2.7.4: Final iteration

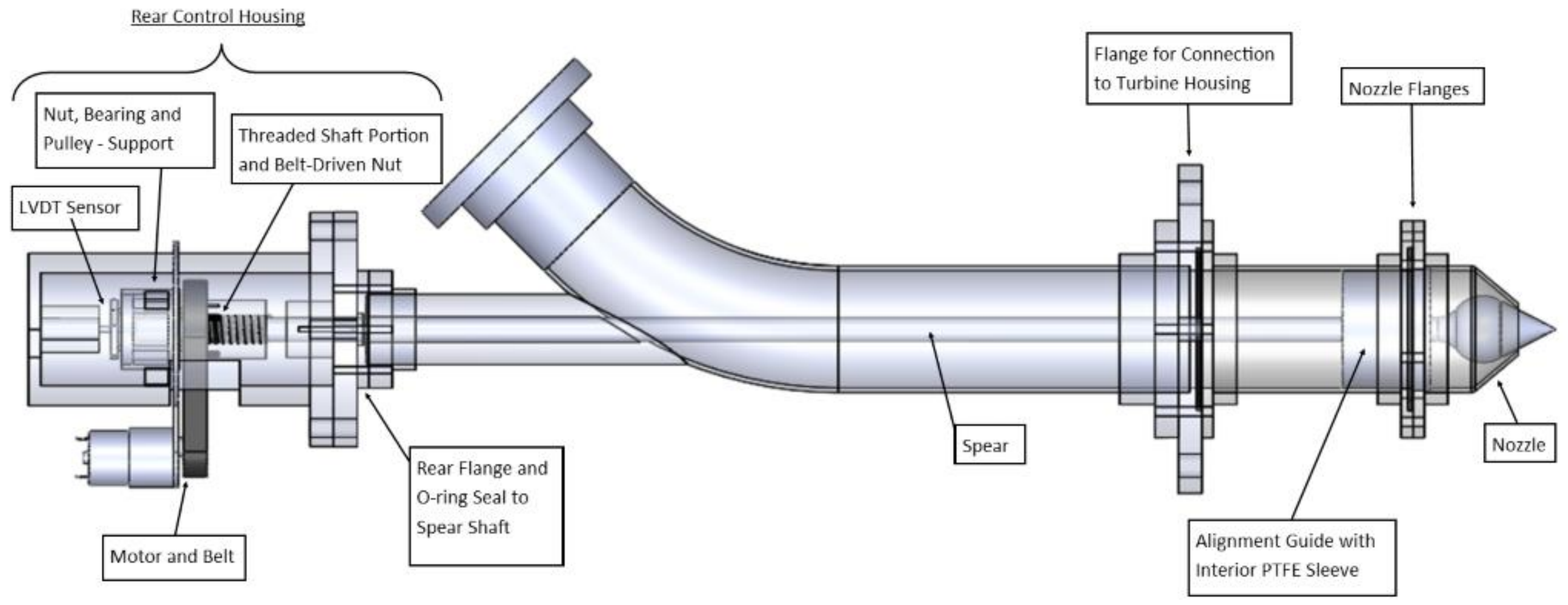


Figure 24: General assembly of the final production design

The final production design shown in Figure 24 accounts for the previous concerns. It includes a rear-control structure, which houses the drive nut, its supporting bearings and pulleys. A notch in the cage allows transmission between the motor (fixed by a bracket to the cage) to the drive-nut via a toothed belt and a recess in the rear of the cage accommodates the LVDT sensor. The housing and windings are fixed into this recess, whereas the core/pin fixes to the spear shaft. As the core moves relative to the housing, a differential measurement is taken, and a position reading produced

2.8: Final design

2.8.1: Final design – section: front

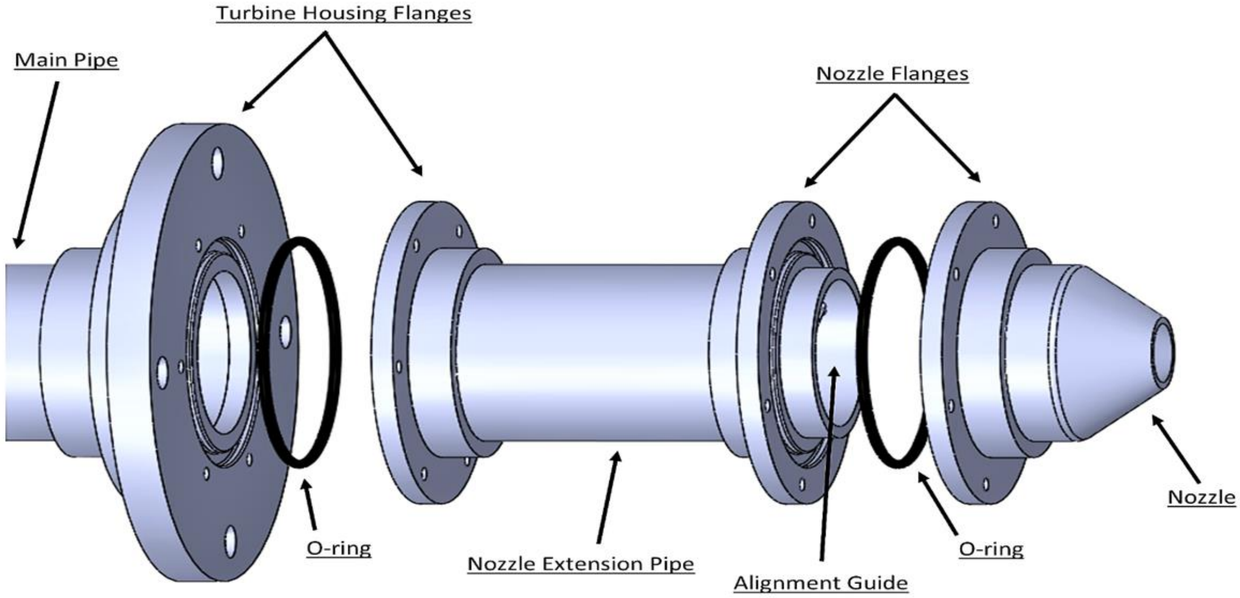


Figure 25: Exploded assembly diagram of the front section

Figure 25 is an exploded representation of the front section. The right-most component is the nozzle, this is welded to the flange immediately to the left of it. This flange is for connection to the identical one, on the other side of the spear 'head'. The alignment guide fits into a recess in the wall of the nozzle and is held in by the left nozzle flange (when bolted to the right nozzle flange). This solution allows the guide to be removable and avoids an interior weld that would otherwise be needed to fix it in place. This entire section is described as the nozzle sub-assembly and is positioned to the right of the nozzle extension pipe. To the left is a flange pair, of which one is larger radially, this connects to the turbine housing and is welded to the left end of the nozzle extension pipe. The other flange (shown to the left of the large flange) is welded to the right end of the main pipe section.

The nozzle extension pipe was added after the third iteration to give the nozzle enough prominence from the turbine housing. The turbine is held deep within the housing, so this prominence is necessary to prevent excessive jet divergence which occurs if the jet has too far to travel to the turbine buckets. A jet travel of less than 1.5x the jet diameter (21.6mm) is recommended for minimal divergence (Thake, 2000) and to produce efficiencies of ~ 90%. The extension adds an extra 55mm from the flange connection, alongside the housing this gives the recommended clearance.

2.8.2: Final design - section: prismatic slot and spear pin

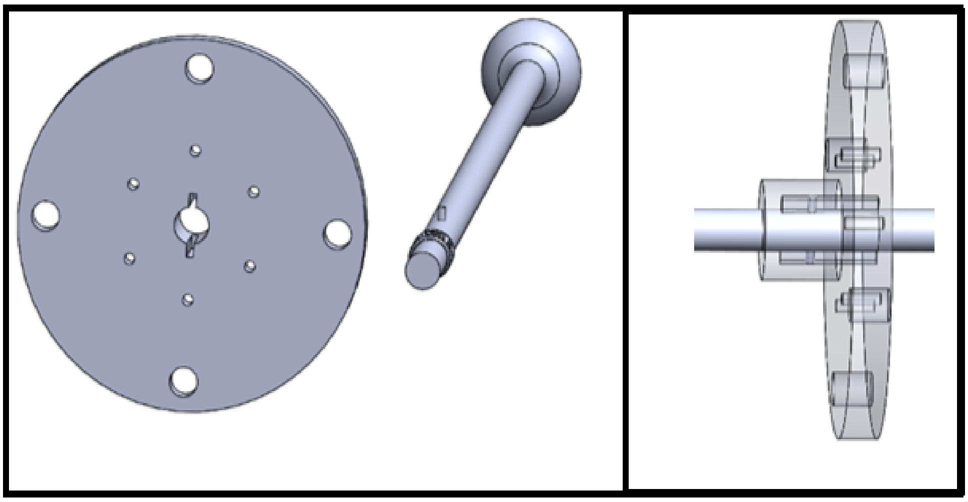


Figure 26: (left) Spear and slot shown separately (right) Prismatic constraint shown with mate, in assembly

Figure 26 shows the mechanism by which rotation is prevented in the spear. The spear shaft accommodates a shrink-fitted pin. This slides through and is restrained by the corresponding groove in the prismatic slot (the groove is at the centre of the plate on the left, in the left diagram).

2.8.3: Final design - section: rear flanges and O-ring assembly

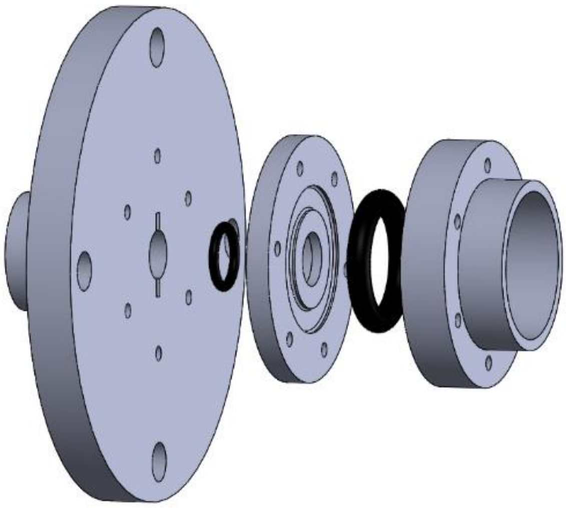


Figure 27: Rear flange and sealing assembly - left - prismatic slot, mid - sealing plate with O-rings, right - pipe flange

Figure 27 depicts the rear flange assembly. The right most component is a flange which welds onto the rear of the tee-pipe. After this, is the sealing plate with O-rings shown on either side. The face groove on the right side facilitates the right O-ring; when bolted to the flange - this forms a static seal to stop water escaping radially out of the flange joint.

