Honeybee surface locomotion flapping arm apparatus:

This document is to help guide the completion of the IP Project Apparatus I designed and commenced manufacturing. This will outline the remaining tasks and machining, required components and assembly order.

The creation of this document has flagged up several issues I was not yet aware of, and was additionally made in haste as to try not delay progress any further. If any questions arise you feel I can help with, I can try my best to assist. Contact me with the details below:

James Maybey, Student Email: jdm1g20@soton.ac.uk, (email or teams),

Personal email: jamesmaybey@hotmail.co.uk

I do not have all the details of these tasks figured out, and they will likely require personal judgement to resolve.

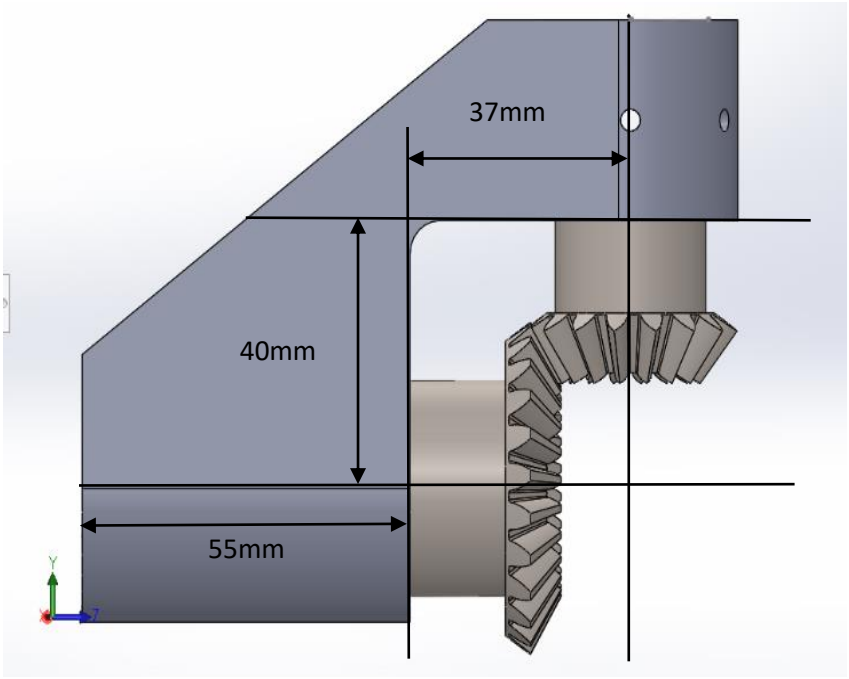
Reading the Assembly order may help understand how all the components were intended to fit together.

List of components (Before additional work):

- 2 x stepper motors (STM-23S-3RE)
- 2 x Serial adapter/data converter (ES-U-3001-M)
- 1 x Ruland Jaw Coupler Set (10mm bore Jaw 33mm Outer Diameter, 12mm bore Jaw 33mm ODs, 33mm OD rubber spacer)
- 1 x Small pulley 12-tooth (bore at 6.5mm needs fixing method added – set screw?)
- 1 x large pulley 48-tooth with 1 x locking bush 30mm Inner Diameter
- 1 x Toothed belt
- 1 x Plywood mounting board
- Inner shaft (10mm Diameter)
- Outer Shaft (30mm outer diameter -NEEDS CHANGE-, 24 inner diameter) w/ welded additional mounting cylinder (50mm OD, 4 x M6 mounting holes)
- Mechanism block (Aluminium)
- Wing axle w/ wire slot
- Axle retention ring/cap (21mm ID, mm OD)
- Axle-to-sensor backplate coupler/sleeve (21mm ID, mm OD)
- Sensor back plate (NEEDS ALTERATION/REMANUFACTURING)
- 2 x ball bearings (10mm ID, 26mm OD)
- 1 x ATI NANO17 IP68 (using 3 x M2 screw mounting, no alignment pins)
- 1 x acrylic wing (34mm x 107mm)
- 1 x 3D printed wing adapter/holder (may need redesign/printing)
- 1 x 16-tooth bevel gear (10mm ID, + set screw)
- 1 x 24-tooth bevel gear (21mm ID, + set screw)

- 1 x flange shaft bearing (30mm Bore)
- 1 x Aluminium shaft flange plate (Mounts to Outer shaft with 4 x M6)
- 1 x gearbox Mounting plate (Mounts to gearbox with 4 x M5)
- 4 x Metal Standoffs/spacers (mounts the flange plate and gearbox mounting plate together with M6)
- 1x Gearbox compatible with stepper motor
- + Fixings

One of the first things that needs to be done is check the mounting of the gears in respect to the holes bored in the block. The spacing was based on the distances specified by the manufacturers however I never got to test these aligned in the received components. If these do not align the block or gears may need redesigning/manufacturing and this could be a huge problem and setback. The gears may want a few millimetres taken off the base anyway to stop them being positioned against the aluminium block and increasing friction.



Tasks to be completed:

- 1. Collect Components from EDMC (if not already done so) – EDMC was to make the bores of the '24-tooth bevel gear', 'axle retention ring' and 'axle-to-sensor plate coupler/sleeve' to 21mm, this is to ensure the 20.1mm sensor can pass through inside. The EDMC was also supposed to machine the inner diameters of the Outer shaft to 26mm (from 24mm) to a minimum depth of 8mm on both ends (this is to hold the alignment bearings)
- 2. The outer shaft OD needs to be reduced on a lathe from 30mm diameter downwards until it can pass into the 30mm bore of the flange bearing, this is only required on the longer length of the shaft below the additional welding piece.
- 3. Get a 700mm length of aluminium 10mm diameter rod (inner shaft) from the EDMC, may require a material order as they did not have stock when I checked. This can then be cut to final length during assembly (expected closer to 640mm). The inner shaft may need its diameter reduced to pass through the 10mm ID bores of the Alignment bearings and the 16-tooth bevel gear. (Making sure the 10mm Ruland jaw will still have a solid connection/grip)
- 4. The serial adapters need to be positioned and mounted appropriately. (availability of this part in the labs is questionable so ordering the component may be necessary). Wiring also needs to be arranged with wires long enough to run into the tank and between components (Electronics workshop on highfield campus can help with this).

- 5. The Stepper Motors need to be coded for a sinusoidal motion with 1Hz frequency resulting in angles of attack between ±45°. For further motion requirements, discuss with Swathi Krishna. (Wiring also needs to be arranged) (Ben may be able to assist with Coding)
- 6. A mounting frame needs designing and creating with the available lengths in Building 185 that is compatible with the Tank and mounting plate and positions the wing at a suitable depth.
- 7. Alter/Remanufacture/Redesign Sensor Back plate, The current back plate is compatible with the standard Nano17 model however the IP68 submergible model has different mounting arrangements and so this needs a new piece or alterations. An example suitable design has been provided. This can be used if deemed suitable.
- 8. The 3D printed Wing adapter that holds the acrylic wing may require redesigning and reprinting if the mounting holes for M2 screws do not align with new sensor and also aren't positioned for easy assembly.
- 9. Check wing size gives an estimate torque reading that does not exceed the rating of the sensor. If not Lasercut new wing to new chosen design – Discuss with Swathi Krishna.
- 10. If alignment bearings don't stay in the outer shaft with a pressure fit, add an additional method of retention.
- 11. Where deemed applicable and possible add countersinks if time permits.
- 12. During assembly it may be found the 'Axle coupler/sleeve' needs to be machined to a shorter length if the bevel gear and coupler interact.
- 13. Make the jaw couplers support axial load

