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College of Engineering

Department of Mechanical Engineering

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Senior Design Project Final Report

Stirling Engine Powered By Solar Collector

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

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Symbol	Parameter
T	Temperature
R_{air}	Ideal Gas Constant for Air
P	Pressure
r_c	Compression Ratio
V	Volume
P_{atm}	Atmospheric Pressure
H	Efficiency
W	Work
W_c	Work in Compression
W_e	Work in Expansion
T_h	Hot Temperature
T_c	Cold Temperature
L	Length
d	Diameter

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Abstract:

Yearly, Saudi Arabia utilizes huge mass of its fossil fuel within the country. 30 percent of its oil production is consumed within the kingdom. Therefore, Saudi government is nowadays looking for alternative renewable power generation plants to reduce the dependence on fossil fuel to improve and increase the country's economy and consider the environmental negative impaction on the kingdom more seriously.

Stirling engines are one of the environmentally friendly devices that can be used to convert mechanical energy into electrical energy. The functionality of these engines is to have heat energy flowing in and out within and out of the Stirling engine' walls to create a small temperature difference, where it is the important aspect of operating any Stirling engine and achieve continuous motion. Although, Stirling engines are clean to be used for not having any exhaust gases out to the atmosphere, the common way used to provide that external energy for the Stirling engine to operate is burning fuel or coals which still is harmful to the environment. Alternatively, a very useful external renewable source of heat especially in the kingdom is solar energy, where temperatures is more doable to utilize throughout the year. Therefore, our aim is to develop a Stirling engine that will work by solar collector to have completely clean power generation system and minimize the negative impact on our environment.

Acknowledgements:

The success and outcome of this senior project required a lot of guidance, assistance and support from many people within the boundaries of the university campus and outside of it in numerous workshops. We are extremely privileged and grateful to have completed our project with such professional supervision and assistance provided by the faculty of Prince Mohammad Bin Fahd University, we would not have been able to finish this project without the immense encouragement and support that we received.

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Chapter # 1: Introduction

1.1 Project Definition:

This project aims to design and fabricate Stirling engine using solar energy as a heating source. The Stirling engine works on the principle of a closed volume system in which air produces work through cyclic expansion and compression due to large temperature difference between the cold and the hot chambers. The heat energy is transformed into mechanical work when the hot air expands to moves the piston while the cold air compresses to release the piston to its original location. The crank shaft mechanism allows for translating the linear motion of the piston into rotary motion taking place in the flywheel. The objective is to implement the utilization of renewable energy to provide the heating source for the engine by designing a concentrated solar collector to produce a very high temperature similar to that of a small gas burner. Furthermore, this project will demonstrate the Stirling engine capacity to produce power that is echo friendly and very practical for many applications.

1.2 Project Objectives:

The specific objectives of this project are:

1. To produce power with a high efficiency relative to similar alpha engines.

2. To further decrease our dependence on fossil fuels.

3. To showcase the practicality of using Stirling engine to power various applications.

4. To use a concentrated solar collector as a heating sources.

5. To showcase the environmental and financial benefits of using renewable energy instead of fossil fuels.

1.3 The Cycle of Stirling Engine:

Stirling engines are thermodynamic devices working theoretically on the Stirling cycle and using a compressible fluid, such as air, hydrogen, helium, nitrogen or even vapors, as working fluid. The Stirling engine offers possibility for obtaining highly efficient engine with less exhaust emissions in comparison with the internal combustion engine. The earlier Stirling engines were huge and inefficient due to its complexity and large weight. In recent years, however, several new Stirling engine models have been developed to overcome such deficiencies.

Stirling cycle engines are classified based on the arrangement of pistons and drive system. They can be categorized into alpha, beta and gamma types from the aspect of the arrangement of the pistons. Also, several types of drive systems are normally used to ensure the appropriate movements of the working gas to complete the Stirling cycle. From this perspective, Stirling engines can be classified into kinetic, thermoacoustic, free-piston, and liquid piston types.

In this project, Stirling engines with a liquid piston drive system will be deigned. Stirling engines have two power pistons in separate cylinders installed at either side of the cooler, regenerator and heater. Both pistons need to transfer the work and must be sealed to contain the high pressure working gas. The Stirling engine can be arranged in a double-acting configuration by interconnecting several alpha units in a series to form a loop. The power pistons of the adjacent units are merged into one, so that the power piston acts as not only the expansion piston for one unit but also the compression piston for the next unit.

1.4 Stirling Engine and Renewable Energy:

Worldwide attempts are being made to increase the use of our renewable energy sources as well as to use our current fossil fuel energy sources wisely. Stirling technology finds application in both the renewable energy sector and in waste heat recovery. Solar energy is one of the more attractive renewable energy sources that can be used as an input energy source for heat engines. In fact, any heat energy source can be used with the Stirling engine. The solar radiation can be focused onto the displacer hot-end of the Stirling engine, thereby creating a solar-powered prime mover. The direct conversion of solar power into mechanical power reduces both the cost and complexity of the prime mover. In theory, the principal advantages of Stirling engines emerge in their operation from external heat source and their possession of high efficiency. Stirling engines are able to use solar energy that is cheap source of energy. Since during two-thirds of the day, solar energy is not available, solar/fuel hybrids are of certain essential.

The continuous exhaustion of fossil fuels and the associated environmental impact have driven a growing interest in increasing energy efficiency and exploiting renewable energy sources. A large amount of low and moderate temperature heat is released from various industrial processes. It was reported that more than one third energy consumption in the world is used by industries, of which about 20–50% is finally exhausted as the waste heat into atmosphere. Low temperature renewable heat resources, such as geothermal and solar energy, are huge in quantity all over the world. Exploiting these low-grade waste and renewable energies provides significant opportunities for addressing the energy related problems, such as energy safety and shortage, greenhouse gas emission, water dissipation, etc.

1.5 Project Applications:

The kinetic Stirling engines and thermoacoustic engines have the greatest application prospect in low and moderate temperature heat recoveries in terms of output power scale, conversion efficiency, and costs. In particular, kinetic Stirling engines should be oriented toward two directions for practical applications, including providing low-cost solutions for low temperatures, and moderate efficient solutions with moderate costs for medium temperatures. Thermoacoustic engines for low temperature applications are especially attractive due to their low costs, high efficiencies, superior reliabilities, and simplicities over the other mechanical Stirling engines. This work indicates that a cost effective Stirling cycle engine is practical for recovering small-scale distributed low-grade thermal energy from various sources.

Chapter # 2: Literature Review

2.1 Project Background:

Nowadays, 80% of global power generation is dependent on oil, coal, and natural gas. Although fossil fuel as a heat input can produce a large amount of power, the damaging outcome to the environment particularly climate change through the constant rise in temperature is the main concern that is affecting the whole world. The limited and unsustainable nature of fossil fuel energy is another obstacle in maintaining the needed global power production when dealing with high rate of population growth. Therefore, the shift toward a less harmful and more sustainable source of energy is necessary and implementing ways to harness renewable energy for mass power generation is in the top of many countries' economical plans especially the Kingdom of Saudi Arabia. Moreover, a significant aspect of the 2030 vision is to invest on harnessing solar and wind energy for mass power production with an initial target of generating 9.5 gigawatts of renewable energy (Renewable Energy, n.d.). This incredible amount of power will provide the country with enough energy and diversify its economy. Furthermore, this project was considered for design and manufacturing in line with our country's vision and future power generation.

2.2 Previous Work:

The Stirling engine is a simple type of engine in which fluid is subjected to cyclic expansion and compression. One of the most important aspects in designing the Stirling engine is maximizing the heat transfer to the working fluid. Also, good heat transfer needs high mass flow and low viscosity fluid to reduce pumping losses. Moreover, using higher pressure or lower viscosity could reduce the high mass flow required. The Stirling engine theoretically has a high efficiency in upgrading from heat to mechanical work with the Carnot efficiency. The thermal limit of the operation of the Stirling engine depends on the material used for construction. Engine efficiency ranges from about 30 to 40% resulting from a typical temperature range of 923–1073 K, and a normal operating speed range from 2000 to 4000 rpm. In regenerative cycle, the heat transferred to the matrix of the regenerator by the working fluid can be recovered back and used to increase the thermal efficiency of the engine. The simulation of the design showed that the thermal efficiency of the engine increased to 61% when the effectiveness of the regenerator is maximum. However, the effectiveness of the regenerator has no effect on maximum cycle pressure, net cycle work, and power output (Bhagat, 2016).

Finite-time thermodynamics is used in this study to determine the thermal efficiency of the Stirling engine and output power. The output power of the engine was maximized in two optimization scenarios in which the hot temperature and temperature ratio of the engine were considered as design parameters. It appeared that in the second optimization scenario where two design parameters were considered, the magnitude of the thermal efficiency and maximized power were more than the corresponding values of the first scenario where only the hot temperature of the engine was taken as a design variable. Moreover, it was shown that heat exchanger and regenerator parameters including effectiveness, thermal capacitance rate and fluid inlet temperatures as well as engine characterizing parameters including volumetric ratio, temperature ratio and thermal bridge coefficient have a significant effect on the maximized power and its analogous thermal efficiency, in one hand, and on work and heat transfer of the engine, on the other hand (Ahmadi, 2016).

These articles provided clear insights on the most important parameters to consider for designing an alpha type Stirling engine with high efficiency. As mentioned, the compression ratio is a significant factor in increasing the power output of the engine. In addition, designing a highly effective heat regenerator can increase the thermal efficiency of the engine.

2.4 Comparative Work and Studies:

Aside from gathering information from previous work, we had to explore recent Stirling engine projects in order to improve the design of our engine. Furthermore, these projects provide a great source of information specifically in the fabrication stage. They illustrate the challenging aspects in fabricating the engine along with the expected output power and efficiency. A senior project was taken as a reference from Worcester Polytechnic Institute where a group of undergraduate students conducted data analysis by calculating the performance and parameters of both Alpha and Gamma types engines and in the end Gamma type was given the priority to be used for project prototype since manufacturability was less required that Alpha type engine. The following table shows the Alpha and Gamma types work comparison:

Gamma- Type Design Work	Alpha- Type Design Work
Work done by Thermal Expansion $W = P \cdot \Delta V$ $W_1 := P_3 \cdot \Delta V = 100.348\,J$ $W_2 := P_1 \cdot \Delta V = 43.102\,J$ $Work_{Net} := W_1 - W_2 = 57.246\,J$ At 500 RPM $Power := Work_{Net} \cdot S_c = 476.857\,W$	Work done by Thermal Expansion $W = P \cdot \Delta V$ $W_1 := P_3 \cdot \Delta V = 101.902\,J$ $W_2 := P_1 \cdot \Delta V = 43.088\,J$ $Work_{Net} := W_1 - W_2 = 58.814\,J$ per cycle At 500 RPM $Power := Work_{Net} \cdot S_c = 489.919\,W$

Table 2.3: Alpha and Gamma Types Work Comparison

Furthermore, we found that the Alpha type will give higher power that Gamma type, but the manufacturing cost of Alpha type it will be higher that Gamma type engine. Also, the original design of Gamma type engine was intended to produce more than 500 watts as predicted by the result of the analysis.

Unfortunately, they were not able to make the manufactured prototype run. The main obstacle was that the piston got stuck in the cylinder when the piston rings were attached. The group investigation concluded that the problem was not caused by inaccurate dimensions but instead with the fabrication of the cylinder. Furthermore, the group concluded that using drawn cylinder could loosen the tolerance which will prevent the crankshaft from turning. The group also recommended that machine constraints must be taken into consideration in order to avoid further major complications.

Another project done by a group of undergraduate students from Kathmandu University was examined. The group decided to design and fabricate a Gamma- type Stirling engine powered by a parabolic dish collector. the output power of their design was 5.54 watts and the total reflection of radiation by the parabolic dish was around 7kw per day. The group encountered many obstacles in locating the required materials with the right dimensions and fabricating the pistons. Furthermore, they chose PVC material for the power piston and light wood for the displacer. They emphasized the importance of fitting the displacer cylinder and cylinder which should be prioritize when fabricating the parts. In addition, they mentioned that precise connections of connected rod and crankshaft with power piston and displacer is very significant in reducing friction.

Chapter # 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints:

Since the moment decided to plan and design our Stirling engine for the project, there were some of geometrical constraints we considered. Firstly, has to do with the shape and dimensions of the Stirling engine since we decided to implement a solar parabolic dish collector as the heating source, we decided to design a smaller size so that it can be mounted on the solar collector very easily. In addition, opting for a smaller design will minimize the impact of vibrations that could destabilize the whole system and most importantly the vocal point. Secondly, we decide to go with the horizontal layout to have more stability in operation due to the large surface area. Moreover, it is easier to focus the vocal point directly on the heating chamber in a horizontal layout than a vertical one. Thirdly, the weight of the engine was taken into consideration by optimize the weight of the engine because it will be mounted on the solar collector. Lastly, the selection of materials and component dimension were decided to optimize the overall weight while maintaining a good thermal efficiency.

3.1.2: Manufacturing Constraints:

According to our extensive research, manufacturing and assembly of the parts of the engine is probably the most challenging step to complete the prototype. We had to select a workshop that can manufacture the parts within the dimensional tolerance limit especially for the cylinders, pistons and sealing's. Moreover, we decided to select Pyrex Glass as the material for the cylinders, but the lack of specialized workshop in glass manufacturing made us opt for other materials such as stainless steel. However, we decided to only manufacture the necessary parts and buy the rest as we decided to join most of the parts through bolts and joints instead of welding.

3.1.3 Sustainability:

Since the Stirling engine components are exposed to high temperature, high pressure and constant movements, many considerations in material selection had to be made. The metallic components can corrode after a while due to high temperature, so choices of anti-corrosion materials such as stainless steel were considered. Components under high temperature such as the pistons must be made with low thermal conductivity materials like glass wool and stainless steel. Moreover, the joints and the bearings need to be examined after considerable time of operation.

3.1.4: Social Impact:

One of the main objectives of our system is to design to the common population in order to provide a renewable energy and get a lifestyle shift within people's lives, so they can prefer renewable energy instead of grid energy with save money and prevent the atmosphere from pollutants like in camping where one can stay off without the grid energy for several days. Moreover, Stirling engine can be used without a need for fuel but just a considerable amount of heat to get the Stirling engine cycle fired up.

3.1.5: Safety:

There are many safety notes we need to consider in our Stirling engine. First of them, the vocal point is very dangerous, and we need to create a technique that prevents the heat that coming to the chamber so the engine will cool down. Another safety point, we need to make a stand plate for the engine in order to prevent the engine from filling to the ground.

3.1.6: Economics:

One of the most important factors in design a good project is to design a project with high benefits and low cost. Our system consists of Stirling engine which is not be an economic system as compared by other systems, but in the long-run it does offer a great financial profit. In addition, you can save some cost by powering up a Stirling engine instead paying for fuel for grid energy. Moreover, Stirling engine requires less maintenance in order to keep the system operate well. Also, manufacturing and assembling the parts correctly will reduce the chances of breaking down and save some cost.

3.1.7: Ethics:

According to the University policy, each team should design and fabricate a unique idea in order to make a specific project stand out from the previous teams. In our system, we take some ideas and concepts from previous teams and modify these ideas in order to make a project that is different from previous teams and apply the University policy.