The left O-ring fits into an interior, radial cavity in the same plate. This O-ring seals dynamically with the spear shaft, allowing it to translate whilst stopping water from escaping out of the rear of the assembly. The left-most component is the prismatic slot, as above. The second set of larger holes are for connection to the rear control housing, which contains the drive-nut and LVDT.

2.8.4: Final design – section: rear control assembly (with motor, drive nut and LVDT housing)

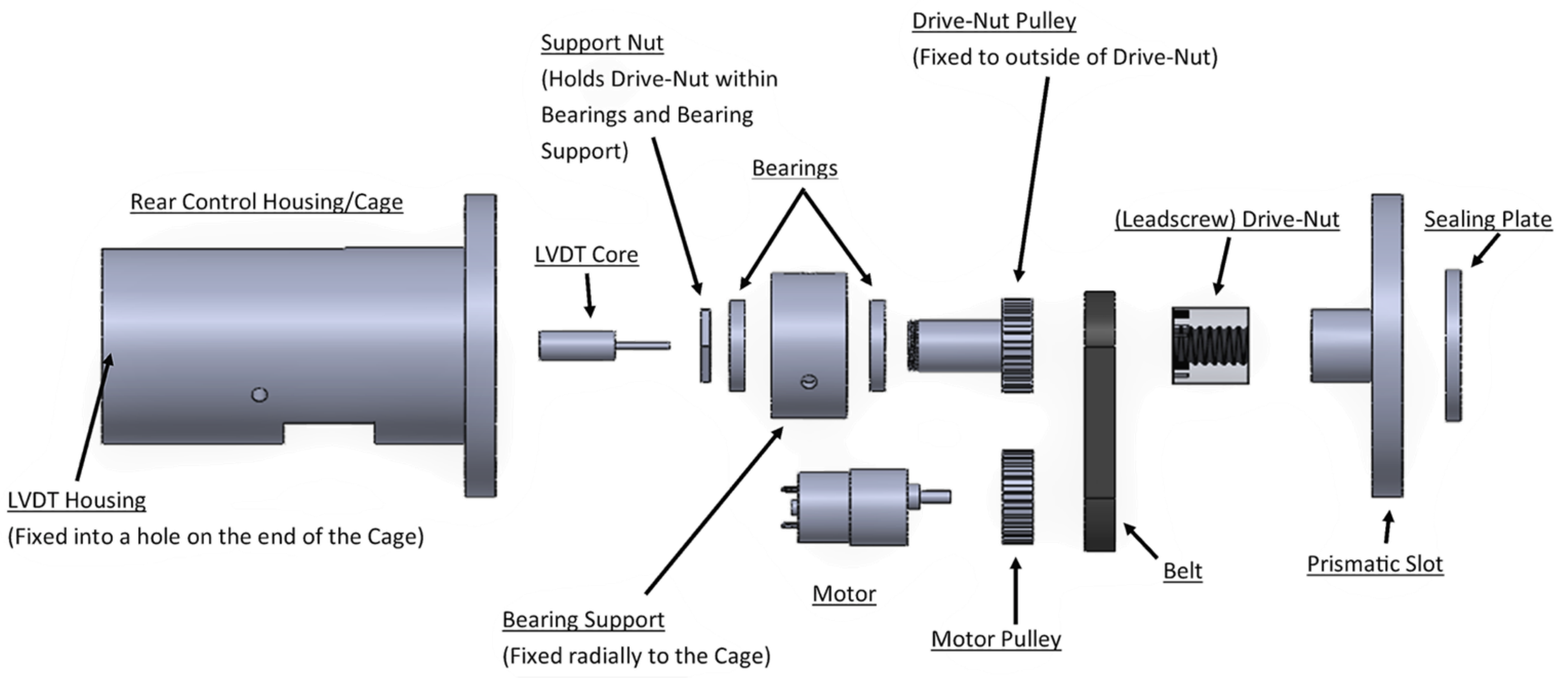


Figure 28: Rear Control Assembly

Both pulleys have the same number of teeth, producing uniform transmission between the drive nut and motor. The motor drive speed is proportional to the maximum speed at which the drive nut can rotate, simplifying control of the spear valve. The belt is used so that the motor can be offset from the shaft allowing for the linear variable differential transformer (LVDT) to be mounted in line with the shaft. The bearings and bearing support allow for the drive nut pulley to be held in position, while allowing for free rotation to occur. Due to the small forces acting on the drive pulley the axial forces are negligible. The bearing support is screwed into the rear control housing and the support nut keeps all the components in the correct positions. The LVDT sensor will be used to identify the position of the spear and therefore flow rate through the spear valve, this will allow for the spear position to be precisely controlled. The LVDT sensor has an operational range of 10mm which covers the 7mm of spear travel.

2.9: Spear valve diagrams showing the arrangement of the spear valve with respect to the turbine

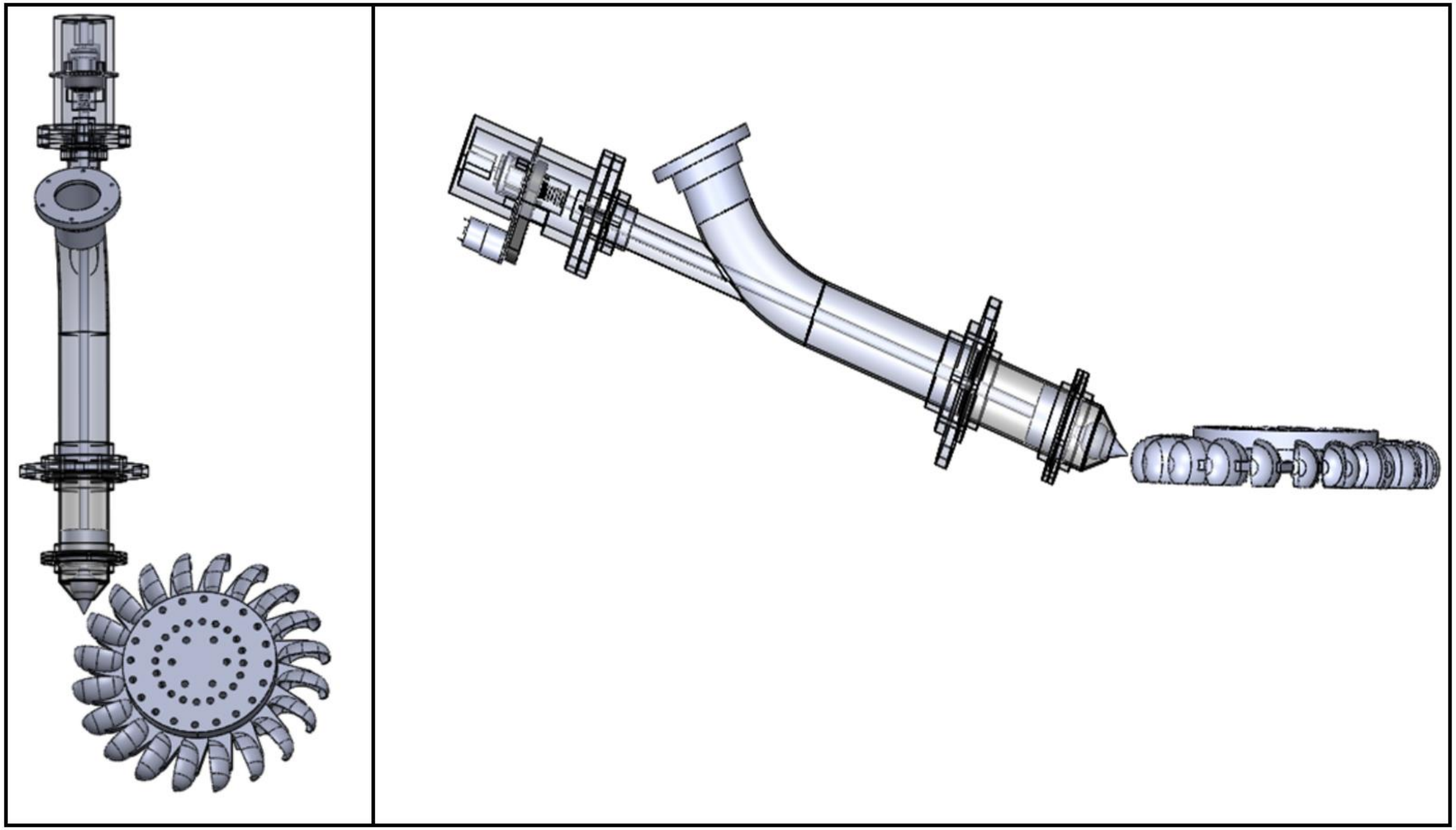


Figure 29: Left – spear valve positioned tangentially to the turbine, right – spear valve with inclination of 20° to the plane of rotation of the turbine

The spear valve will, occupy both positions simultaneously but this is hard to represent in 2D – hence both viewpoints.

