جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

Design and Manufacturing Directional Drilling

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

Team 15

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Abstract

Oil industry is one of the biggest sectors in Saudi Arabia. There are many leading drilling companies consider Saudi Arabia as their main client. However, exploration drilling is one of the main concerns for those companies. Due to depth of drilling and limitations on changing drilling direction, exploration drilling is very challenging. Our prototype will try to find a solution to direct the drill bit with an angle while drilling without the need to pull out BHA. We will implement the concepts of Fluid Dynamics in order to control the angle and maintain it. The changing of angle can be done through using a piston will be connected to the drilling pipe. The piston helps to bend the drilling pipe with certain forces that will make the drill bit bends as well in the other direction. By controlling the force of piston, we can control bending angle of the drill bit.

Acknowledgments

First of all, we would like to express our appreciation to all those who provided us the possibility to complete this project. A kindly appreciation to senior project advisor Dr. Panos Sphicas for his continued support for our project and his sincere encouragement and suggestions.

Moreover, we would like also to acknowledge with much appreciation to the faculty of Mechanical Engineering Department at Prince Mohammed Bin Fahd University who were interested in helping us to proceed.

Finally, Special thanks go to our team Muteb Alshmmari*, Nayef Alfaleh, Nawaf Alhammad and Fayed Ibrahim, whom participating with high protentional and ultimate energy to build Directional Drilling.

List of Acronyms (Symbols) used in the report:

Symbol	Definition
P	Pressure
F	Force
E	Modulus of Elasticity
r_o	Outer radius
r_i	Inner radius
θ	Deflection of angle
I	Moment of Inertia
D	Diameter
A	Area
L	Length
y_{max}	Curvature

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Chapter 1: Introduction

Many engineering applications, require the drilling a hole deep under the surface of the earth. Such applications include installation of utility lines, land surveying, oil and gas extraction, anchoring of foundations, etc. For these applications, drilling rigs are used. Typically, drilling rigs, are very big structures with many tools and equipment. The size, shape and complexity of rigs vary with the purpose and location of the rig. Medium to small sized rigs, are usually mobile and used in exploration for water or for testing materials. On the other hand, large sized drilling rigs can penetrate deep inside the earth with a depth of thousands of meters, therefore this type of rigs are fixed and mainly used for oil and gas extraction.

Rigs can be classified based on their power source, the pipe used, their height, the method of drilling and the inclination of their derrick. A common characteristic of most rigs is their inability to direct the axis of drilling. Such an ability is called directional drilling and can be categorized into four groups of drilling. 1) The first one is called oil field directional drilling. 2) The second is called utility directional drilling and is mainly horizontal or parallel to surface. 3) The forth is Surface in Seam (SIS). SIS is used to penetrate a wall of reservoir from a horizontal line.

The benefits of directional drilling are generally categorized in three groups. The first one is to increase the exploration parts inside the earth crust by going horizontal instead of vertical. The second reason is some of targeted areas are beneath a very hard to drill formation, therefore best answer is to drill horizontally to reach those areas. Lastly to connect reservoirs from different areas into one main hole, to simplifies the workload and more efficient way rather than building several drilling rigs.

There are many drilling techniques used in drilling sites such as Auger drilling and Hydraulic Rotary Drilling. HRD method is mainly used when there is no need to bring samples of formations to surface for testing.

Although there are many types and methods of drilling, however there are limitations on directional drillings. One of the limitations is the technique on how to build it and control the angle of inclination. As the drilling can reach huge depths, it's hard to control it through cables and wires. One of the ways that is used nowadays is to use a tilted drill bid with fixed angle. But it takes time and efforts for changing the angle of drilling. Drilling companies are searching for ways to control angles of bid while drilling, but few of them worked or can't be implemented on site locations.

1.1 Project Objectives

- Study the literature of drilling.
- Find Applications of directional drilling.
- Design one/two prototypes of directional drilling.
- Successful approach to gathering natural gas and oil.

1.2 Project Specifications:

This project is applicable to all types of Drilling. The Directional Drilling has been selected for this project which has the specifications as listed in table 1.1.

Item	Size
Steel Pipe (Length)	1 m
Steel Pipe (Diameter)	6.5 in
Aluminium Pipe (Diameter)	3.5 in
Aluminium Pipe (Length)	1 m
Pistons (Diameter)	0.5 in

Pistons (Length)	0.75 in
Sleeve Centralizer (Diameter)	6 in
Sleeve Centralizer (Distance between two holes)	1.40 in
Sleeve Centralizer (Diameter of holes)	0.51 in
Sleeve Centralizer (Length)	7.87 in
Spacer (Thickness)	2.50 in
O-ring (Thickness)	0.03 in
Drill Bit (Diameter)	6.5 in

Table1.1: The system measurements

1.3 Applications:

The main applications for the project are:

- To be used for Horizontal Wells
- To be used in Deep oil drilling
- To be used in Drilling beneath inaccessible locations

Chapter 2: Literature Review

2.1 Project Background:

1Whipstock

After drilling the well to the kickoff point, the bit is pulled out of the hole. A whipstock is a wedge that is set in the hole. The fat edge of the wedge is on the bottom of the hole. The drill string is rotated and the bit drills formation to the planned direction. Forced against the side of the hole, it starts to cut out of the original hole. After drilling below the whipstock, the bit is pulled out of the hole again. The drilling assembly is run back in. The deviation at the bottom of the hole will be worn and cut away as operations continue.

Whipstocks are often used to sidetrack the well out of casing. Instead of a drill bit, a mill is used that can cut metal. In this application, the whipstock is left in place to guide tools through the cut in the casing. The drill string will bend to allow the bottom hole assembly to go around the curved hole.

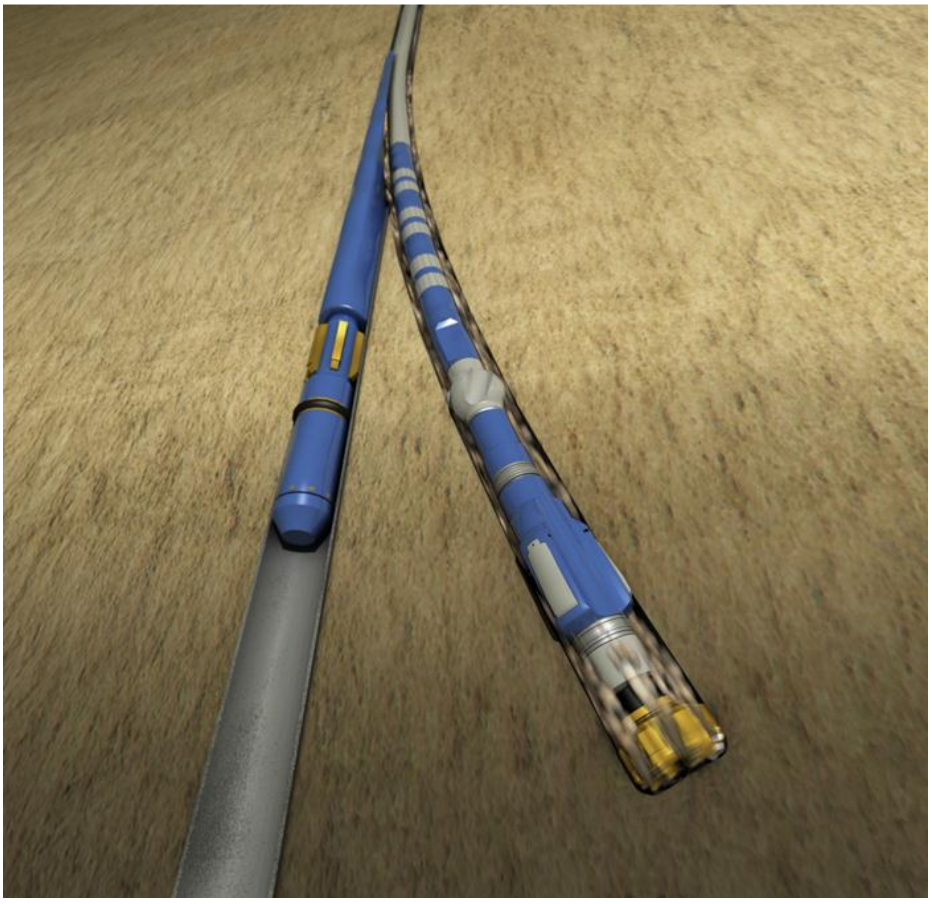


Figure 2.1: Whipstock

2 Rotary Bottom Hole Assembly

Rotary Bottom hole Assemblies
There are three basic types of rotary bottom hole assemblies used in directional drilling: Building Assemblies, Dropping Assemblies, and Holding Assemblies

A building assembly is intended to increase hole inclination, a dropping assembly is intended to decrease hole inclination, and a holding assembly is intended to maintain hole inclination. It should be noted that a building assembly might not always build angle. Formation tendencies may cause the assembly to drop or hold angle. The building assembly is intended to build angle. The same is true for the dropping and holding assemblies.

Before the invention of measurement while drilling (MWD) tools and steerable motors, rotary bottom hole assemblies (BHA) were used to deflect wellbore. A bottom hole assembly is the arrangement of the bit, stabilizer, reamers, drill collars, subs and special tools used at the bottom of the drill string. Anything that is run in the hole to drill, ream or circulate is a bottom hole assembly. The simplest assembly is a bit, collars and drill pipe and is often termed a slick assembly. The use of this assembly in directional drilling is very limited and usually confined to the vertical section of the hole where deviation is not a problem.
In order to understand why an assembly will deviate a hole, let's consider the slick assembly, which is the simplest and easiest to understand. The deviation tendency in this assembly is a result of the flexibility of the drill collars and the forces acting on the assembly causing the collars to bend. Even though drill collars seem to be very rigid, they will bend enough to cause deviation.
The point at which the collars contact the low side of the hole is called the tangency point. The distance L from the bit to the tangency point is dependent upon collar size, hole size, applied bit weight, hole inclination, and hole curvature. Generally, the distance L is less than 50m (150 feet).

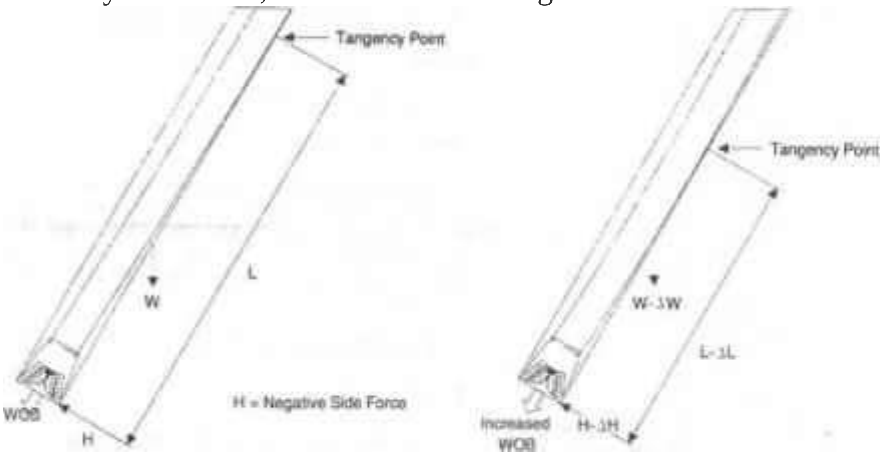
Above the tangency point of the slick assembly, the remainder of the drill string generally has no effect on deviation. As weight is applied to the bit, the tangency point will move closer to the bit.

Because of the bending of the drill collars, the resultant force applied to the formation is not in the direction of the hole axis but is in the direction of the drill collar axis. As bit weight is applied, the tangency point moves toward the bit increasing the angle. It can readily be seen that an increase in bit weight leads to an increase in deviation tendency.

Unfortunately, the direction of the resultant force is not the only force involved. The resultant force can be broken up into its components. The primary force would be the drilling force in line with the axis of the borehole. The bit side force is caused by the bending of the collars and is perpendicular to the axis of the borehole. The force due to gravity (acting on the unsupported section of drill collars) is in the opposite direction and counteracts the side force.

The net deviation force is then equal to the summation of the bit side force and the force due to gravity. If the force due to gravity is greater than the bit side force the angle will drop.

Changing the weight on bit can control the deviation tendency. Increasing the bit weight will lower the tangency point increasing the angle. Since resultant force is proportional to the sine of angle, an increase in bit weight increases the bit side force and ultimately the deviation tendency. Of course, a decrease in bit weight will decrease the deviation tendency.



Effect of Increased Bit Weight

Another factor affecting deviation tendency is the stiffness of the drill collars. Stiffer collars will bend less, which increases the height to the tangency point. If the tangency point moves up the hole, then the deviation tendency will be reduced. Therefore, small diameter drill collars will enhance the deviation tendency.

The addition of a stabilizer above the bit significantly affects the deviation tendency of a bottom hole assembly. The stabilizer acts as a fulcrum around which the unsupported section of the bottom hole assembly reacts. The addition of the moment arm between the bit and stabilizer increases the bit side force. In fact, the single stabilizer assembly is a very strong building assembly.