- 14. Add set screw to small pulley/ make shaft extension+coupler

Task 1:

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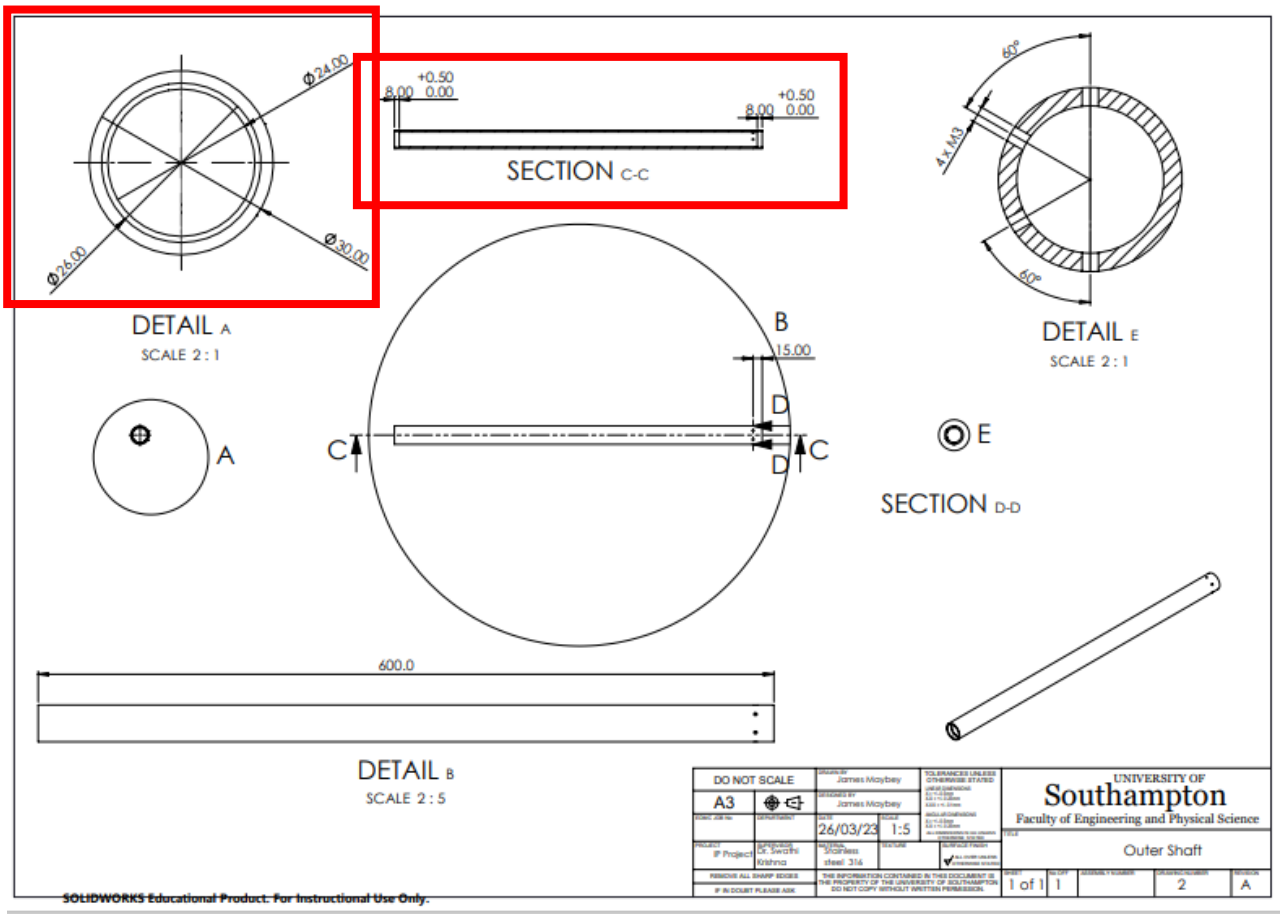
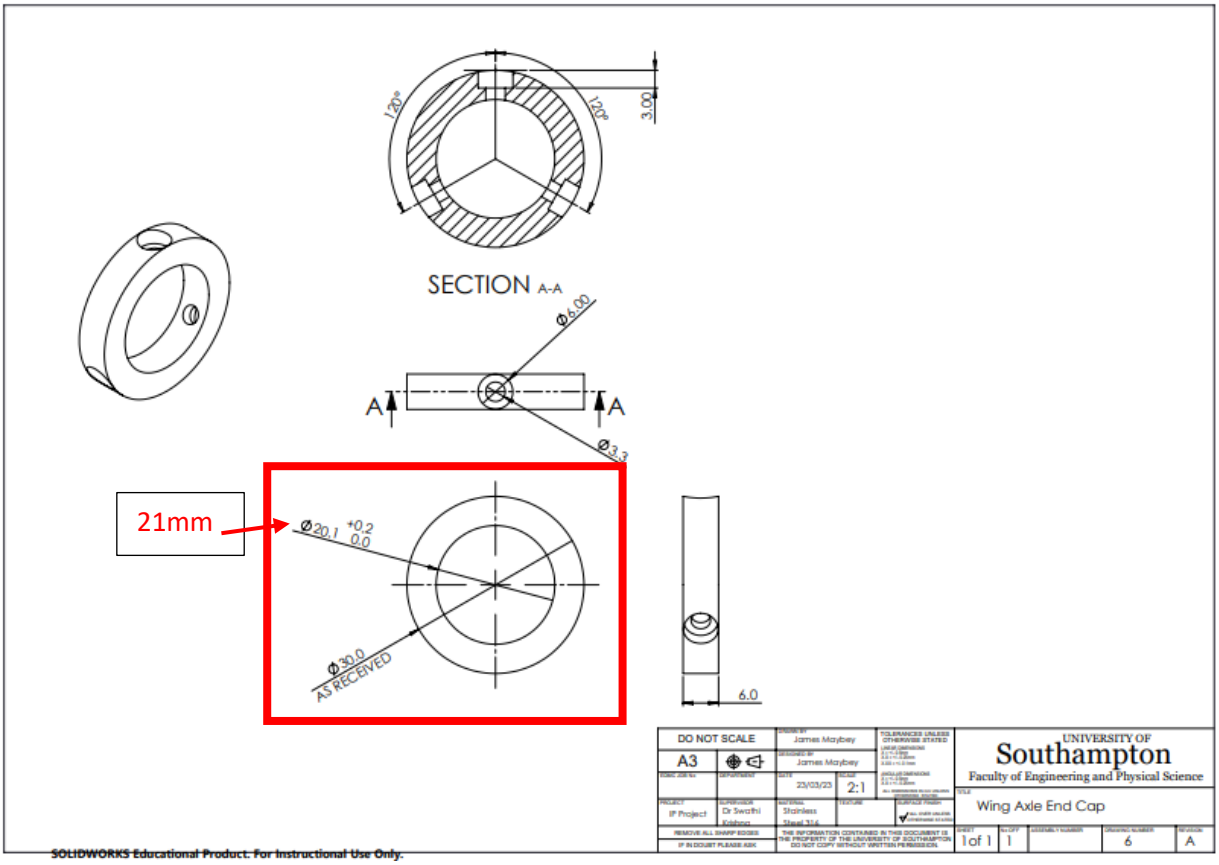
Technical drawings shown below highlighting the mentioned changes referred to.