3.2 Design Specifications

The specification of our project Gamma-Type Stirling engine is based on the following parameters given in table # 3.2:

Engine Type	Gamma-Type Stirling engine
Engine power (P)	0.2 Watt
Engine Speed (N)	400-600 rpm
Mean average pressure (Pm)	101.3 kPa
Hot space temperature (Th)	423 K
Cold space temperature (Tc)	293 K
Working gas	Air
Gas constant (R)	287 J/kg. k
Displacer bore (Bpd)	0.016m
Displacer Stroke (Sdp)	0.0373m
Swept volume displacer (Vsd)	1.748E-5 m3
Power piston bore (Bpp)	0.014m
Power piston stroke (Spp)	0.0143m
Swept volume power piston (Vsp)	2.201E-6 m3

Table # 3.2.: Design Specifications

3.3 Material Selection &Engineering Standards

3.3.1 Material Selection:

For this project, the team has extensively considered the broad variety of materials to pick from in order to assign them for the project’s design and has also took into consideration the restrictions and limitations of each material in terms of its special properties and its cost. However, the following selected materials are considered to be the first draft of selections due to the fact that the team is still not fully informed on the fabricability and availability of the materials in the Saudi market, the following selections might differ from the final product due to unknown future restrictions.

As of now there are 7 main parts for the design of our Stirling Engine:

- Power Piston
- Displacer

- Crankshaft
- Flywheel
- Displacer connecting rod
- Cooling fins
- Cylinder

And there are 3 main materials that will be used for the design:

- Aluminum
- Stainless Steel
- Brass

The team will explain which material will be used for which part in this design and explain our reasoning behind picking these specific materials:

Power Piston:

For the power piston the team will be using 6061-(Al) for its notorious self-lubricating properties under sliding conditions in order to ensure that the power piston will be moving smoothly along the cylinder without causing any disruptions.

Cylinder:

For the cylinder that will be used for heating the team has picked 6061-(Al) for several reasons, the most important reason is for its low thermal expansion property to make sure the cylinder does not elongate or change its shape when put under extensive heating. Another reason is because Stainless Steel has a high melting point that will not be reached in our demonstration for this project.

Displacer:

The material used for the Displacer will be B36-(Brass) depending on its availability and cost in the Saudi market. The reason Brass has been picked for the displacer is because it will be inside and sliding along the heated cylinder, the important properties that Brass has to ensure no inconveniences occur during the demonstration is its high melting point and its self-lubricating property, the combination of these two properties makes it the ideal choice to use for such an important part within the design.

Crankshaft and Displacer Connecting Rod:

6061 Aluminum will be used for the crankshaft and B36 Brass will be used the displacer connecting rod, the reason behind choose aluminum for crankshaft is that aluminum has high corrosion and fatigue resistance. The Brass has been selected for displacer connecting rod because it has high resilience and high fatigue resistance to ensure that the parts do not fail, break or wear after only several demonstrations.

Cooling Fins:

6061 Aluminum has been picked for the cooling fins because they are light, it does not apply heavy loading on the engine itself. As well as its known dissipation of heat, it is considered an ideal material for good heat transfer due to its ability to absorb heat from the engine and dissipate it to the air at a higher rate from most materials.

Flywheel:

For the flywheel, B36 Brass has been picked because the brass is easy to shape and very light weight material.

3.3.2 Engineering Design Standards:

Component	Engineering Standards
Cooling Fins	ASTM: 6061-(Al)
Flywheel	ASTM: B36-(Brass)
Displacer Connecting Rod	ASTM: B36-(Brass)
Crankshaft	ASTM: 6061-(Al)
Displacer	ASTM: B36-(Brass)
Cylinder	ASTM: 6061-(Al)
Power piston	ASTM: 6061-(Al)

Table3.3.2: Engineering Standards

3.4 Theory and Theoretical Calculations

Length of Working Piston Cylinder = 0.043 m

Length of Displacement Cylinder = 0.086 m

Length of Heating Zone of Displacement Cylinder = 0.06 m

Length of Cooling Zone of Displacement Cylinder= 0.026 m

Bore of Displacement Piston = 0.016 m

Bore of Working Piston = 0.014 m

Stroke of Displacement Piston = 0.0373 m

Stroke of Working Piston = 0.0143 m

Total dead Volume = 5.56062E-6 m^3

Parameter	Symbol
Pressure	P
Maximum Volume	V_1
Minimum Volume	V_2
Maximum Temperature	T_h
Minimum Temperature	T_c
Work	W
Compression ratio	r_c
Heat Energy	Q
Efficiency	η
Net Power	$Pnet$

Table # 3.4: Calculations Parameters

Assumptions:

$P_1 = P_{atm} = 101.325$ kPa

$T_1 = T_{min} = 293$ K

Gas Constant for Air = $R_{air} = 287$ J/kg-K.

$T_2 = T_{max} = 423$ K

Compression ratio = $r_c = 1.2$

Calculations of Volumes:

1) $V_{SE} = \left(\frac{\pi}{4}\right) * B_{dp}{}^2 * S_{dp}$

= 7.4996E-6 (m^3)

2) $V_{SC} = \left(\frac{\pi}{4}\right) * B_{pp}{}^2 * S_{pp}$

= 2.2013E-6 (m^3)

3) $V_E\ (\alpha) = \frac{V_{SE}}{2} * (1 - \cos\alpha)$

4) $V_C\ (\alpha) = \frac{V_{SE}}{2} * (1 + \cos\alpha) + \frac{V_{SC}}{2} * (1 - \cos(\alpha - \varphi))$

5) $V\ (\alpha) = V_E + V_D + V_C$

$\alpha = 0\ to\ 360$ $\varphi = 90$

A	V_E	V_C	V
0	0	8.60025E-6	1.416087E-5
90	3.7498E-6	3.7498E-6	1.306022E-5
180	7.4996E-6	1.10065E-6	1.416087E-5
270	3.7498E-6	5.9511E-6	1.526152E-5
360	0	8.60025E-6	1.416087E-5

V max = V1 = 1.526152E-5 (m^3)

V min = V2 = 1.306022E-5 (m^3)

Calculations:

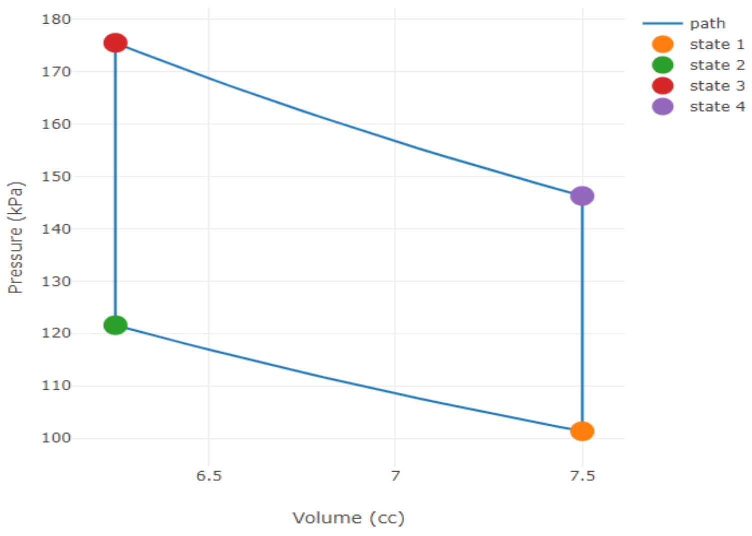


Figure # 3.4 (a): Stirling Cycle PV Diagram

At State 2;

$$P_2 = \frac{P_1 V_1}{V_2} = P1 * r_c$$

$$P_2 = (101.325) * (1.2)$$

$$P_2 = 121.59\ kPa$$

At State 3;

$$P_3 = \frac{P_2 T_h}{T_c}$$

$$P_3 = \frac{(121.59)(423)}{(293)}$$

$$P_3 = 175.53\ kPa$$

At State 4; $P_4 = \frac{P_3}{r_c}$

$$P_4 = \frac{(292.563)}{(1.2)}$$

$$P_4 = 146.28\ kPa$$

For work done in Process 1-2; $Q_{1-2} = W_{compression} = P_1 V_1 \ln(\frac{1}{r_c})$

$$Q_{1-2} = W_{compression} = (101325)(1.526152 \times 10^{-5})\ln(\frac{1}{1.2})$$

$$Q_{1-2} = W_{compression} = -0.2819\ J$$

For work done in Process 3-4; $Q_{3-4} = W_{expansion} = P_3 V_3 \ln(r_c)$

$$Q_{3-4} = W_{expansion} = (175530)(1.306022 \times 10^{-5})\ln(1.2)$$

$$Q_{3-4} = W_{expansion} = 0.4179\ J$$

For Total Work Done in Cycle; $W = W_e + W_c$

$$W = (0.4179) + (-0.2819)$$

$$W = 0.136\ J$$

For Cycle Efficiency; $\eta_{total} = 1 - \frac{T_C}{T_H}$

$$\eta_{total} = 1 - \frac{293}{423}$$

$$\eta_{total} = 30.7\ \%$$

Power calculation:

Let, us assume the rpm of flywheel (N) = 300 rpm

Since, rpm is not the SI unit so, we convert it into either the rad/sec or unit of frequency (Hz or per sec).

$1rpm = \frac{1}{60}Hz$, the corresponding frequency = $\frac{300}{60}$ = 5 HZ

$Pnet = Wnet * frequency = 0.136 * \frac{300}{60} = 0.68\ watt$

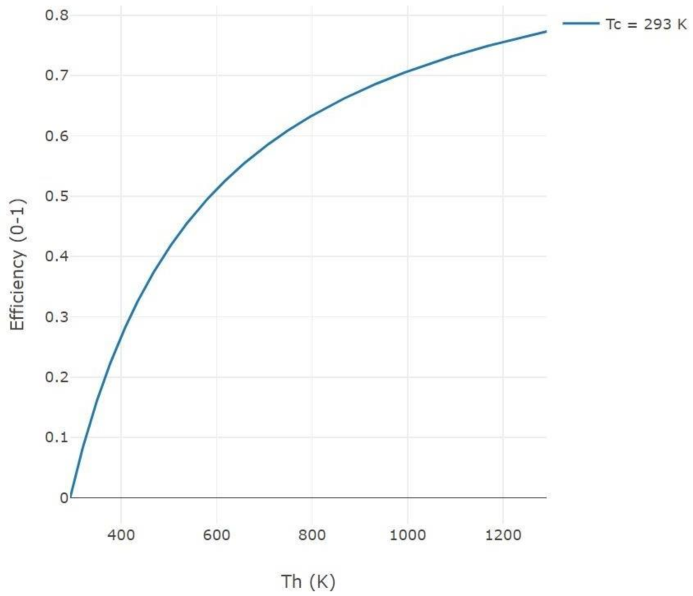


Figure # 3.4 (b): Stirling Cycle Efficiency Graph

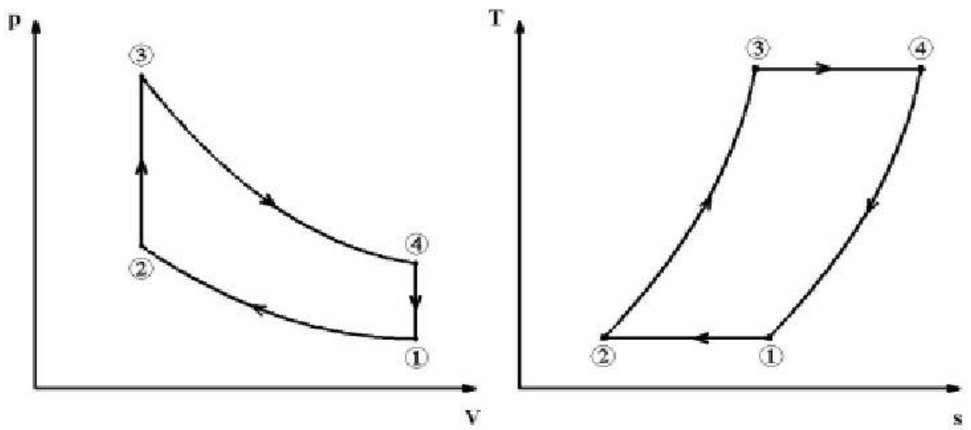


Figure # 3.4 (C) PV (left) and TS (right) Diagrams of an Ideal Stirling Cycle

Calculation of Solar collector:

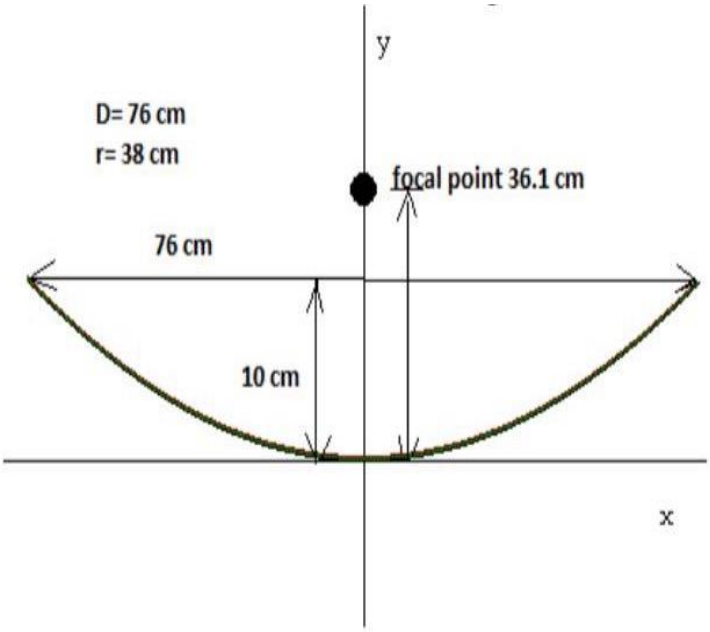


Figure # 3.4 (d): Solar Collector focal point

- The diameter of the curvature is 76 cm and the width is 60 cm
- The focal point is 36.1 cm from the vertex
- The following equation was used to decide on the focal point;

  Y= x2 /4a

  x2 = 1444 cm2

  4a = 4*10 = 40 cm

  1444 cm2 / 40 cm = 36.1 cm (focal point)