3 Steerable motor

A mud motor incorporating a bent housing that may be stabilized like a rotary bottom hole assembly. A steerable motor can be used to steer the wellbore without drill string rotation in directional drilling operations, or to drill ahead in a rotary drilling mode.

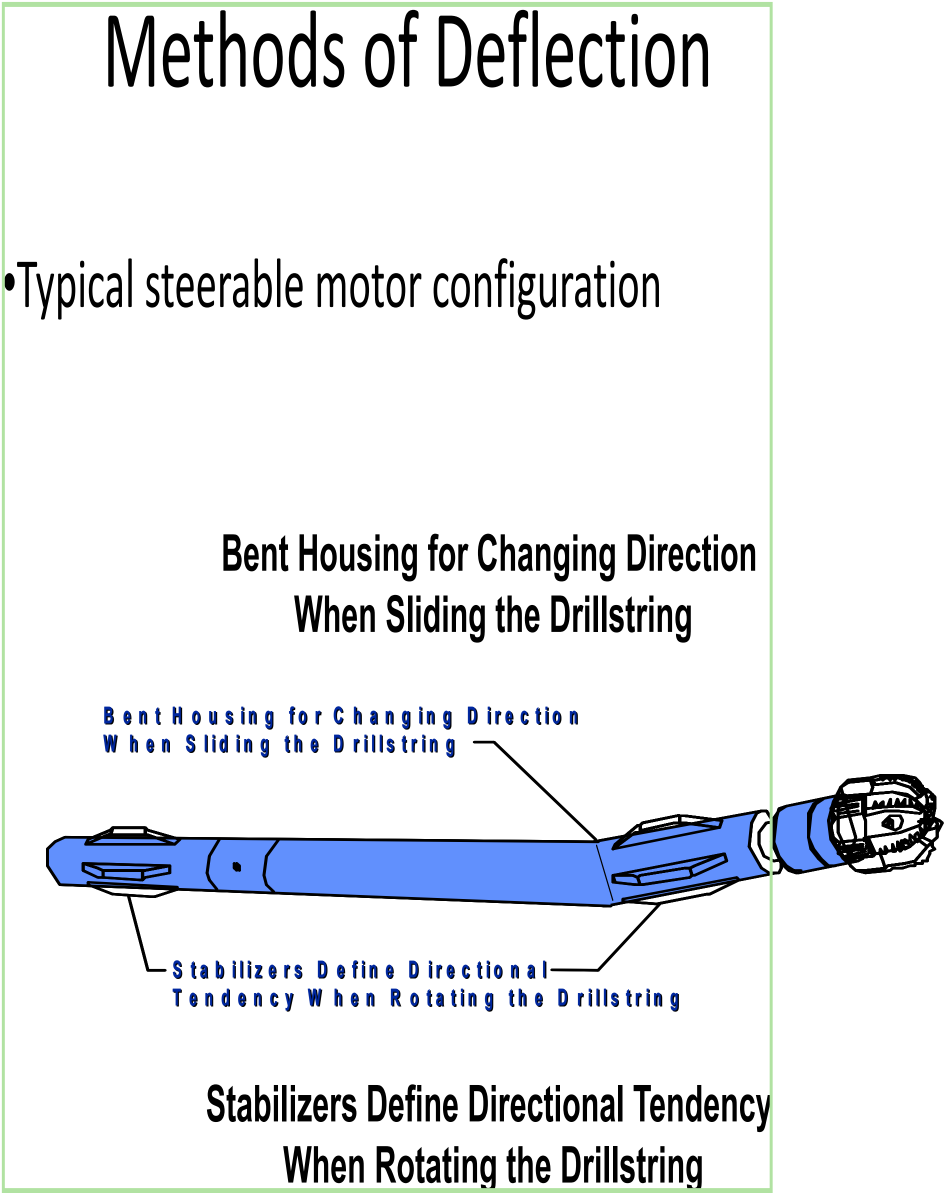


Figure 2.2: Bent points

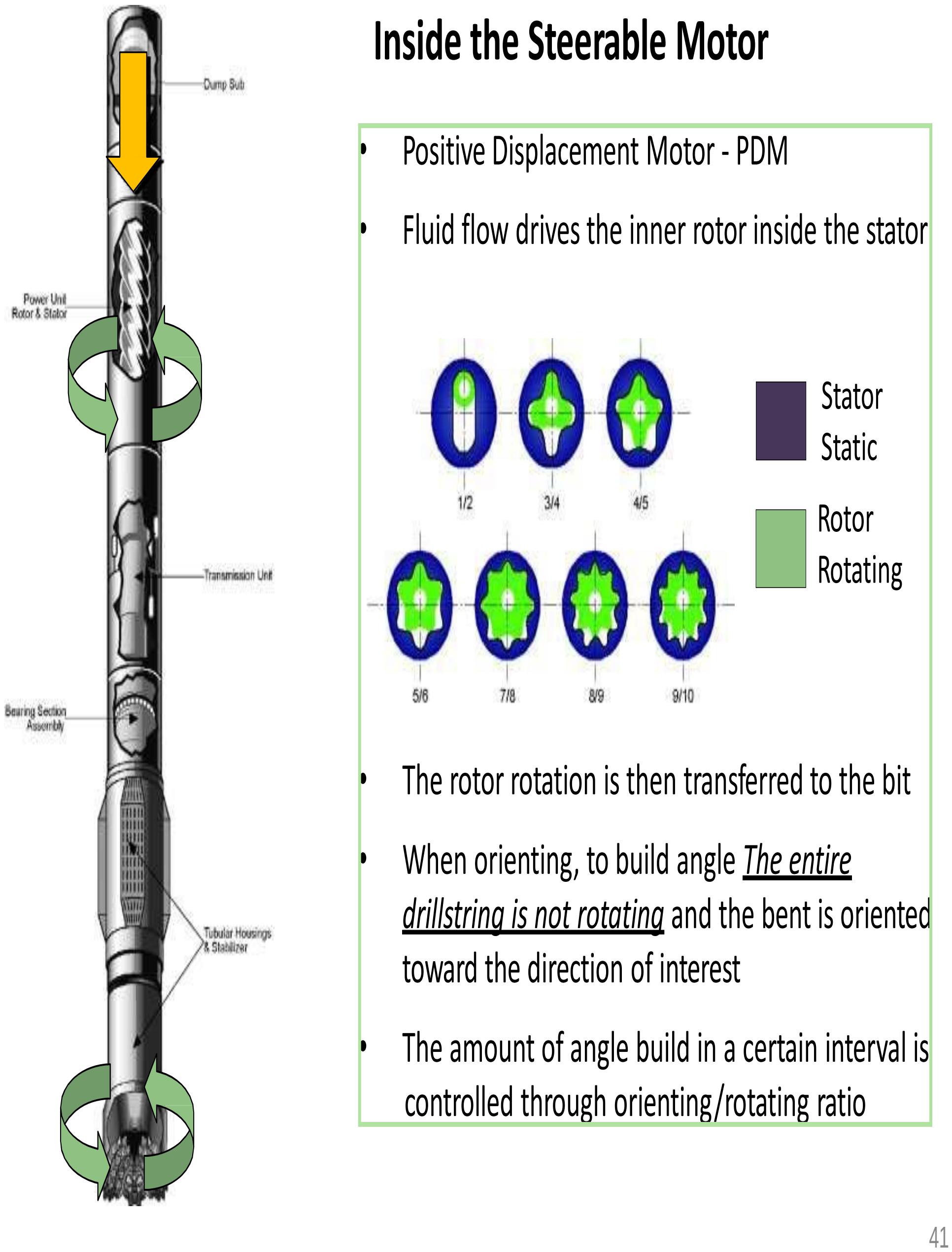


Figure 2.3: How motor work

4Rotary steerable assembly

Typically, are deployed when drilling directional, horizontal, or extended-reach wells. State-of-the-art rotary steerable systems have minimal interaction with the borehole, thereby preserving borehole quality. The most advanced systems exert consistent side force similar to traditional stabilizers that rotate with the drill string or orient the bit in the desired direction while continuously rotating at the same number of rotations per minute as the drill string. Then, Rotary Steerable System has Revolution Control unit inside it has Battery Power (Lithium Battery Pack), Navigation Sensors that help to obtain such as the velocity of drilling and Microprocessor control. Next, as we seen in (Figure 2) Rotary Steerable System works by apply power from turbine into Collar Rotation and motor that help drill rotating with an angle. Furthermore, ROTARY MODE steerable motor become "locked" with respect to trajectory and the hole direction and inclination maintained while drilling.

Methods of Deflection

- Rotary steerable Systems
  - Steerable without sliding (100% rotation)
  - Can change both inclination and direction downhole

Figure 2.4: Methods of RSS

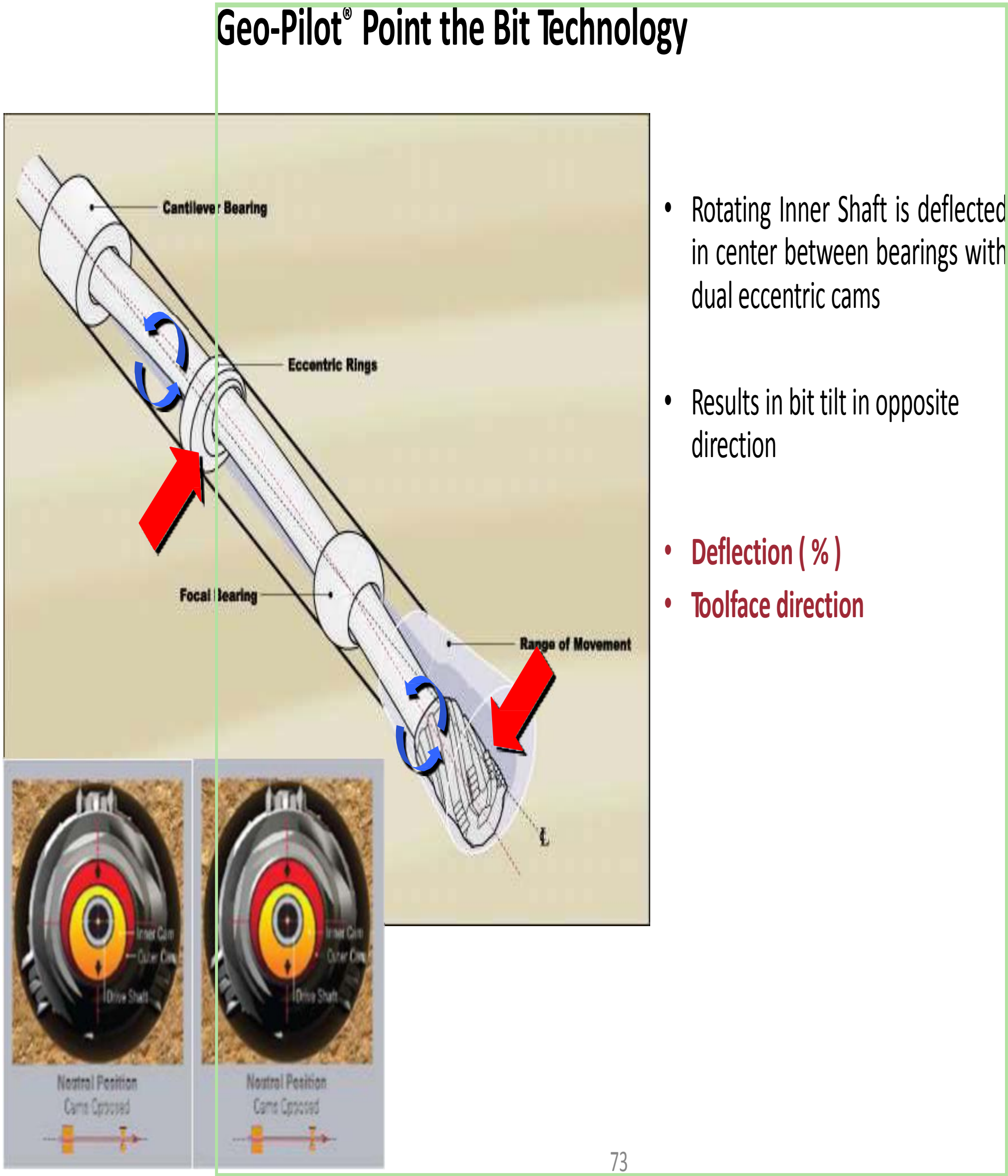


Figure 2.5: How RSS work

2.2 Previous Work:

1) Moody et al., built a new Rotary Steerable System (RSS) and results from its field-testing program. The RSS has been designed to handle the technical requirements of the most challenging wells, but also to be economical for use in low cost wells. This important feature was achieved by a unique hydraulics and electronic design and through the use of durable but low-cost materials. The tool itself consists of three active and independent steering blades placed close to the bit, and a near-bit stabilizer which acts as a fulcrum. The steering blades apply a constant force to the formation. The displacement of the blades is measured to offset the Bottom Hole Assembly (BHA) in the desired direction. The clamping force of the tool in the hole acts to stabilize the lower part of the BHA and remove unwanted vibration and instability from the drill bit. This significantly improves BHA response, borehole quality, ROP and bit life. Since the RSS has a full 3D capability, it can drill constant curvature boreholes in any direction.