120°
120°
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SECTION A-A
Ø6.00
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Ø3.3
21mm
Ø20.1 +0.2 0.0
Ø30.0
AS RECEIVED
6.0
DO NOT SCALE
A3
James Maybey
23/03/23
2:1
IP Project
Dr Swathi Krishna
Stainless Steel 316
1 of 1
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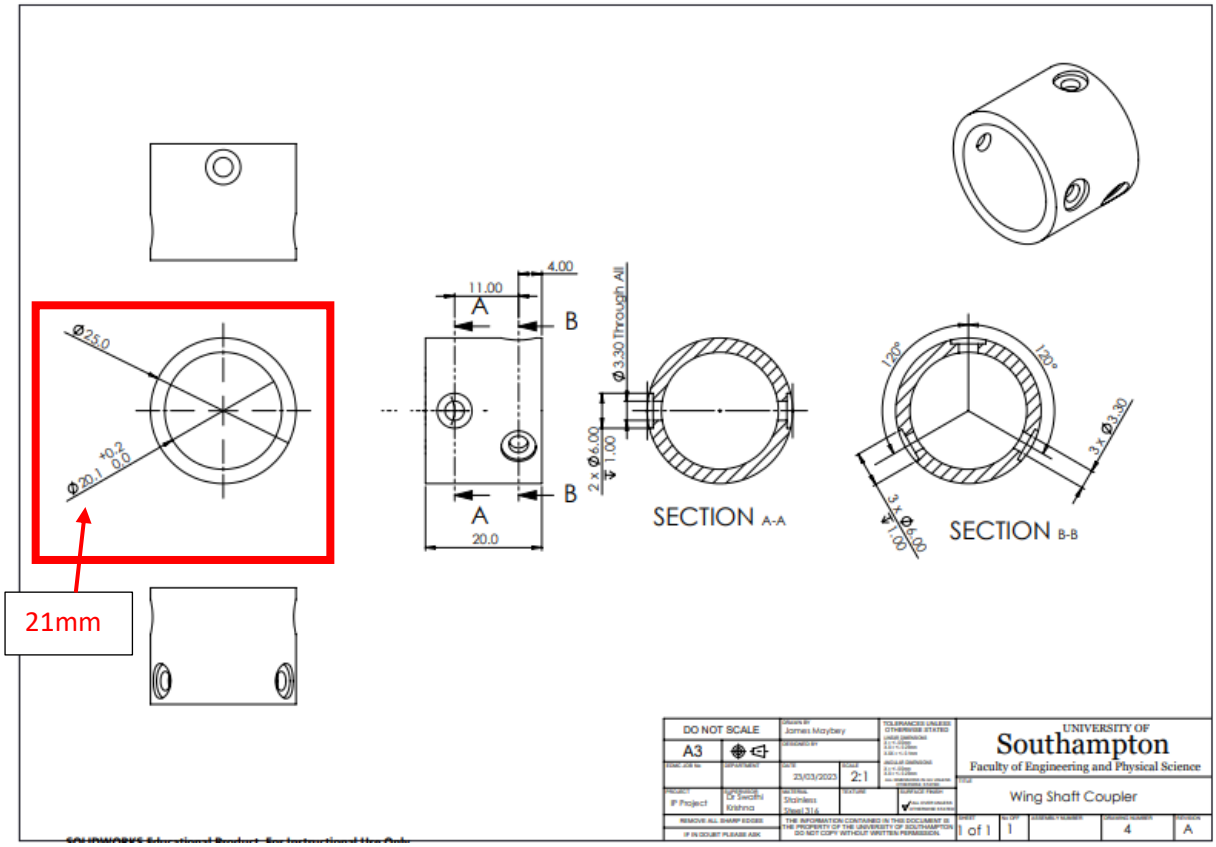
6
A
UNIVERSITY OF
Southampton
Faculty of Engineering and Physical Science
Wing Axle End Cap
SOLIDWORKS Educational Product. For Instructional Use Only.


Ø25.0
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120°
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SECTION B-B
DO NOT SCALE
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James Maybey
23/03/2023
2:1
IP Project
Dr Swathi Krishna
Stainless Steel 316
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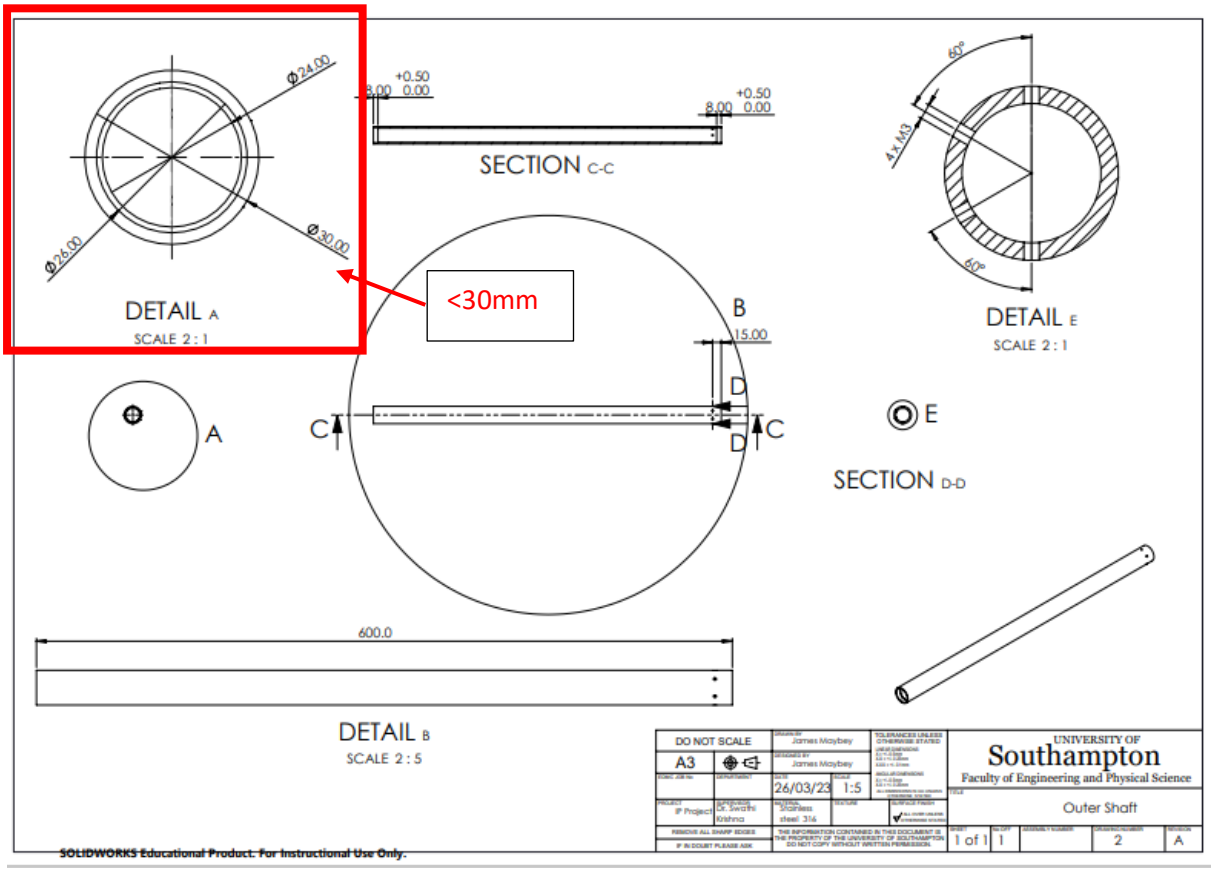
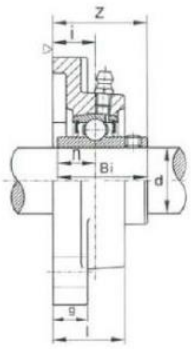
A
UNIVERSITY OF
Southampton
Faculty of Engineering and Physical Science
Wing Shaft Coupler