3.5 Manufacturing Processes & Assembling

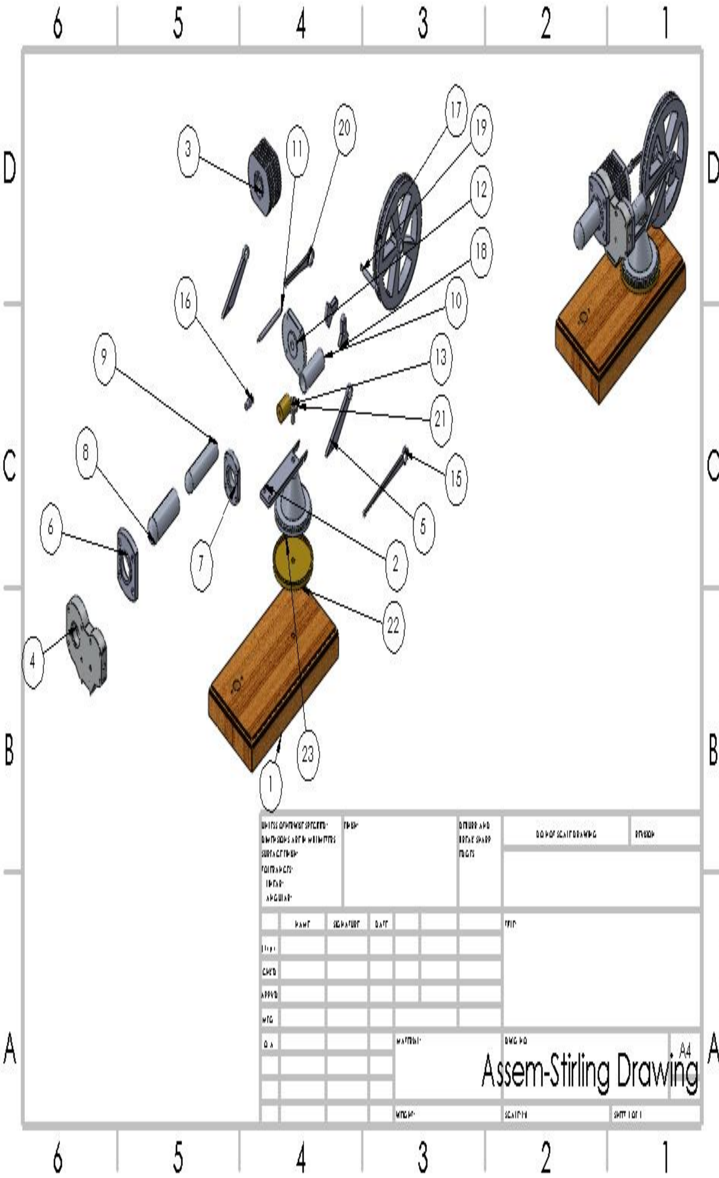
Most of parts are made by using three manufacturing processes which are turning, milling and drilling process. Also, most of parts selected from aluminum alloy due to its ability to stand heat and it has light weight. The Stirling engine's flywheel of a 100 mm diameter as the largest part in this design first was made by brass with turning and milling processes using CNC 3D universal machine. However, brass was found to be heavy on the system, so aluminum was the better choice and the same processes were used to make aluminum flywheel. Heating chamber/cylinder of a size of 20 mm and 60 mm in length is made from aluminum with using turning manufacturing process to stand high heat and for its light weight. Similarly, the displacer of the heating chamber/cylinder was made out aluminum to stand heat and be self-lubricate with the same process which is turning process. The connecting rods made of brass that is connected to the displacer of the heating chamber/cylinder are made by milling process with the drilling process to achieve the final dimensions of 94 mm and 13 mm diameter / 2 mm diameter with the rods ends. The other connecting rod for the working piston with 58 mm length and 10 mm diameter / 2.5 mm diameter at ends was made out of brass as well to balance the system.

Moving to bearing support and base of a size of 128 mm length and 20 mm in width was made of steel with milling process to have strong support to all components being assembled.

Figure # 3.5 (a): CNC Universal Machine

Assembling:

Assembly the parts was done using proper sizes of 2.5 mm pins and 11* 5/4 ball bearing placed at the bearing support. Simply flywheel is mounted by a shaft of a size of 4 mm diameter with cranks placed with the bearing support. Then displacer and working piston are mounted by pins with their proper connecting rods to be placed inside the chamber/cylinder of the heating and cooling. Furthermore, glide bearing, and cylinder plate are mounted with the cooling fins to have the hole system mantled together and ready to be tested.



ITEM NO.	PART NUMBER	QTY.
1	Wooden Plate	1
2	Plate	1
3	Fins	1
4	Connecting Channel	1
5	Supports	2
6	Displacer Flange(Alu)	1
7	Clamping Flange Work Cylinder	1
8	Displacer Cylinder (Aluminium)	1
9	Displacer (Aluminium)	1
10	work cylindrer	1
11	Displacer axis	1
12	cylinder plate	1
13	brass piston	1
14	Piston Fork	1
15	Piston Driving Rod	1
16	Fork for Displacer Rod	1
17	Fly Wheel	1
18	Crank Web	2
19	Fly Wheel Axis	1
20	Displacer Driving Rod	1
21	central engine fastening	1
22	circular base 1	1
23	circular base 2	1

Figure # 3.5 (b): Stirling Engine Assembly & Exploded View

Chapter # 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

Since our design was still under construction, we used an alpha type Stirling engine designed and fabricated by a previous group in order to test the concept of providing heat energy by a parabolic solar collector.

4.1.1 Tachometer

We started this data acquisition by measuring all the significant parameters needed to evaluate the engine performance. Moreover, we measured the output flywheel's angular speed in revolutions per minute (rpm) using a tachometer. The setup was conducted by attaching a small strip on the side of the flywheel and then the laser was directed towards it to read the revolutions. However, the reading was around 738 rpm while the temperature of heating chamber was around 160 degrees Celsius. Moreover, the tachometer has following specifications;

Non-Contact Measurement	50 to 9999RPM ± (0.03% + 2)
Measuring Distance	50 mm to 250 mm
MAX/MIN/AVG Function	Yes
Data Hold	Yes
Display Back Light	Yes
Low Battery Indication	Yes
Size	19 x 11 x 16 cm/ 7.6 x 4.4 x 2.4
Weight	288g / 9.6 oz

Table # 4.1.1: Tachometer Specifications

Figure # 4.1.1: Tachometer

4.1.2 Multimeter

The data acquisition was conducted determine the amount of voltage being produced by the flywheel towards the attached DC motor via a narrow strip of rubber belt. At the other end, a DC motor with LED strip was attached to the engine and the voltages were measured by attached the LED to the output (with load).

Additionally, the current reading was needed to determine the power output of the system and the reading of the tachometer was 16.1 mA. This value of current was then used to calculate the power our system was making under optimum conditions from the formula ***P =I* x *V***.

Furthermore, the multimeter used to measure the data in the table above has following specifications;

Manufacturer	B & K Precision
Category	Digital Multimeter
Accuracy	3%
Number of Digits	3 ¾ Digit LCD
Voltage Range	66 mVDC to 1000 VDC, 660 mVAC to 750 VAC
Resistance Range	660 ohms to 66 MOhms
Capacitance Range	6.6 nF to 66 mF
Display Count	6600
Frequency	660 Hz to 66 MHz
Ranging	Auto, Manual
True RMS	Yes
Data Hold	Yes
Weight	285 g
Size	165 mm x 42.5 mm x 78 mm

Table # 4.1.2: Multimeter Specifications

Figure # 4.1.2: Multimeter

4.1.3 Infrared Thermometer

For this testing parameter, the heat provided by the solar collector to the heating chamber was measured. Infrared thermometer was used to measure the temperature in a non-contact manner. Given the fact that the vocal point can reach up to 275 degrees Celsius this type of testing equipment was necessary. After exposing the heating chamber to the vocal point, the reading of the temperature in the heating chamber were calculated. Additionally, the infrared thermometer used had the following specifications;

Temperature range	-50 - 380℃ (-58~716°F)
Accuracy	±1.5% or ±1.5℃
Repeatability	±1% or ±1℃
Distance Spot Ratio	12:1
Emissivity	0.95 preset
Response Time	500 ms
Wavelength	8-14µm
Data Hold	Yes
Auto Power Shut Off	Yes
Power supply	2 x 1.5V AAA battery
Weight	115.1g
Size	144.5 x 38 x 93 mm

Table # 4.1.3: Infrared Thermometer Specifications

Figure # 4.1.3: Infrared Thermometer

Testing Equipment	Objective
Tachometer	**To obtain the output angular speed (rpm)**
Multimeter	**To obtain the electrical outputs**
Infrared Thermometer	**To obtain the operating temperatures**

Table # 4.1 (a): Testing Equipment Objectives

4.2 Results, Analysis and Discussion

Data obtained from performing the setups in order to get our system performance figures, following tables have been compiled which illustrates the electrical and temperature outputs separately.

Parameter	Reading
V: Voltage (V)	2.6
I: Current (A)	0.0161
Power (W) **P = I x V**	0.04186

Table # 4.2 (a): System Electrical Outputs

Hot Cylinder Temp. (°C)	Cold Cylinder Temp. (°C)
275	34

Table # 4.2 (b): System Temperature Outputs

Discussion

As visible from table 4.2 (a), the power output was calculated at the output flywheel since it was attached to the 12 Volt D.C. motor which would eventually produce enough current and voltage to light up an LED strip. In addition, the table 4.2 (b) shows us the temperature input given to the hot cylinder which heats up to a certain limit as there is a cooling reservoir concentric to the hot cylinder to keep it at a controlled level of heat, the cooling cylinder reached to a maximum temperature of 34 ^{O}C from standard room temperature of 20 ^{O}C. As out LPG stove could reach a temperature of 900 ^{O}C, the flame was regulated effectively and controlled to avoid the temperature levels reaching at a risky point where it can affect some of the components in our system.

Parabolic Dish Solar Collector

Since we decided to implement a solar parabolic dish collector as the heating source, we decided to measure the temperature of solar collector at different times using Infrared Thermometer. The following table shows the temperature of solar collector at different times.

Figure # 4.2.1: Parabolic Dish Solar Collector

Time	Temperature (^{o}C)
2:10 PM	120
2:20 PM	144.3
2:30 PM	170.7
2:40 PM	196.3

Table # 4.2 (c): Solar Collector Temperatures

Chapter # 5: Project Management

5.1 Project Plan

In our project, there are many different tasks included. Each task is assigned almost equally to every member of our team. Each member of the team has enough time in order to accomplish his part successfully. The following tables 5.1 (a) & 5.1 (b) presents all information about tasks, team members and the duration of each task to be completed.

#	Tasks		Start	End	Duration
1	Chapter 1: Introduction		1/22/2019	1/29/2019	7
2	Chapter 2: Literature Review	Project Background Previous Work Comparative work	1/22/2019	2/3/2019	12
3	Chapter 3: System Design	Design Methodology Design Constraints Material Selection Engineering Standards Design Specification Theoretical Calculations Designing all parts in solidworks, assembly and exploded view Manufacturing of parts and Assembling	2/4/2019	3/5/2019	30
4	Chapter 4: System Testing & Analysis	Testing the Prototype Data Acquisition Calculation of actual efficiency, work and power output Results & analysis	3/13/2019	3/23/2019	10
5	Chapter 5: Project Management & Project Analysis	Project Plan Contribution of Team members Project Execution Monitoring Challenges & Decision Making	3/24/2019	4/7/2019	12

		Project Bill of Materials & Budget			
6	Chapter 6: Project Analysis	Life Long Learning Impact of Engineering Solution Contemporary Issues Addressed	4/9/2018	4/15/2018	7
7	Chapter 7: Conclusion & Recommendation	Conclusion Future Recommendation	4/16/2018	4/19/2018	4

Table# 5.1 (a): Tasks and their duration

S. No.	Task	Assigned Members
1.	Chapter # 1: Introduction	All Members
2.	Chapter # 2: Literature Review	Abdulaziz AL-Olayan Abdullah AL-Shammari Mohammed AL-Otaibi
3.	Chapter # 3: System Design	Abdulaziz AL-Janoubi Abdulaziz AL-Olayan Abdullah AL-Shammari
4.	Chapter # 4: System Testing & Analysis	All Members
5.	Chapter # 5: Project Management	Abdulaziz AL-Olayan Abdullah AL-Shammari Mohammed AL-Otaibi
6.	Chapter # 6: Project Analysis	Abdulaziz AL-Janoubi Abdullah AL-Shammari Mohammed AL-Otaibi
7.	Chapter # 7: Conclusion & Recommendation	Abdulaziz AL-Olayan Abdulaziz AL-Janoubi
8.	Design of Prototype	All Members
9.	Parts Purchased	Abdullah AL-Shammari Abdulaziz AL-Janoubi
10.	Manufacturing	All Members
11.	Testing	All Members

Table #5.1(b): Assigned members for Tasks

5.2 Contribution of Team Members

The performance of each team member play a significant role in fulfilling the requirements of the project. Each task was assigned to each team member depending on his ability of doing the task and the time required to complete the task. The table (5.2) below illustrates how much contribution was made by each team member.

#	Tasks		Assigned	Cont. %
1	Chapter 1: Introduction		All	100%
2	Chapter 2: Literature Review	Project Background	Al-Olayan	33%
			Al-Shammari	33%
			Al-Otaibi	34%
		Previous Work	Al-Olayan	25%
			Al-Shammari	25%
			Al-Otaibi	50%
		Comparative Study	Al-Olayan	30%
			Al-Shammari	30%
			Al-Otaibi	40%
3	Chapter 3: System Design	Design Constraints and Design Methodology	Al-Janoubi	50%
			Al-Olayan	25%
			Al-Shammari	15%
			Al-Otaibi	10%
		Material Selection Engineering Standards Design Specification	Al-Janoubi	50%
			Al-Shammari	50%
		Theoretical Calculations	Al-Shammari	50%
			Al-Olayan	30%
			Al-Otaibi	20%
		Designing all parts in solidworks, assembly and exploded view	Al-Janoubi	50%
			Al-Shammari	40%
			Al-Otaibi	10%
		Manufacturing and Assembly	Al-Janoubi	50%
			Al-Shammari	50%
4	Chapter 4: System Testing & Analysis	Testing the Prototype Data Acquisition	All Members	100%

		Calculation of actual efficiency, work and output power Results & Analysis	All Members	100%
5	Chapter 5: Project Management	Project Plan Contribution of Team members Project Execution Monitoring Challenges & Decision Making Project Bill of Materials & Budget	Al-Shammari Al-Olayan Al-Otaibi	100%
6	Chapter 6: Project Analysis	Life Long Learning Impact of Engineering Solution Contemporary Issues Addressed	Al-Janoubi Al-Olayan Al-Otaibi	100%
7	Chapter 7: Conclusion & Recommendation	Conclusion Future Recommendation	Al-Shammari Al-Janoubi	100%

Table # 5.2: Contribution of Tasks

5.3 Project Execution Monitoring

In order to make our project reach a high level of developing, we had many activities which relates to improve our project. These activities include meetings with our adviser and among our team members. Moreover, these activities present important feedback on the project. The following table (5.3) shows the list of meeting and other activities for our project:

Time/Date	Activities/Events
Once in week	Assessment Class
Weekly	Meeting with the group members
Bi-Weekly	Meeting with the Advisor
19 March, 2019	First Finished Prototype
21 March, 2019	Midterm Presentation

27 March, 2019	First Test of System
10 April, 2019	Finishing Final Prototype
14 April, 2019	Test of the System
18 April, 2019	Final Submission of Report
18 April, 2019	Final Presentation

Table # 5.3: Dates of Activities and Events

5.4 Challenges and Decision Making

In order to develop our project and reach a final stage of development, we faced some problems which effect the progress of our project and acted as obstacle to overcome. However, after successions of different suggestions and review, they were eventually rectified. The problems that we faced are the following:

5.4.1 Equipment and Device Problems

Cylinder

In order to make system very light weight and transferring heat very effectively, we had difficulty in select the type of material that will be used for heating and cooling cylinders. Since, Pyrex Glass was not available in the market, aluminum came out the best alternative material that it can be used for heating and cooling cylinders.