The tool has been tested in wells in Texas, Louisiana, Oklahoma and the Gulf of Mexico. The results of these tests will be presented in detail. It is shown that BHA optimization can make a significant difference to the quality of directional holes drilled with a RSS

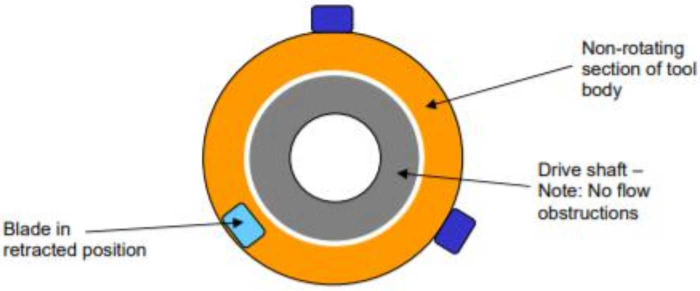


Figure 2 - Cross section through non-rotating section of PathMaker tool

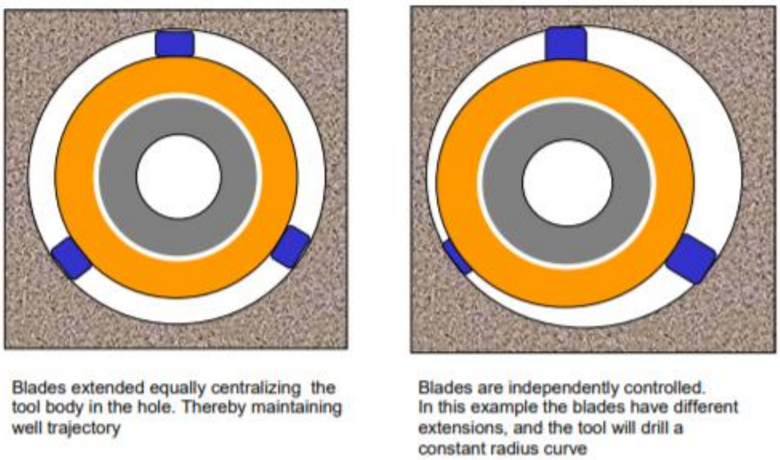


Figure 3 – Cross section shows movement of tool body

2) Stuart Schaaf et al.

Rotary steerable systems have been introduced in the past few years to respond to these more complex requirements. These systems have shown the potential for reducing the costs of drilling while providing improved directional control. Elimination of sliding increases rates of penetration, provides better hole cleaning, smoother boreholes, less chance of differential sticking; and the ability to drill further.

Schlumberger has developed a new rotary steerable system, which functions on a point-the-bit principle. The system has no non-rotating or stationary parts in contact with the formation. The system is implemented in a 6 ¾-inch platform and operates in bore-hole diameters between 8 3/8-inch and 9 7/8-inch.

This paper will present an overview of the new point-the bit system. Benefits of the system will be discussed. Case studies from two wells will be presented. The presentation will discuss the well objectives, the plan implementation, and include operational highlights and issues. Project results and improvements in implementation will be presented with discussion on how the system was utilized to insure value-added savings.

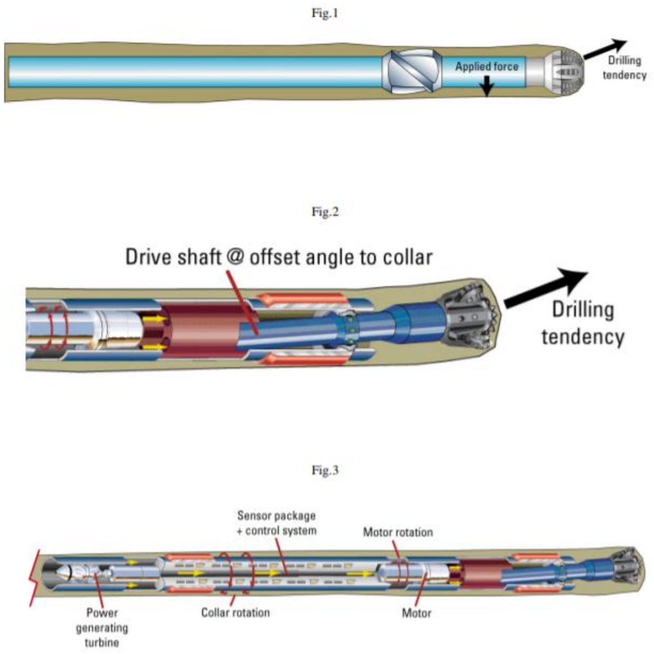


Figure 2.6: Function of Drill Pipe

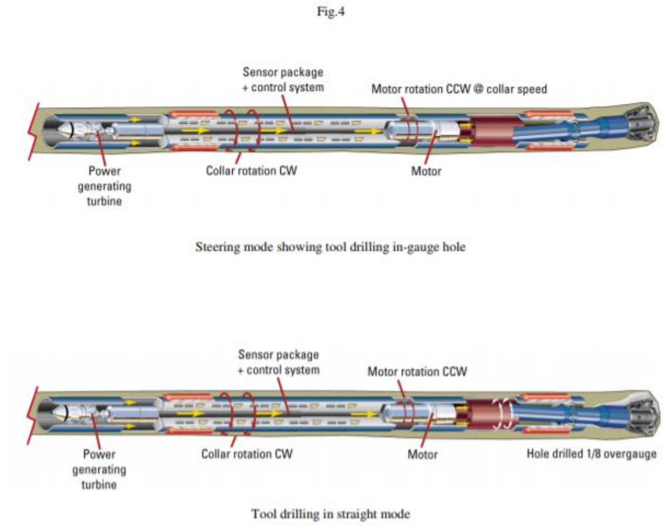


Figure 2.7: Component of inside Drill Pipe

3) Ali Al Dabyah et al.

To address the client needs, a new generation of RSS has been introduced.

In 2014, a 6¾-in. high-build rate RSS was developed primarily for conventional markets, which have a need for high build rates and simultaneous acquisition of LWD data. The use of a high-build rate RSS in

conjunction with an optimized bottom hole assembly (BHA) for build-rate capability has enabled operators

to achieve build-up rates up to 12°/100 ft.

In 2015, a 4¾-in. high-performance RSS was developed to fill the need of higher weight on bit and to

provide a simple, rugged design with enhanced reliability.

In this paper the authors present the new generation of rotatory steerable and its impact on the market.

This paper will be supported by number of case studies from oil and gas.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1 Geometrical Constraints

There were few constraints that the project has to find a way around them. One of the constraints was the size of the drill hole pipe. In our project we simulated the 6.5’’ hole in real life application by 6.5’’ pipe. In many operation locations around the world, the size of the hole can be much bigger. That can help a lot regarding the size of the machined parts. The bigger the size would result in durability in tools life.

3.1.2 Sustainability

Due to the small size that we forced to use; we faced an issue regarding sustainability of our project. If we able to make the prototype bigger than 6.5’’ in diameter, we could have used bearings. In Engineering applications bearings offer great help in connected shafts (or pistons in our project) to a rotating pipe. In this way we can minimize corrosion and wear of both pistons and drilling pipe.

3.1.3 Environmental

Our prototype has very little impact on the environmental aspect, as it will be implanted deep inside earth crust. However, we used compressor to force pistons to bend the drill pipe instead of oil pump. Leakage of oil might be harmful for both environments and the operators around it. Therefore, using compressed air would be sufficient on both safety and environmental aspects

3.1.4 Social

Our system can be shared by multi companies. Some companies can use it to drill boreholes for the customers while others are able to use it to gathering the oil and natural gas to increase production rate. Thus, the system shall have social impact.

3.1.5 Economic

Our prototype is mainly mechanical parts fit together. This means the costs are very low comparing with installing electronics or electrical components. The maintenance of mechanical parts can be done with ease and no time waste. This result saving money and time for companies of oil drilling. Also, our prototype reduces the numbers of maintenance operators to mechanical engineers, instead of having mechanical, electronics and electrical engineers to finish maintenance.

3.1.6 Safety

Safety was one of the most concerns in our prototype. We machined every part to the 0.01’’ in most accurate manufacturing machines we had. By having such accuracy, we managed to lower friction to minimum. By minimizing fumes resulted from frictions between pistons and drill pipe, we managed to minimize health issues to operator.

3.1.7 Ethical

This project has homogenous previous works. Thus, we took some general ideas from them and we improved the work by our suggestions to improve the design in terms of safety, economically, and sustainability.

3.2 Engineering Design Standard:

Engineering standards should be followed in each components of our system. In this section, we described each component that have been selected for our project. The selected components are the following; Aluminium Pipe, Drill Bit and O-ring. The Aluminium Pipe standard has been taken according to Seamless Aluminium Pipe - Series 6061-T6 Schedule 40. The standard of Drill Bit has taken from American Petroleum Institute (API) standard rock bits. The O-ring was taken from AS-568 Standard O-Rings. See table 3.1

Components	Engineering Standard	Details
Aluminium Pipe	Seamless Aluminium Pipe - Series 6061-T6 Schedule 40	ASME S241MASME SB241ASTM B241Mil-P-25995UNS A96061
Drill Bit	American Petroleum Institute (API) standard rock bits	-0.0 to +1/32 Rock Bit
O-ring	As-568 Standard O-ring	.426 ± .005

Table 3.1: Engineering Standards

3.2.1 Aluminium Pipe:

Length: 39.37 in

Diameter: 3.5 in

3.2.2 Drill Bit:

Diameter: 6.5 in

3.2.3 O-ring:

Inner Diameter: 0.45 in

Outside Diameter: 0.51 in

Thickness: 0.03 in

3.3 Theory and Theoretical Calculation

In theory, we can control the directional drilling by controlling the bend of the drill pipe. By controlling pressure, we can control the bend angle and set it to the desired one.

Maximum Bending calculations

- **$I = \pi (r_o^4 - r_i^4) / 4$**
- **$I = \pi (0.0460^4 – 0.04392^4) / 4$**
- **$I = 6.031X10^{-7}$ KN/m^2**
- **$\theta = PL^2 / 16EI$**
- **$0.02618 = P*1^2 / 16*6.031X10^{-7}*117X10^6$**
- **P = 29.561 KN**

Calculation

$F_y = 2F \sin(30) + 2F \sin(60) + F$

Forces on each piston -> F=268N

Formula to calculate pressure -> PA=268

$P \pi (r_o^2) = 268$

Pressure on each set -> $P_{each\ set} = 2115.6$ kpa

Force on each piston - > P_{total}=423 kpa

3.4 Product Subsystems and selection of Components

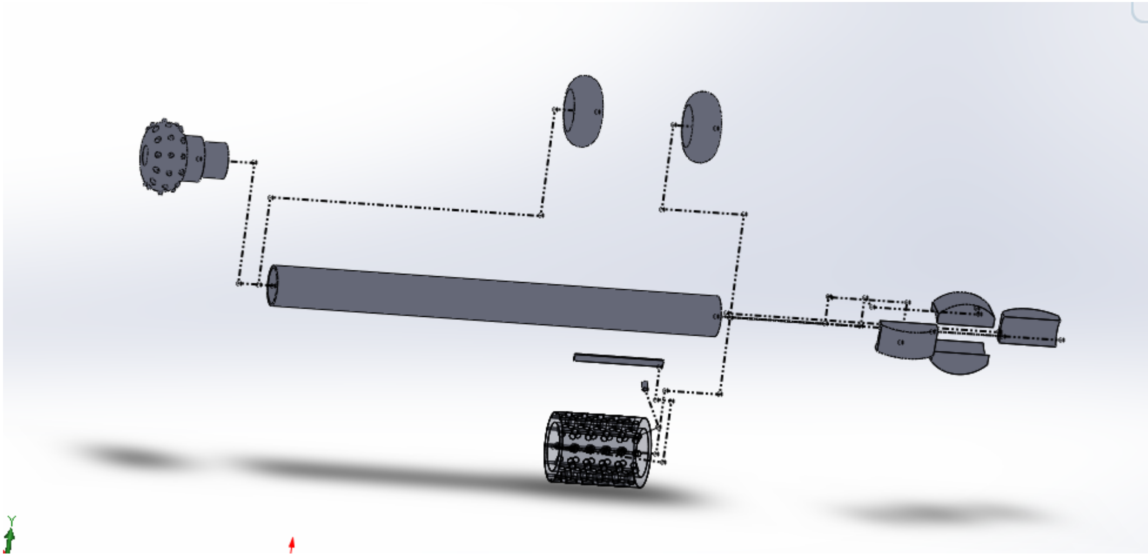
Product Subsystems and Selection of Components