2.10: Spear valve exploded drawing and parts list

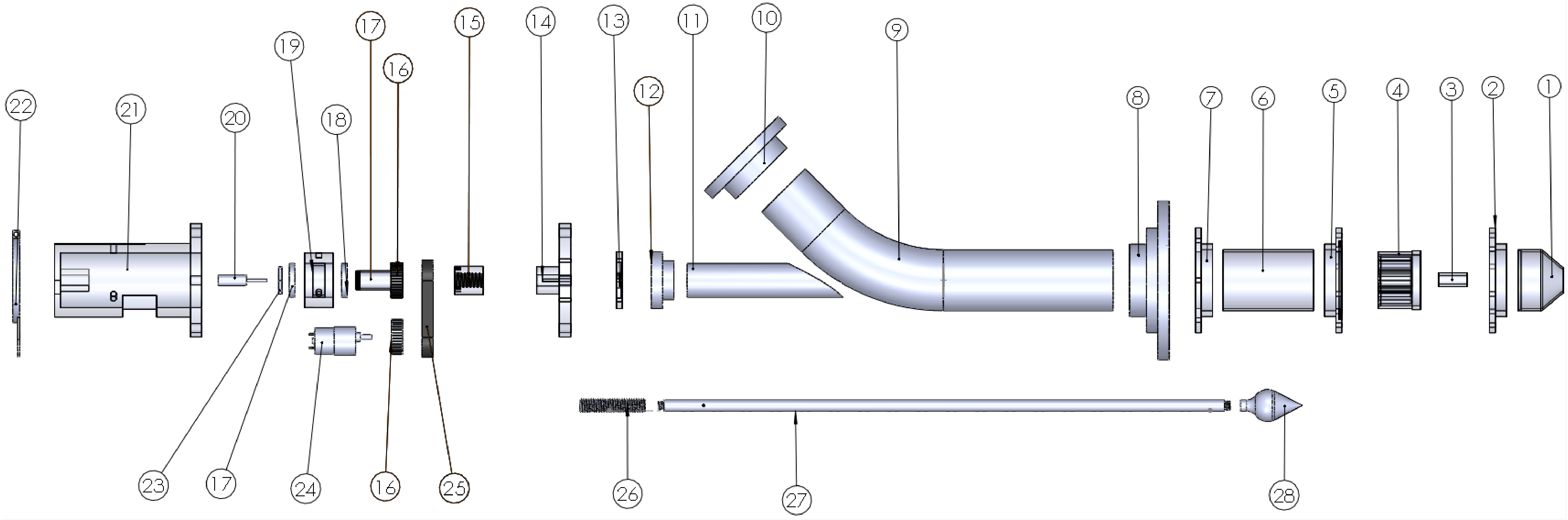
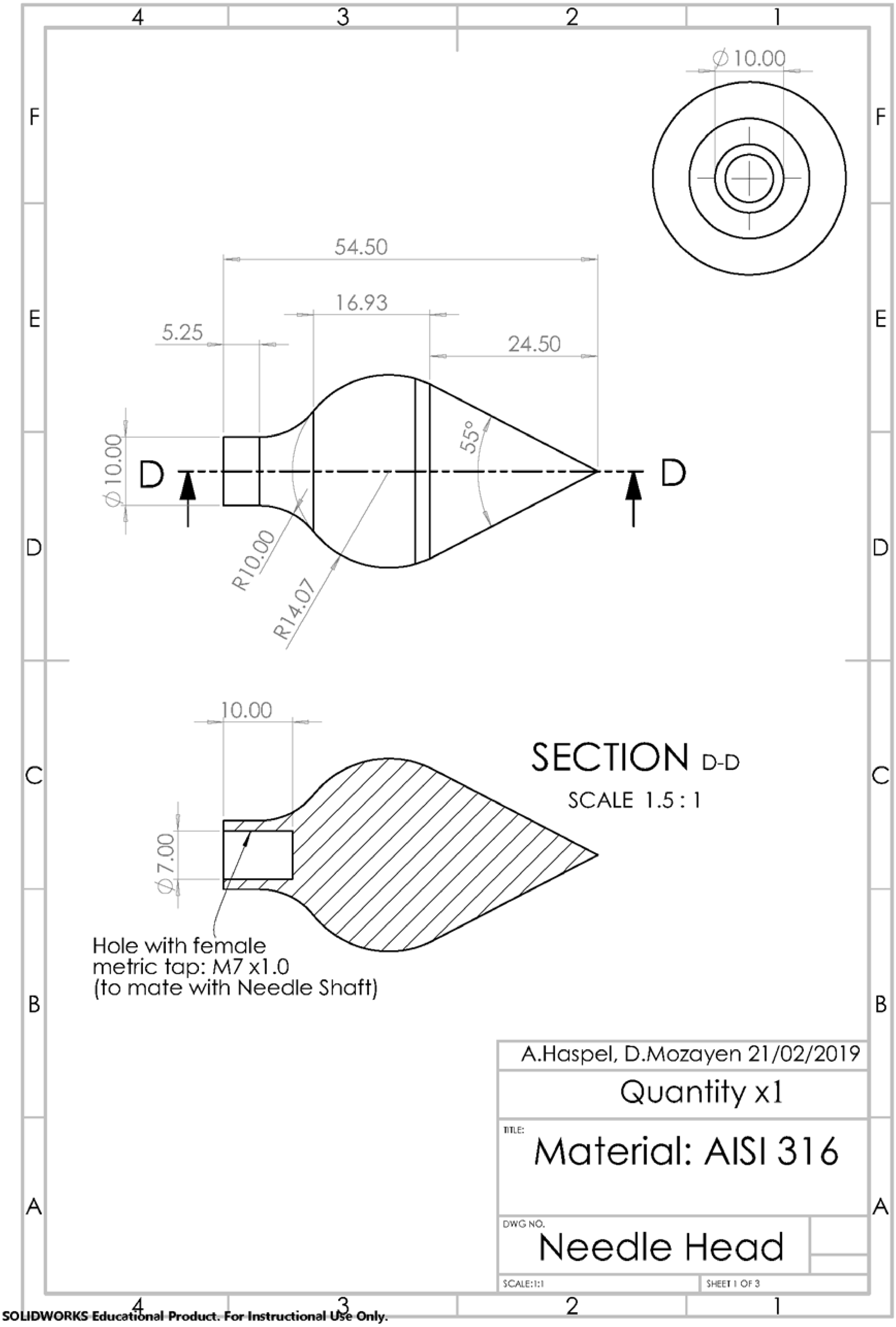


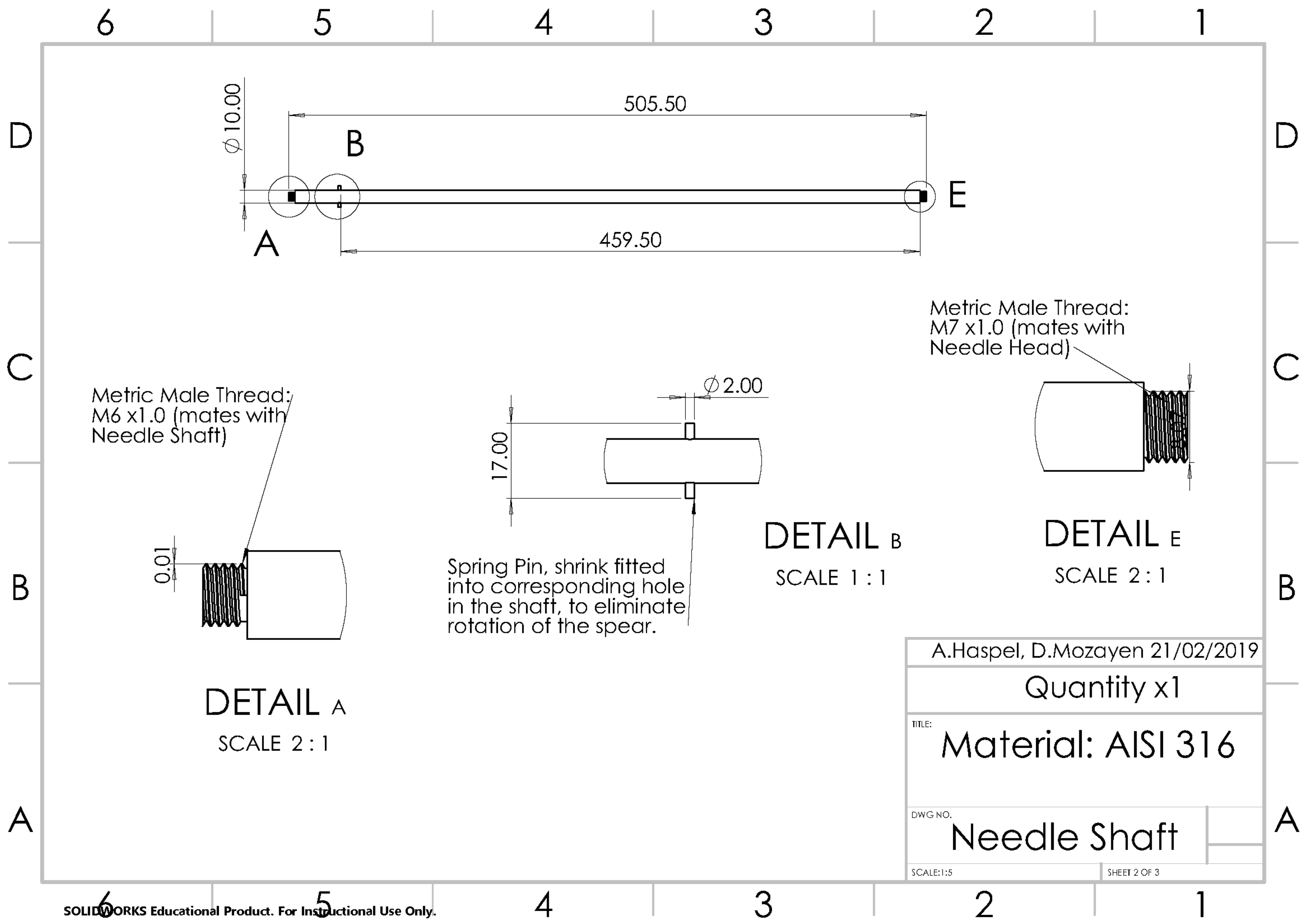
Figure 30: Final assembly exploded view excluding O-rings