Pistons

Since our system requires a proper seal while operation, piston selection became a struggle in identifying the alternative material that can achieve the goals of our project. Eventually, after doing some research and visited a lot of material markets, aluminum was subjected to be the best alternative as it very light weight and its structure allow for compression.

5.4.2 Testing & Safety Issue

Since our project depends on providing heat through the vocal point, measures of cautions were considered. Moreover, the heat from the vocal point can reach up to 200 degree Celsius which might cause severe injuries when exposed to the human body. Therefore, we used non-contact measuring equipment such as the infrared thermometer and the tachometer. Also, we had to make sure that the vocal point is covered to provide an easier way to shut down the engine properly.

5.4.3 Design Problems

In our system, there were two main problems which are workshop and vibrations. For the workshop, we faced many difficulties to find a workshop that can manufacturing our system with correct dimensions. For vibrations we did not realize about the vibrations that the system will produce when we will mount the engine on the parabolic solar collector dish and there was no chance to reduce the weight of engine. We ran in a trouble to reduce the vibrations of the engine since we have no chance to make modifications on the design of engine. So, we decided to design a stand plate for the engine in order to prevent the engine from filling to the ground and reduce the occurrence of vibrations.

5.5 Project Bill of Materials & Budget

The following table illustrates the materials that we purchased and their costs in Saudi Riyals (SAR). This table includes also the manufacturing costs of the parts.

Materials	Cost (SAR)
Crankshaft	300
Displacer Connecting Rod	200
Flywheel	500
Power Piston	150
Cooling Fins	450

Displacer piston	150
Flanges	200
Base	150
Bearings	90
Rubber O-rings	35
Bearing Supports	100
Fasteners	50
Piston Cap	80
Crank Webs	180
Screws	50
Washers	45
Piston Fork	45
Manufacturing all parts	1000
Workshop Cost	1000
Total	4775

Table # 5.5: Project Bill of Materials

Chapter # 6: Project Analysis

6.1 Life-long learning:

Throughout the semester our group has taken the opportunity of using our senior project as a way of applying the competencies that we have learned through our core curriculum, most importantly the critical thinking, problem solving and teamwork competencies. By effectively communicating and working with each other as a team we were able to keep a timely-schedule in order to efficiently finish our project in time. For this chapter we will be discussing the important skillsets and experiences that we have gained by working on this project.

6.1.1 Software skills:

For this project the most helpful and effective software that we have utilized is SolidWorks, in order for us to manufacture our project, the team had to design each part of the prototype using the skills we learned from our Computer Aided Design course so that the team can acquire the specific details and dimensions to provide workshops to manufacture the parts for us to assemble. We were also able to finish all of the milestone and monthly progress requirements with the help of Microsoft Word and Excel by using them to write our reports and contract our own Gantt chart.

6.1.2 Hardware Skills:

During this project we have utilized certain devices in order to collect the required data and test our engine to acquire the results, the group has used three main devices: The tachometer, voltmeter and infrared thermometer. The tachometer is a device that instantaneously measures and displays the amount of rotations the flywheel undergoes every minute. The thermometer is a device that infers temperature from the thermal radiation emitted by the engine, we have used this device to obtain the temperature that the solar collector is able to emit onto the insulated cylinder of the engine. Lastly, the group has used the voltmeter which is an instrument that is used to measure electric potential between two points of the electric circuit, this has helped the group acquire the voltage that the engine is able to generate.

6.1.3 Time Management Skills:

The most important factor in the completion of our senior project is our time management. By creating, dividing and assigning tasks to each member of the group to finish in a specific time frame, we were able to submit all our reports, milestones, and monthly progresses before their respective deadlines. The task of creating our own Gantt chart in the beginning of the semester was helpful for us to initiate and maintain our time management skills.

6.1.4: Project Management:

As a group of four we were able to evenly divide the work between each member, for some tasks the work was done in pairs and for other tasks each member had his own individual task. The team would meet three times a week to update each other on our work, share and collect other work from other members and to make sure that no one is facing any issues with his particular task. The work was divided due to each person’s specialization, for example the members that were very good at SolidWorks were assigned to design the parts while the members that were articulate and fast at typing were assigned to handle the research and reports in order to finish both tasks on time.

6.2 Impact of Engineering Solutions:

6.2.1 Society:

Our project aims to replace other sources of energy in areas where Stirling engines are able to work in order to produce a cheaper alternative for people in need, it is portable enough to leave it on a rooftop or next to a window in order to charge a battery or a cell phone.

6.2.2 Economy:

The Stirling engine can be viewed as an affordable alternative for people who are not fortunate enough to be able to pay for other means of energy or electricity. It also has the capability to replace other engines in areas where there are huge differences in temperature in order to minimize economical cost.

6.2.3 Environmentally:

The Stirling engine is unique because unlike other engines it does not have an exhaust and the working gas can be pure air, it is complete solar and clean energy that does not contaminate nor cause any sort of pollution to its surrounding environment.

6.3 Contemporary Issues Addressed

Saudi Arabia has been well known as the country producing most of the world's fossil fuels after the United States of America. However, as of recently the country has announced that limiting our dependence from fossil fuels to be one of the backbone goals of Vision 2030. We believe that focusing and learning about renewable, solar and overall clean energy is the most effective way to further our dependence of oil. By studying and learning more about clean engines such as the Stirling engine we will be able to put it in effective use in fields and that can minimize the use of other internal combustion engines. This direction can also be a very important path to tackle an issue even more important than just Saudi Arabia's dependence of oil, which is the issue of climate change, the faster we rely on clean energy the better it will be to minimize and stop the effects of climate change not just in Saudi Arabia but all over the world.

Chapter # 7: Conclusion & Future Recommendations

7.1 Conclusion

To sum up, this senior year project was a necessity, not just as a degree requirement for the Bachelor of Mechanical Engineering but also for the judgement of our understanding, knowledge and the skill sets we have gained over the timespan of 4 years while in the pursue of completing our bachelor's program. We faced numerous setbacks during the overall completion of our prototype and had to face some really tense situations where we had a face a big troublesome hurdle as we have had numerous design flaws, manufacturing defects and poor material selections over the time. On the other hand, we were finally able to produce a working setup of our prototype.

The overall prototype was constructed on the framework of a parabolic solar concentrator which was effectively powering the Stirling engine by heating up the lower part of the hot-cylinder to create compression and give us those much-desired power cycles. Even though the produced amount of power from our scrap-built Stirling engine was not enough to be used in the domestic applications, it overall is productive and gives us the result we were opting for which eventually was the main objective of this whole project.

Additionally, we would like to thank and pay gratitude for all the personnel who assisted us in making this project possible and productive. Moreover, we are confident enough that to further decrease the consumption of a burning source for Stirling engines, we can harness and use the solar heat from the sun to power up the Stirling engine.

7.3 Future Recommendations

As the overall project for our design project progressed very well, due to time limitations and a very tight plan to work in, we often experienced setbacks and failures which were bound to show up as a surprising factor. But, nevertheless, after proper commitment and teamwork, those were very well handled, managed and rectified. However, as a team, we still think that our recent project could be revamped in the following manner:

- Use a secondary source of heat at night times when there is no sunlight for powering the Stirling engine.
- Add vibrational dampers to absorb operational vibrations at high speeds.
- A sturdy and reliable elastic sheath in the cold cylinder to avoid puncturing and compression losses as experienced with the balloon.

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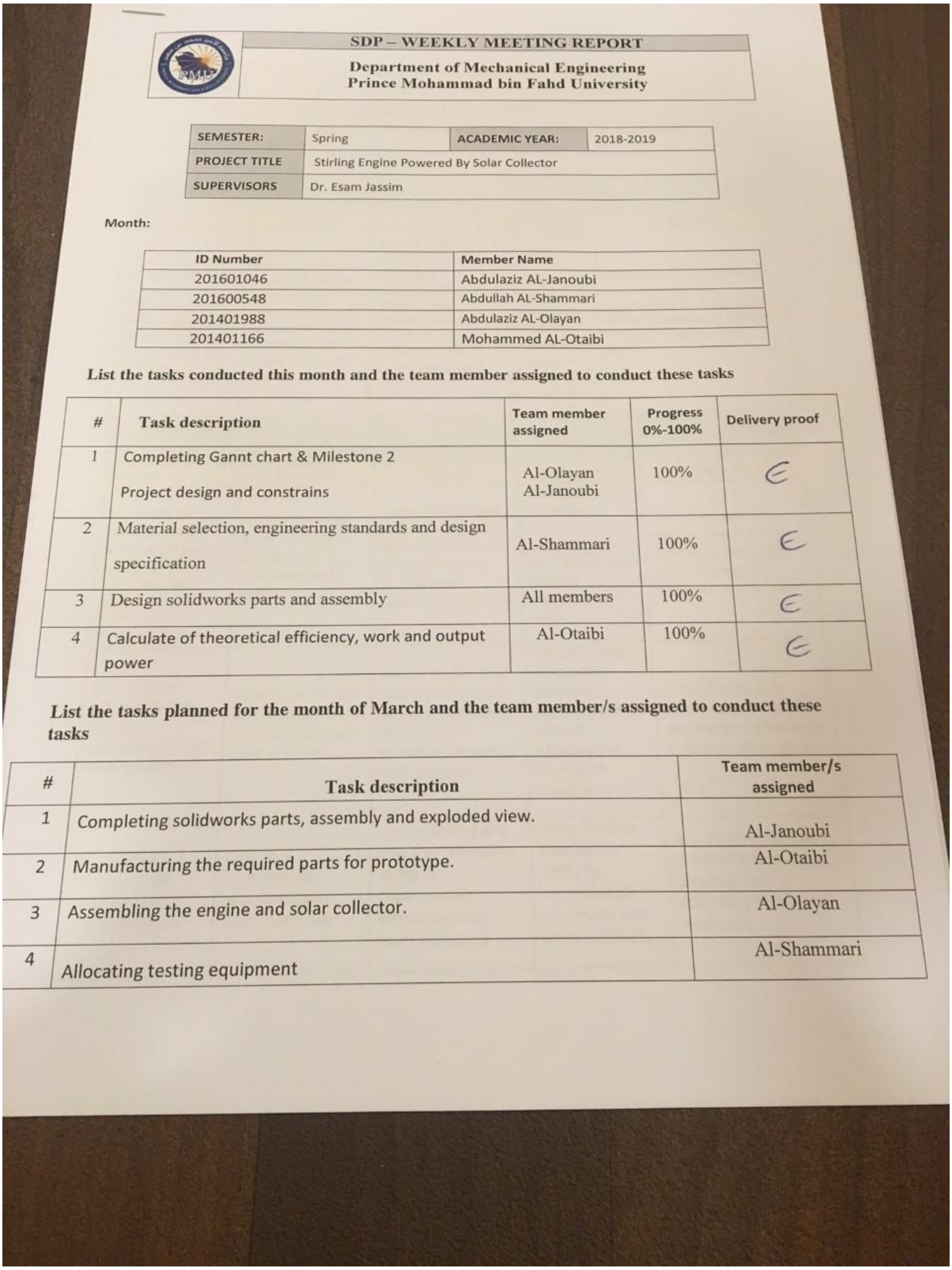
Appendix I: Monthly Progress Reports



SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2018-2019
PROJECT TITLE	Stirling Engine Powered By Solar Collector		
SUPERVISORS	Dr. Esam Jassim		

Month:

ID Number	Member Name
201601046	Abdulaziz AL-Janoubi
201600548	Abdullah AL-Shammari
201401988	Abdulaziz AL-Olayan
201401166	Mohammed AL-Otaibi

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	Completing Gannt chart & Milestone 2 Project design and constrains	Al-Olayan Al-Janoubi	100%	E
2	Material selection, engineering standards and design specification	Al-Shammari	100%	E
3	Design solidworks parts and assembly	All members	100%	E
4	Calculate of theoretical efficiency, work and output power	Al-Otaibi	100%	E

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	Completing solidworks parts, assembly and exploded view.	Al-Janoubi
2	Manufacturing the required parts for prototype.	Al-Otaibi
3	Assembling the engine and solar collector.	Al-Olayan
4	Allocating testing equipment	Al-Shammari

5	Completing Milestone 4 & 5	All Members

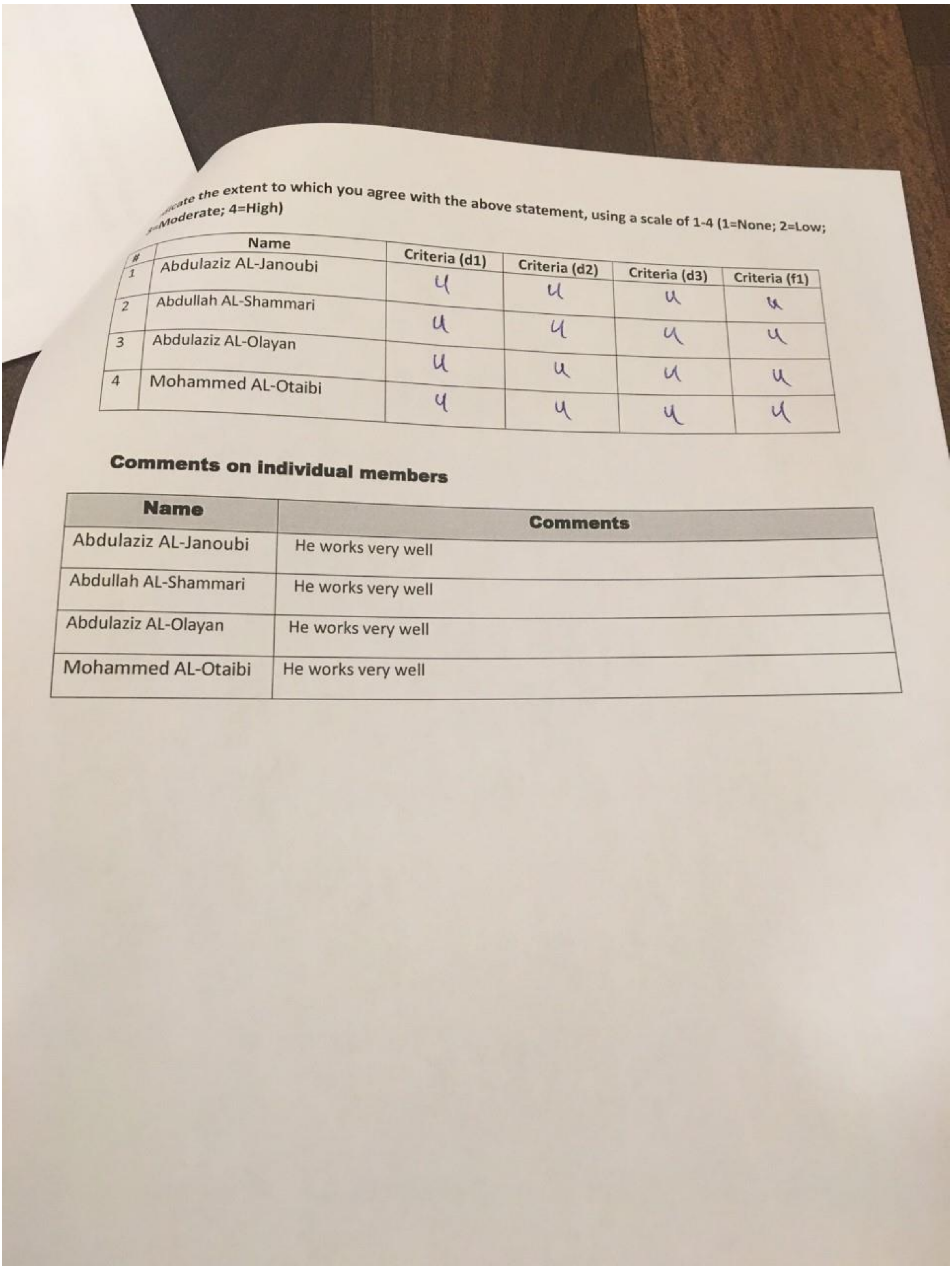
- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f:
An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d:
An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. 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	3. Understands and communicates properly and effectively with team members



icate 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 (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	Abdulaziz AL-Janoubi	4	4	4	4
2	Abdullah AL-Shammari	4	4	4	4
3	Abdulaziz AL-Olayan	4	4	4	4
4	Mohammed AL-Otaibi	4	4	4	4

