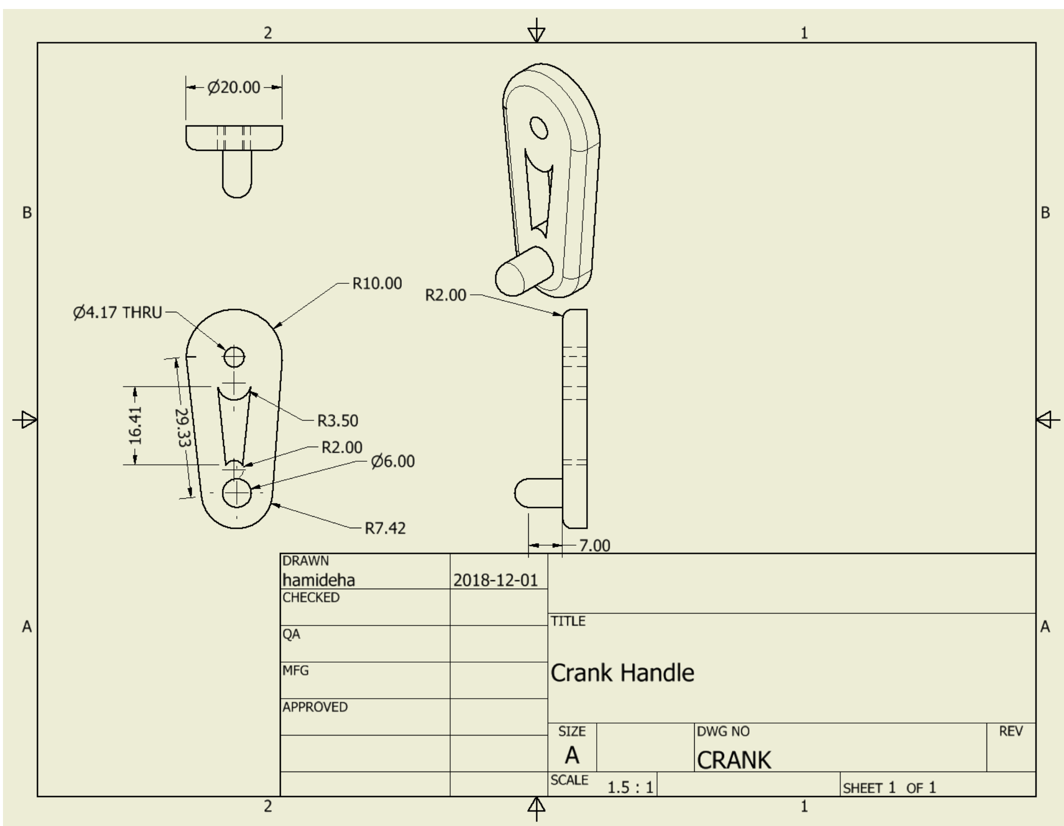

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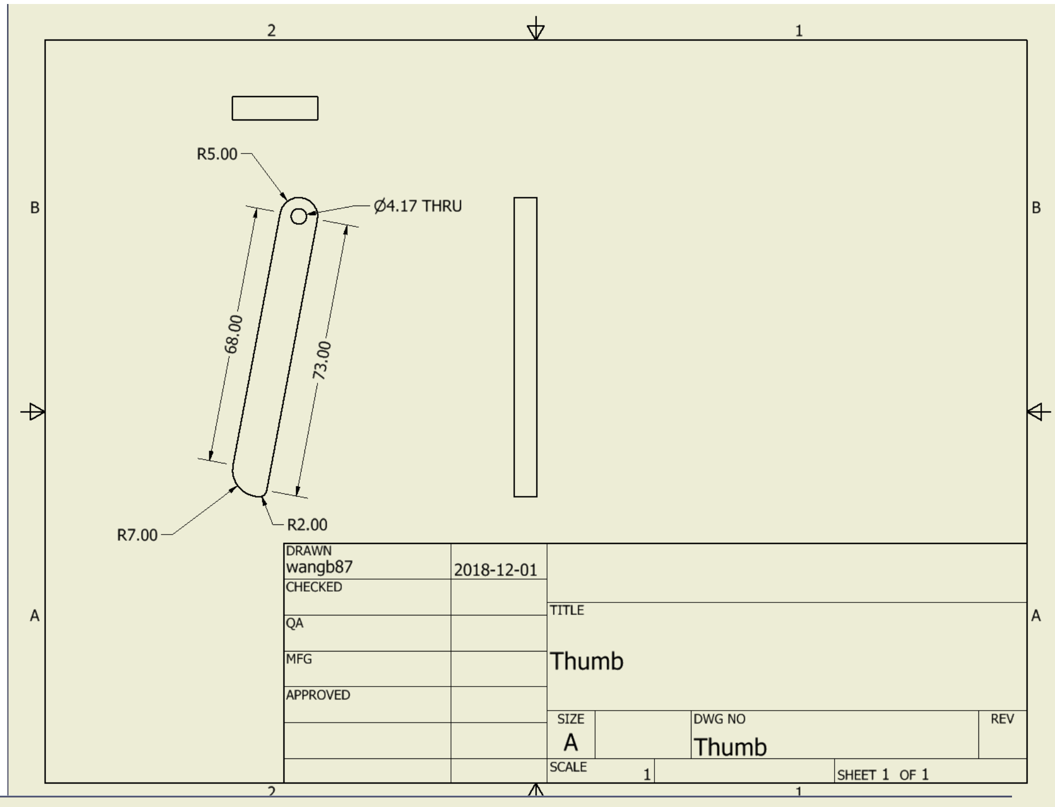
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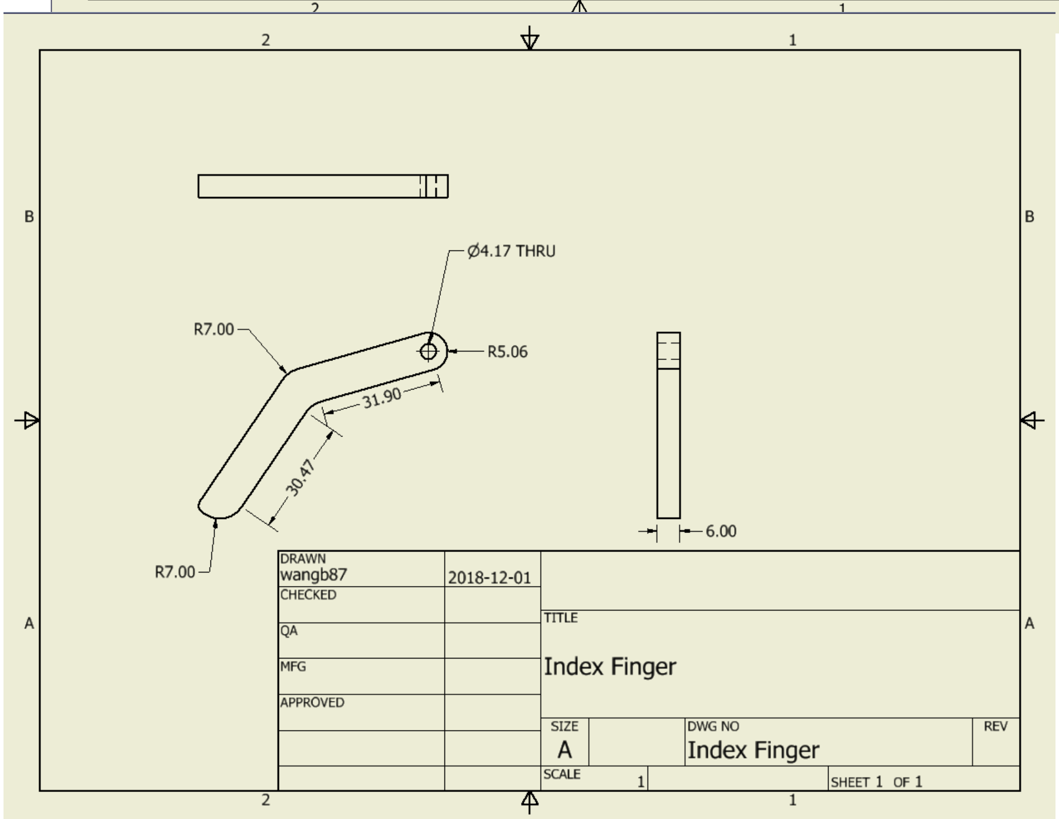
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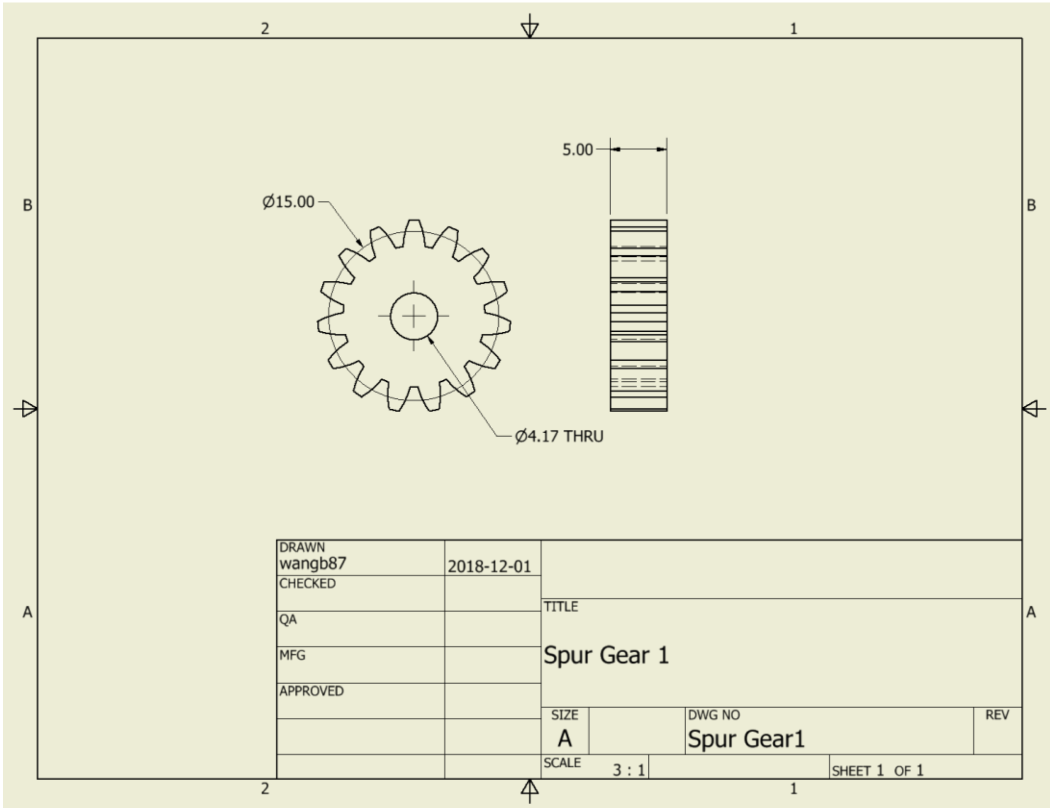
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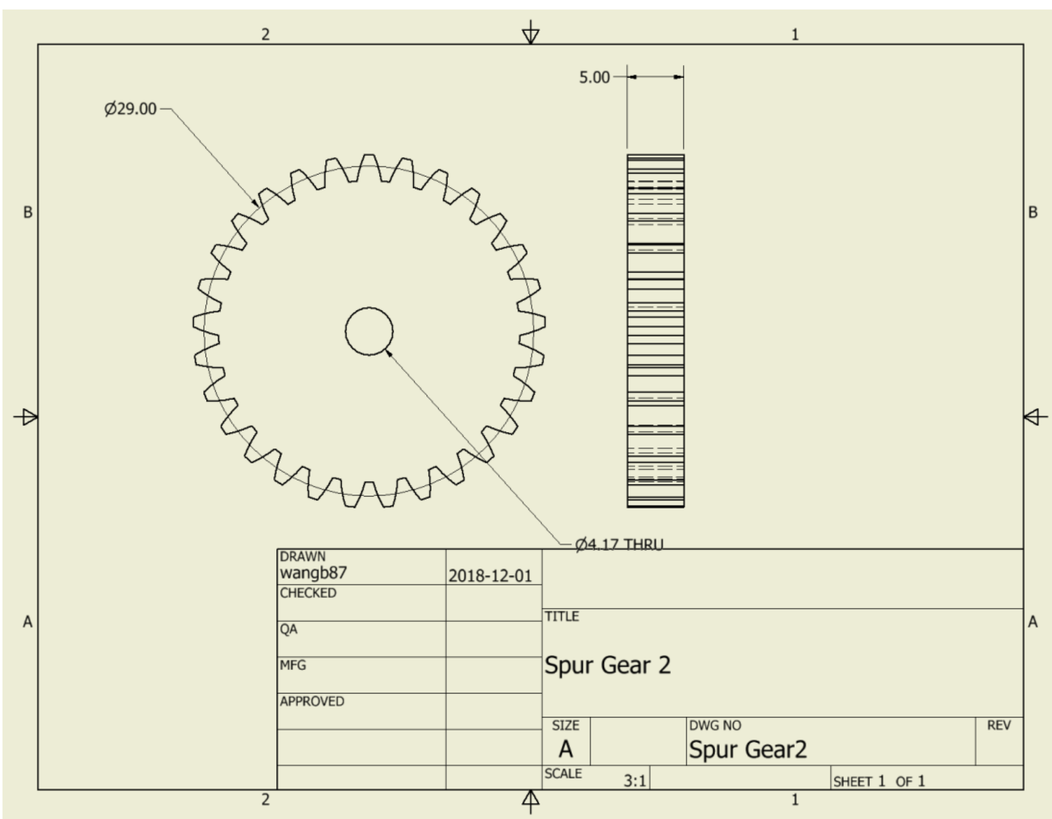