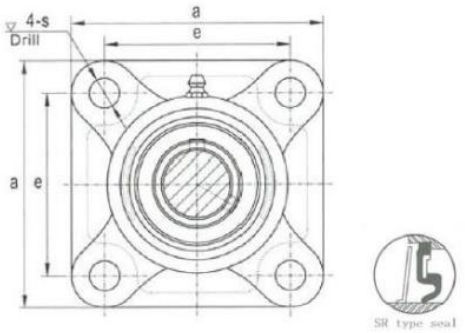
Task 2:

'The outer shaft OD needs to be reduced on a lathe from 30mm diameter downwards until it can pass into the 30mm bore of the flange bearing, this is only required on the longer length of the shaft below the additional welding piece.'

Technical drawings of Outer shaft assembly and flange bearing with areas of change highlighted.







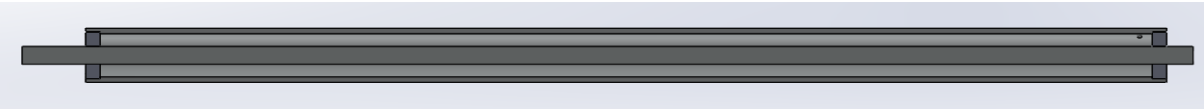
RS Article no.	Bearing unit No.	Shaft Dia. d (mm)	Dimension (mm)									Bolt used (mm)	Bearing No.	Housing No.	Weight (kg)
			a	e	i	g	l	s	z	Bi	n				
7508762	UCF201	12	86	64	15	12	25.5	12	33.3	31.0	12.7	M10	UC 201	F 201	0.63
7508766	UCF202	15	86	64	15	12	25.5	12	33.3	31.0	12.7	M10	UC 202	F 202	0.63
7508775	UCF203	17	86	64	15	12	25.5	12	33.3	31.0	12.7	M10	UC 203	F 203	0.63
7508778	UCF204	20	86	64	15	12	25.5	12	33.3	31.0	12.7	M10	UC 204	F 204	0.63
7508781	UCF205	25	95	70	16	14	27.0	12	35.7	34.0	14.3	M10	UC 205	F 205	0.82
7508784	UCF206	30	108	83	18	14	31.0	12	40.2	38.1	15.9	M10	UC 206	F 206	1.1
7508788	UCF207	35	117	92	19	16	34.0	14	44.4	42.9	17.5	M12	UC 207	F 207	1.5
7508790	UCF208	40	130	102	21	16	36.0	16	51.2	49.2	19.0	M14	UC 208	F 208	1.9
7508794	UCF209	45	137	105	22	18	38.0	16	52.2	49.2	19.0	M14	UC 209	F 209	2.3
7508804	UCF210	50	143	111	22	18	40.0	16	54.6	51.6	19.0	M14	UC 210	F 210	2.5
7508801	UCF211	55	162	130	25	20	43.0	19	58.4	55.6	22.2	M16	UC 211	F 211	3.4
7508810	UCF212	60	175	143	29	20	48.0	19	68.7	65.1	25.4	M16	UC 212	F 212	4.4

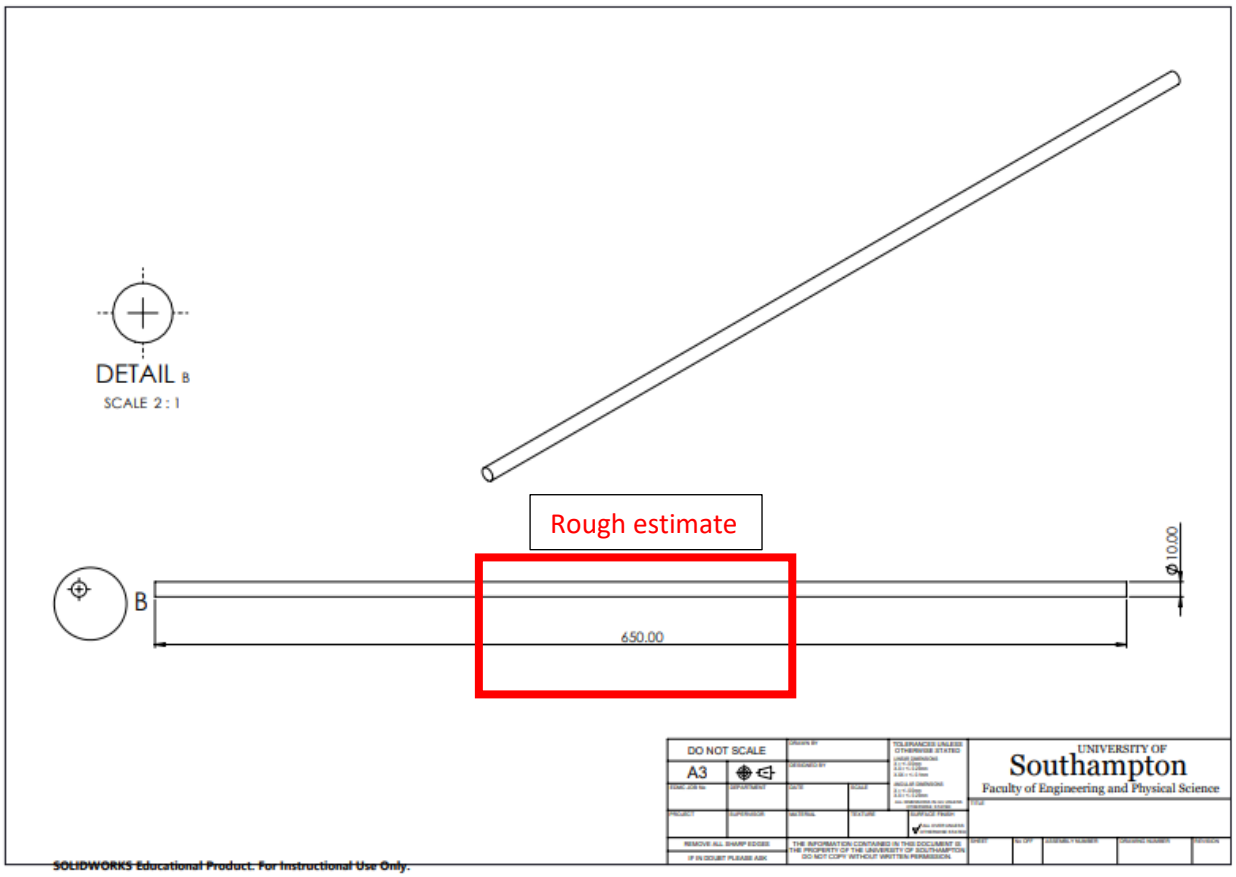
^^^Using 30mm shaft diameter size (d)^^^

Task 3:

'Get a 700mm length of aluminium 10mm diameter rod (inner shaft) from the EDMC, may require a material order as they did not have stock when I checked. This can then be cut to final length during assembly (expected closer to 640mm). The inner shaft may need its diameter reduced to pass through the 10mm ID bores of the Alignment bearings and the 16-tooth bevel gear. (Making sure the 10mm Ruland jaw will still have a solid connection/grip)'

Drawings of inner shaft and alignment bearings assembly.