Table 4: Parts corresponding to exploded assembly, Figure 30

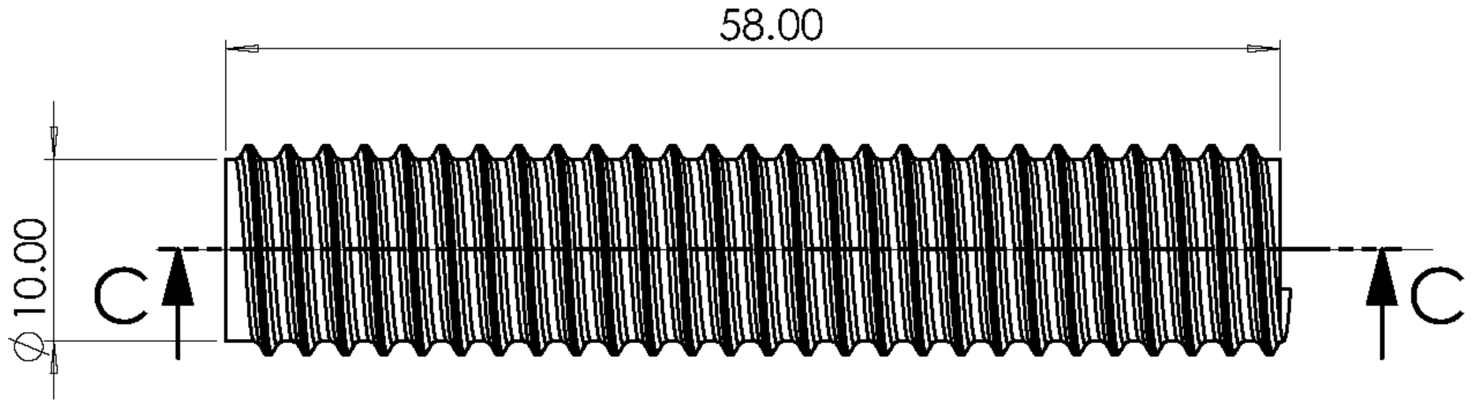
No. Item	Part Name	Material Source	Material	Quantity
1	Nozzle	University Workshop	304L Stainless Steel	x1
2	Nozzle Flange	University Workshop	304L Stainless Steel	x1
3	PTFE Tube	RS Components	PTFE	x1
4	Guide	University Workshop	304L Stainless Steel	x1
5	Nozzle Extension Flange with O-ring	University Workshop	304L Stainless Steel	x1
6	Nozzle Extension	University Workshop	304L Stainless Steel	x1
7	Nozzle Extension Flange without O-ring	University Workshop	304L Stainless Steel	x1
8	Front Flange	University Workshop	304L Stainless Steel	x1
9	Main Pipe	HS-Umformtechnik GmbH	304 Stainless Steel	x1
10	Flange	University Workshop	304L Stainless Steel	x1
11	Back Pipe	University Workshop	304L Stainless Steel	x1
12	Back Flange	University Workshop	304L Stainless Steel	x1
13	Sealing Plate	University Workshop	304L Stainless Steel	x1
14	Back Plate with Pin	University Workshop	304L Stainless Steel	x1
15	ACME nut	ACCU Ltd.	Bronze	x1
16	Pulley	RS Components	Aluminium	x2
17	Pulley Support	University Workshop	304L Stainless Steel	x1
18	Bearing	Bearing Station	N/A	x2
19	Bearing Fixing	University Workshop	304L Stainless Steel	x1
20	LVDT Sensor	RS Components	Titanium (core), Nickel-Iron (housing)	x1
21	LVDT Support	University Workshop	304L Stainless Steel	x1
22	Gear Support	University Workshop	304L Stainless Steel	x1
23	Nut	RS Components	N/A	x1
24	Motor	RS Components	Iron core	x1
25	Belt	RS Components	Polyurethane	x1
26	Leadscrew	ACCU Ltd.	316 Stainless Steel	x1
27	Shaft	University Workshop	304L Stainless Steel	x1
28	Spear	University Workshop	304L Stainless Steel	x1

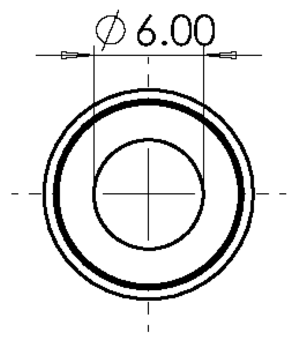
2.11: Final production drawings

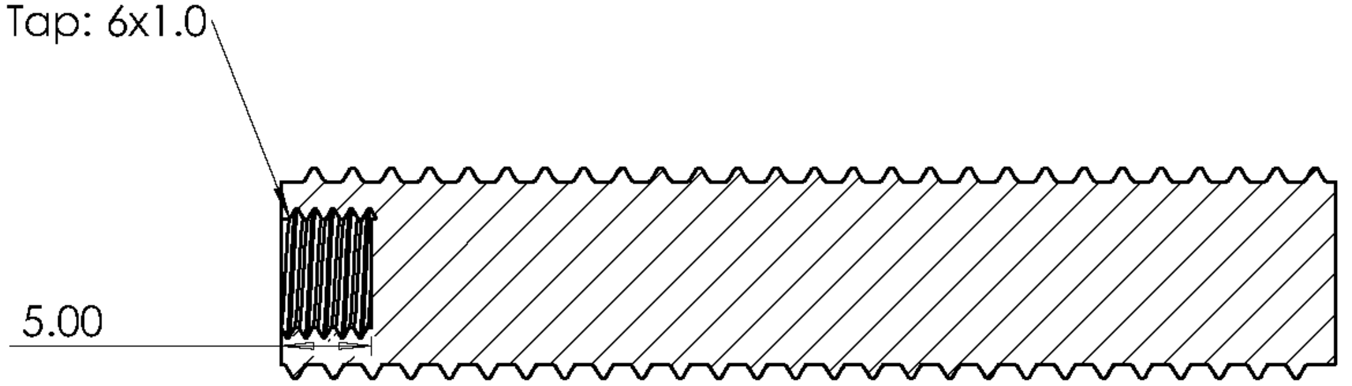




505.50
∅ 10.00
B
E
A
459.50
Metric Male Thread:
M6 x1.0 (mates with
Needle Shaft)
0.01
DETAIL A
SCALE 2 : 1
∅ 2.00
17.00
Spring Pin, shrink fitted
into corresponding hole
in the shaft, to eliminate
rotation of the spear.
DETAIL B
SCALE 1 : 1
Metric Male Thread:
M7 x1.0 (mates with
Needle Head)
DETAIL E
SCALE 2 : 1
A.Haspel, D.Mozayen 21/02/2019
Quantity x1
TITLE:
Material: AISI 316
DWG NO.
Needle Shaft
SCALE:1:5
SHEET 2 OF 3
SOLIDWORKS Educational Product. For Instructional Use Only.







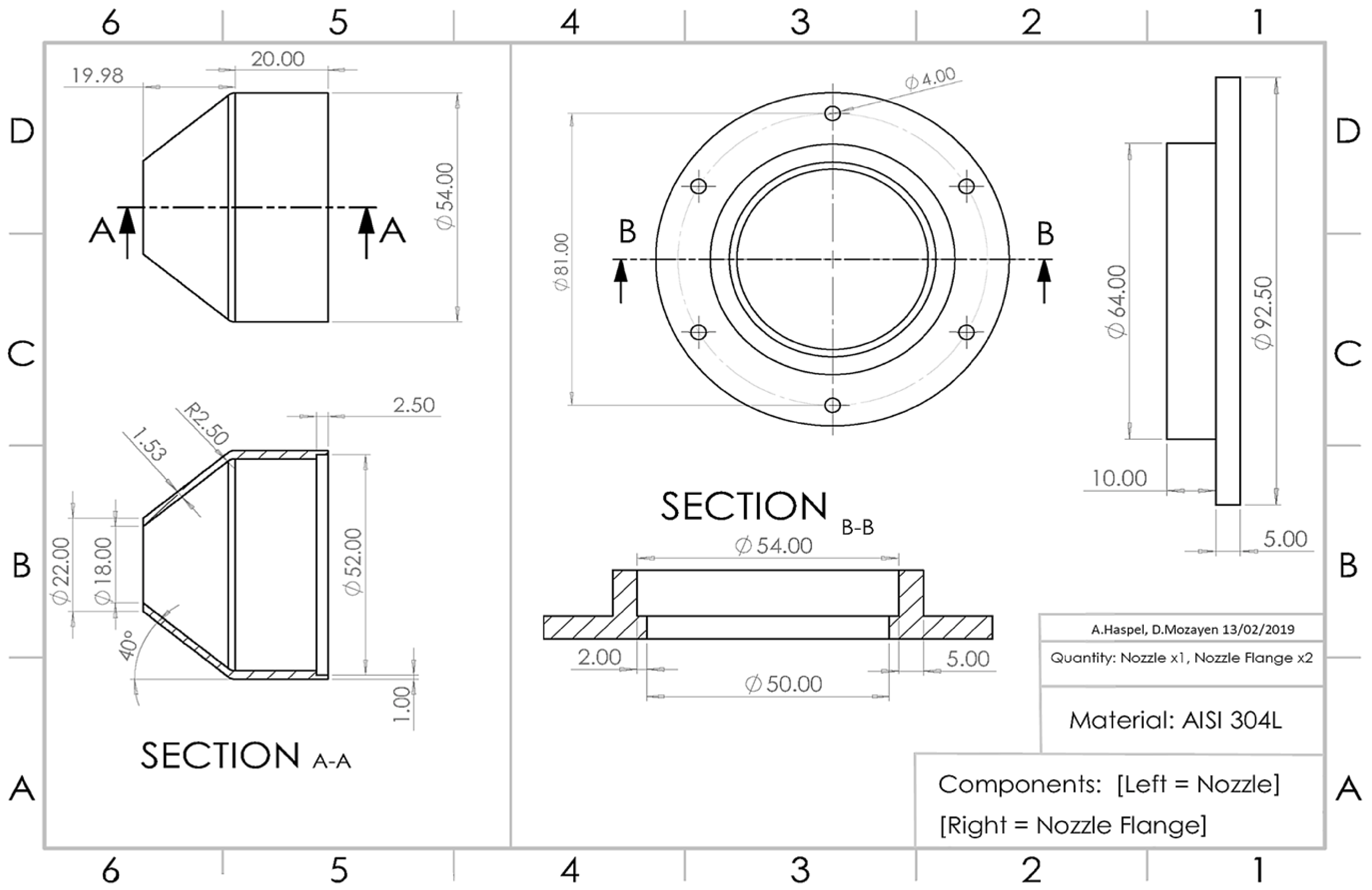
SECTION C-C
SCALE 2 : 1

We are buying a leadscrew from ACCU which comes with a pitch of 2mm and length of 200mm.