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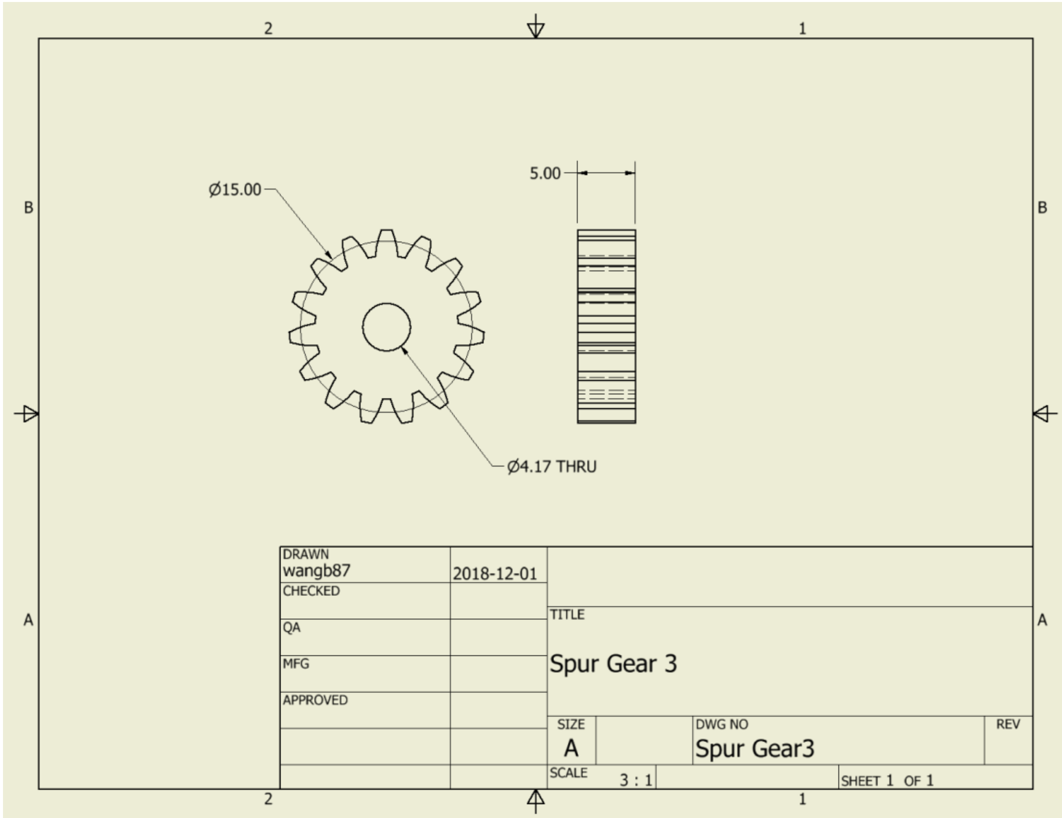
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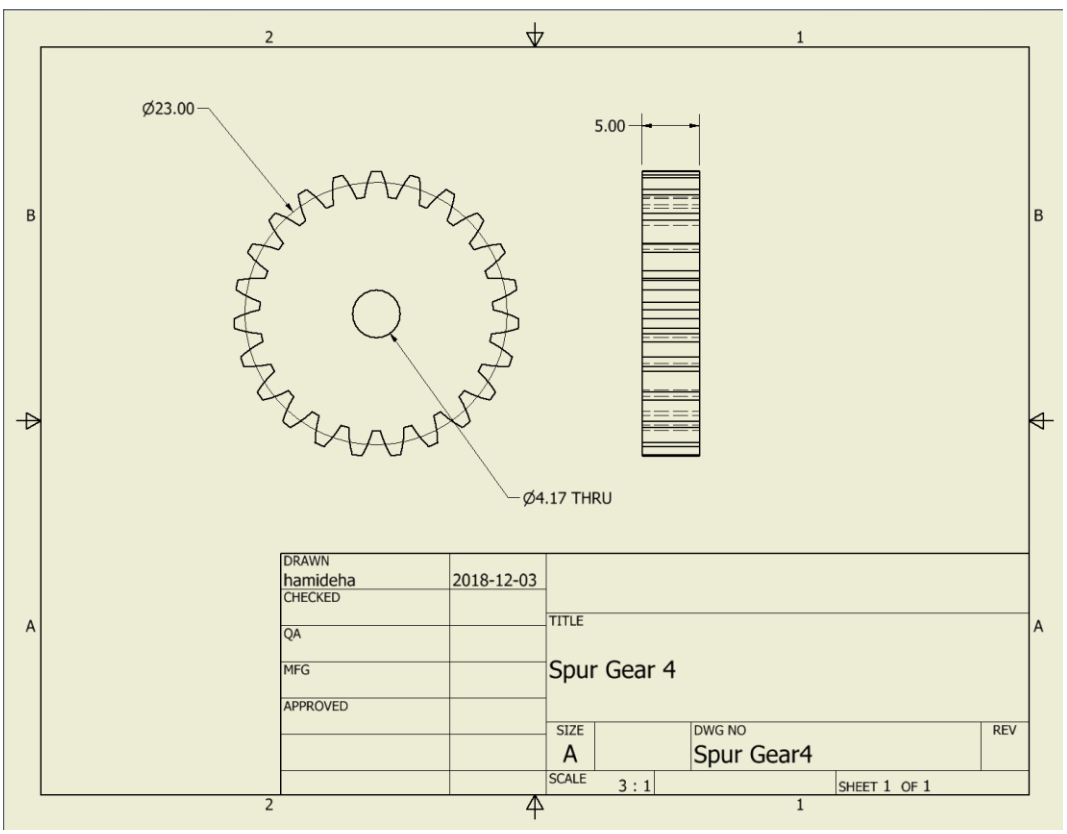
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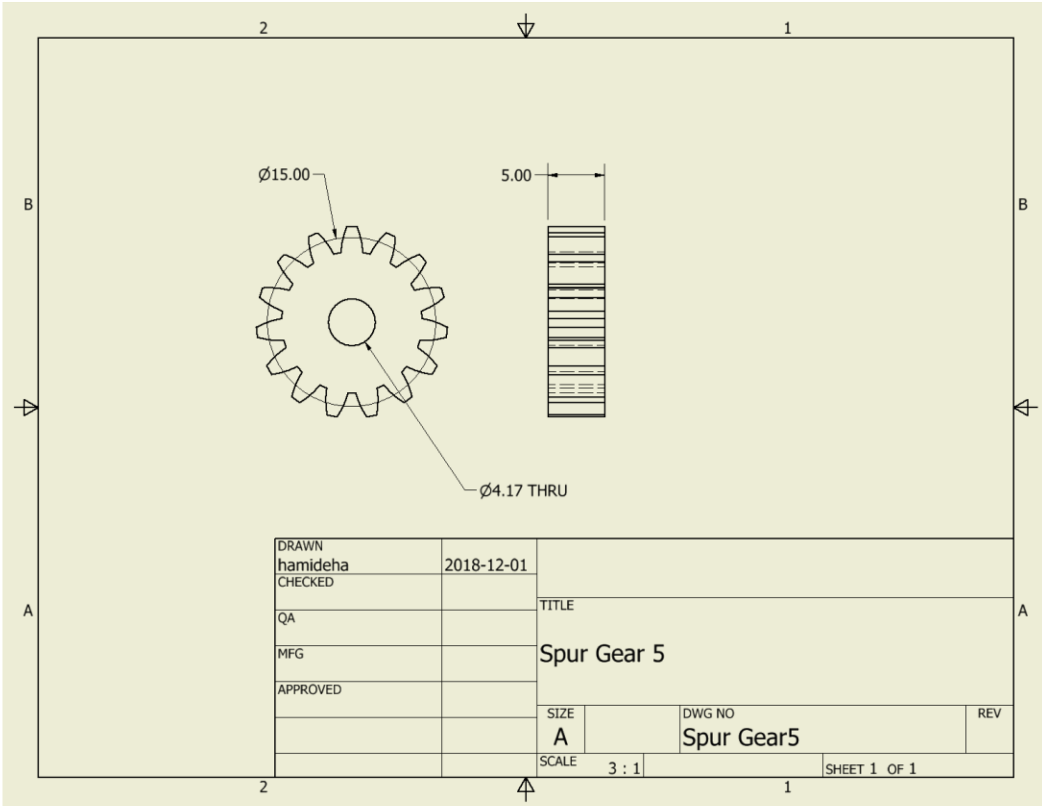
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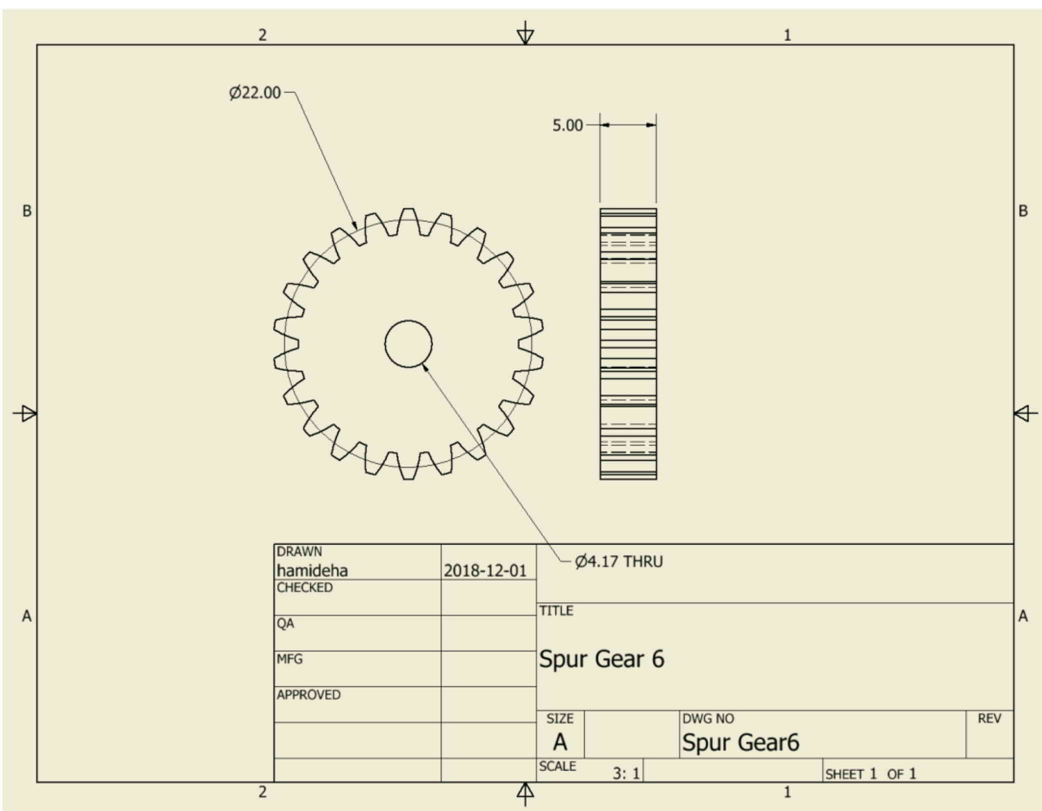
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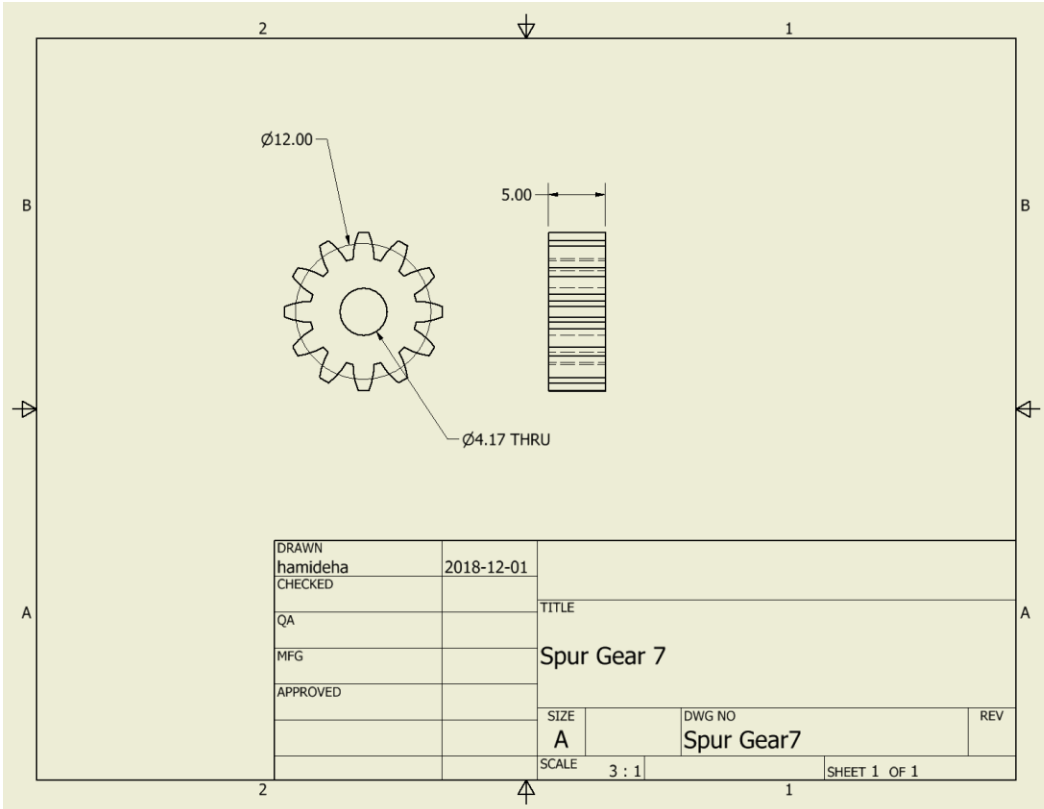