Comments on individual members

Name	Comments
Abdulaziz AL-Janoubi	He works very well
Abdullah AL-Shammari	He works very well
Abdulaziz AL-Olayan	He works very well
Mohammed AL-Otaibi	He works very well

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2018-2019
PROJECT TITLE	Stirling Engine Powered By Solar Collector		
SUPERVISORS	Dr. Esam Jassim		

Month:

ID Number	Member Name
201601046	Abdulaziz AL-Janoubi
201600548	Abdullah AL-Shammari
201401988	Abdulaziz AL-Olayan
201401166	Mohammed AL-Otaibi

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	Assembling all the parts, engine and solar collector.	Al-Janoubi	100%	E
2	Testing the prototype by using different methods	Al- Shammari	100%	E
3	Run the tests and obtain the values of hot cylinder temperature and speed of the flywheel.	Al-Olayan	100%	E
4	Calculation of actual efficiency, work and output power.	Al-Otaibi	100%	E
5	Completing Milestone 5	All members	100%	E

List the tasks planned for the month of (April) and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Gathering testing results and analysis of the results.	Al-Janoubi
2	Project management and project analysis.	Al-Otaibi
3	Project analysis	Al-Olayan
4	Future recommendations of the project.	Al-Shammari
5	Completing Milestone 6& 7	All Members

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

Outcome f:
An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d:
An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. 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	3. Understands and communicates properly and effectively with team members

icate 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 (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	Abdulaziz AL-Janoubi	4	4	4	4
2	Abdullah AL-Shammari	4	4	4	4
3	Abdulaziz AL-Olayan	4	4	4	4
4	Mohammed AL-Otaibi	4	4	4	4

Comments on individual members

Name	Comments
Abdulaziz AL-Janoubi	He works very well
Abdullah AL-Shammari	He works very well
Abdulaziz AL-Olayan	He works very well
Mohammed AL-Otaibi	He works very well

Appendix II: Gannt Chart

Task	Start Date	Days to Complete	Assigned Member
Project definition	1/22/2019	5	Al-Olayan
Project objectives	1/22/2019	2	Al-Olayan
Project specifications	1/22/2109	3	Al-Otaibi
Project applications	1/22/2019	3	Al-Otaibi
Background	1/25/2019	7	Al-Janoubi
Previous work	1/25/2019	6	Al-Shammari
Comparative work	1/25/2109	5	Al-Shammari
Design methodology	2/3/2019	5	Al-Janoubi
Design Constraints	2/3/2019	3	Al-Janoubi
Design specification	2/3/2019	3	Al-Olayan
Material selection	2/4/2019	3	Al-Otaibi
Engineering standards	2/4/2019	3	Al-Shammari
Theoretical calculations	2/5/2019	7	Al-Shammari
Design parts in Solidworks	2/8/2019	7	Al-Janoubi + Al-Shammari
Manufacturing of parts	2/9/2019	21	Al-Janoubi + Al-Shammari
Design Stirling engine base	2/11/2109	10	Al-Olayan + Al-Otaibi
Assembling	3/7/2019	5	All team members
Testing the prototype	3/13/2019	3	All team members
Data acquisition	3/13/2019	3	All team members
Calculation of work	3/16/2019	2	Al-Olayan
Calculation of efficiency	3/16/2019	3	Al-Otaibi
Calculation of power	3/16/2019	3	Al-Shammari
Results and Analysis	3/19/2019	3	Al-Janoubi
Project plan	3/23/2019	3	Al-Olayan
Contribution of team members	3/23/2019	3	Al-Otaibi
Project execution monitoring	3/24/2019	3	Al-Shammari
Challenges and Decision making	3/25/2019	3	Al-Janoubi

Project bill of materials and budget	3/26/2019	2	Al-Otaibi
Life long learning	4/2/2019	2	Al-Shammari
Impact of engineering solutions	4/3/2019	3	Al-Janoubi
Contemporary issues addressed	4/4/2019	3	Al-Olayan
Conclusion	4/6/2019	2	Al-Shammari
Future recommendations	4/8/2019	3	Al-Otaibi
Complete the final report	4/12/2019	3	All team members
Brochure & Banner	4/13/2019	3	All team members
Booklet	4/13/2019	3	All team members