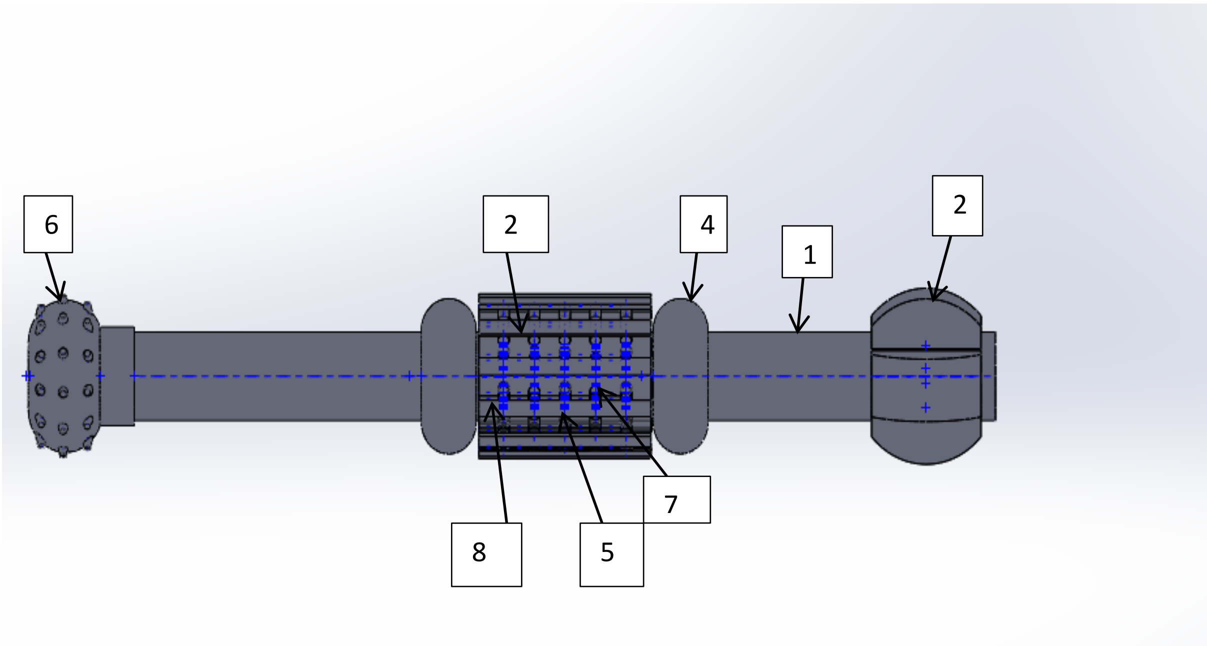
In our prototype there are two main systems. The first system is the motor for drill pipe. We had to choose a specific motor power in order to maintain a constant rotation for the drill pipe. This was to illustrate how our mechanism works in reality. The second system is a compressor that is attached to the sleeve centralizer. As mentioned above, our main component is the sleeve centralizer where we manufactured more than sixty holes. We distributed the holes in twelve sets, each set has five holes. From the top of the sleeve we drilled twelve smaller holes to connect the holes in each set. As the drill pipe rotates, the sleeve centralizer doesn’t affect from the rotation and stays still.

The top twelve holes are connected to a compressor that can push the pistons inside the holes to force the drill pipe to bend. The selection of the materials for the sleeve centralizer and the pistons was steel. As the drill pipe is Aluminium, steel was the best choice for us to have more strength than Aluminium.

3.5 Manufacturing and assembly (Implementation)

In terms of selection of materials, we have chosen three different materials. The first one was steel for the most of the components as steel is harder than many materials also on economical side it is cheaper. For the drill pipe we chose Aluminium for mainly one reason, which was modulus of elasticity. To bend Aluminium, it requires much less force by the piston than Steel. The final material was wood, for the drill bit. As our project aims to direct the drilling, it has nothing to do with the drill bit, therefore we had to lower the costs of our prototype. The set-up of the project was the hardest part in our manufacturing phase. It required both time and efforts to fit all the parts together. The drill pipe was the principle part that all other components are attached to it. we first fit the sleeve centralizer in middle of the drill pipe. Also, we had for centralizers that need to be welded on top of the Aluminium pipe to minimize vibrations and enforce the pipe while bending. On the other side of the pipe we fit the wooden drill bit with a hole in middle of it to fit a laser pointer. The goal of laser pointer is to show the deflection of the drill bit while the drill pipe is bended.





1	Drill Pipe	1 Piece
2	Centralizer	12 pieces
3	Centralizer 2	4 pieces
4	Spacer	2 pieces
5	Piston	60 pieces
6	Drill Bit	1 piece
7	O-ring	60 pieces
8	Sleeve Centralizer	1 piece

Figure 3.1: Exploded assembly of the system

Component Name	Picture
Composer	
Sleeve Centralizer	
Drill Bit	
Steel Pipe	

Aluminium Pipe	
Motor	
Spacer	
Centralizer	

Small Tube	
Dispenser Tool	

Table 3.2: Pictures of components

Chapter 4: System Testing and Analysis

4.1 Tools:

Figure 4.1: Tape measure

Figure 4.2: Leisner pointer

Figure 4.3: Ruler

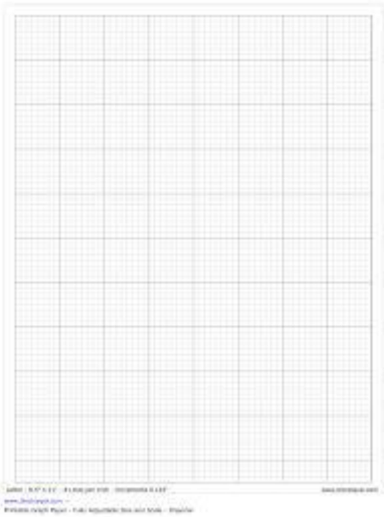


Figure 4.4: Board

4.2 Calculation:

4.2.1 Calculation several Materials:

- $I = \pi (r_o^4 - r_i^4) / 4$
- $\theta = PL^2 / 16EI$
- $y_{max} = PL^3 / 48EI$

Material	Force (KN)	y_{max} (mm)
Copper	29.561	0.872
Aluminum	28.9	5.313
PVC	1.96	8.69

4.2.2 Calculation Pressure:

D= 0.5 in =1.25 cm=0.0125 m

F_y= 2F sin (30) +2F sin (60) +F

F_y= F (2sin (30) +2sin (60) +1)

=3.737F

1000=3.732F

F= 1000/3.732

F=268N

PA=268

P π ($r_o^{2)}$ =268

P=268/ π *r^2

P=268/ π *$(0.0635)^2$

$P_{each\ set}$ = 2115.6 kpa

P_{total}=423 kpa

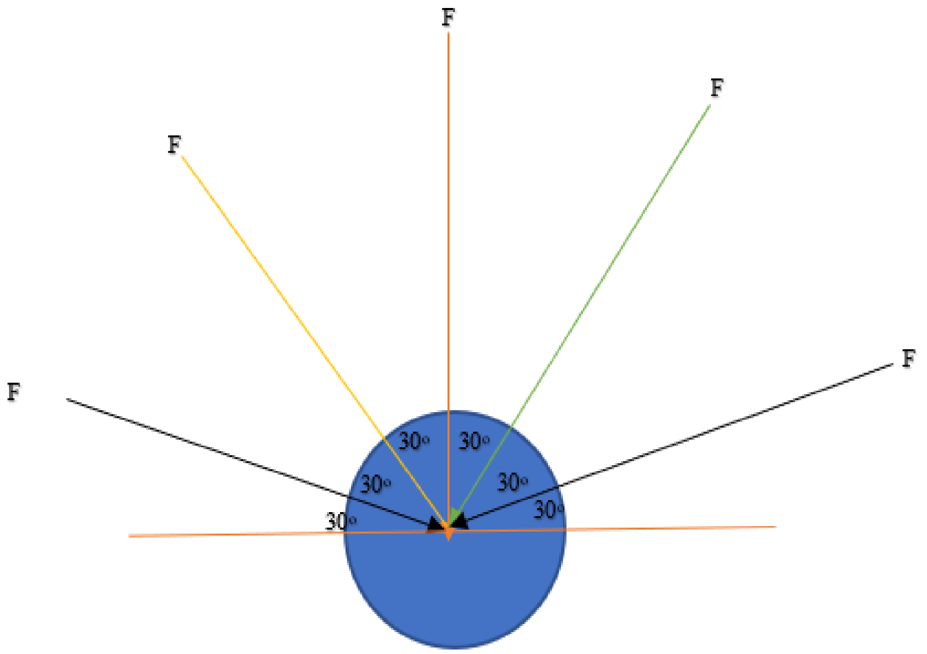


Figure 4.5: Force in different direction with same angle acting a point

4.3 Procedure:

1. We fixed the laser pointer to the middle of the drill bit and point it to the board.

2. We connected the top holes of the sleeve together and then connect them to the compressor.
3. Then we set the compressor to the calculated pressure that is needed to bend the Aluminium pipe.
4. Record the deflection of the laser pointer on the board.
5. Apply Pythagoras theorem to record the angle of the bend.

$$\tan(\theta) = \frac{Opposite}{Adjacent}$$

4.4 Results

$$\boldsymbol{\theta = \frac{PL\hat{}2}{16EI}}$$

Angle of Deflection	**Force (KN)**
0.5°	65.688
0.7°	91.96
0.9°	118.238
1.1°	144.5136
1.3°	170.788

Table 4.1: Calculation Force

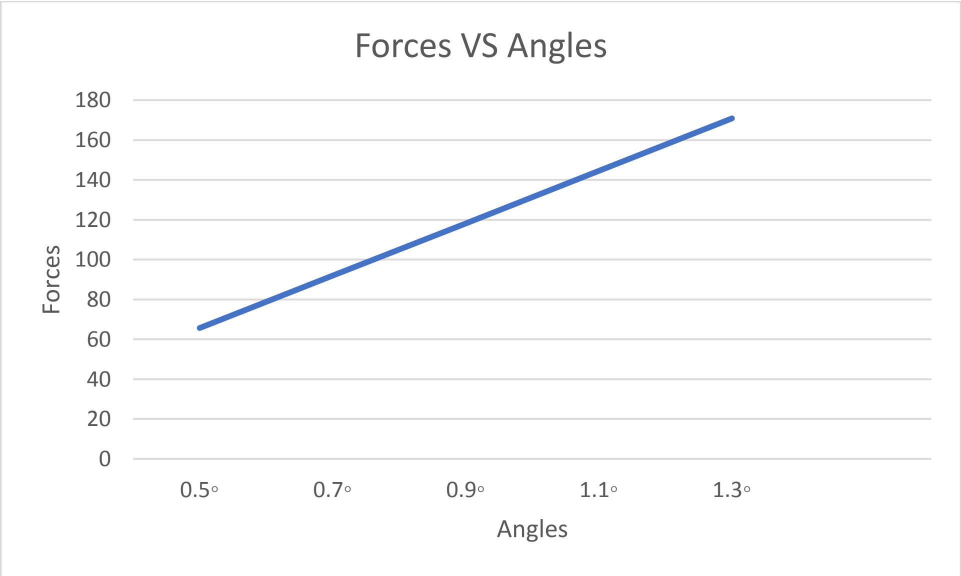


Figure 4.6: Graph of Force Vs Angle

We notice on graph between force and deflection of angle is direct relation if we want to increase the deflection of angle, we need to increase the amount of force.

PA=F

Force (KN)	**Pressure (Kpa)**
65.688	406
91.96	658.5
118.238	846.6
144.5136	1034.8
170.788	1223.02

Table 4.2: Calculation Pressure

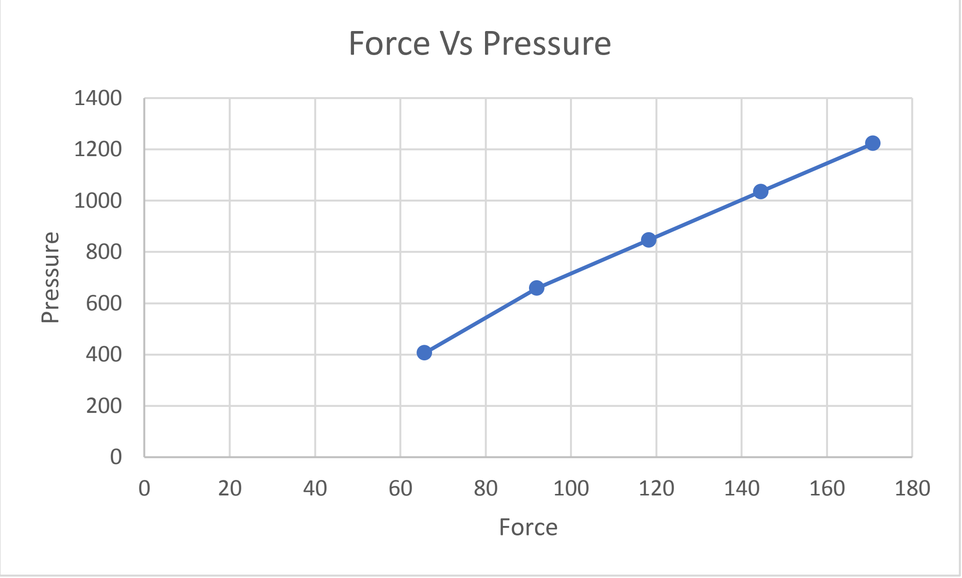


Figure 4.7: Graph of Force Vs Pressure

Also, we realize between the force and pressure is direct relation, if we want to bend the drill pipe, we need high pressure to push the pistons with high amount of force.