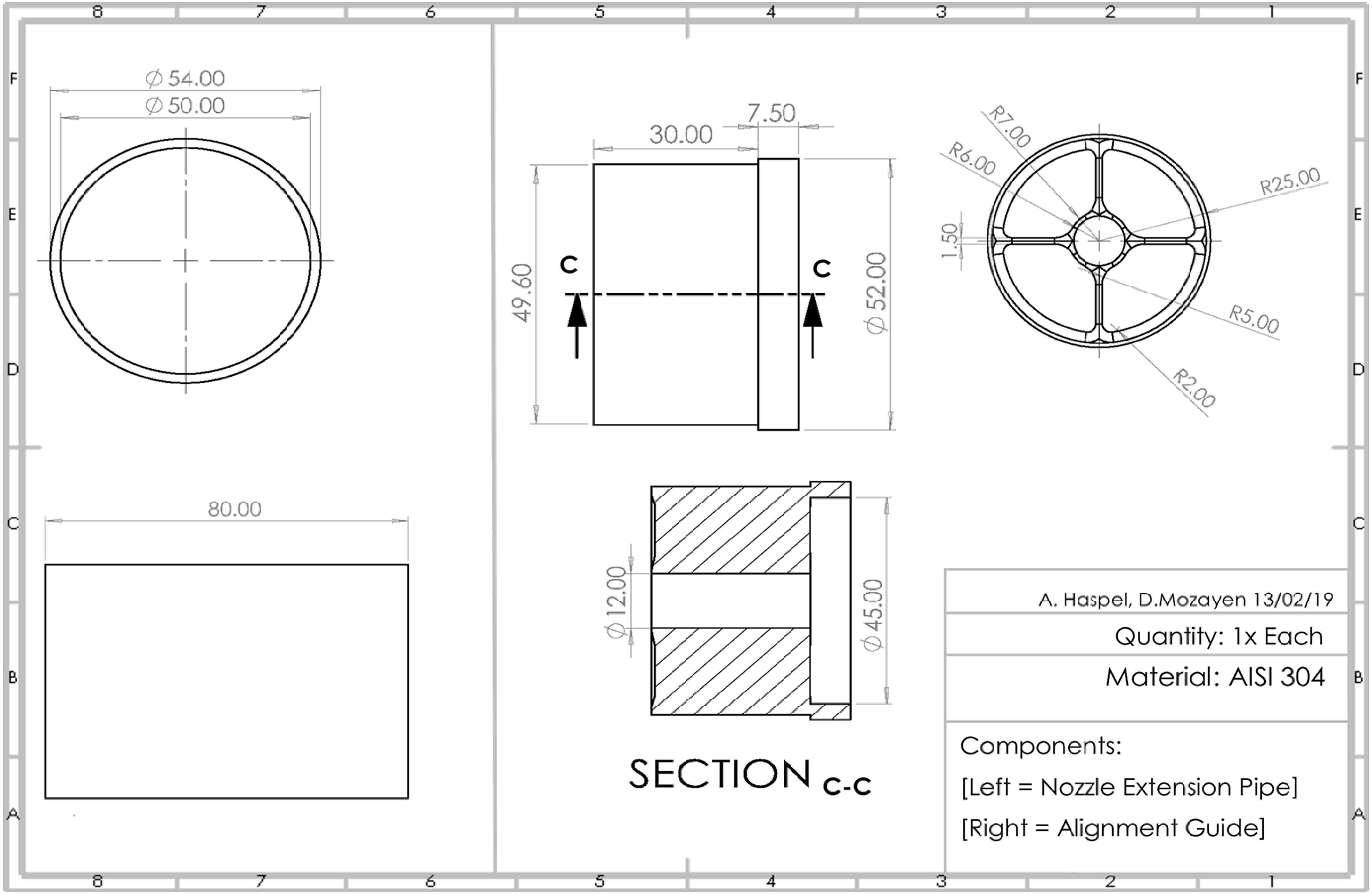
Tapping a hole into the leadscrew end face will allow the leadscrew and the shaft to be screwed and secured together.

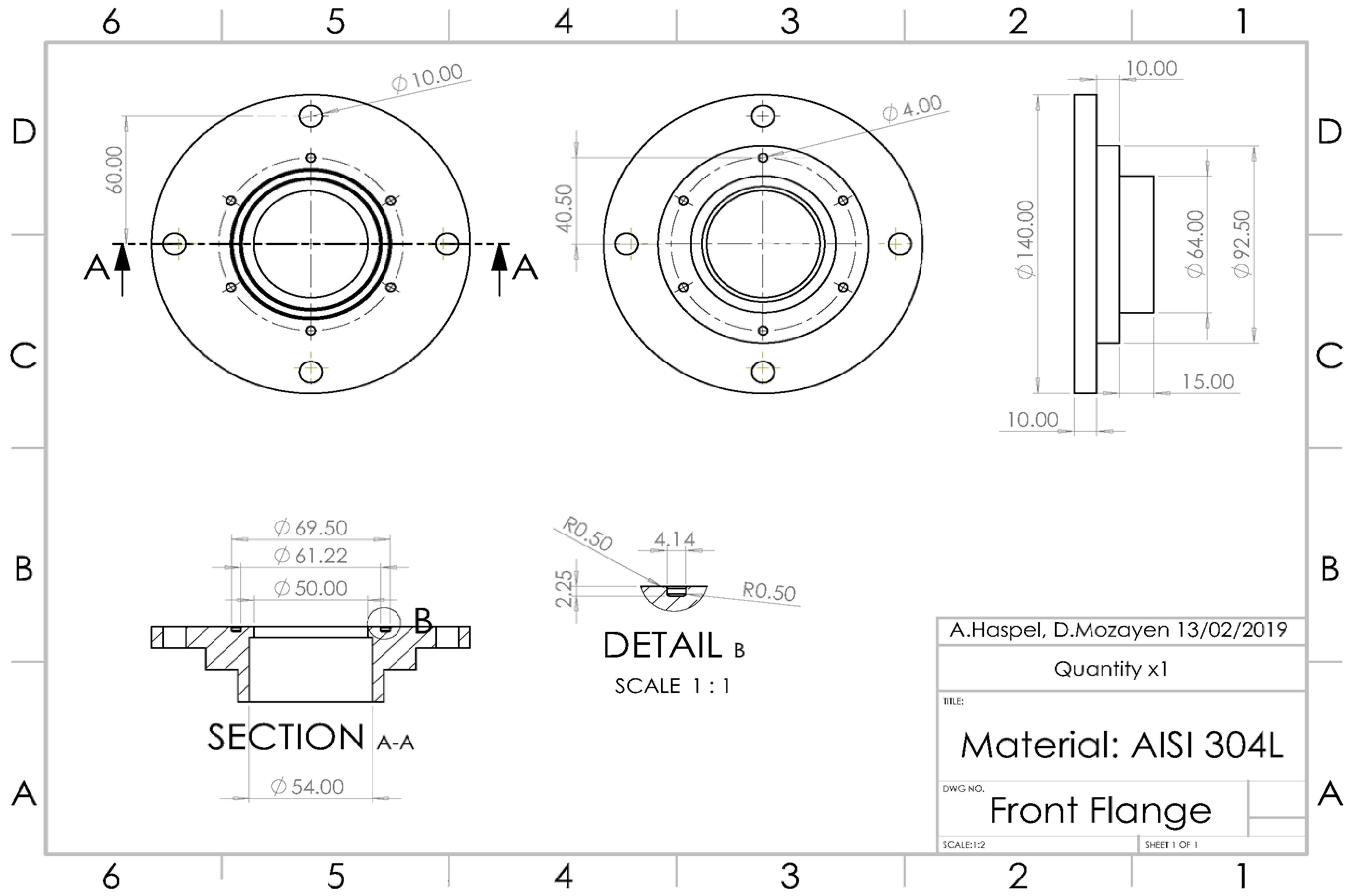
The extra length of leadscrew will then be cut away.

A.Haspel, D.Mozayen 21/02/2019
Quantity x1
TITLE: Material: AISI 316
DWG NO. Leadscrew
SCALE:1:1 SHEET 3 OF 3

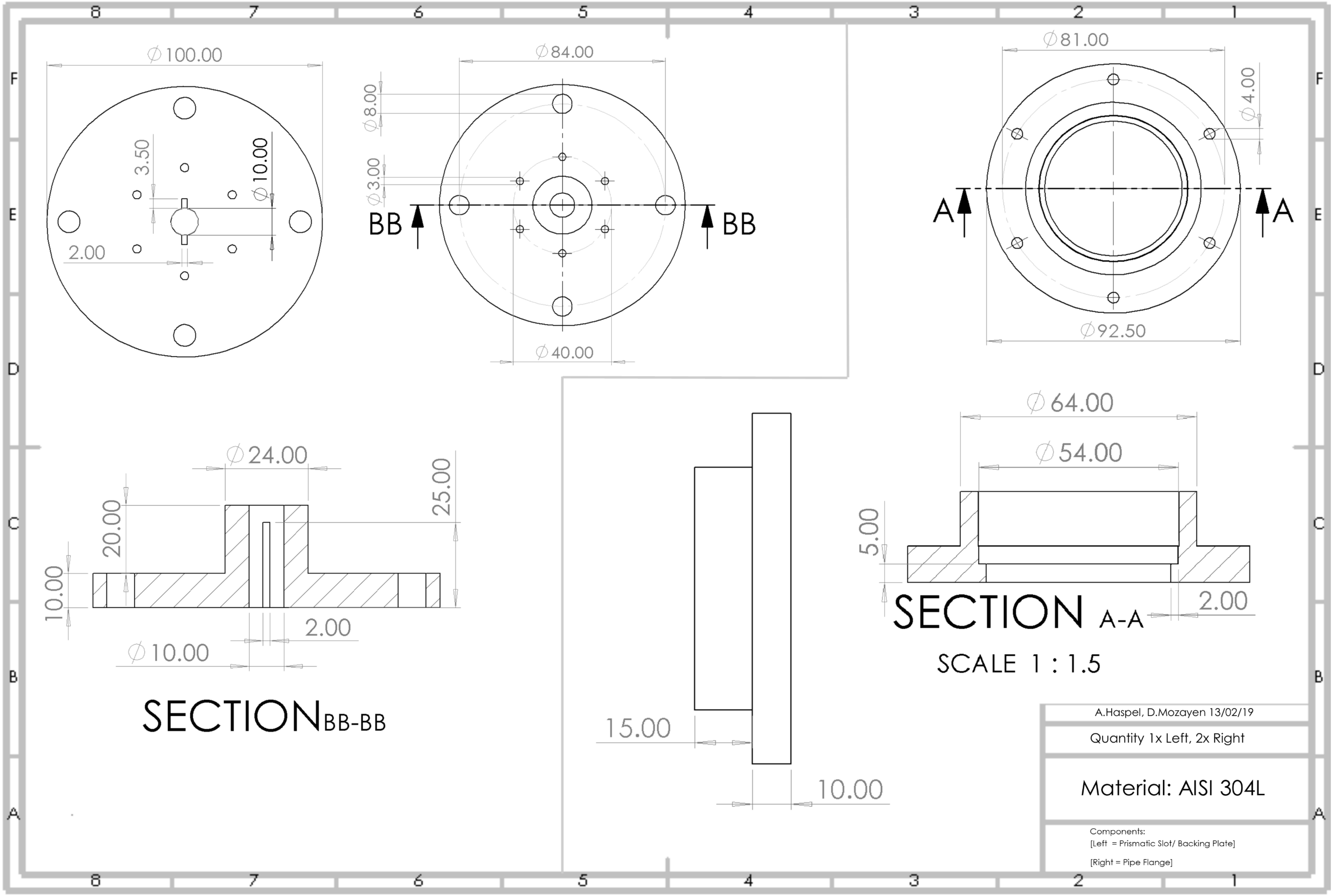


20.00
19.98
A
A
⌀54.00
R2.50
1.53
2.50
⌀22.00
⌀18.00
⌀52.00
40°
1.00
SECTION A-A
⌀4.00
⌀81.00
B
B
SECTION B-B
⌀54.00
2.00
⌀50.00
5.00
⌀64.00
⌀92.50
10.00
5.00
A.Haspel, D.Mozayen 13/02/2019
Quantity: Nozzle x1, Nozzle Flange x2
Material: AISI 304L
Components: [Left = Nozzle]
[Right = Nozzle Flange]