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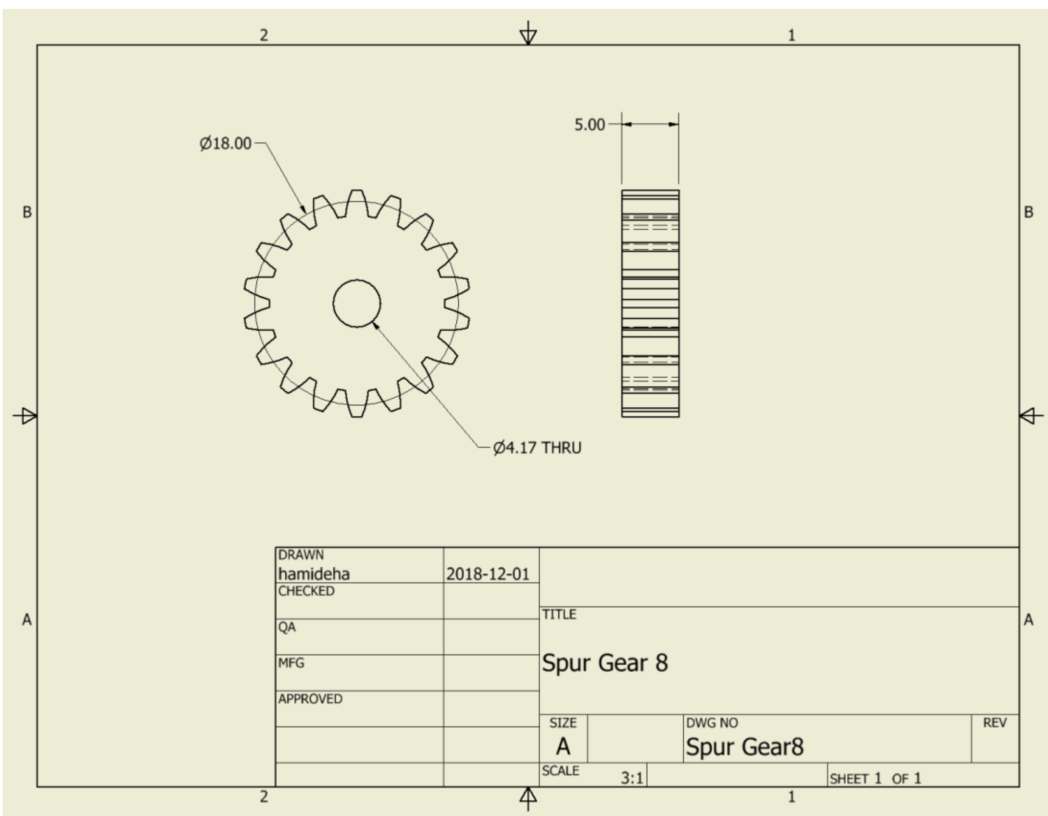
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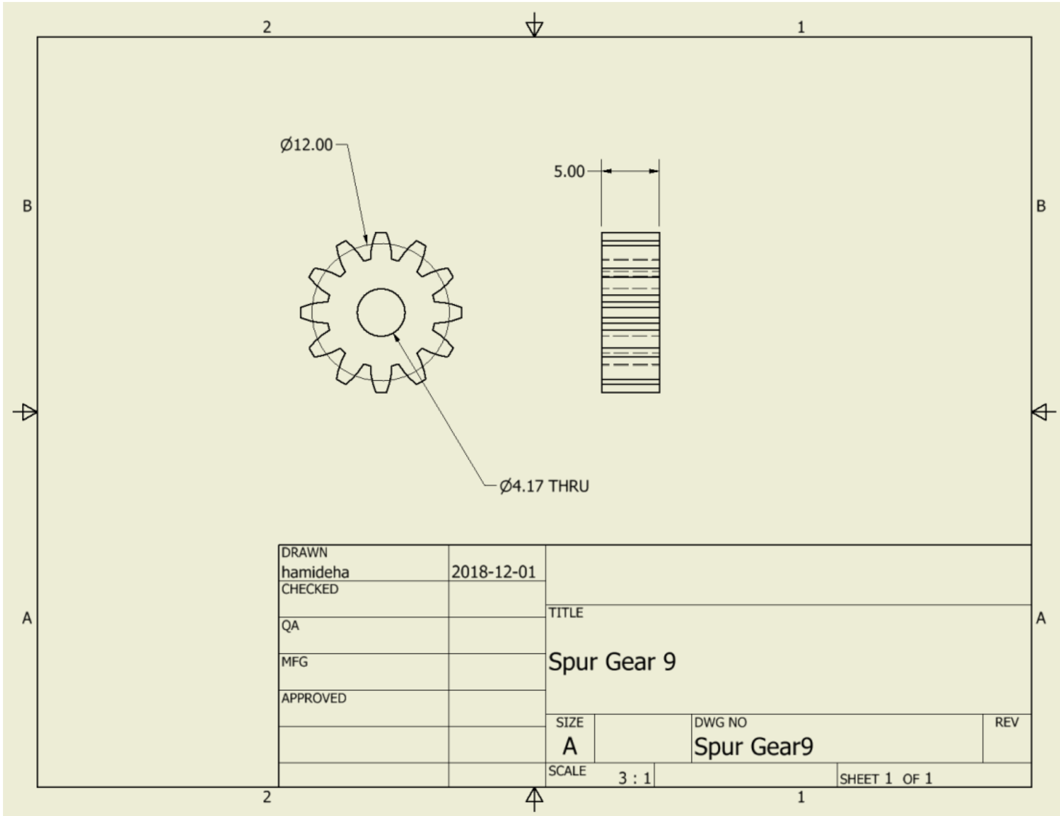
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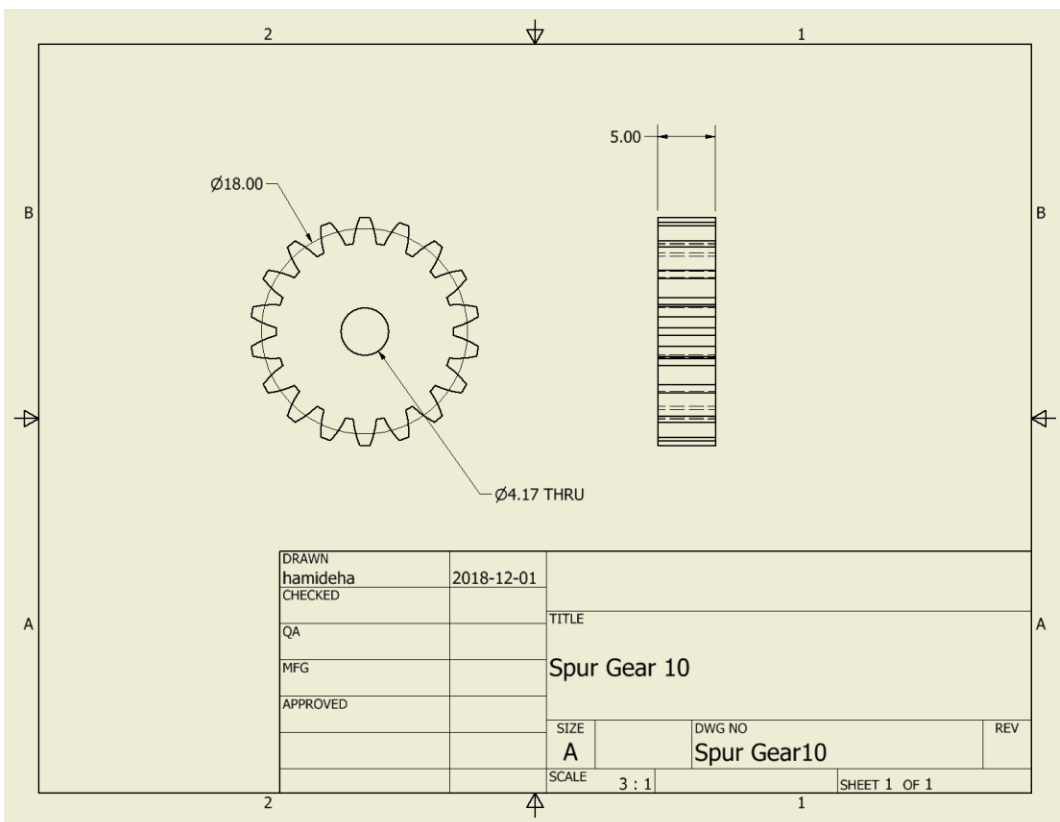
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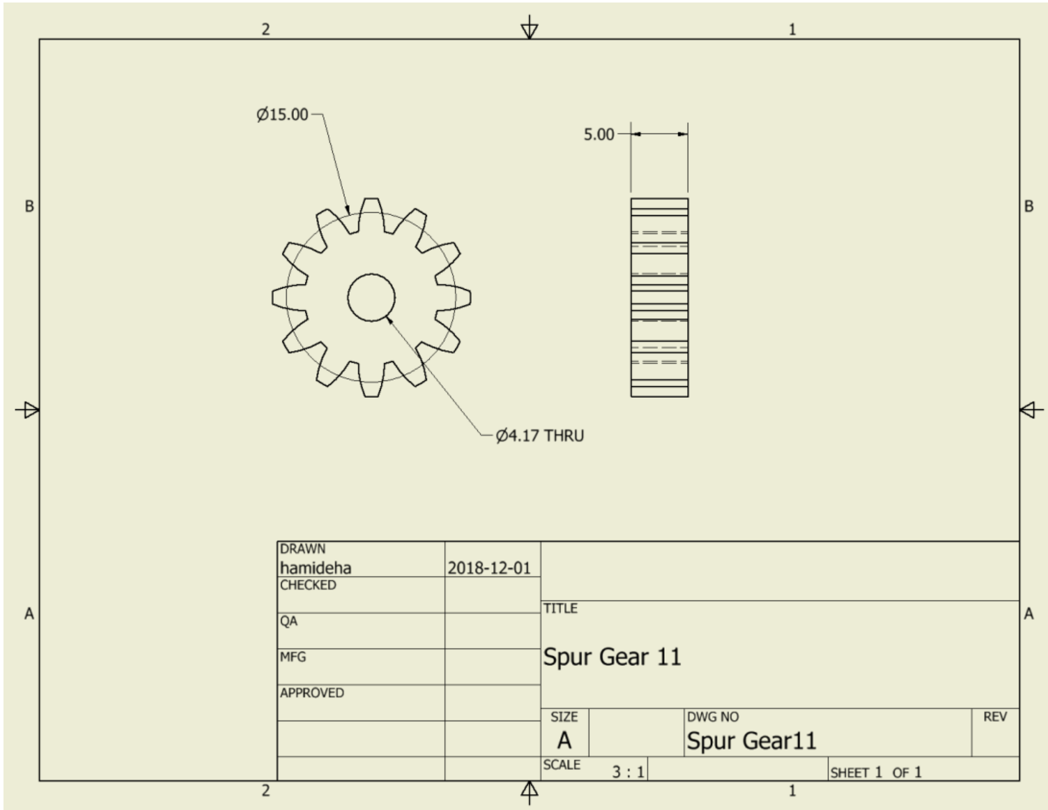