Task 4:

'The serial adapters need to be positioned and mounted appropriately. (availability of this part in the labs is questionable so ordering the component may be necessary). Wiring also needs to be arranged with wires long enough to run into the tank and between components (Electronics workshop on highfield campus can help with this).'

ES-U-3001-M USB-to-Serial data converter

Converter Pin	Corresponding Stepper Motor pin
TxD-	RxD-
TxD+	RxD+
RxD-	TxD-
RxD+	TxD+
GND	GND

Wiring guide between converter and stepper motor

The switches on the converter should display S1,2 and 4 ON and S2 OFF, using this table below as guide.

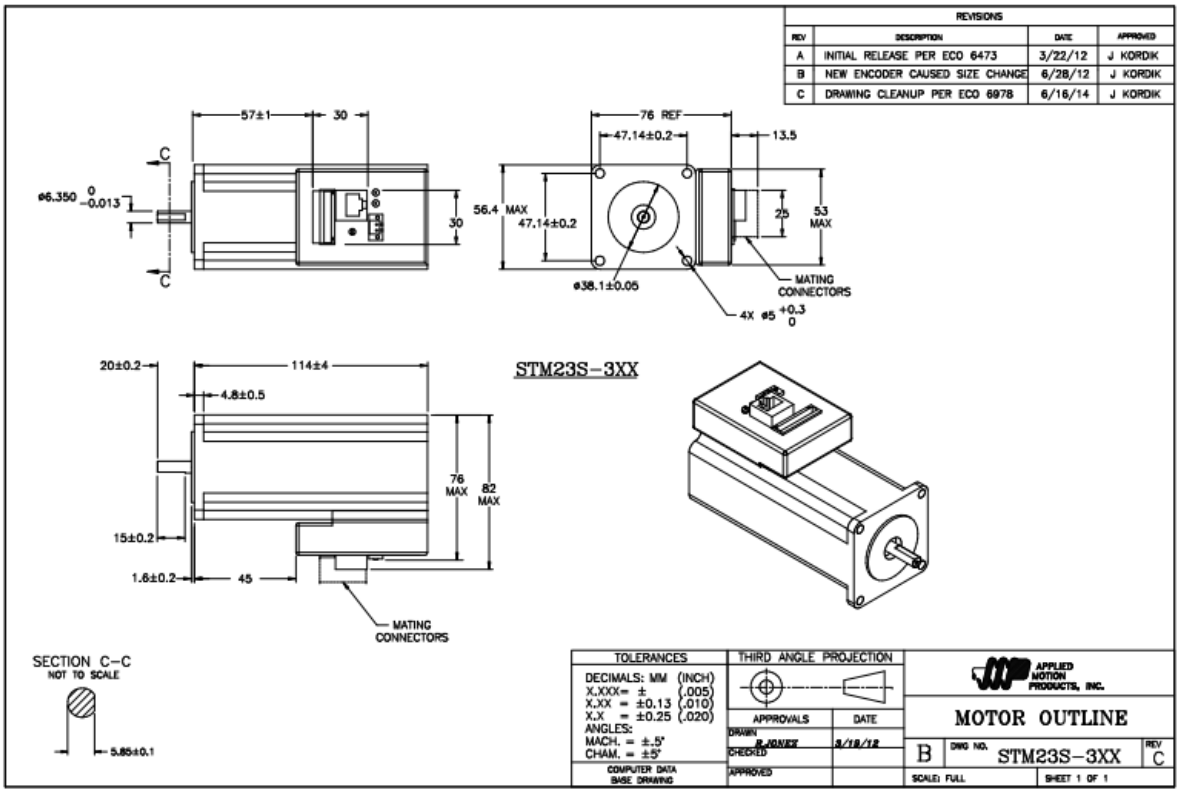
	Operation Mode	S1	S2	S3	S4
RS-232		OFF	ON	ON	ON
RS-422	4 Wire with handshaking	ON	ON	ON	ON
RS-485	Full Duplex (4 wire)	ON	OFF	ON	ON
	Half Duplex (2 wire) with Echo	ON	OFF	OFF	ON
	Half Duplex (2 wire) without Echo	ON	OFF	OFF	OFF

Table 10 - RS-232, RS-422 & RS-485 Mode Configuration

Task 5:

'The Stepper Motors need to be coded for a sinusoidal motion with 1Hz frequency resulting in angles of attack between ±45°. For further motion requirements, discuss with Swathi Krishna. (Wiring also needs to be arranged) (Ben may be able to assist with Coding)'

Link to control codes and documentation



Useful links for setup and coding:

https://appliedmotion.s3.amazonaws.com/920-0020F_STM23_24_S_Q_QuickSetup.pdf

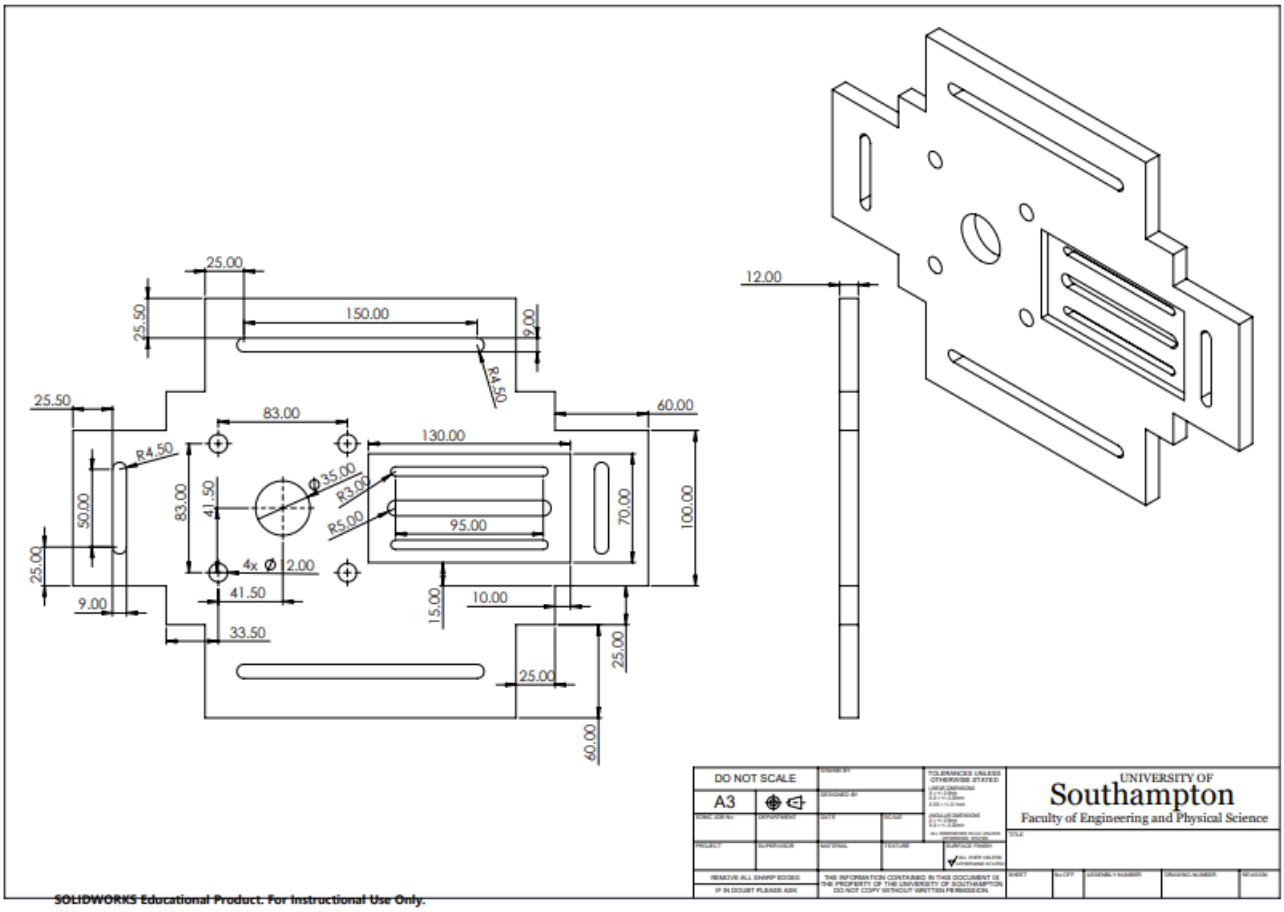
https://www.applied-motion.com/s/product/integrated-drivemotorstm23s3re/01t5i000000xylkAAA