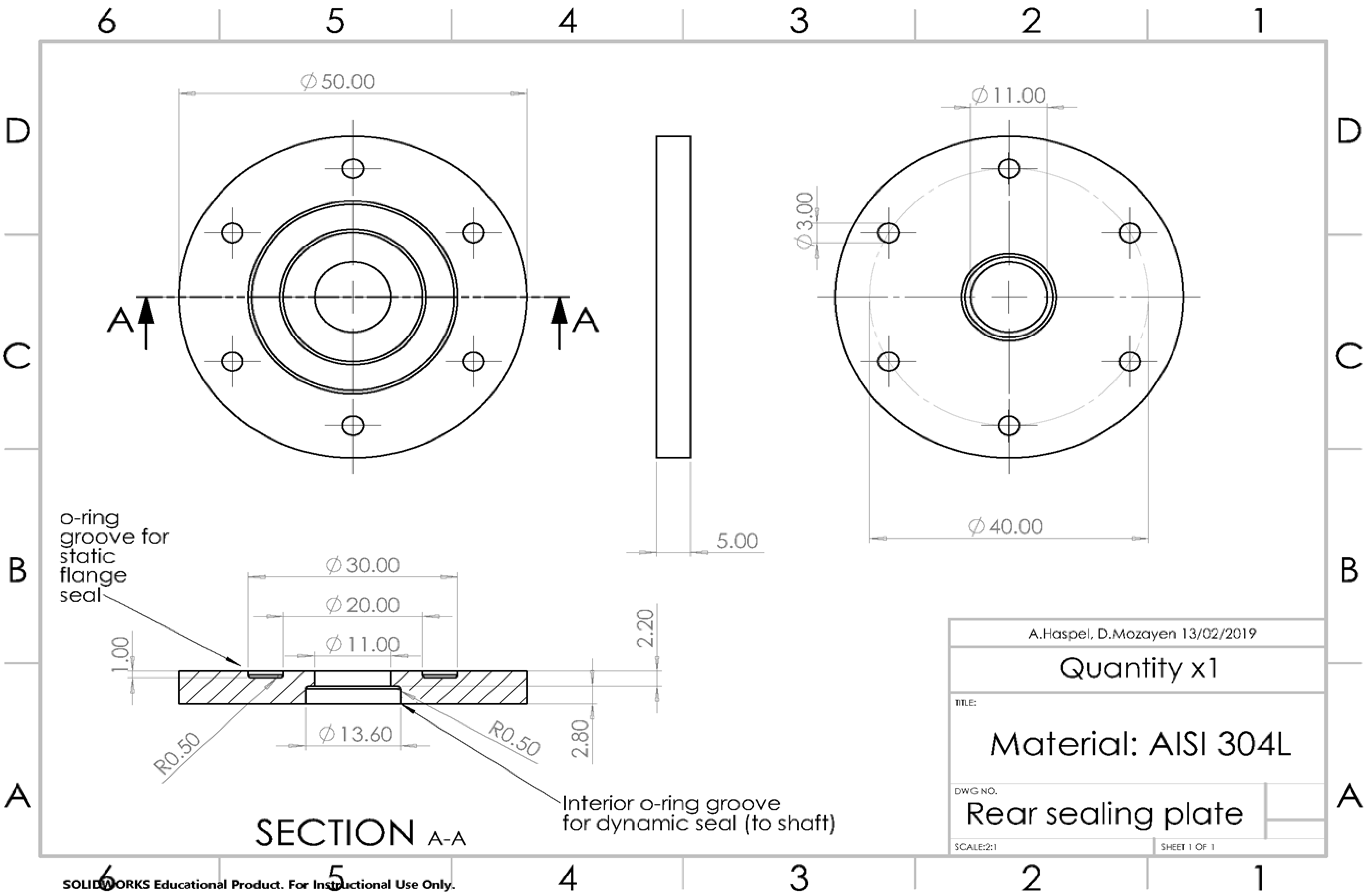

∅ 54.00
∅ 50.00
80.00
30.00
7.50
49.60
C
C
∅ 52.00
R7.00
R6.00
R25.00
1.50
R5.00
R2.00
∅ 12.00
∅ 45.00
SECTION C-C
A. Haspel, D.Mozayen 13/02/19
Quantity: 1x Each
Material: AISI 304
Components:
[Left = Nozzle Extension Pipe]
[Right = Alignment Guide]



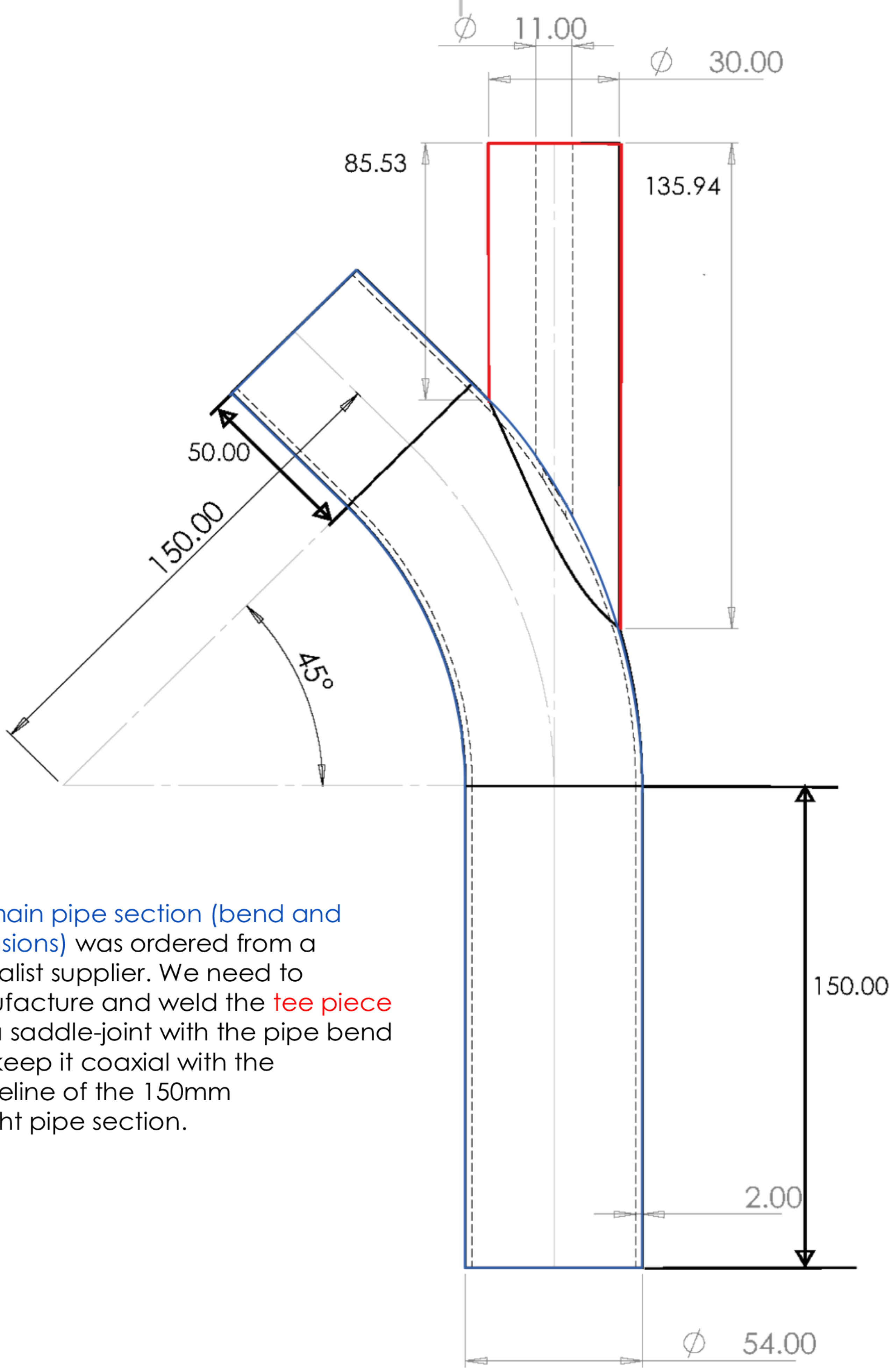
⌀ 10.00
60.00
A
A
40.50
⌀ 4.00
10.00
⌀ 140.00
⌀ 64.00
⌀ 92.50
15.00
10.00
⌀ 69.50
⌀ 61.22
⌀ 50.00
B
SECTION A-A
⌀ 54.00
R0.50
4.14
2.25
R0.50
DETAIL B
SCALE 1 : 1
A.Haspel, D.Mozayen 13/02/2019
Quantity x1
TITLE:
Material: AISI 304L
DWG NO.
Front Flange
SCALE:1:2
SHEET 1 OF 1