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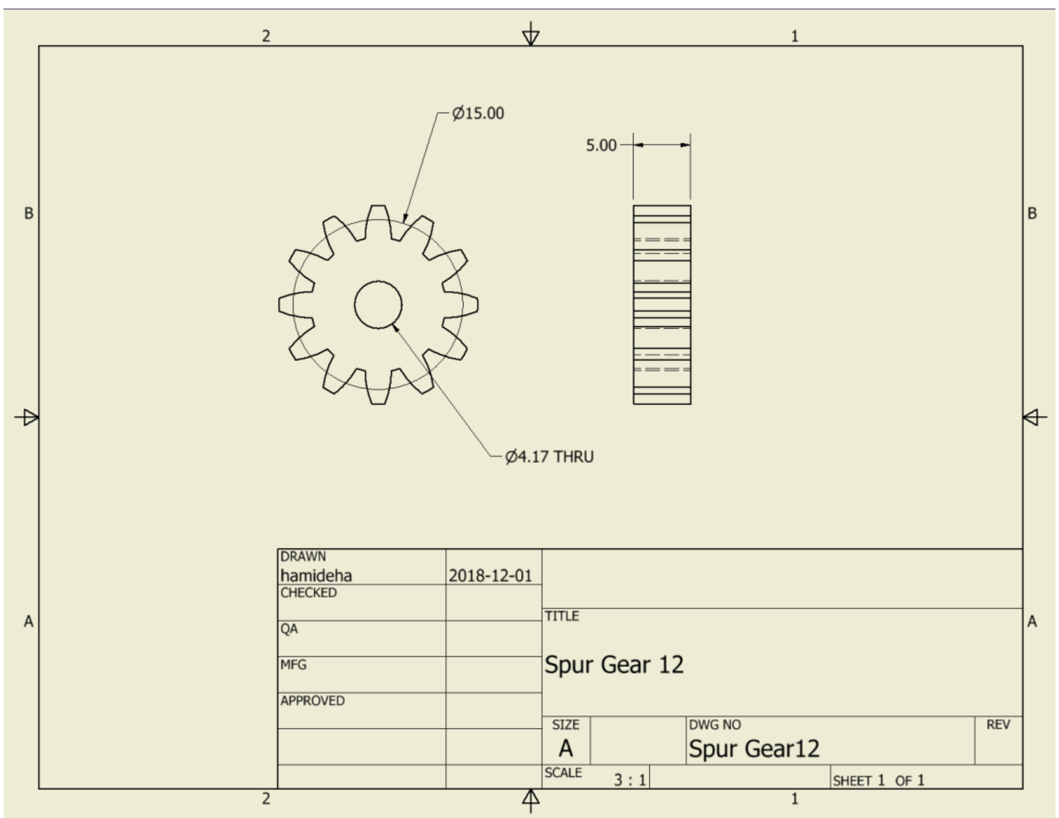