Appendix III: CAD Model

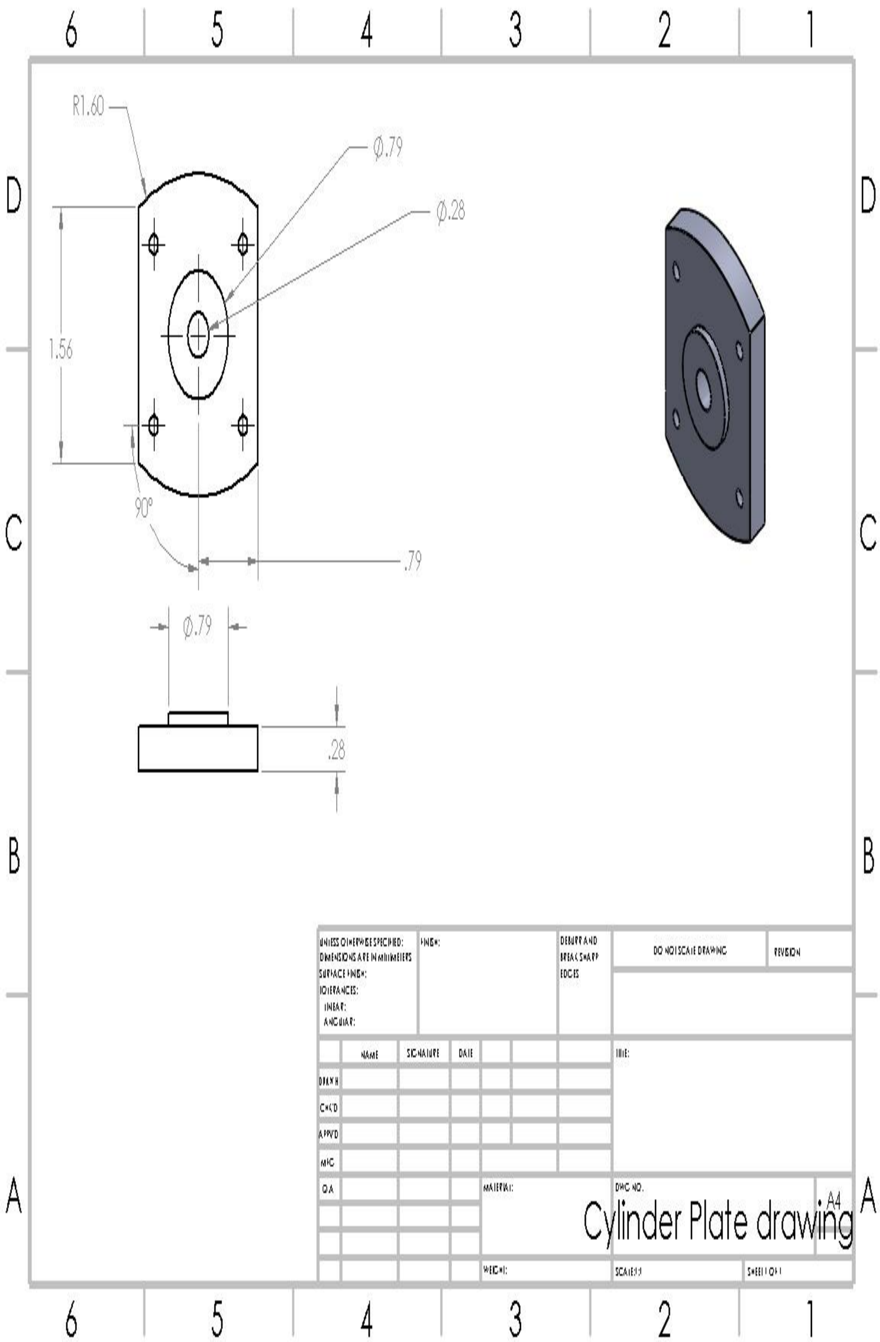


Figure 1: Cylinder Plate drawing

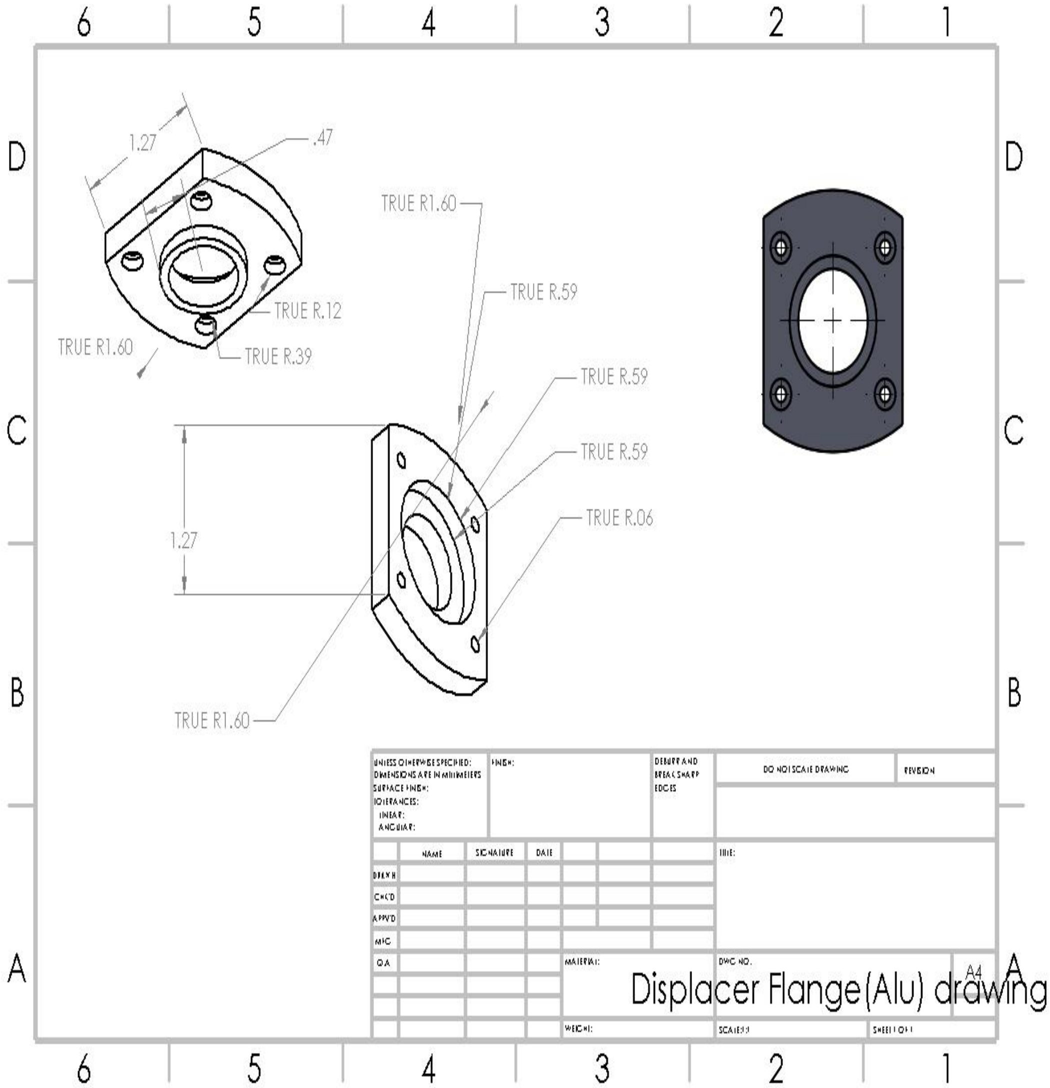


Figure 2: Displacer Flange (Aluminum) drawing

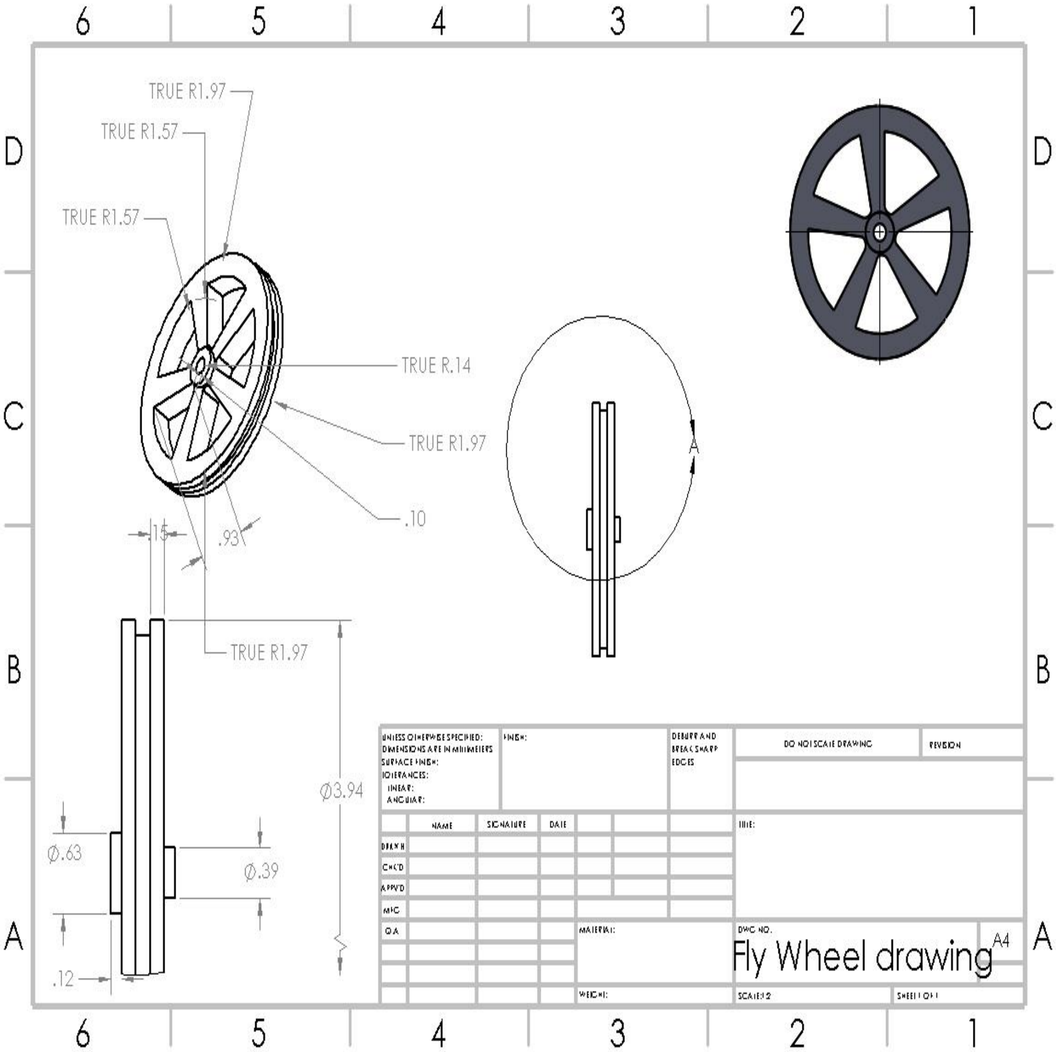


Figure 3: Fly Wheel drawing

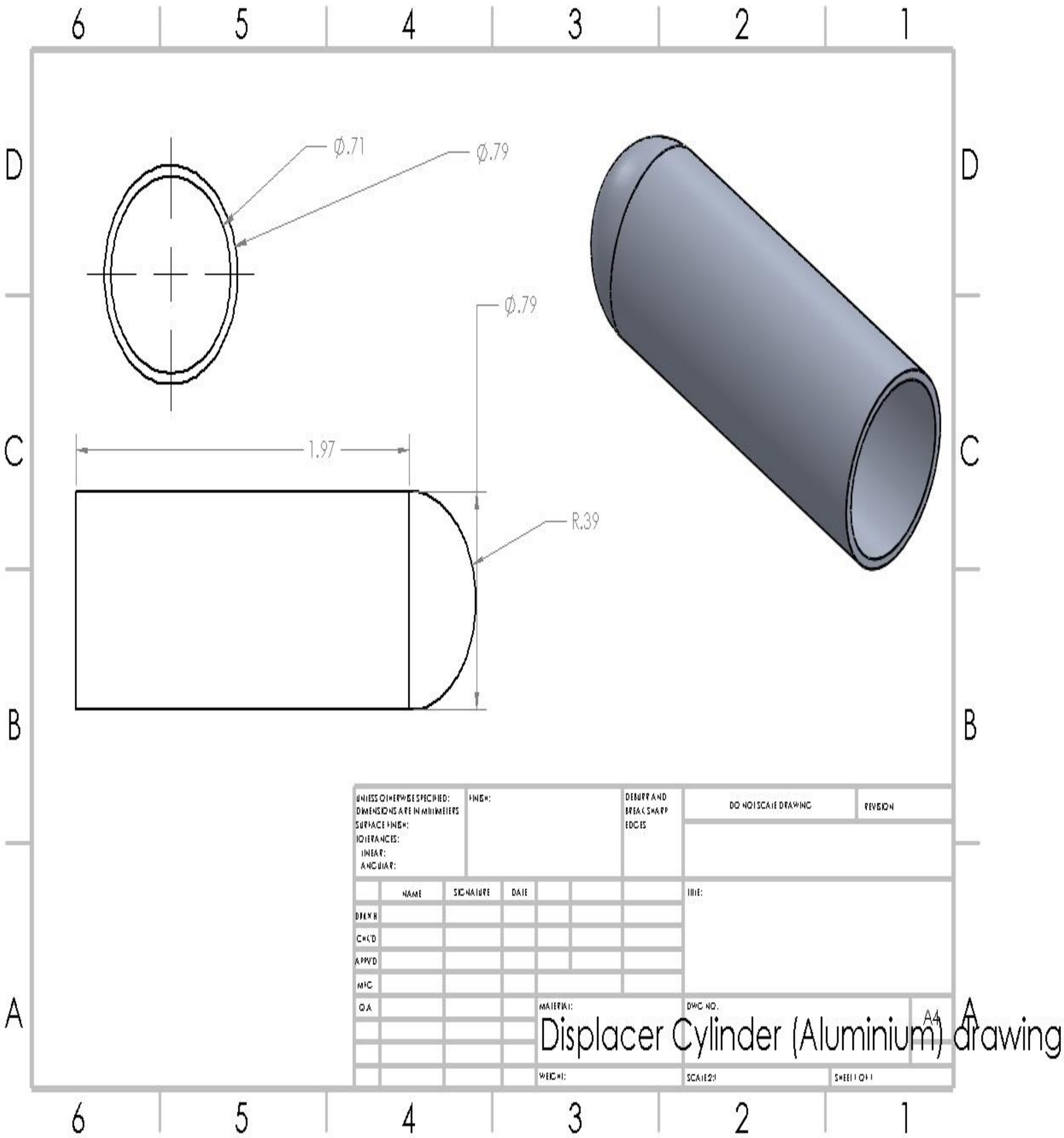