∅100.00
3.50
∅10.00
2.00
∅84.00
∅8.00
∅3.00
BB
BB
∅40.00
∅81.00
∅4.00
A
A
∅92.50
∅24.00
20.00
25.00
10.00
2.00
∅10.00
SECTION BB-BB
15.00
10.00
∅64.00
∅54.00
5.00
SECTION A-A
2.00
SCALE 1 : 1.5
A.Haspel, D.Mozayen 13/02/19
Quantity 1x Left, 2x Right
Material: AISI 304L
Components:
[Left = Prismatic Slot/ Backing Plate]
[Right = Pipe Flange]



Ø50.00
Ø11.00
Ø3.00
A
A
5.00
Ø40.00
o-ring groove for static flange seal
Ø30.00
Ø20.00
Ø11.00
1.00
2.20
R0.50
Ø13.60
R0.50
2.80
Interior o-ring groove for dynamic seal (to shaft)
SECTION A-A
A.Haspel, D.Mozayen 13/02/2019
Quantity x1
TITLE:
Material: AISI 304L
DWG NO.
Rear sealing plate
SCALE:2:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



The main pipe section (bend and extensions) was ordered from a specialist supplier. We need to manufacture and weld the tee piece into a saddle-joint with the pipe bend and keep it coaxial with the centreline of the 150mm straight pipe section.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
			A.Haspel, D.Mozayen	

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

25.01.2019

WEIGHT:

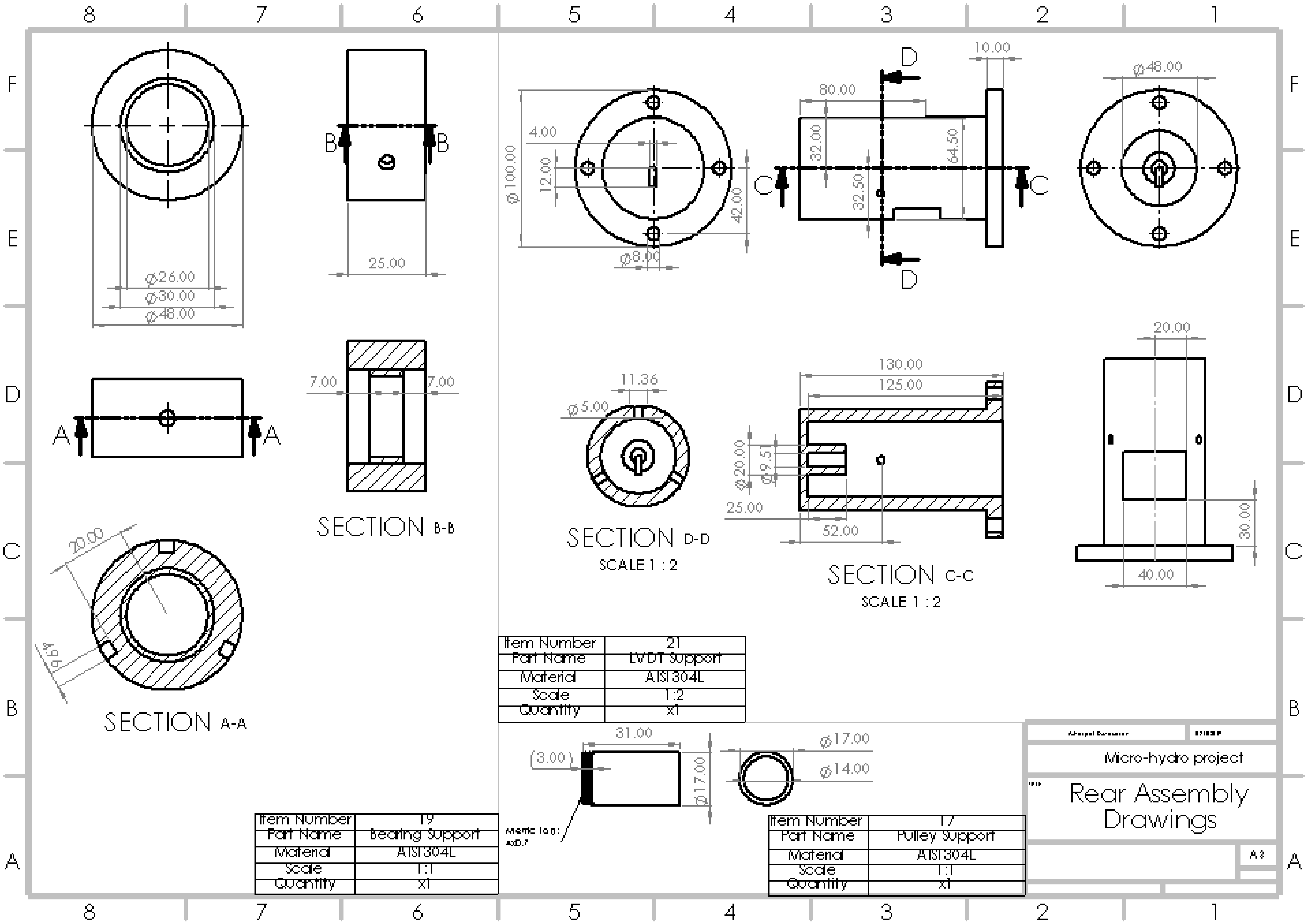
Material
AISI 304

DWG NO.
Bend_Assembly

A4

SCALE:1:5

SHEET 1 OF 1



Item Number	19
Part Name	Bearing Support
Material	AISI304L
Scale	1:1
Quantity	x1

Item Number	21
Part Name	LVDT Support
Material	AISI304L
Scale	1:2
Quantity	x1

Item Number	17
Part Name	Pulley Support
Material	AISI304L
Scale	1:1
Quantity	x1

2.12: Spear valve parts and cost analysis

Table 5: List of standard components

Component	Quantity	Source	Additional Info
Belt	x1	https://uk.rs-online.com/web/p/timing-belts/4745319/	RS Stock No. 474-5319
Pulley	x2	https://uk.rs-online.com/web/p/timing-belt-pulleys/0744980/	RS Stock No. 744-980
LVDT sensor	x1	https://uk.rs-online.com/web/p/lvdt/7753861/	RS Part No: 775-3861
10mm ID and 14mm OD Thickness 2mm	x1	https://www.amazon.co.uk/BargainBitz-Metric-Rings-Plumbing-Washer/dp/B0083GNI98/ref=sr_1_1?s=diy&ie=UTF8&qid=1547806103&sr=1-1&keywords=10mm+id+o+ring	
27mm ID and 30mm OD Thickness 1.5mm	x1	https://www.bearingstation.co.uk/Products/O_Rings/Nitrile_O_Ring_Metric/25mm_-_49.99mm/OR26X2	
64mm ID and 70mm OD	x2	https://www.bearingstation.co.uk/Products/O_Rings/Nitrile_O_Ring_Metric/50mm_-_74.99mm/OR64X3	
17mm Deep Groove Ball Bearing 30mm OD	x2	https://uk.rs-online.com/web/p/ball-bearings/8937477/	RS Stock No. 893-7477
Leadscrew	x1	https://www.accu.co.uk/en/a4-stainless-steel-trapezoidal-lead-screws/90248-L-Tr10x2-1R-200-A4	Code: L-Tr10x2-1R-200-A4
Leadscrew Nut	x1	https://www.accu.co.uk/en/bronze-trapezoidal-lead-screw-nuts/429127-N-Tr10x2-1R-C-BR	Code: N-Tr10x2-1R-C-BR
Main Pipe Bend	x1	HS Umformtechnik GmbH	

Table 6: Component and service cost

COMPONENTS OR SERVICE	COST
PIPE	£115
LVDT SENSOR	£205.31
MOTOR	£36.29
BELT AND PULLEY	£25.48
LEADSCREW	£4.08
LEADSCREW NUT	£7.96
O RINGS	£15

2.13: Manufacture plan

The components will be manufactured by the University of Warwick workshop using the final drawings above. The machining process will involve CNC machines and lathes. The most difficult component to manufacture is the back pipe as it requires a special cut which must closely resemble the curve of the bend in the main pipe.

The subassemblies will be welded together by an external company, as the university workshop is not capable of producing reliable welds at this pressure. After welding the spear valve will screw together.

2.13.1: Welding plan

2.13.1.1: Main pipe assembly

The main pipe assembly contains three flanges which allow the open ends of the main pipe to be sealed. Additionally, the back pipe must be welded to the main pipe bend, creating a T-piece. Figure 31 below shows an exploded view, with the three flanges and back pipe. The back pipe must be concentric with the main pipe, as the spear shaft passes through the entire length towards the nozzle.

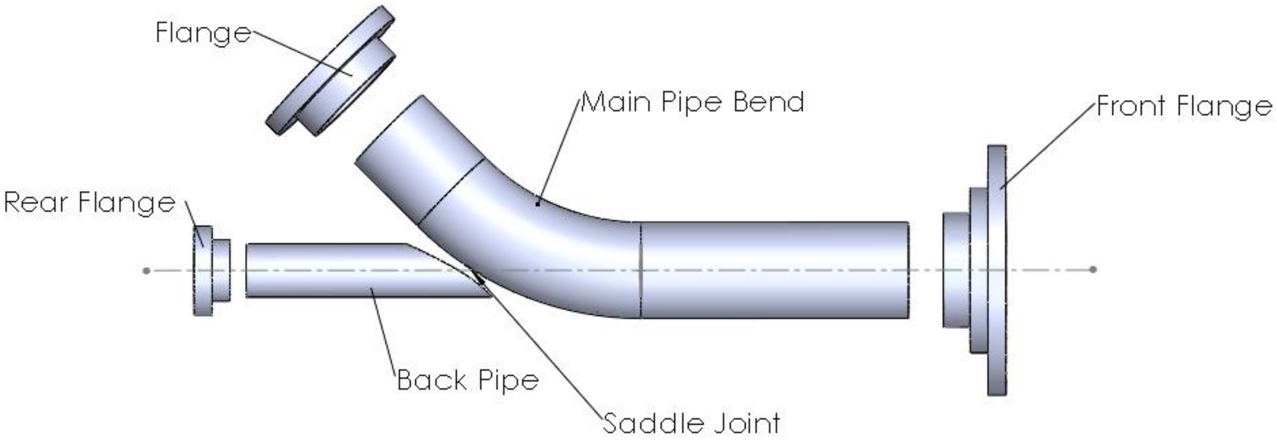


Figure 31: Exploded view of the main pipe assembly

All the flanges have bosses allowing them to sit on the pipe without being held; aiding welding.