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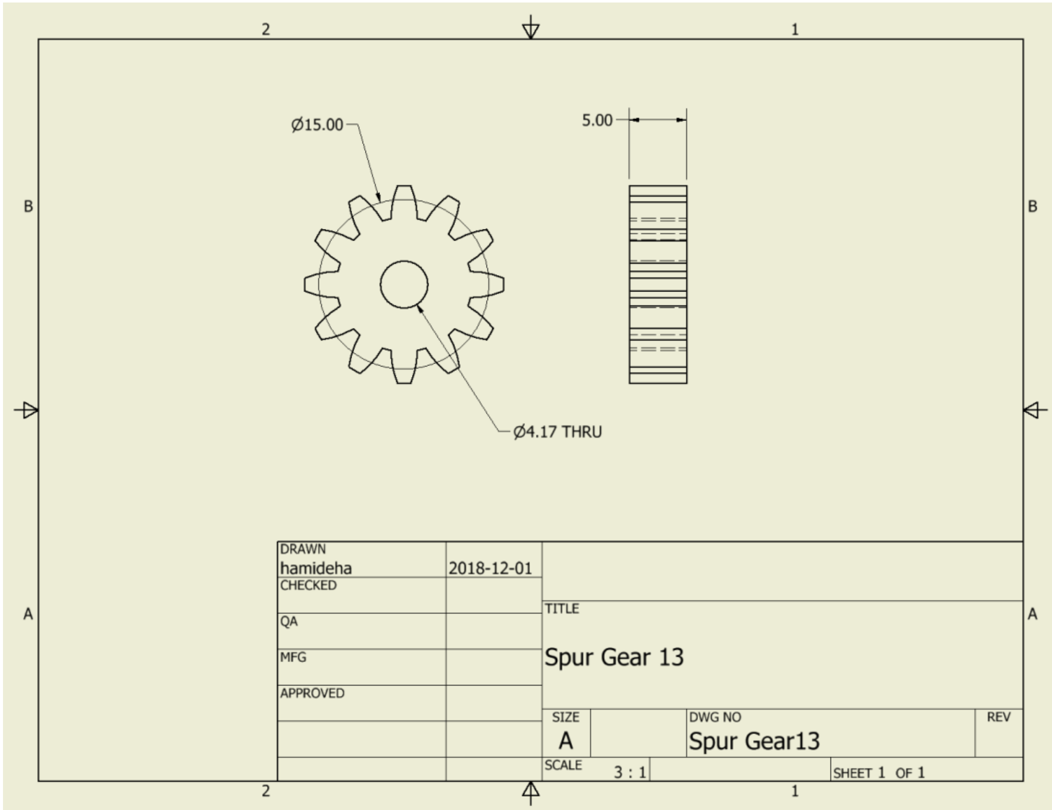