Chapter 5: Project Management

5.1 Project Plan

In our project, there are many tasks included. Each task is assigned to one or more members. Here is the all information about the tasks, team members, and the duration of each task to be completed. See table 5.1 for tasks & durations and table 5.2 for the assigned members.

Task 1	**Start Date**	**Days to complete**
Identifying the project	6/01/2019	16
Determine the objectives		
Subdividing small tasks to collect information		
Search and review the previous work		
Writing chapter 1 of the report		
Preparing and submit the forms		
Write chapter 2		
Task 2		
Brain storming and gathering ideas for the conceptual design	20/01/2019	10
Draw the first conceptual design		
Selected the appropriate Materials		
Searching for the parts		
Order the parts what we want on global sites	30/01/2019	3
Buying the available part from local shop		2
Task 3		
Solid works Design	1/02/2019	12
Calculation of hole diameter		
Calculation pipe diameter		
Type of material of drilling pipe		
Power of motor	5/02/2019	6
Write chapter 3	6/02/2019	3
Task 4		
Initial prototype	10/02/2019	10
Preparing the Mid-term presentation	14/02/2019	2
Writing chapter 4		8

Task 5		
Start assembly the project	3/03/2019	15
Testing the system		
Finding the errors and upgrade the system		
Task 6		
Finishing the final report	06/04/2019	6
Finalized the project		
Final presentation	11/04/2019	

Table 5.1: Tasks and their durations

Task 1	**Responsible**
Identifying the project	All Team
Determine the objectives	
Subdividing small tasks to collect information	
Search and review the previous work	
Writing chapter 1 of the report	
Preparing and submit the forms	
Write chapter 2	
Task 2	
Brain storming and gathering ideas for the conceptual design	All Team
Draw the first conceptual design	Metab
Selected the appropriate Materials	Nayef
Searching for the parts	
Order the parts what we want on global sites	
Buying the available part from local shop	
Task 3	
Solid works Design	Nayef + Metab
Calculation of hole diameter	Fayed + Nawaf
Calculation pipe diameter	Metab + Nayef
Type of material of drilling pipe	All Team
Power of motor	Nawaf + Fayed
Write chapter 3	Nayef + Fayed
Task 4	
Initial prototype	Fayed + Nawaf
Preparing the Mid-term presentation	
Writing chapter 4	
Task 5	
Start assembly the project	Nawaf+Nayef
Testing the system	
Finding the errors and upgrade the system	
Task 6	
Finishing the final report	Metab+Nayef
Finalized the project	Fayed + Nawaf
Final presentation	

Table 5.2: Tasks and assigned members

5.2: Contribution of Team Members

The tasks in this project was assigned to one member or more members. It depends to the ability of doing the task and the time required to complete the task. Table 5.3 shows the tasks and the members with how many percentages of contributing for each member.

Task 1	Responsible	Percent Complete
Identifying the project	All Team	100%
Determine the objectives		
Subdividing small tasks to collect information		
Search and review the previous work		
Writing chapter 1 of the report		
Preparing and submit the forms		
Write chapter 2		
Task 2		
Brain storming and gathering ideas for the conceptual design	All Team	100%
Draw the first conceptual design	Metab	100%
Selected the appropriate Materials	Nayef	100%
Searching for the parts		
Order the parts what we want on global sites		
Buying the available part from local shop		
Task 3		
Solid works Design	Nayef + Metab	100%
Calculation of hole diameter	Fayed + Nawaf	100%
Calculation pipe diameter	Metab + Nayef	100%
Type of material of drilling pipe	All Team	100%
Power of motor	Nawaf + Fayed	30%
Write chapter 3	Nayef + Fayed	100%
Task 4		
Initial prototype	Fayed + Nawaf	60%
Preparing the Mid-term presentation		100%
Writing chapter 4		
Task 5		
Start assembly the project	Nawaf+Nayef	30%
Testing the system		
Finding the errors and upgrade the system		
Task 6		
Finishing the final report	Metab+Nayef	10%
Finalized the project	Fayed + Nawaf	
Final presentation		

Table 5.3: Tasks the contribution of the members

5.3: Project Execution Monitoring

During our project, we had many activities which relates to improve our project. These activities including the important meeting and events that related to our senior project. In table 5.4 shows the list of meeting and other events for our project during spring semester 2019.

Time / Date	Activities / Events
Three times a week	Assessment Class
Weekly	Meeting with group members
Biweekly	Meeting with advisor
14 March 2019	Finish first prototype
21 March 2019	Midterm presentation
14 April 2019	Finishing final prototype
16 April 2019	Test the system
18 April 2019	Final submission of report
2 April 2019	Final presentation

Table 5.4: Dates of the activates and events

5.4: Challenges and Decision Making:

During the project phases, we faced some challenges that effect the progress of the project. Following challenges are the main challenges we have faced:

1) Finding the Materials

2) Dimensions of Components

3) Manufacture complex component

5.4.1: Finding the Materials:

In our Project, we faced an issue for choosing a material such as Aluminium, Copper and PVC. Furthermore, we did calculation for three materials depending on the standards then we chose which material is applicable in our project in order to bend the pipe without broken.

5.4.2: Dimensions of components:

Some diminution part is not available in market, so we had to manufacture it, such as we manufacture aluminium pip and steel pipe in casting with rolling operation. Also, we manufacture the drill bit in order to fit inside a hole by using a shaft and cutting edges.

5.4.3: Manufacture complex component:

In our project we had a problem that we cannot manufacture complex part in any workshop, so we looking for a workshop that they have CNC machine in order to manufacture centralizer which is the reacquired part. Even we find a workshop with CNC machine, they can't do finishing in the part, so the piston will not fit.

5.5: Project Bill of Materials and Budget

Table 5.5 shows the materials that we purchased and their costs in Saudi Riyals (SR). This table includes also the manufacturing and failed part costs.

Materials	Costs (SR)
Steel Pipe	400
Aluminium Pipe	1500
Sleeve Centralizer	1850
Centralizer	1500
Compressor	400
Wood Bit Drill	150
Welding the prototype	750
30 Pistons	1500
Total	**8050**

Table 5.5: Bill of Materials

Chapter 6: Project Analysis

6.1: Life-long Learning

When we are working in our project, we have learned and gain some knowledge about the important skills which was required to complete our project. By working as a team, we succeed to improve our skills in time management, communicate in effective way with members of the group. In this part, we will discuss the skills and experiences which we have learned since we worked in our project.

6.1.1: Software Skills

In this project, we have learned various skills and experiences from some software, such as Solid works and Microsoft Word. These two programs are familiar for us because we have used them during university life. We used some advanced skills in these programs which we have not use it before. For instance, we used our Solid works skills to design our system part by part then, we used mate tools to assemble the parts together.

6.1.2: Hardware Skills:

During our project, we used some new devices that aim us to collect the data. we used two types of measurements. First was measurement tape which able to measure the distance between laser pointer and the board. We learned how to apply mathematical equations such as Pythagoras theorem to calculate deflect angle.

6.1.3: Time Management Skills

By our project life, we gain one of the important skills which is the time management. While we want to reach to our purpose, we have to manage the time to fit with the tasks. We divided the tasks into specific deadline to be finished on or before the deadline. One of the tools that we used to manage our time is Gantt Chart. We divide our tasks and subtasks into start and end dates. Also, we kept updating the Gantt Chart with our advisors to keep them in touch about what we have done weekly.

6.1.4: Project Management

In our project, we divided the works between members of the group. Each one of the members has his own work which should be done individually. Then, we had a meeting two times a week to discuss and collect the work that have done by that member. Mostly, our group has divided to two teams. The first team was focusing on the research and report. While, the other team was focusing on the prototype and manufacturing.

6.2 Impact of Engineering Solutions

Our project has various impacts in terms of society, economy, and environment. In this section, there are all the impacts of our project in terms of what previously mentioned.

6.2.1: Society

Our project is an advantage in terms of society. Installing private water supplies and drilling boreholes for our customers often involves the installation of underground pipework to deliver water from the source to the area of its intended use.

6.2.2: Economy

Our project assists the people in terms of economy. Directional Drilling will merge into the ever-growing inventory of technologies that create the economic that extend the lives of, and yield more reverse from oil and gas fields yielding more production than early estimate even as it remains impossible to count which particular new technology gave rise to so much more production. This project was expected to cost approximately more than 9000 SR. After we finished the final project, we found that it costs around 8000 SR.

6.2.3: Environmentally

Our project helps the society in directional drilling can be further enhanced by taking the right safety precautions. Workers who are supplied with the right safety equipment and trained in the correct operation of all horizontal directional drilling equipment are able to work both efficiently and, in a manner, that most limits the impact of their activities on the environment.

6.3 Contemporary Issues Addressed:

In our prototype there was huge friction fumes coming from pitons forcing drill pipe to bend. Those fumes are harmful to humans for many reasons. The first issue is the bad effects of air pollution on human body. There are many organs and bodily functions that can be harmed, the consequences including: respiratory diseases,

cardiovascular damage, headaches and anxiety, Irritation of the eyes, nose and throat and nervous system damage.

Chapter 7: Conclusion and Future Recommendation

7.1 Conclusion:

In every project, people learn many things that assist them in the normal life. From this project, we gained the experiences, we improved our communication skills, and we learned new things. Also, we achieved important results from this project that will encourage us in terms of working in different projects in future. In engineering science, our project is consisting various areas of engineering including; Mechanical Design, solid mechanics, and thermodynamics which help us to improve our background on these areas. In this project, we learned how to use various manufacturing processes that are essential in our lives such as finishing. Moreover, we improved our skills regarding to engineering software such as solidworks. This project as any other project has some challenges. We faced a problem regrading to finding the workshops that have CNC machining.

7.2 Future Recommendation:

There will be great deal of friction between the pistons and the drill pipe, hence it reduces the life of both parts. Our recommendation is to use special type of lubricants or bearings. Also, some developments can be made by using pressurized fluids to turn the drill pipe instead of regular motor. By having pressurized fluids, the forces can be used in many areas such as to use jetting techniques for directional drilling. Moreover, pressurized fluids can work as a motor by installing turbines inside the bottom hole assembly. Those turbines can either generate electricity to rotate the drill pipe, or/and to helps to record vital data and send it to the operator on the surface.

8. References:

Glossary. [online] Available at: •
https://www.glossary.oilfield.slb.com/en/Terms/r/rotary_steerable_system.aspx

- [online] Available at: https://www.glossary.oilfield.slb.com/en/Terms/s/steerable_motor.aspx

- En.wikipedia.org. (2019). *Drilling rig*. [online] Available at: https://en.wikipedia.org/wiki/Drilling_rig#Drilling_rig_classification [Accessed 17 Feb. 2019].

- Hibbeler, R., & Yap, K. *Mechanics of materials*.

- Ward-Smith, J. (2012). *Mechanics of Fluids, Ninth Edition*. Boca Raton: CRC Press.

- Drilling Formulas and Drilling Calculations. (2019). *Deviating the Wellbore by Jetting and Whipstock (Directional Drilling)*. [online] Available at: http://www.drillingformulas.com/deviating-the-wellbore-by-jetting-and-whipstock-directional-drilling/

- Anon, (2019). [online] Available at: https://www.netwasgroup.us/services-2/rotary-bottomhole-assemblies

- Bybee, K. (2010). Design, Development, and Testing of a Slimhole Rotary-Steerable System. *Journal of Petroleum Technology*, 62(12), pp.81-83.

- SCHAAF, STUART, Schlumberger Oilfie (2000). Application of a Point the Bit Rotary Steerable System in Directional Drilling Prototype Well Bore Profiles for Aera Energy, LLC. *AAPG Bulletin*, 84.

- Wilson, A. (2016). New Rotary-Steerable System Delivers High Dogleg Severity, Improves Penetration Rate. *Journal of Petroleum Technology*, 68(12), pp.60-61

- Li, S. (2013). Construction Monitoring of a Municipal Gas Pipeline during Horizontal Directional Drilling. *Journal of Pipeline Systems Engineering and Practice*, 4(4), p.04013005.

- Jaganathan, A., Shah, J., Allouche, E., Kieba, M. and Ziolkowski, C. (2011). Modeling of an obstacle detection sensor for horizontal directional drilling (HDD) operations. *Automation in Construction*, 20(8), pp.1079-1086

- Inyang, I. and Whidborne, J. (2019). Bilinear modelling, control and stability of directional drilling. *Control Engineering Practice*, 82, pp.161-172

- Muchendu, P., J.G, D. and Njeri, E. (2014). Determination of optimum drilling parameters using 8.5-inch tricone bits in olkaria geothermal steamfield, Kenya. *IOSR Journal of Applied Geology and Geophysics*, 2(2), pp.11-28.