https://appliedmotion.s3.amazonaws.com/Host-Command-Reference_920-0002W_0.pdf

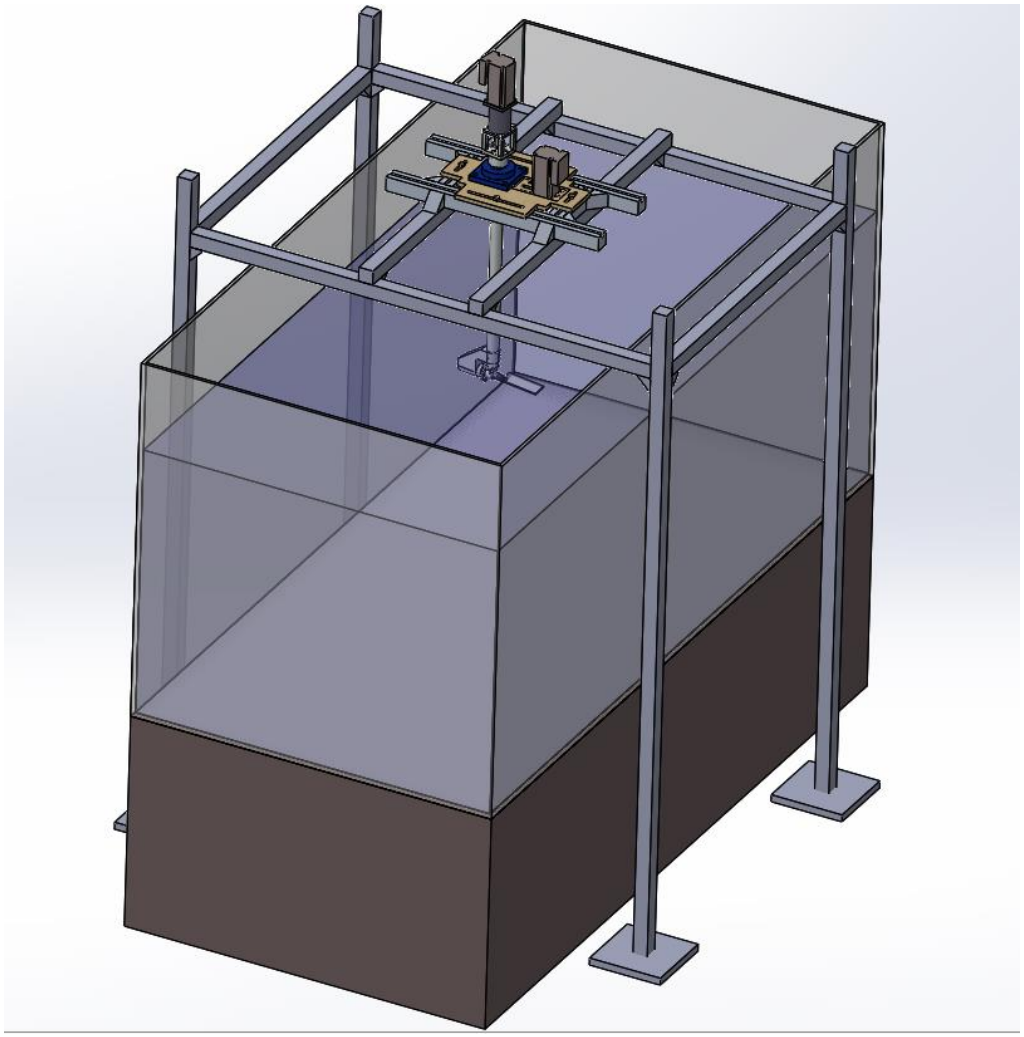
Task 6:

‘A mounting frame needs designing and creating with the available lengths in Building 185 that is compatible with the Tank and mounting plate and positions the wing at a suitable depth.’

Mounting board technical drawing and example image of mounting, can also look at Ben’s cyclorotor for example.