Figure 4: Displacer Cylinder (Aluminum) drawing

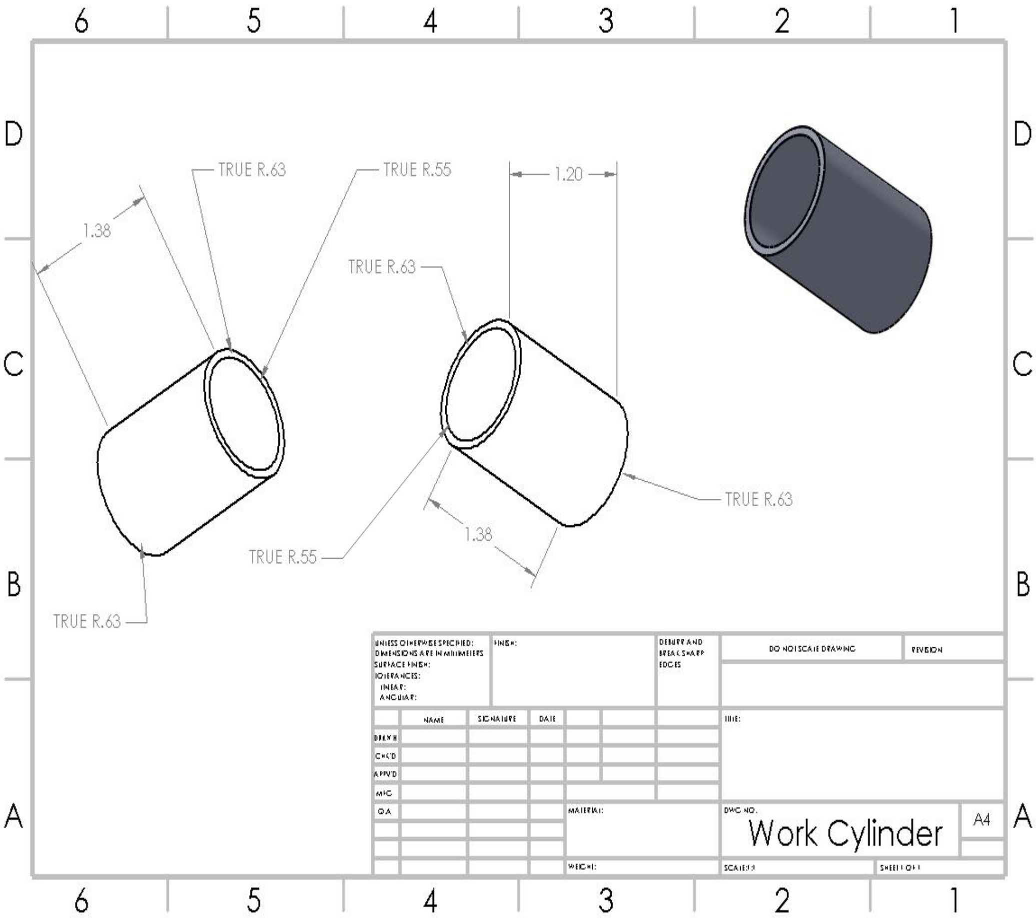


Figure 5: Work Cylinder

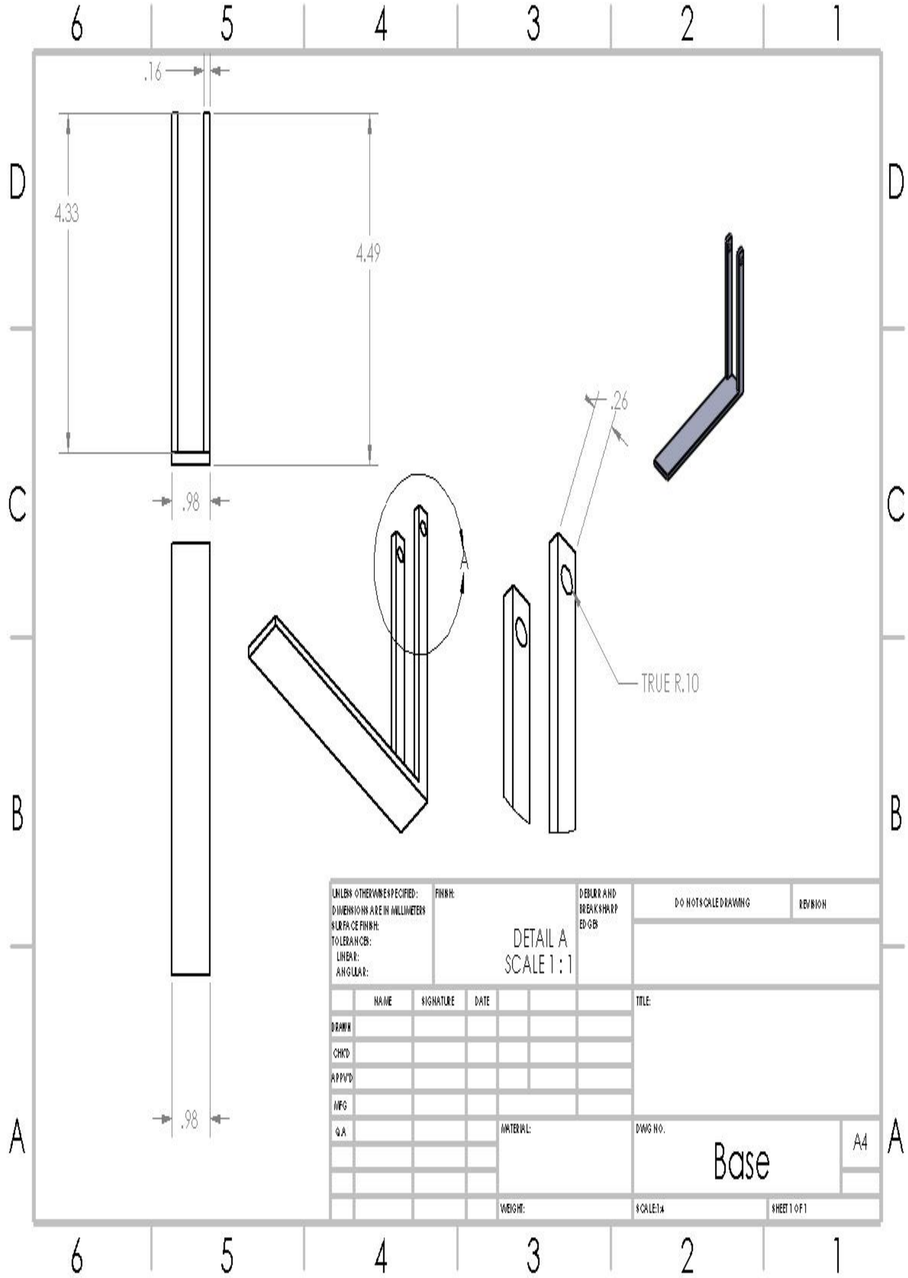


Figure 6: Base

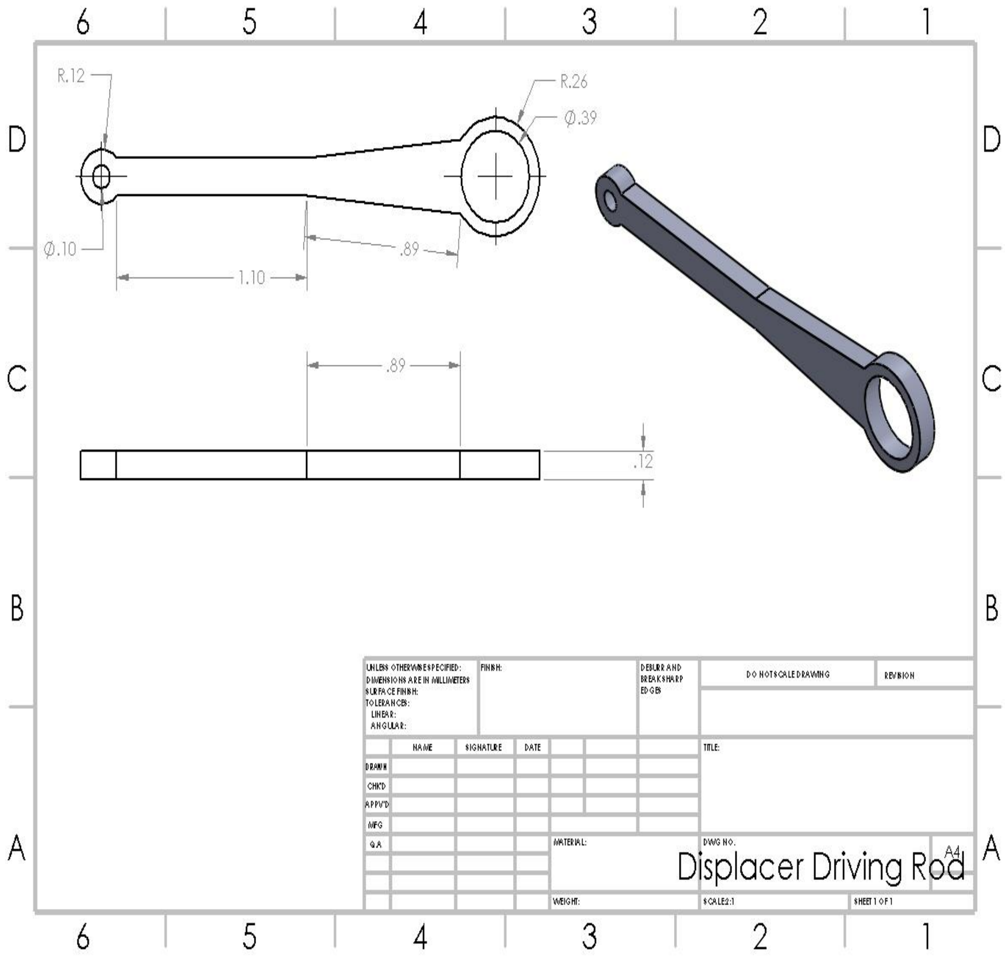


Figure 7: Displacer Driving Rod drawing

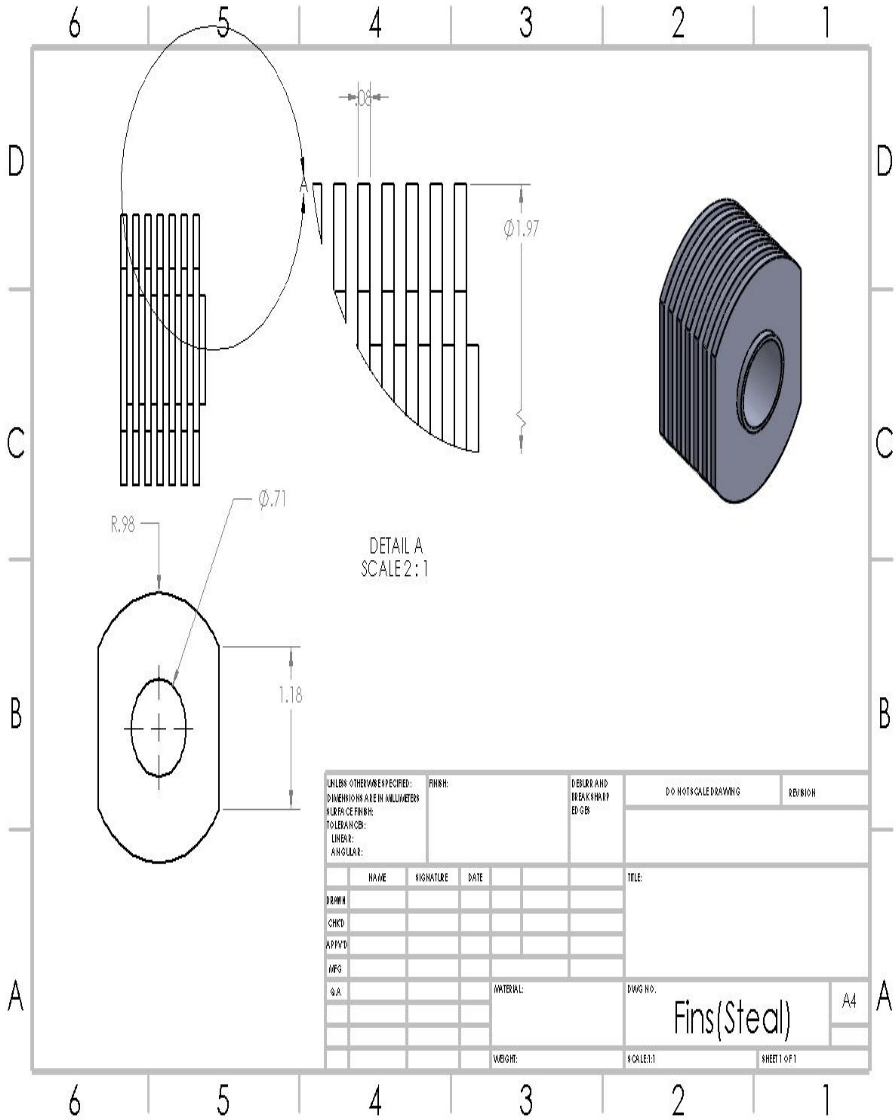


Figure 8: Fins (Steal)