- Fei, Y., Cong, S. and Bian, B. (2011). Hydraulic System Simulation of Heavy Horizontal Directional Drilling Head. *Advanced Materials Research*, 287-290, pp.428-431.

Appendix A: Progress Reports

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

SEMESTER:	Spring	ACADEMIC YEAR:	2018/2019
PROJECT TITLE	Directional Drilling		
SUPERVISORS	PANAGIOTIS SPHICAS		

Month: February

ID Number	Member Name
Muteb Alshmmari	**201600336**
Nayef Alfaleh	**201500173**
Fayed Ibrahim	**201502046**
Nawaf Alhammad	**201300405**

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
	Abstract	**Nawaf**	**100%**	
	Introduction	**Muteb**	**100%**	
	Background	**Nayef**	**100%**	
	Previous Work	**Fayed**	**100%**	

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
	Calculation of Piston Force	Muteb
	CAD Drawing	Nawaf
	Drawing electric motor + Gear	Nayef
	Chapter 3 Writing (Calculation)	Fayed

- **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

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 (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Muteb Alshmmari**	**3**	**3**	**3**	**3**
2	**Nayef Alfaleh**	**3**	**3**	**3**	**3**
3	**Fayed Ibrahim**	**3**	**3**	**3**	**3**
4	**Nawaf Alhammad**	**3**	**3**	**3**	**3**

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

SEMESTER:	Spring	ACADEMIC YEAR:	2018/2019
PROJECT TITLE	Directional Drilling		
SUPERVISORS	PANAGIOTIS SPHICAS		

Month: February

Member Name	ID Number
Muteb Alshmmari	201600336
Nayef Alfaleh	201500173
Fayed Ibrahim	201502046
Nawaf Alhammad	201300405

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
	Solid work Designing	Nawaf	100%	
	Calculation of piston force	Muteb	100%	
	Design Gears (First Approach)	Nayef	100%	
	Writing Chapter 3 (Calculation)	Fayed	100%	

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
	Testing the Prototype	Muteb
	Prepare Component from Workshop	Nawaf + Nayef
	Prepare Final Presentation	Fayed

- **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

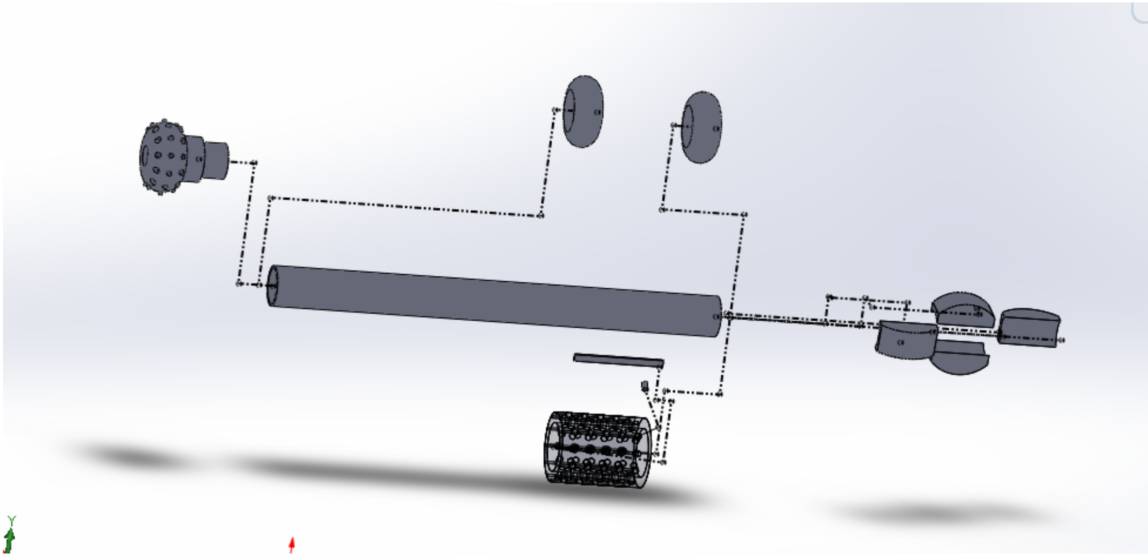
Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

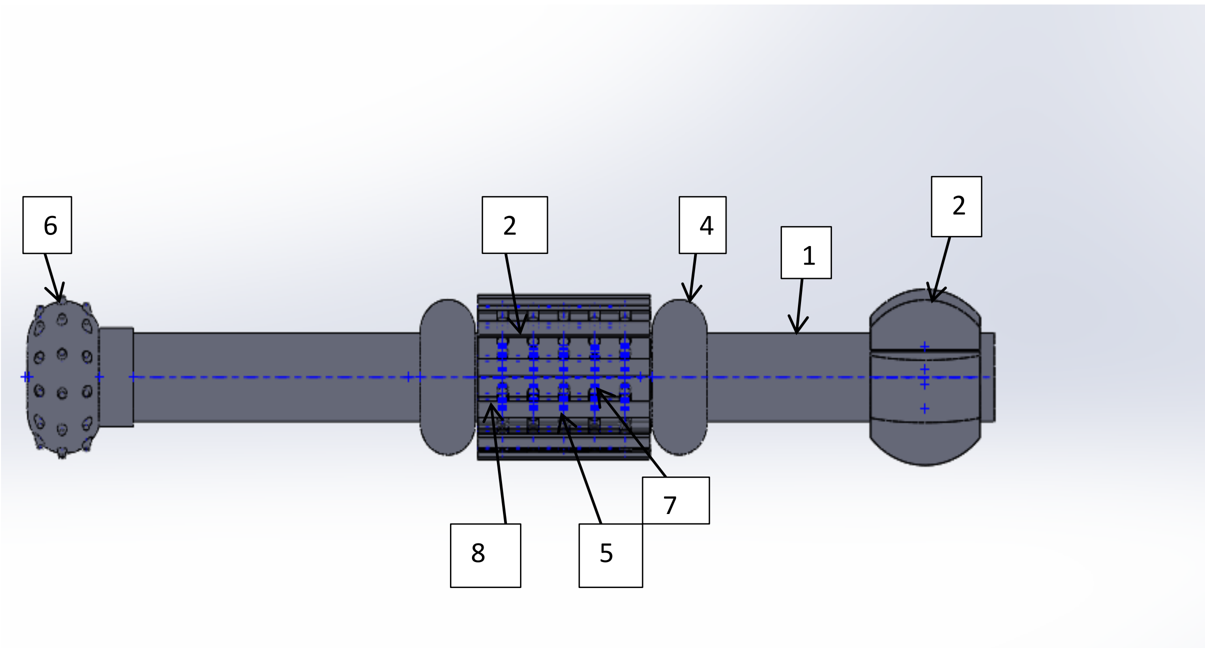
#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Muteb Alshmmari**	4	4	4	4
2	**Nayef Alfaleh**	4	4	4	4
3	**Fayed Ibrahim**	4	4	4	4
4	**Nawaf Alhammad**	4	4	4	4

Appendix B: Engineering standards (Local and International)

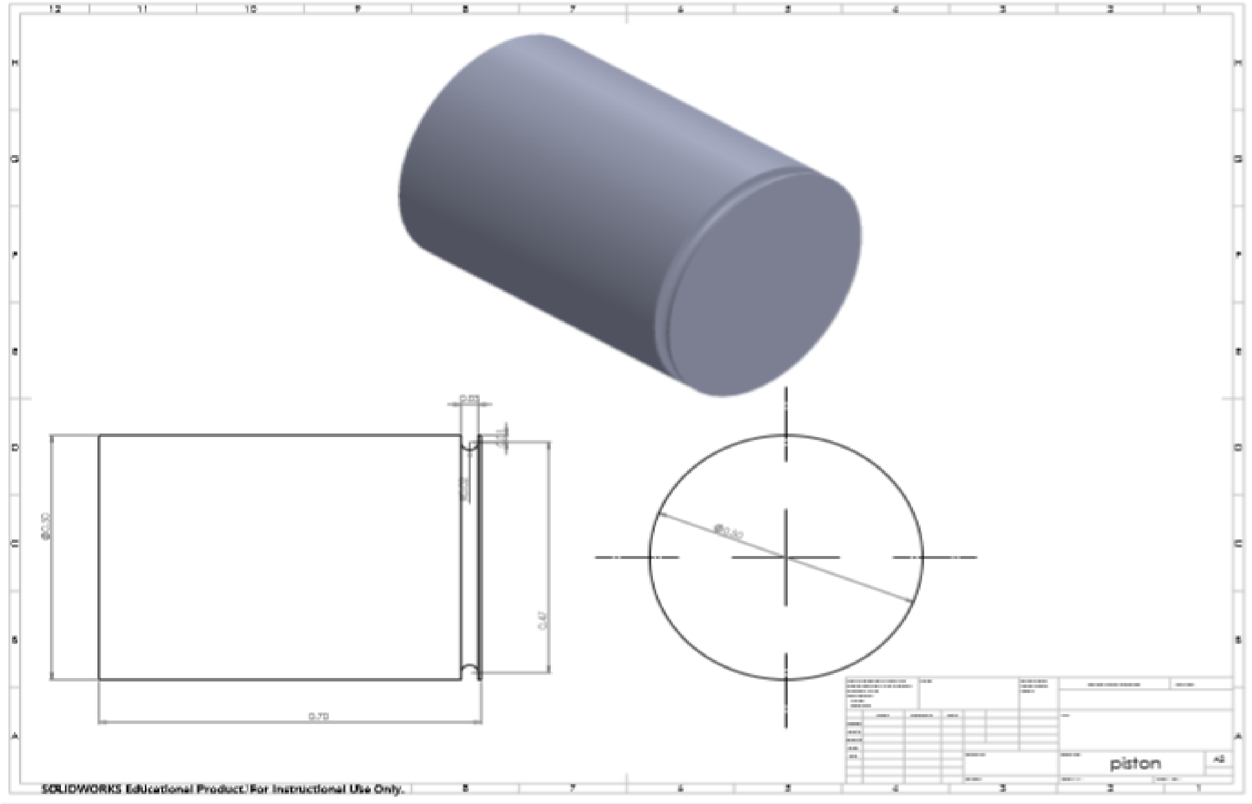
Components	Engineering Standard	Details
Aluminium Pipe	Seamless Aluminium Pipe - Series 6061-T6 Schedule 40	ASME S241MASME SB241ASTM B241Mil-P-25995UNS A96061
Drill Bit	American Petroleum Institute (API) standard rock bits	-0.0 to +1/32 Rock Bit
O-ring	As-568 Standard O’ring	.426 ± .005

Appendix C: CAD drawing and Bill of Materials

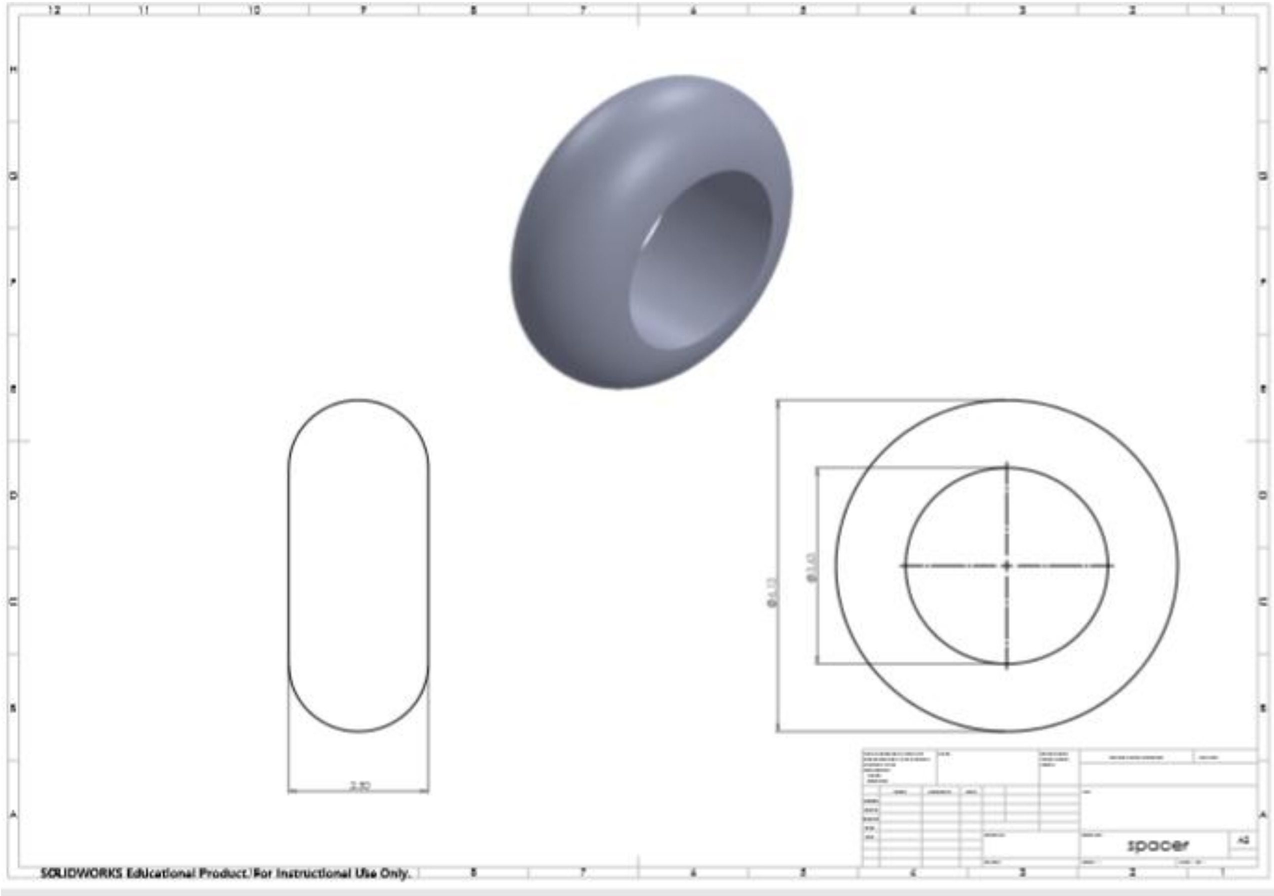




1	Drill Pipe	1 Piece
2	Centralizer	12 pieces
3	Centralizer 2	4 pieces
4	Spacer	2 pieces
5	Piston	60 pieces
6	Drill Bit	1 piece
7	O-ring	60 pieces
8	Sleeve Centralizer	1 piece