Mounting board dimensions, Suitable for M8 bolts to secure to framework

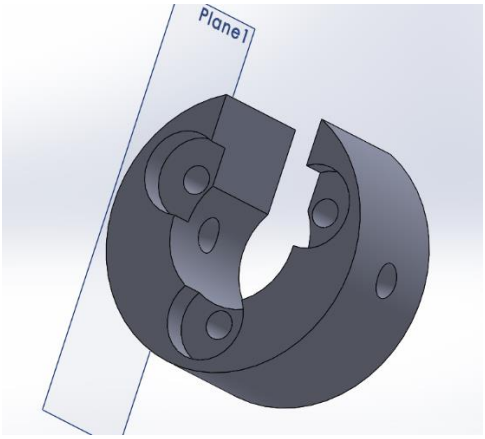


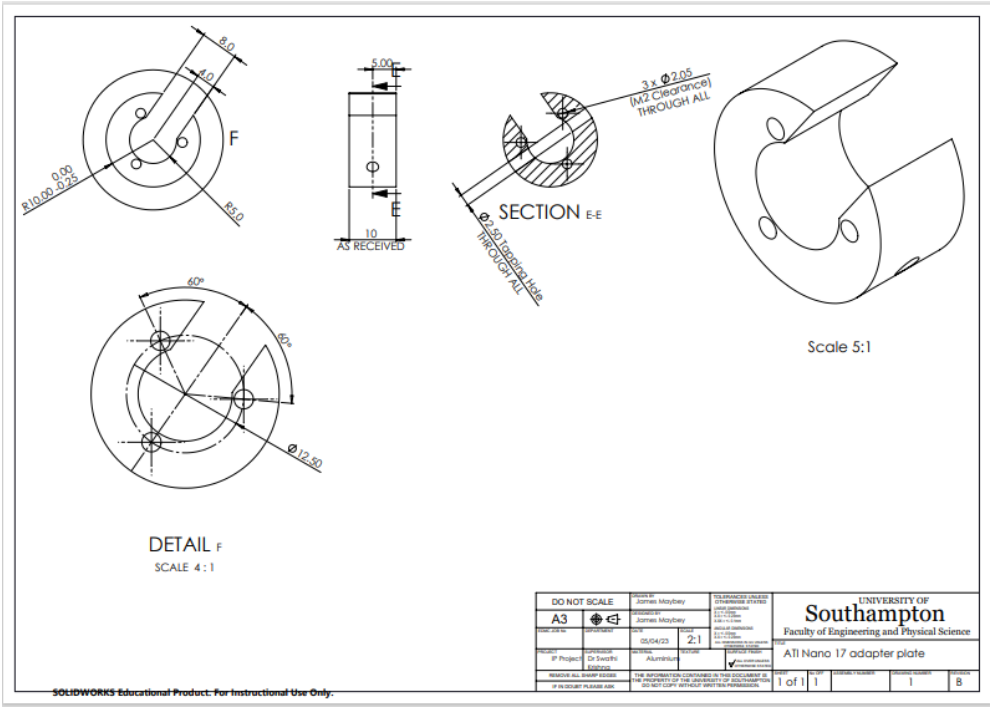
Example mount structure, does not need to be followed

Task 7:

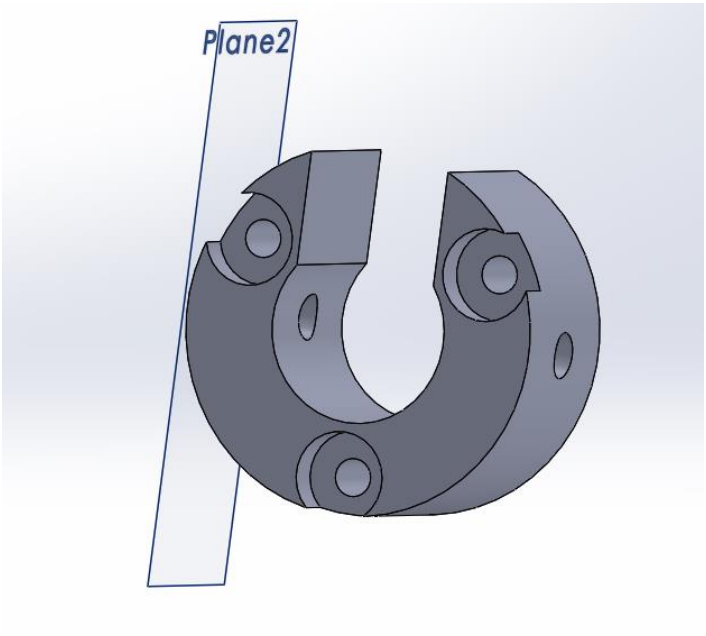
‘Alter/Remanufacture/Redesign Sensor Back plate, The current back plate is compatible with the standard Nano17 model however the IP68 submergible model has different mounting arrangements and so this needs a new piece or alterations. An example suitable design has been provided. This can be used if deemed suitable.’

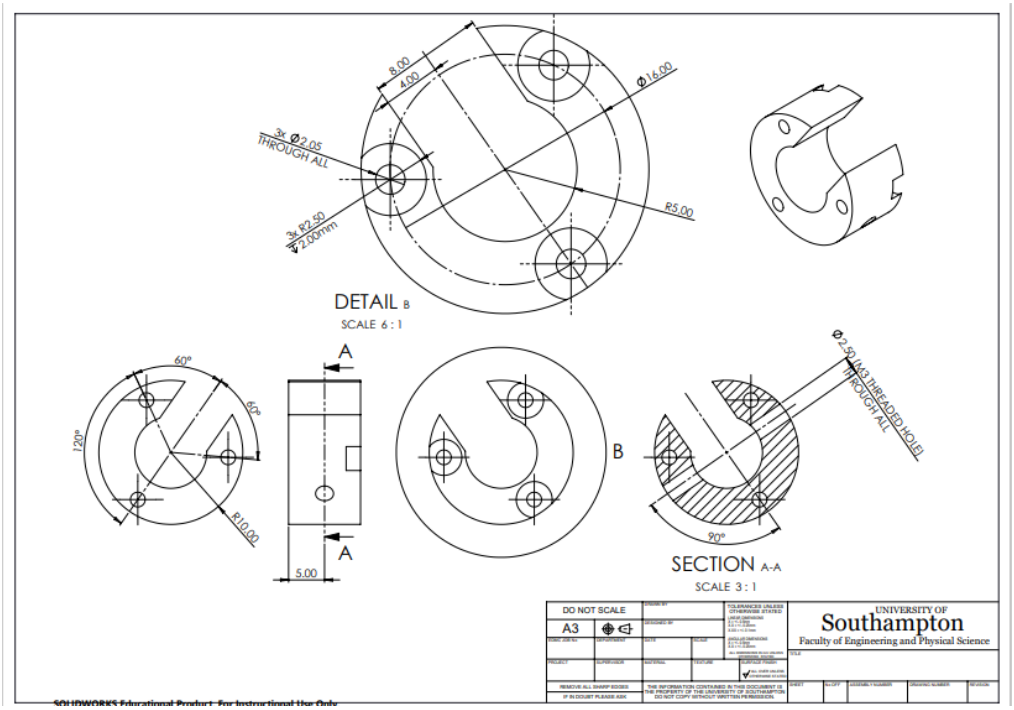
Existing plate (photo of final look, +countersinks, -thread in side M3 holes)(drawings from EDMC order of existing plate):





New plate design (photo of final look, -thread in side M3 holes):





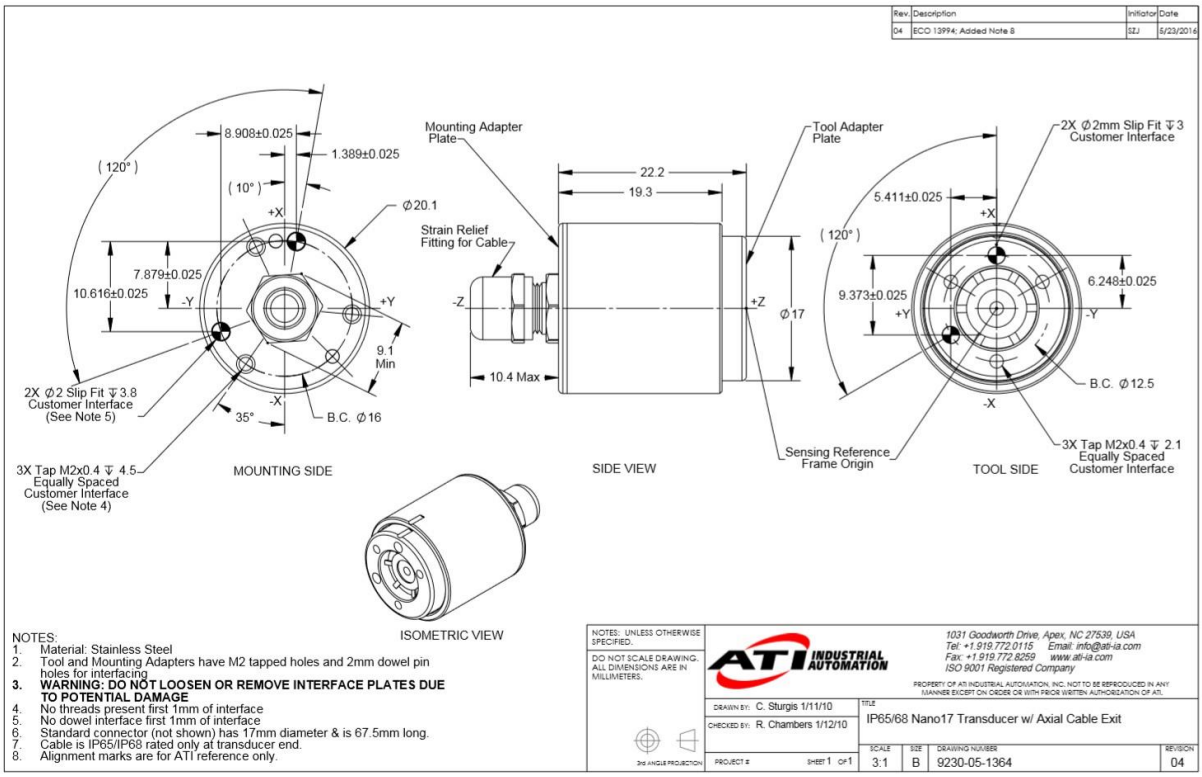
(material is 10mm thick, 20mm diameter aluminium bar)