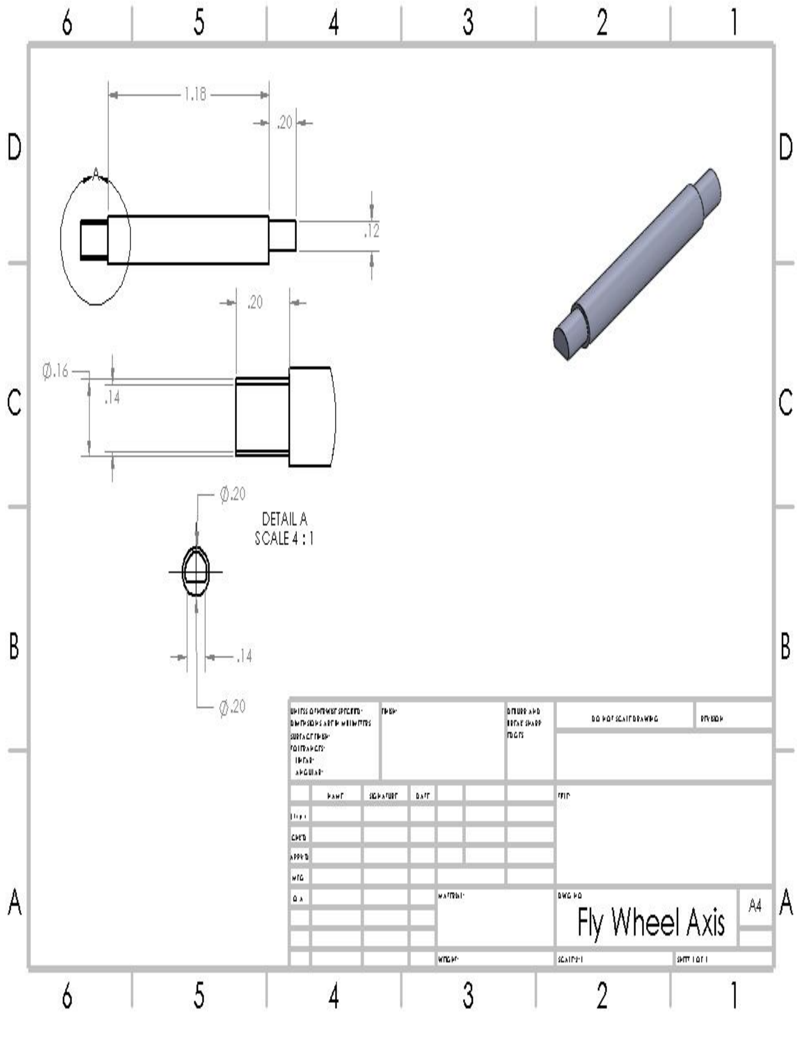


Figure 9: Fly Wheel Axis drawing

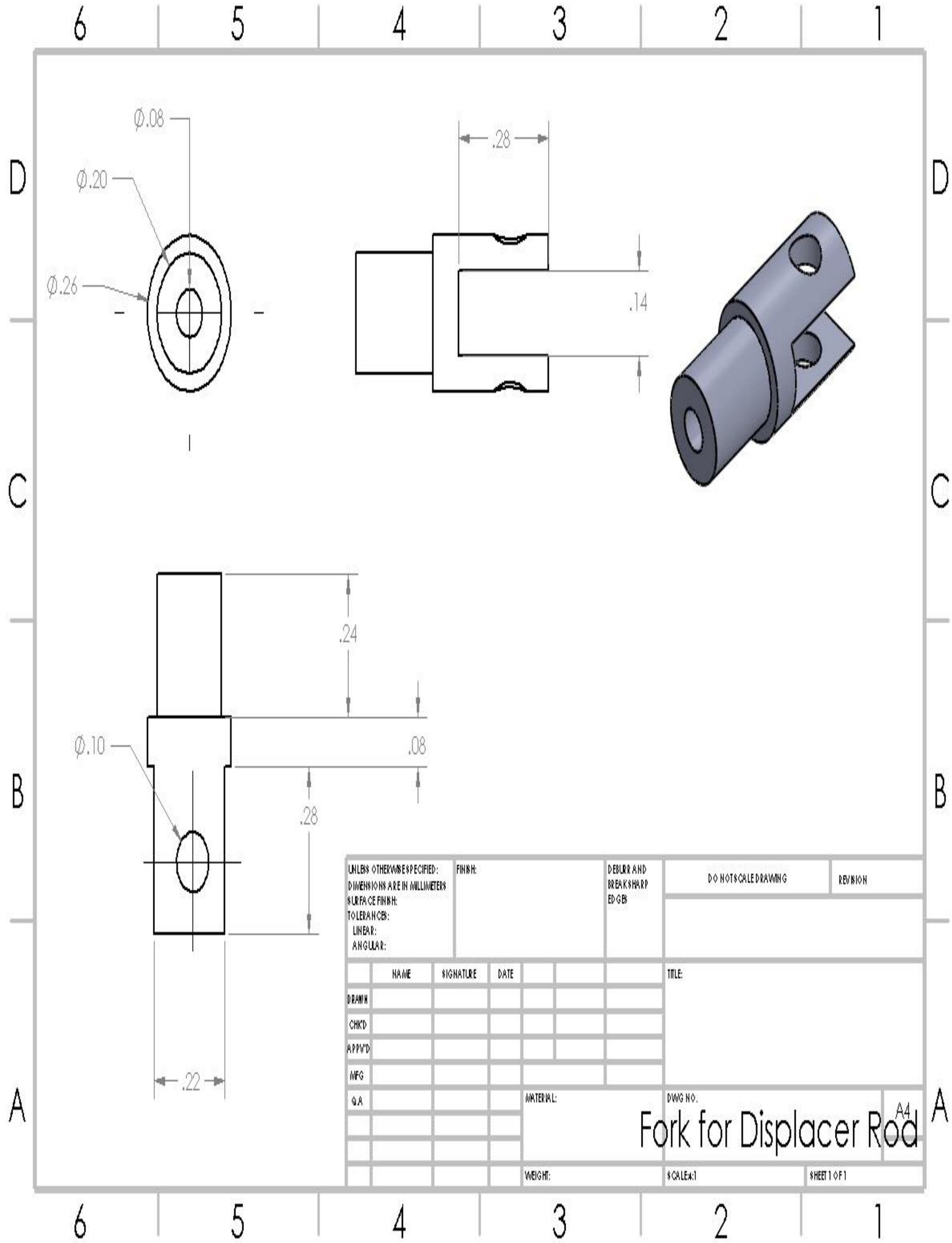


Figure 10: Fork for Displacer Rod

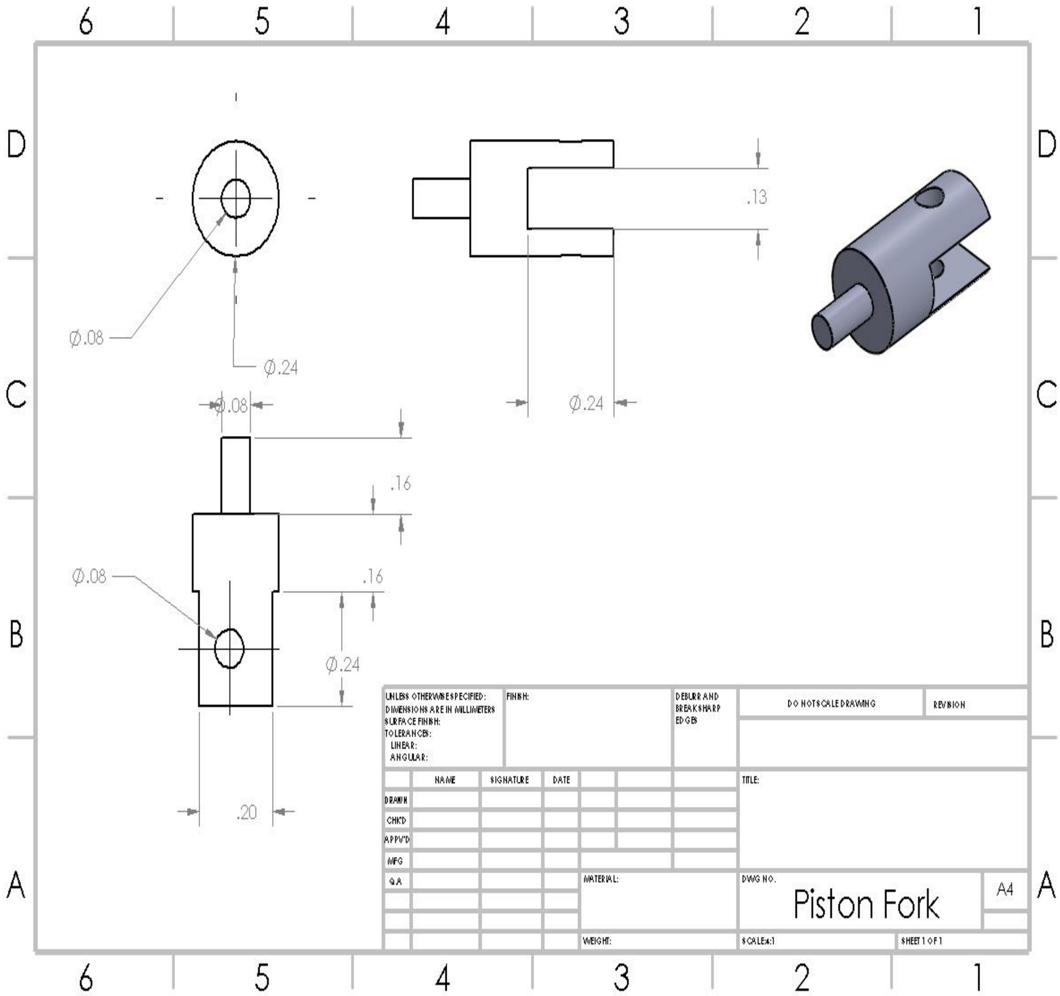


Figure 11: Piston Fork

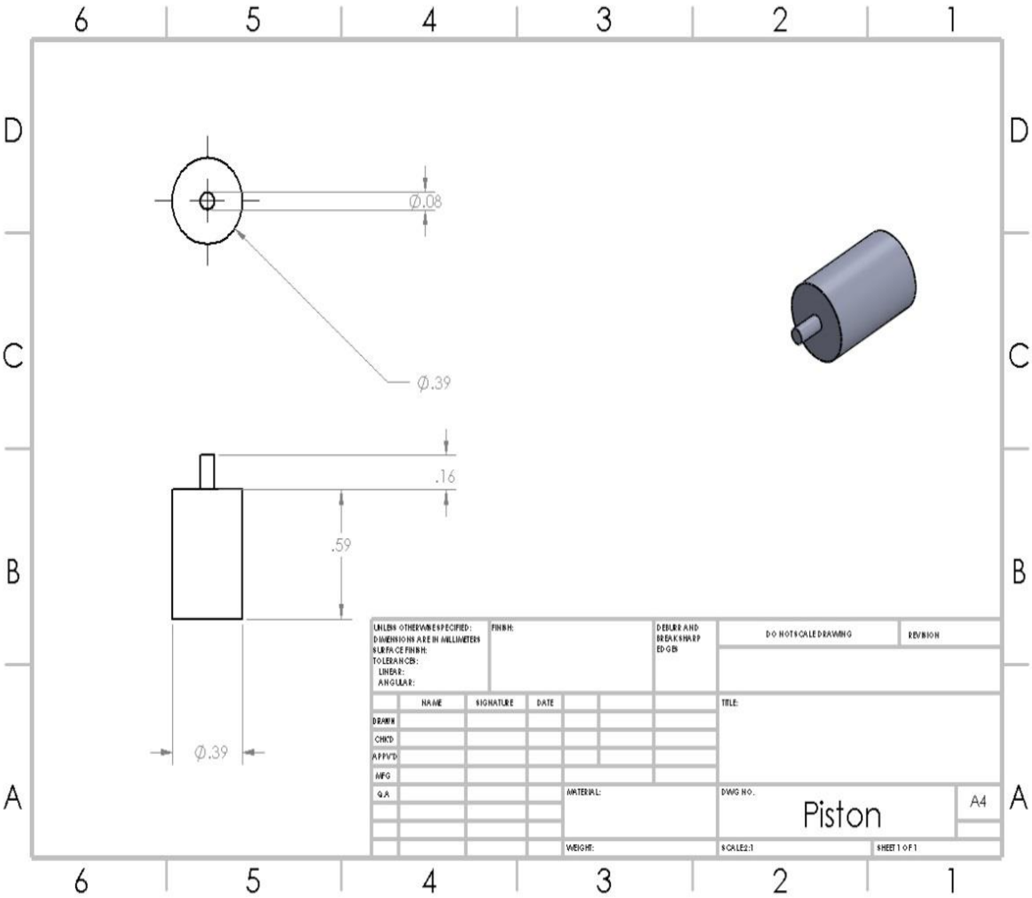


Figure 12: Piston

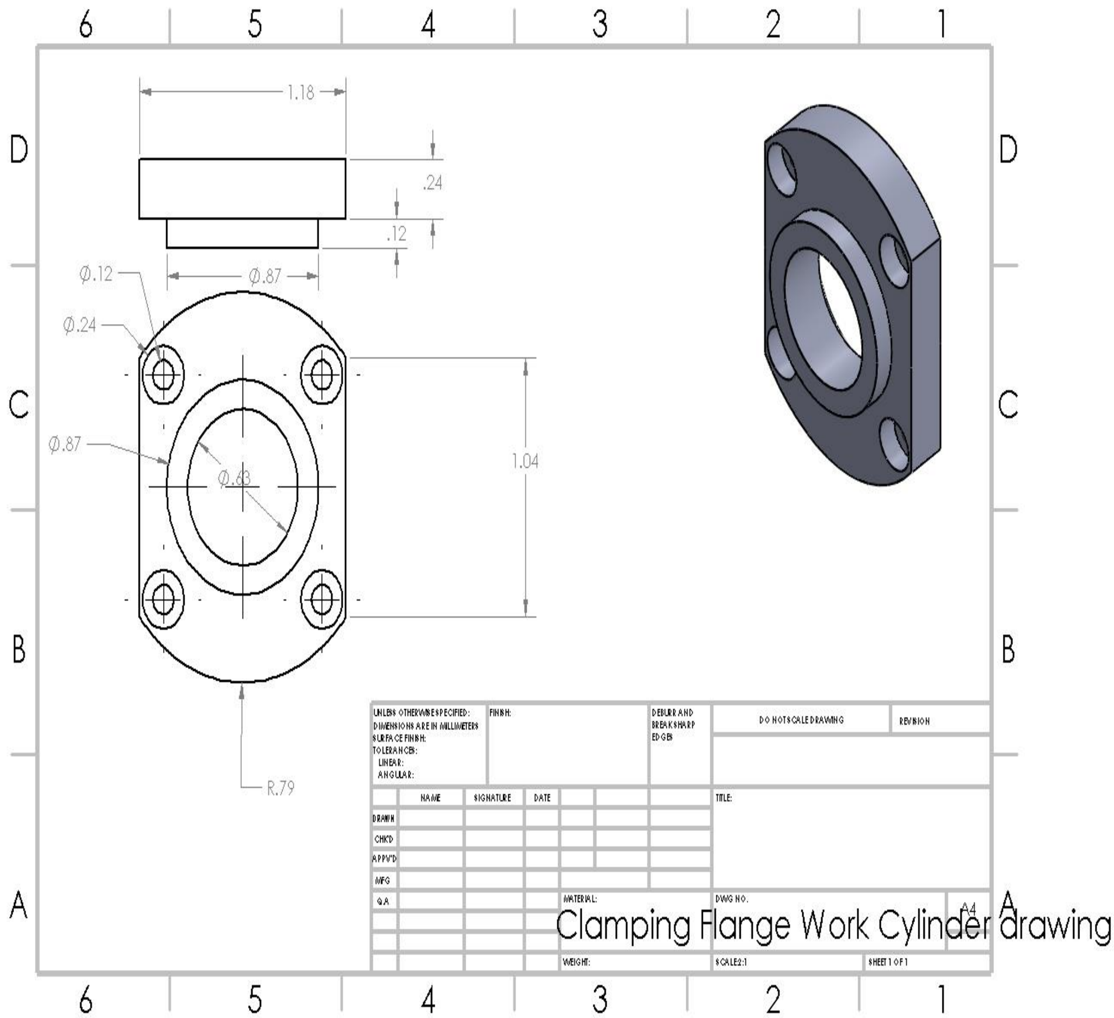


Figure 13: Clamping Flange Work Cylinder drawing

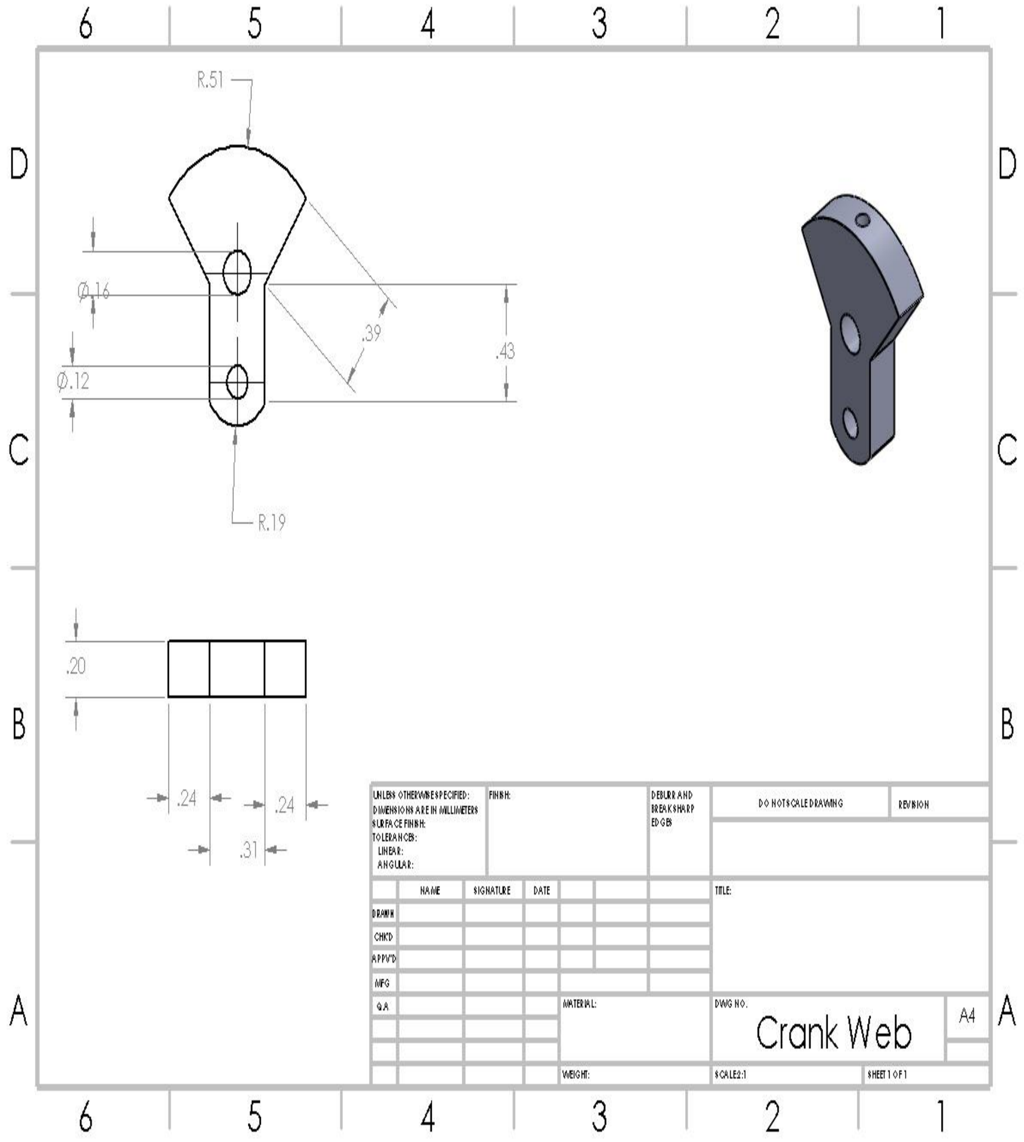


Figure 14: Crank Web drawing

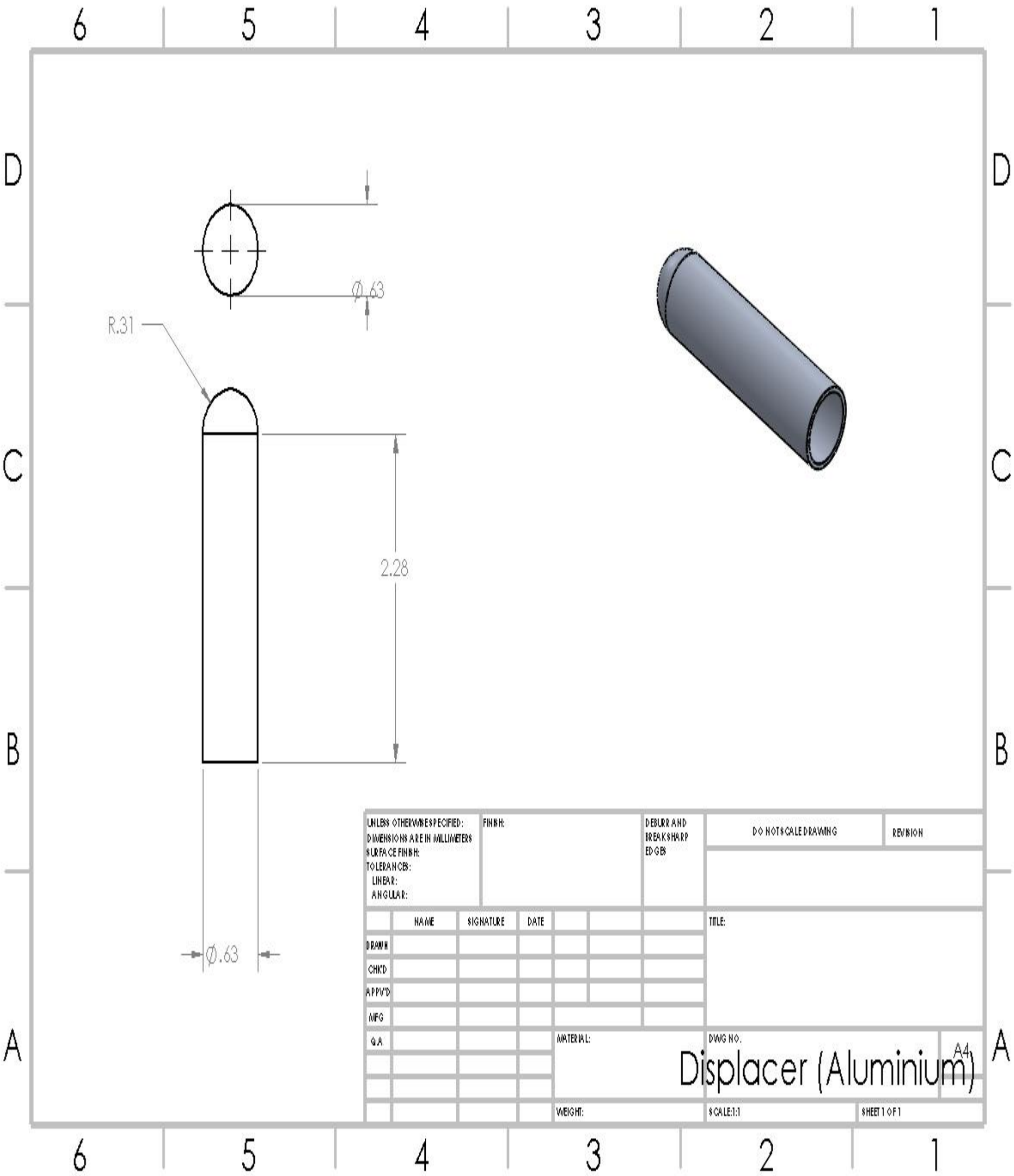


Figure 15: Displacer (Aluminum) drawing

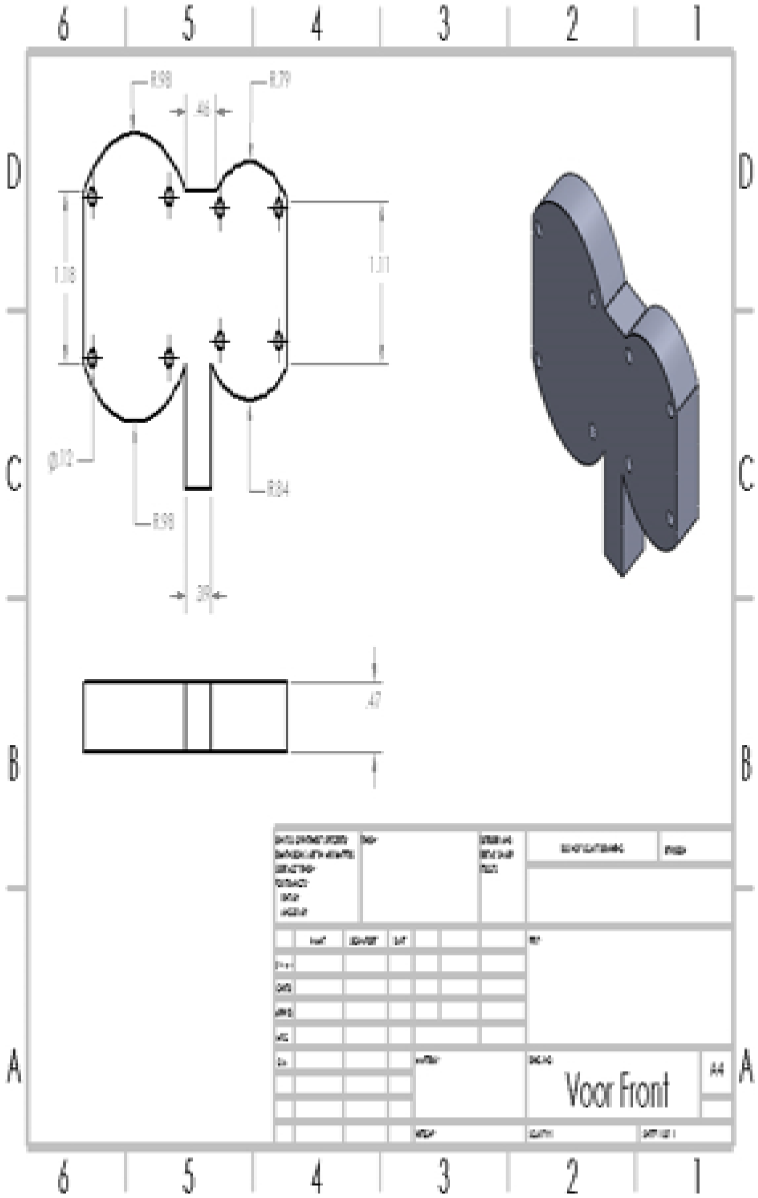


Figure 16: Voor Front drawing

Appendix IIII: Prototype Picture