SOLIDWORKS Educational Product. For Instructional Use Only.
piston
A2



2.50
Ø4.13
Ø3.40
spacer
A3
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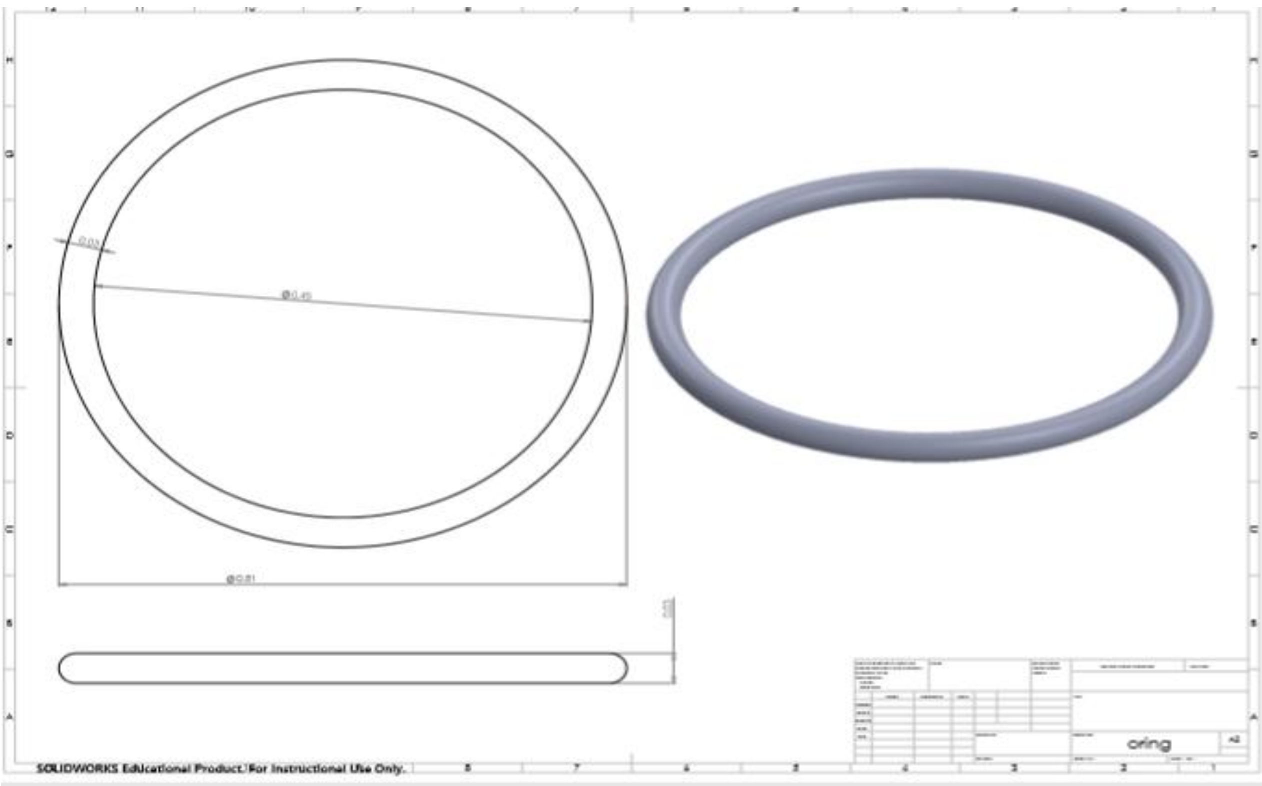
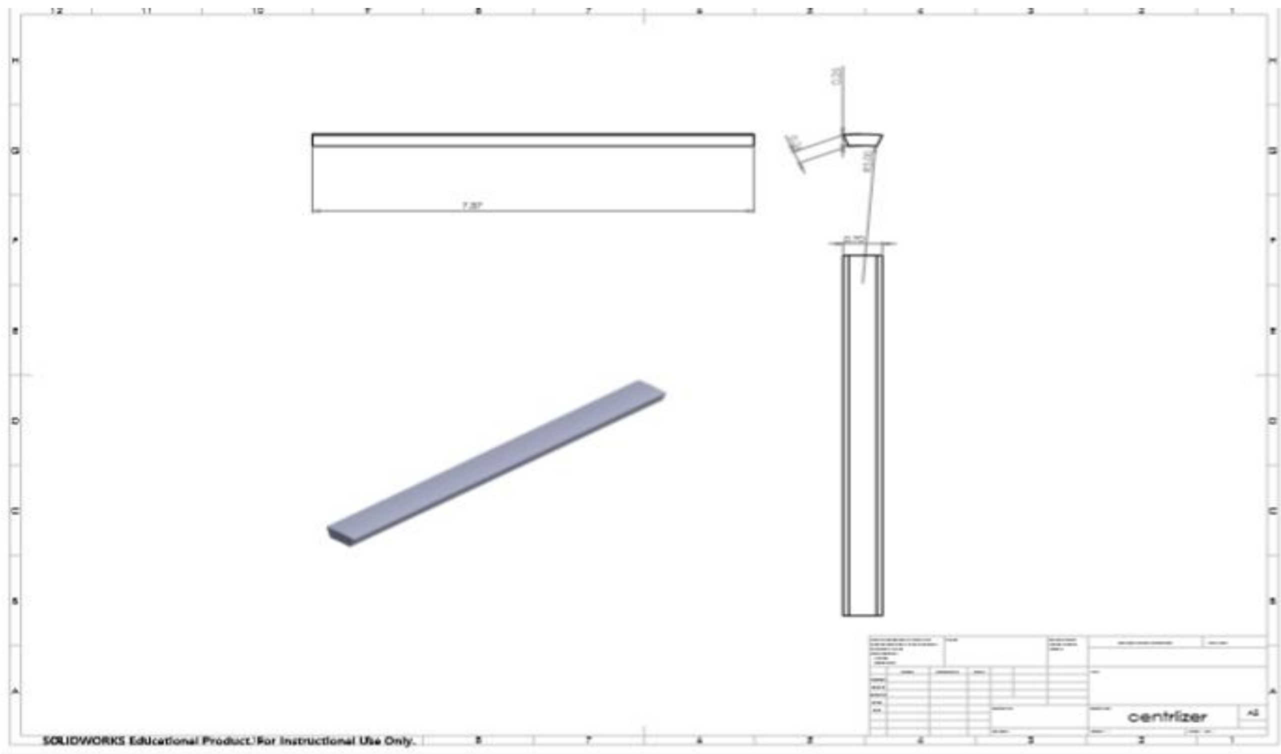
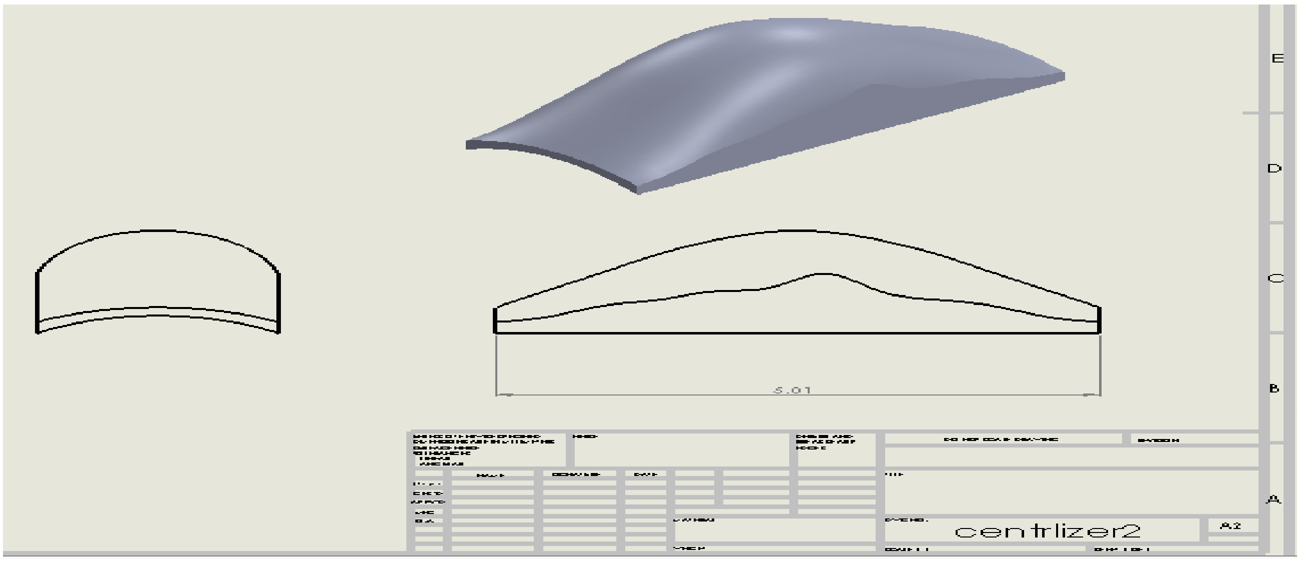
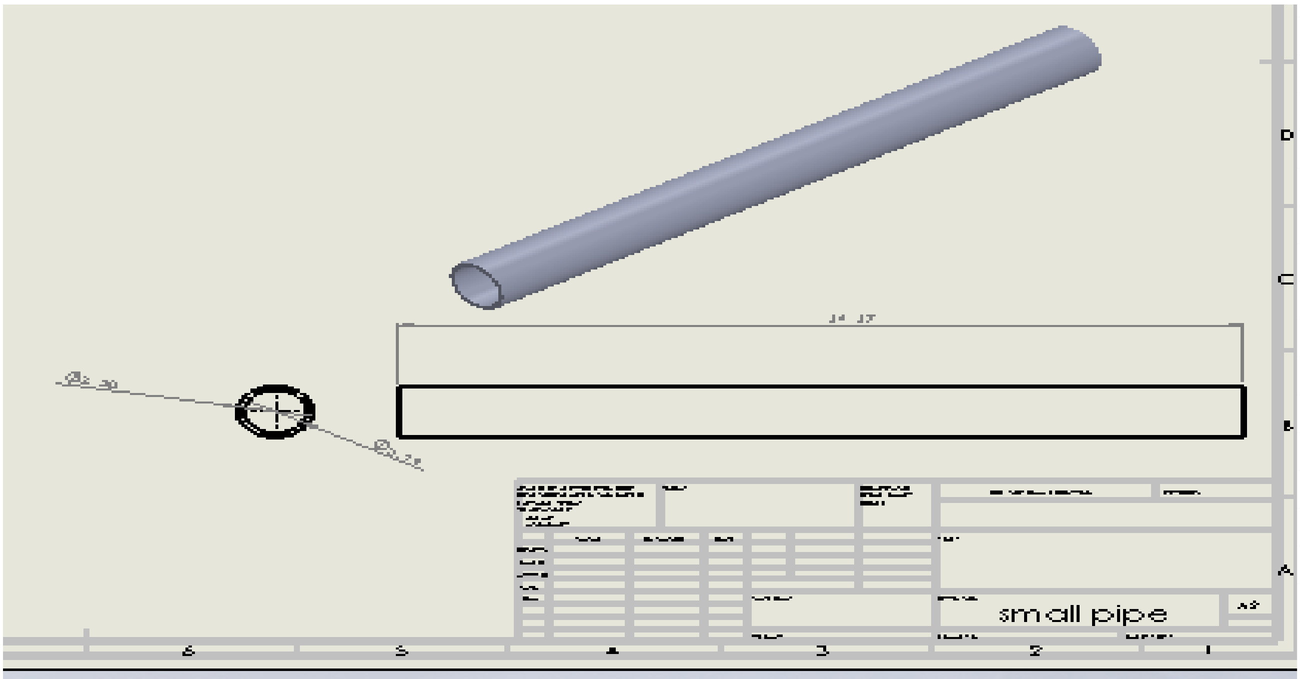