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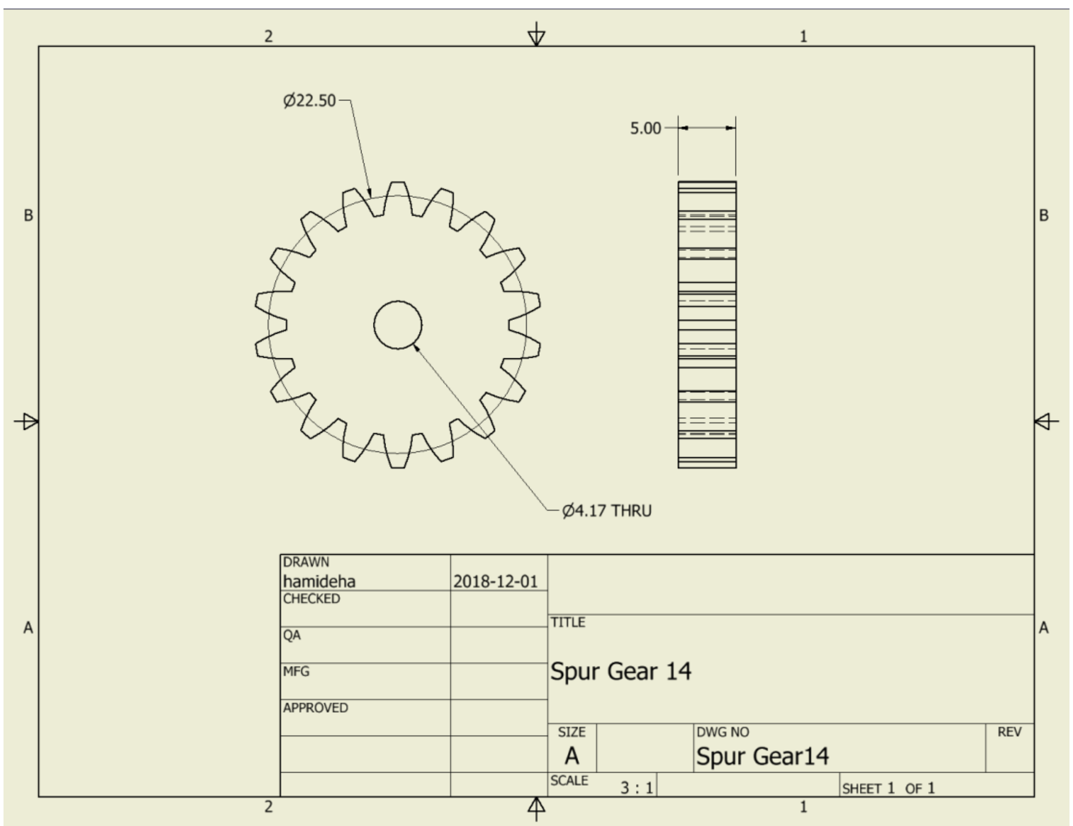