Joining the back pipe and main pipe accurately will use a saddle joint, this may require a jig as the alignment of the back pipe is important.

Component List:

- Flange
- Rear Flange
- Front Flange
- Back Pipe
- Main Pipe Bend

2.13.1.2: Nozzle extension assembly

This extension is a section of pipe with two flanges welded onto each end, allowing the nozzle to protrude. Figure 32: Nozzle extension assembly below is a diagram showing the exploded view of the nozzle extension assembly.

Component list:

- Nozzle extension flange without O-ring groove
- Nozzle extension flange with O-ring groove
- Nozzle extension tubing

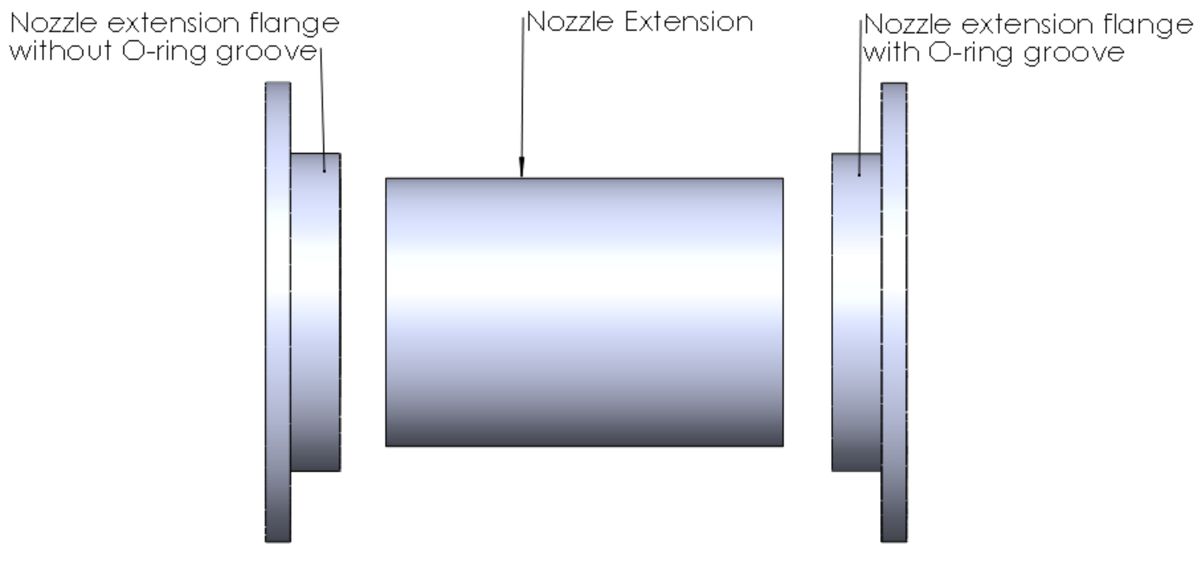


Figure 32: Nozzle extension assembly

2.13.1.3: Nozzle assembly

The nozzle assembly contains the nozzle flange and the nozzle, which need to be welded together. The nozzle flange contains a boss to help with positioning. The Assembly can be seen in Figure 33: Nozzle assembly below.

Component List:

- Nozzle Flange
- Nozzle

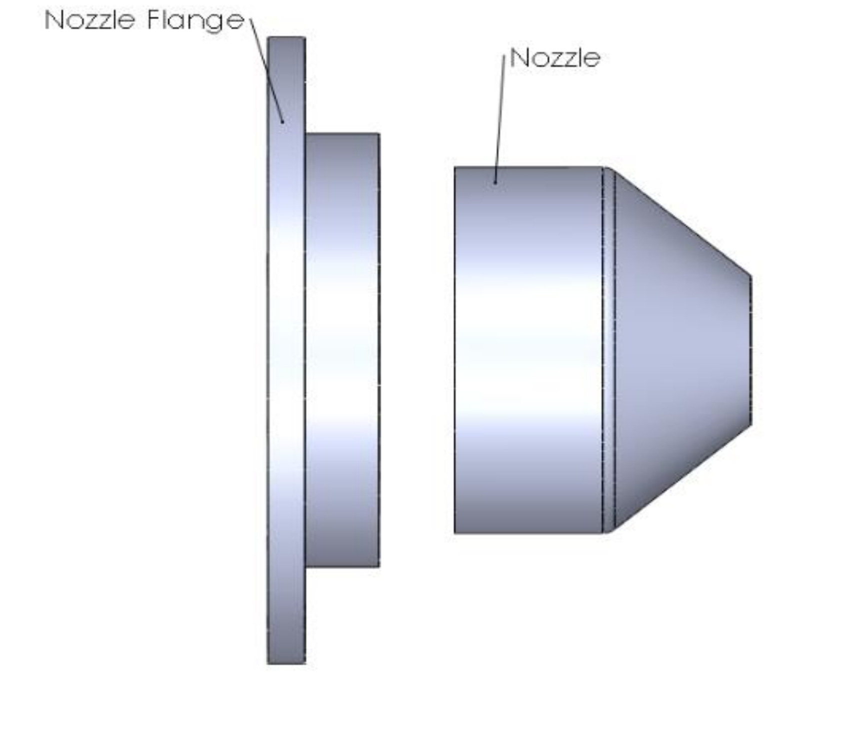


Figure 33: Nozzle assembly

2.13.1.4: Components

All the welded components will be provided by the University of Warwick workshop. The components will be manufactured larger than the drawings suggest, as warping will occur during welding. In correspondence with the workshop it was determined that the distortion will not be greater than 2mm, therefore this much extra material will be left on the dimensions being welded. This will allow the spear valve to be re-machined to accurately match the required dimensions.

2.13.1.5: Pressure testing

The pipe assemblies must be pressure tested using water at a pressure of 24 bar. A pressure of 24 bar is a 50% increase on the standard operating pressure, 16 bar, of the pipe. This will act as a safety factor for any sudden increases in pressure that cannot be controlled, allowing the control system time to adjust the system or close the spear valve.

A blank flange is a piece of metal that is machined to fit onto the open flanges in the main pipe. These flanges will be attached in place of the rear sealing plate and nozzle assembly; this allows the pipe assembly to act as a sealed vessel. Water is passed into the remaining open flange until the pressure reaches 24 bar. If there are no leaks, through the welds and O-rings, then the pressure test is a success.

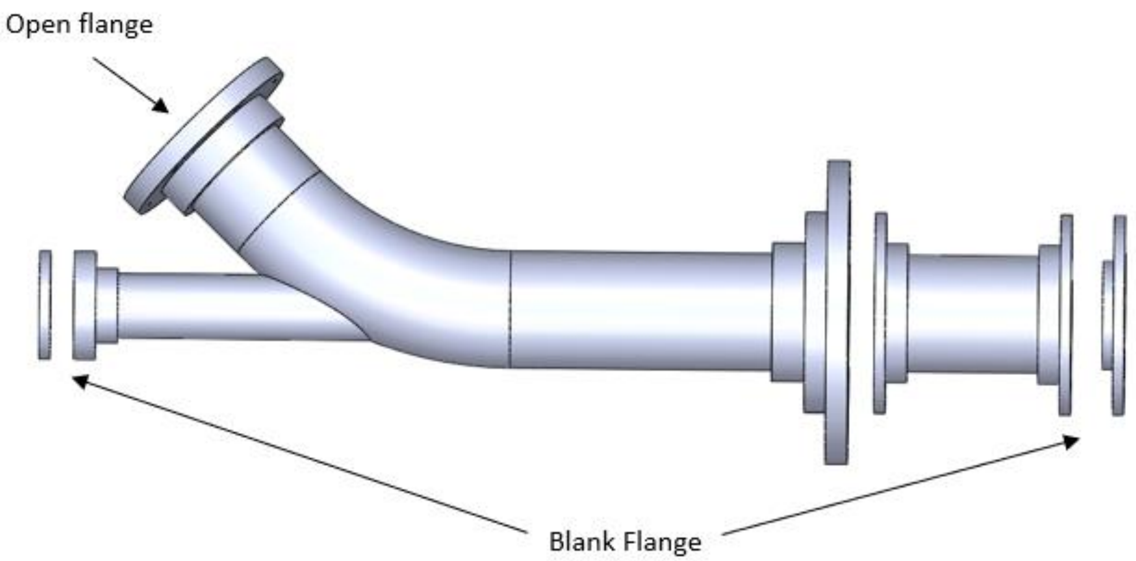


Figure 34: The pipe bend assembly with two blank flanges

2.14: Testing

The spear valve has been designed to operate with an internal pressure of 16 bar. Testing at this pressure will not be possible in the engineering department where the maximum water pressure is ~8 bar. However, calibration for small variations in flowrate is still possible.

As the project only involves creating the spear valve, there is presently no Turgo turbine that can be used for testing. The following test plan was devised to verify functionality.

2.14.1: Testing plan

The spear valve could be attached to a pump that produces high pressure water at 16 bar, but this would only work for a short period of time as it involves filling a tank with water.

Flowrate and Pressure sensors will be placed at important points along the spear valve to measure the properties of the water, checking that the input values and output results are as expected. To test the spear valve, a flange, component 10 in Figure 30 must be created that can attach to the flange on the top of the pipe bend. This flange will attach to a hose that connects to the mains water supply.

2.14.2: Testing objectives:

- Check that the spear valve can turn high-pressure water into a high-speed jet.
- Check all the flange and O-ring seals are secure with no water leakage.
- Check that the motor can actuate the spear, causing changes in the expelled flow area
- Check that the water does not disperse earlier than 21.6mm and see whether it is possible for the Turgo turbine to be close enough to hit the spoons before the water jet starts to disperse.
- Check that the spear can be controlled remotely using a Raspberry Pi and motor with responsive feedback concerning the spear's position.
- Check that LVDT can determine the location of the spear correctly when the control system has been turned off and rebooted.
- Check the minimum close time for the spear running at maximum flow to zero flow.
- Simulate the control circuits demanding more power, requiring the spear valve to produce a larger expulsion area of water.

2.14.3: Health and safety

Testing will require health and safety assessments and documentation to be completed. The water exits the jet at high speed therefore, during testing, goggles must always be worn. Additionally, nobody should stand in front of the jet as this could cause serious injuries. Non-slip boots must be worn as water is likely to get on the floor.