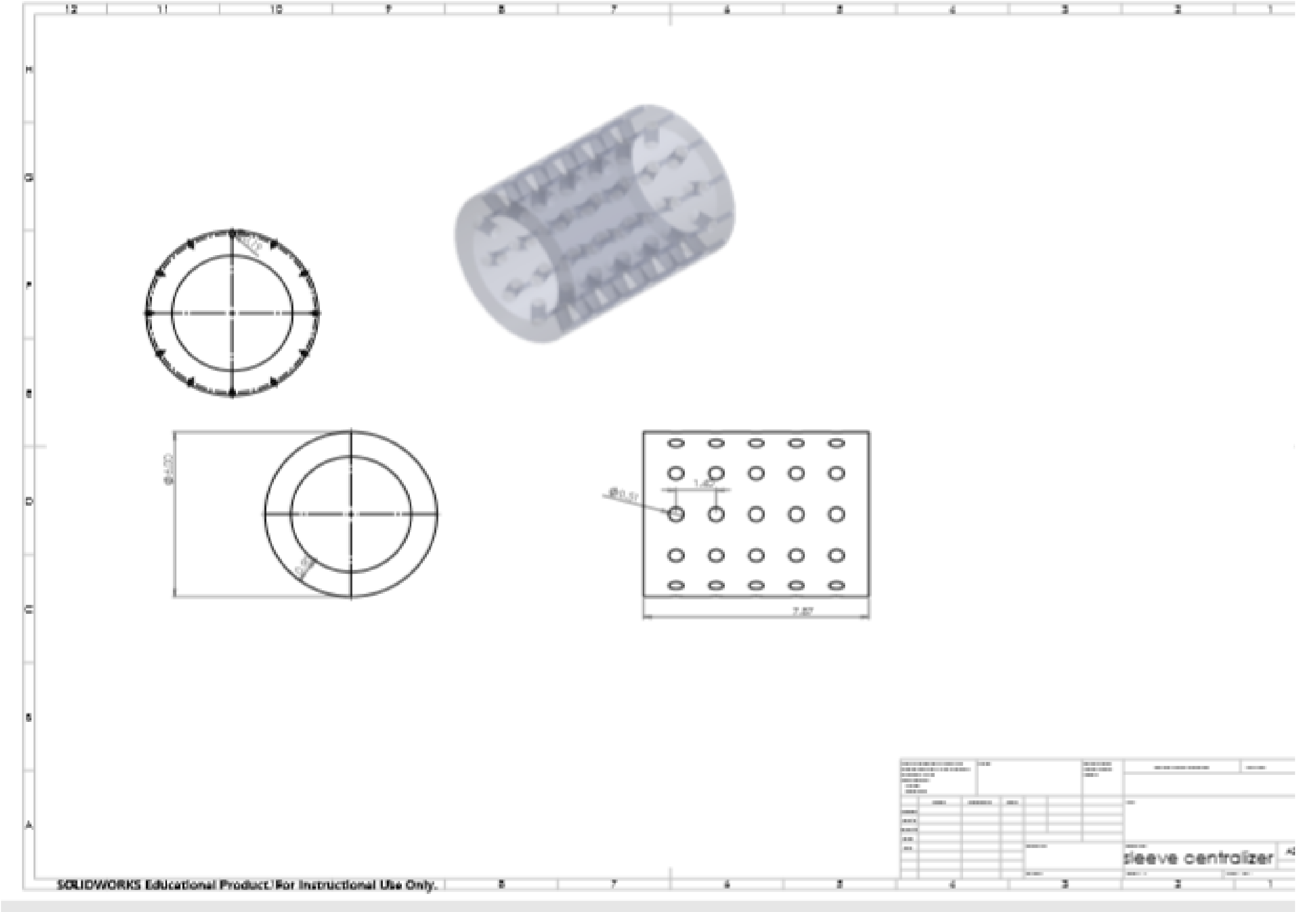
oring
A2
SOLIDWORKS Educational Product. For Instructional Use Only.

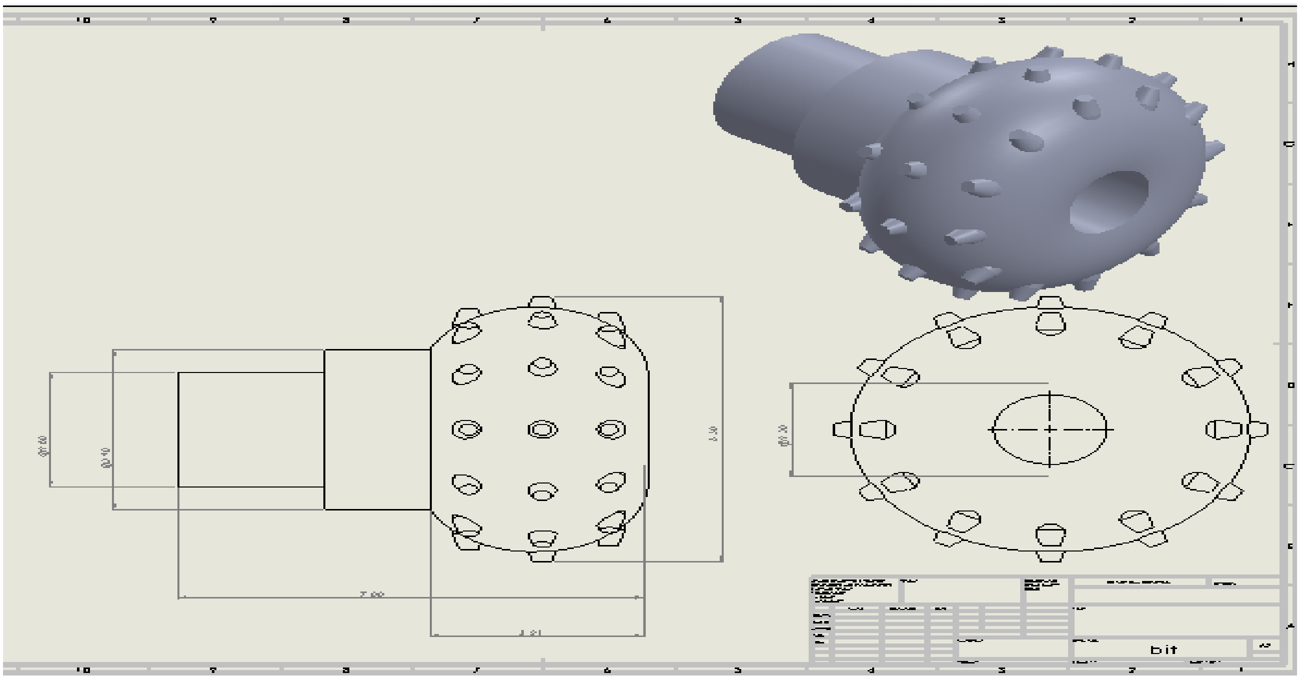


centrilizer
A2
SOLIDWORKS Educational Product. For Instructional Use Only.


centrlizer2
A2


small pipe

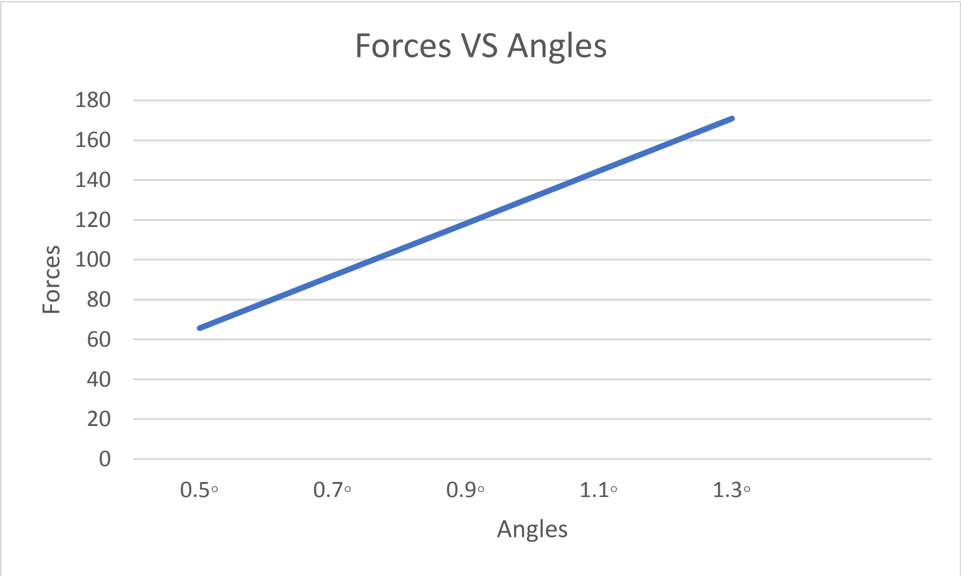

sleeve centralizer
SOLIDWORKS Educational Product. For Instructional Use Only.


bit

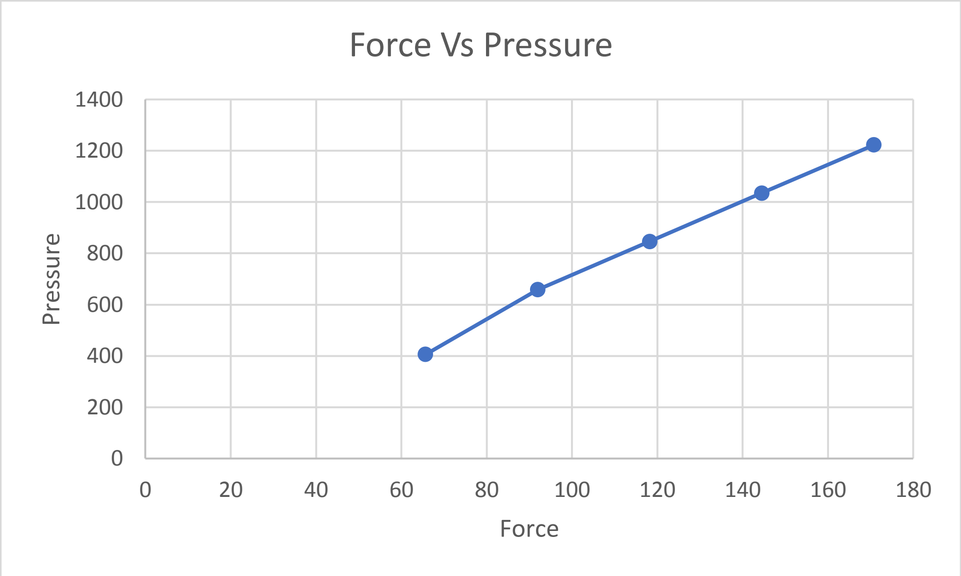
Materials	**Costs (SR)**
Steel Pipe	400
Aluminium Pipe	1500
Sleeve Centralizer	1850
Centralizer	1500
Compressor	400
Wood Bit Drill	150
Welding the prototype	750
30 Pistons	1500
Total	**8050**

Appendix D: Datasheet

Angle of Deflection	Force (KN)
0.5°	65.688
0.7°	91.96
0.9°	118.238
1.1°	144.5136
1.3°	170.788



Force (KN)	Pressure (Kpa)
65.688	406
91.96	658.5
118.238	846.6
144.5136	1034.8
170.788	1223.02


Force Vs Pressure
Pressure
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Force

Appendix E: Operation Manual

To run the prototype, please follow these procedures:

1. We fixed the laser pointer to the middle of the drill bit and point it to the board.

2. We connected the top holes of the sleeve together and then connect them to the compressor.

3. Then we set the compressor to the calculated pressure that is needed to bend the Aluminium pipe.

4. Record the deflection of the laser pointer on the board.

5. Apply Pythagoras theorem to record the angle of the bend

Appendix F: Gantt Chart

Task 1	Start Date	Days to complete
Identifying the project	6/01/2019	16
Determine the objectives		
Subdividing small tasks to collect information		
Search and review the previous work		
Writing chapter 1 of the report		
Preparing and submit the forms		
Write chapter 2		
Task 2		
Brain storming and gathering ideas for the conceptual design	20/01/2019	10
Draw the first conceptual design		
Selected the appropriate Materials		
Searching for the parts		
Order the parts what we want on global sites	30/01/2019	3
Buying the available part from local shop		2
Task 3		
Solid works Design	1/02/2019	12
Calculation of hole diameter		
Calculation pipe diameter		
Type of material of drilling pipe		
Power of motor	5/02/2019	6
Write chapter 3	6/02/2019	3
Task 4		
Initial prototype	10/02/2019	10
Preparing the Mid-term presentation	14/02/2019	2
Writing chapter 4		8
Task 5		
Start assembly the project	3/03/2019	15
Testing the system		

Finding the errors and upgrade the system		
Task 6		
Finishing the final report	06/04/2019	6
Finalized the project		
Final presentation	11/04/2019