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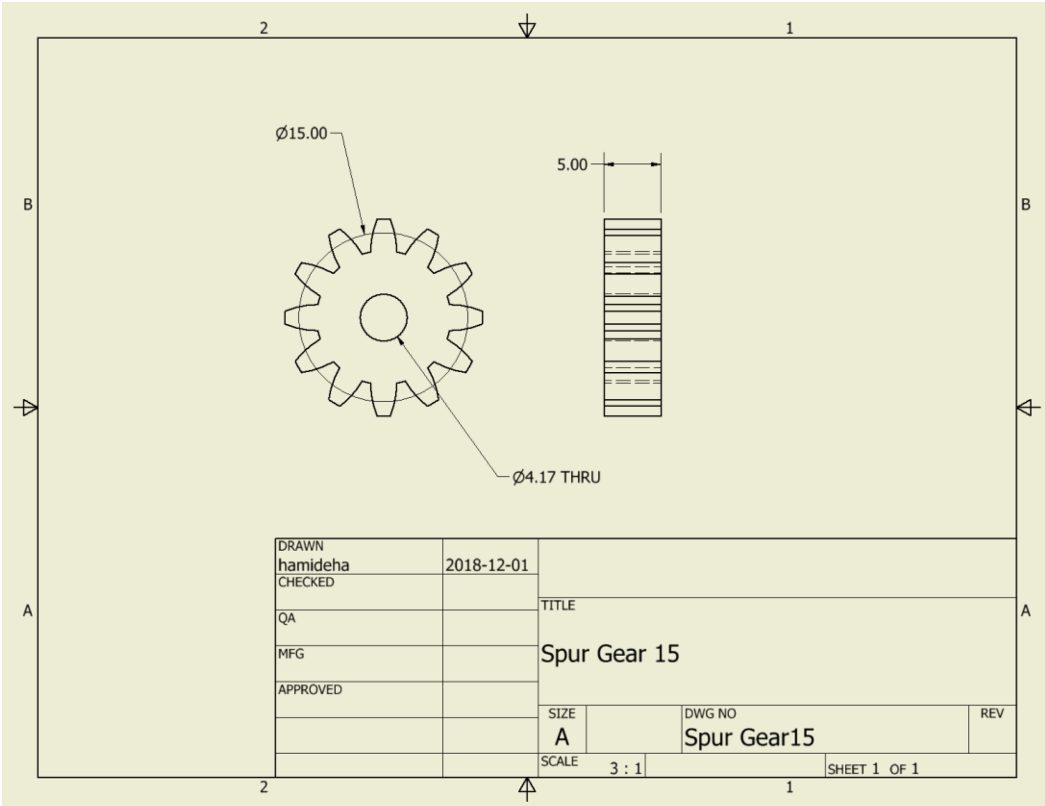
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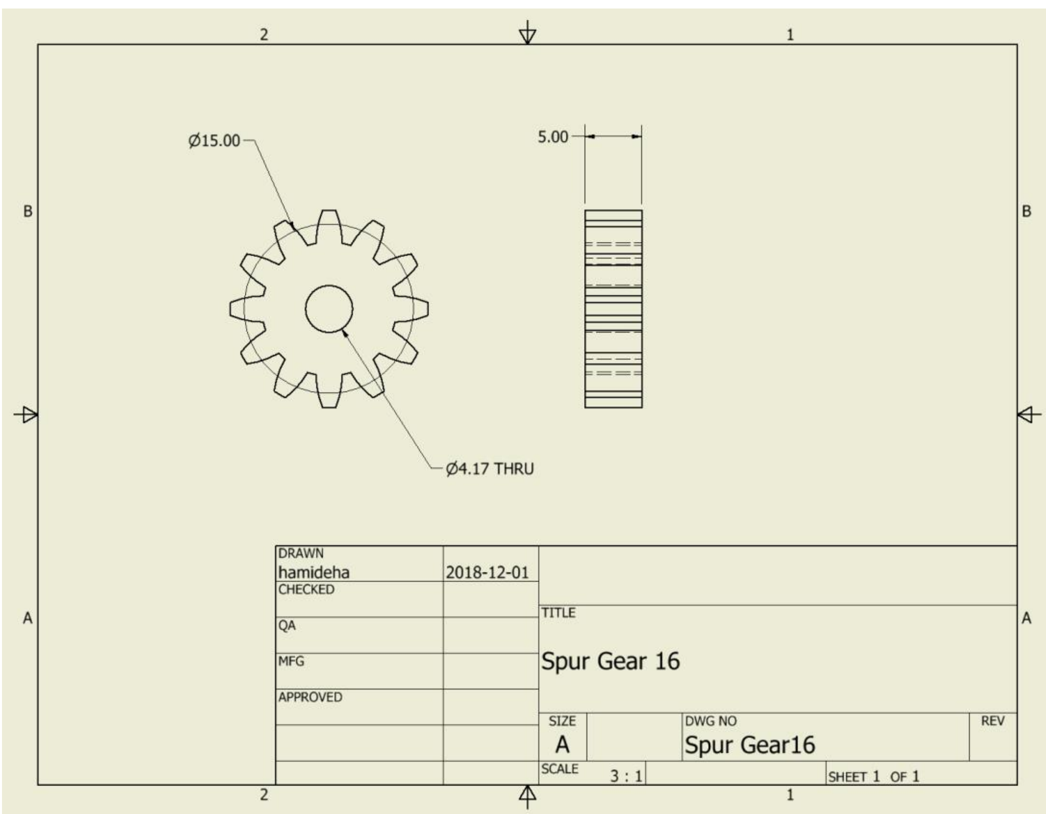
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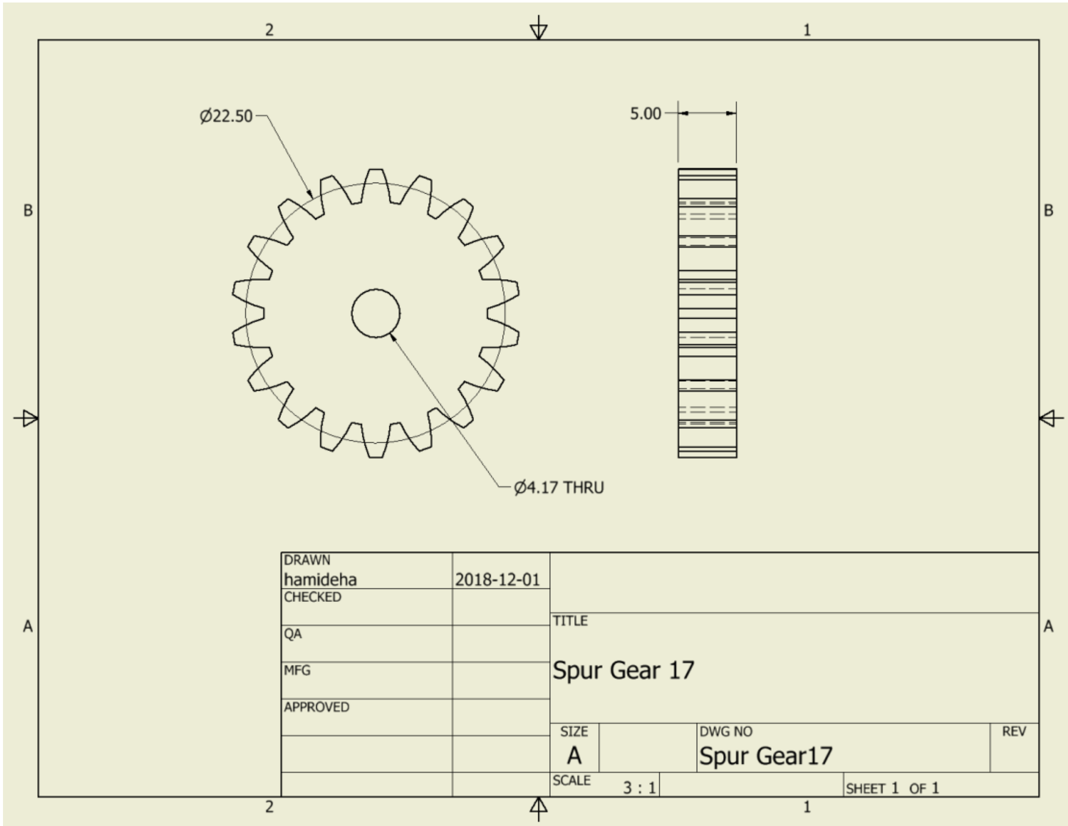
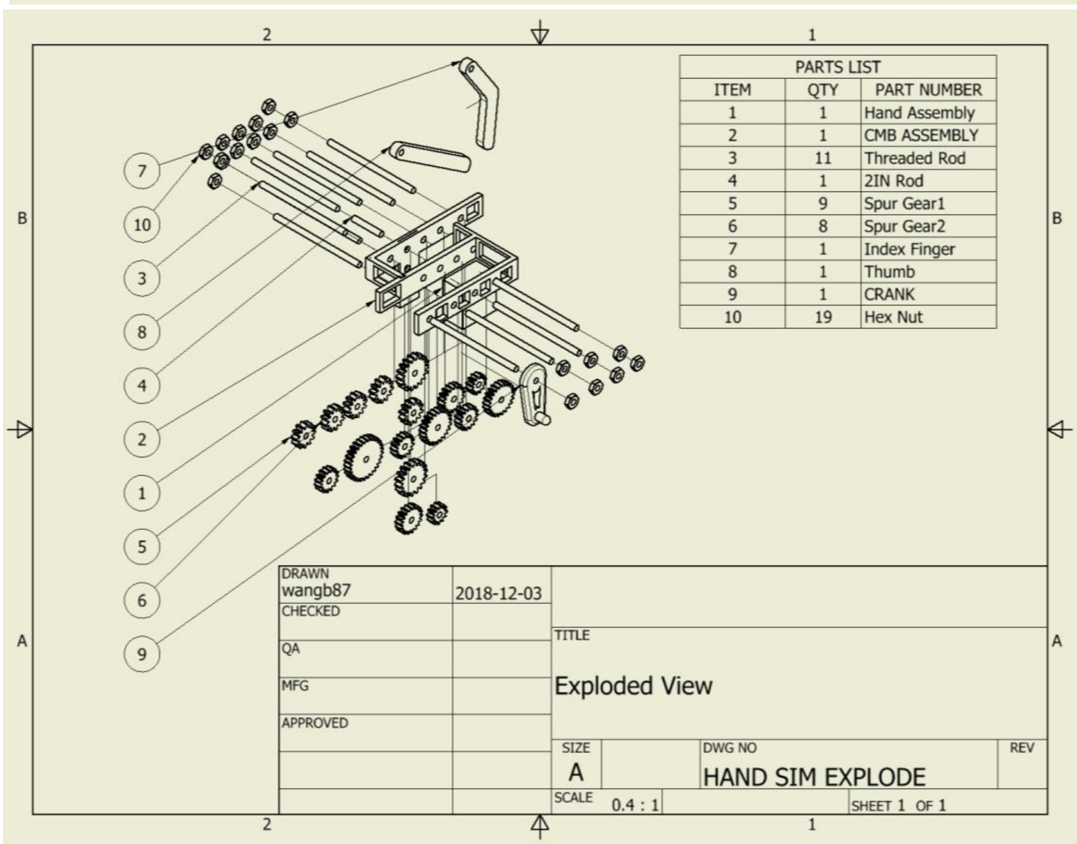


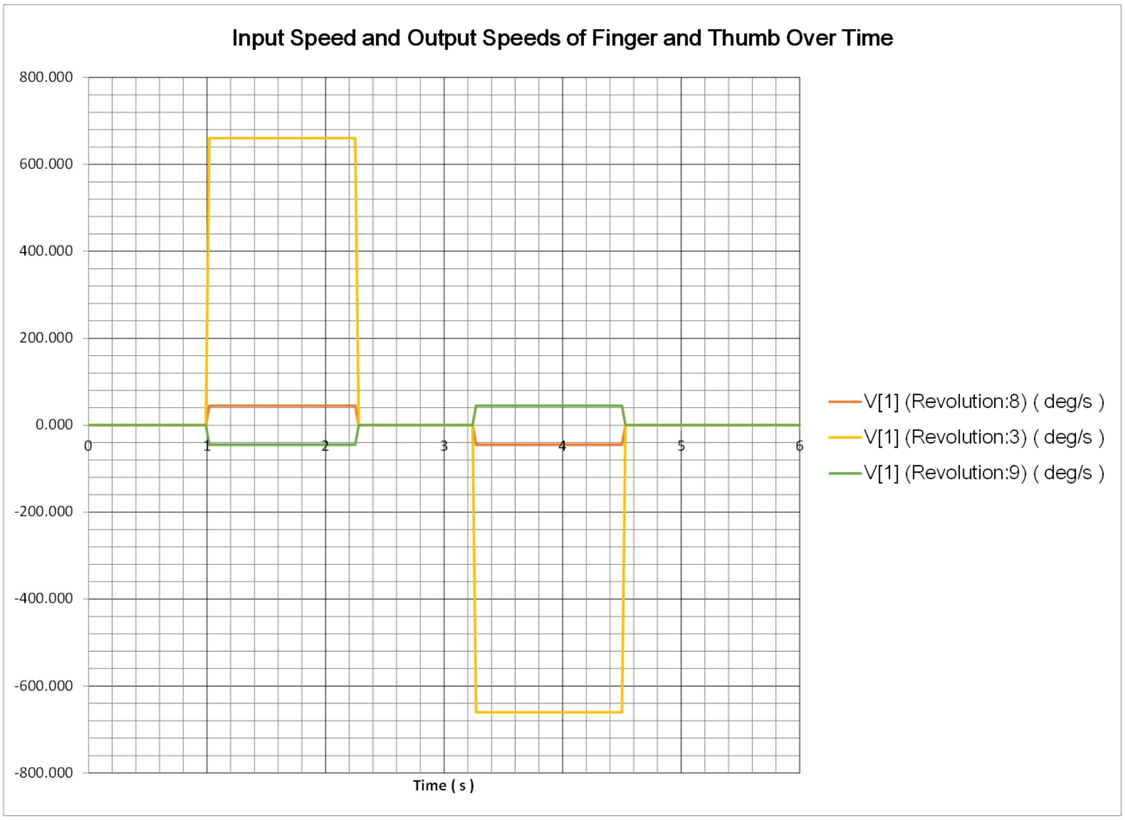


PARTS LIST

ITEM	QTY	PART NUMBER
1	1	Hand Assembly
2	1	CMB ASSEMBLY
3	11	Threaded Rod
4	1	2IN Rod
5	9	Spur Gear1
6	8	Spur Gear2
7	1	Index Finger
8	1	Thumb
9	1	CRANK
10	19	Hex Nut

7.0 Dynamic Simulation Graphs and Tables

Final assembly name in pack'n'go is HAND SIM.IAM



Graph 1

Graph 1 illustrates the input and output speed of the dynamic simulation. The yellow line corresponds to the input speed of the motor; the orange line corresponds to the output speed of the thumb gear; and the green line corresponds to the output speed of the index finger gear. The magnitude of speed of the thumb and index finger are equal.

Export to FEA	Time (s)	V[1] (Revolution:8) (deg/s	V[1] (Revolution:3) (deg/s	V[1] (Revolution:9) (deg/s
	0.99000	0.00000	0.00000	0.00000
	1.02000	45.00280	660.30000	-45.00280
	1.05000	45.00280	660.30000	-45.00280

Table 3

Table 3 is the data table of input and output speeds of the dynamic simulation probes. "Revolution 8" corresponds to the index finger gear; "Revolution 9" corresponds to the thumb gear; "Revolution 3" corresponds to the input.

8.0 Team Meetings and Responsibilities

Date	**Purpose of Meeting**
October 23, 2018 *All attended*	-Discussed project plan and course of action. -Created preliminary designs -Discussed which gears to use and how to achieve the gear ratio.
October 30, 2018 *All attended*	-Finalized the gear train to be used; i.e. decided on gear sizes and type. -Booked first printing session to print gears
November 15, 2018 *All attended*	-Printed all the gears
November 20, 2018 *All attended*	-Completed custom mounting bracket CAD design -Reprinted some gears that had defects
November 22, 2018 *All Attended*	-Printed and assembled mounting bracket -Created fingers and crank handle on Inventor -Worked on dynamic simulation
November 27, 2018 *All attended*	-Completed dynamic simulation
November 29, 2018 *All attended*	-Began assembly of final product
November 30, 2018 *All attended*	-Completed assembly of final product
December 3, 2018 *All attended*	-Proofread final report. -Practiced for interview.

Table 4: Summary and attendance of all meetings during the design project.

8.1 Gantt Chart

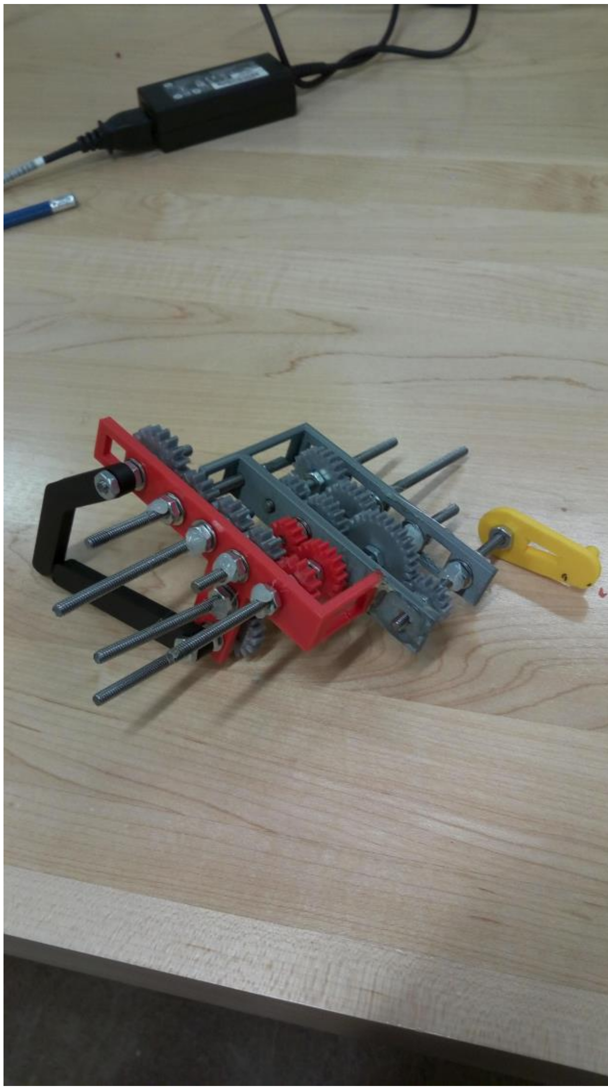
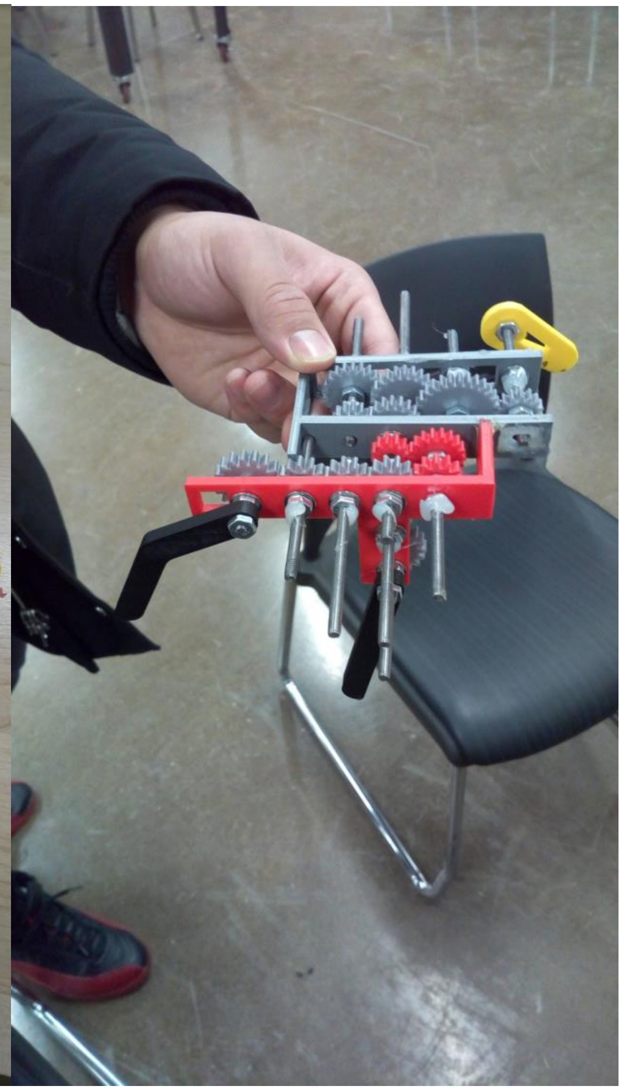
	October 2018					November 2018				December 2018
Tasks	**1**	**8**	**15**	**22**	**29**	**5**	**12**	**19**	**26**	**3**
Select teams										
Complete team agreement and schedule *(Milestone 0)*										
Work on Preliminary Design										
Finish Preliminary Design Report *(Milestone 1)*										
Initial 3D Printed Parts *(Milestone 2)*										
Complete technical specifications and sketches										
Complete Autodesk Inventor Design and Simulation										
Final 3D Parts and Fabrication										
Complete Final Report *(Milestone 3)*										
Complete Peer Reviews *(Milestone 4)*										
Group Meetings										

Table 5: Gantt chart created to track and keep schedule of all tasks required.

8.2 Team Responsibilities and Duties

		Contributors
Milestone 0	- Cover Page - Team Contract - Gantt Chart	All All Abdulrahman and Ahmed
Milestone 1	- Research and Preliminary Design - Sketches - Calculations - Determining appropriate gear specification - Designing of custom mounting bracket on Inventor	All Ahmed Abdulrahman All Abdulrahman and Ahmed
Milestone 2	- Created GCodes for print files - Attended print sessions - Inventor gear train assembly	Abdulrahman All Abdulrahman
Milestone 3	- Assembly of final product - Creation of Dynamic Simulation - Working Drawings - Exploded view drawing - Technical report - Proofreading report	All Barry and Ahmed Barry and Abdulrahman Barry All All

Pictures of Final Assembly

9.0 References

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[2] M. S. H. Bhuiyan, I. A. Choudhury, M. Dahari, Y. Nukman, and S. Z. Dawal, "An Investigation into a Gear-Based Knee Joint Designed for Lower Limb Prosthesis," *Appl. Bionics Biomech.*, vol. 2017, p. 7595642, May 2017.

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