Back plate requirements:

Diameter ~20mm, ATI sensor wire slot and hole suitable for the axial cable, 3x M2 clearance mounting/interface holes, 2 x Connecting M3 threaded holes for sensor-to-axle coupler, Countersinks to keep screw head flush or beneath outerface.

Reducing the backplate to 9.5mm length instead of 10mm allows for further assembly tolerance.

CONSIDER SCREW HEAD SIZE, IF THEY EXCEED OVER THE EDGE IN THE COUNTERSINKS, THE PART MAY NOT FIT INSIDE THE COUPLER, SOLUTIONS: SCREW HEADS COULD BE MACHINED AWAY, OR DESIGN REWORKED



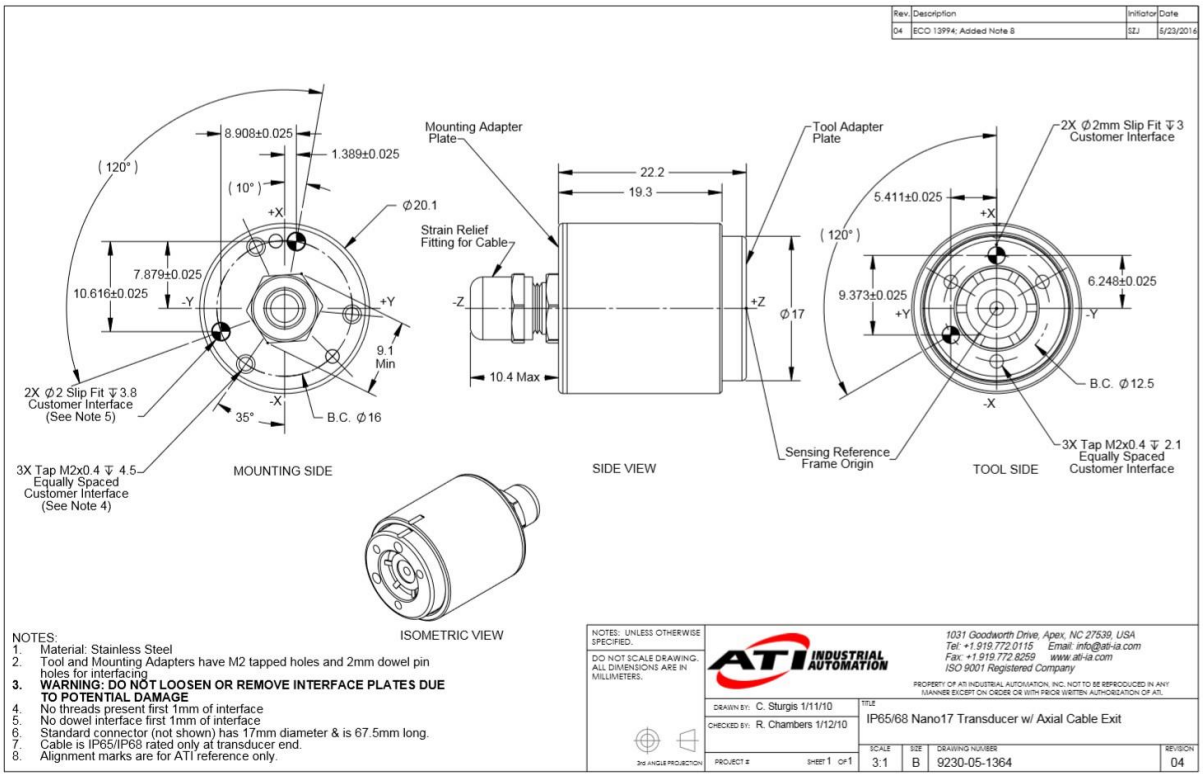
Task 8:

‘The 3D printed Wing adapter that holds the acrylic wing may require redesigning and reprinting if the mounting holes for M2 screws do not align with new sensor and also aren’t positioned for easy assembly.’

Current 3D print problems:

Difficulty screwing in 3x M2 fixing screws

Fixing interface shown below



Requirements:

3x M2 screw interface clearance holes with countersinks, centres on 12.5mm circular arrangement 120 Degrees apart

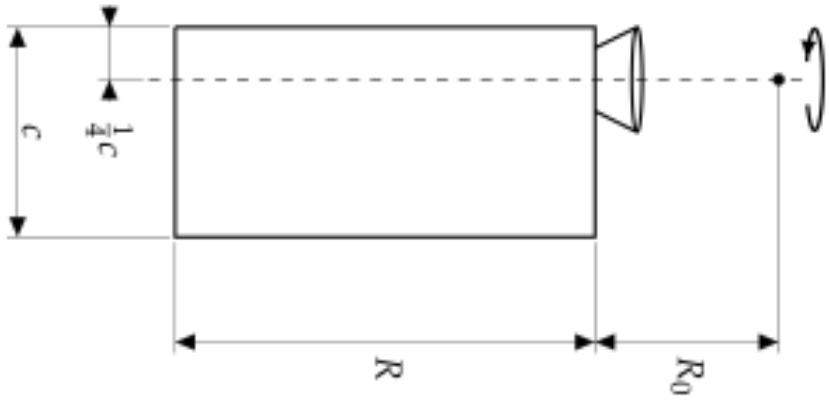
Two pronged forks with semi circular profile to hold plastic wing (current design uses 2.05mm max thickness prongs with 10mm length.)

Task 9:

'Check wing size gives an estimate torque reading that does not exceed the rating of the sensor. If not Lasercut new wing to new chosen design – Discuss with Swathi Krishna.'

Swathi was to check the calculations to make sure the torque on the wing did not exceed the sensors max torque. If change is required arrange measurements with Swathi and laser cut replacement.

Wing plate should be positioned with the forks at a quarter chord length from the leading edge, shown below.



Current wing size 34mmx107mm, 3mm thickness clear acrylic

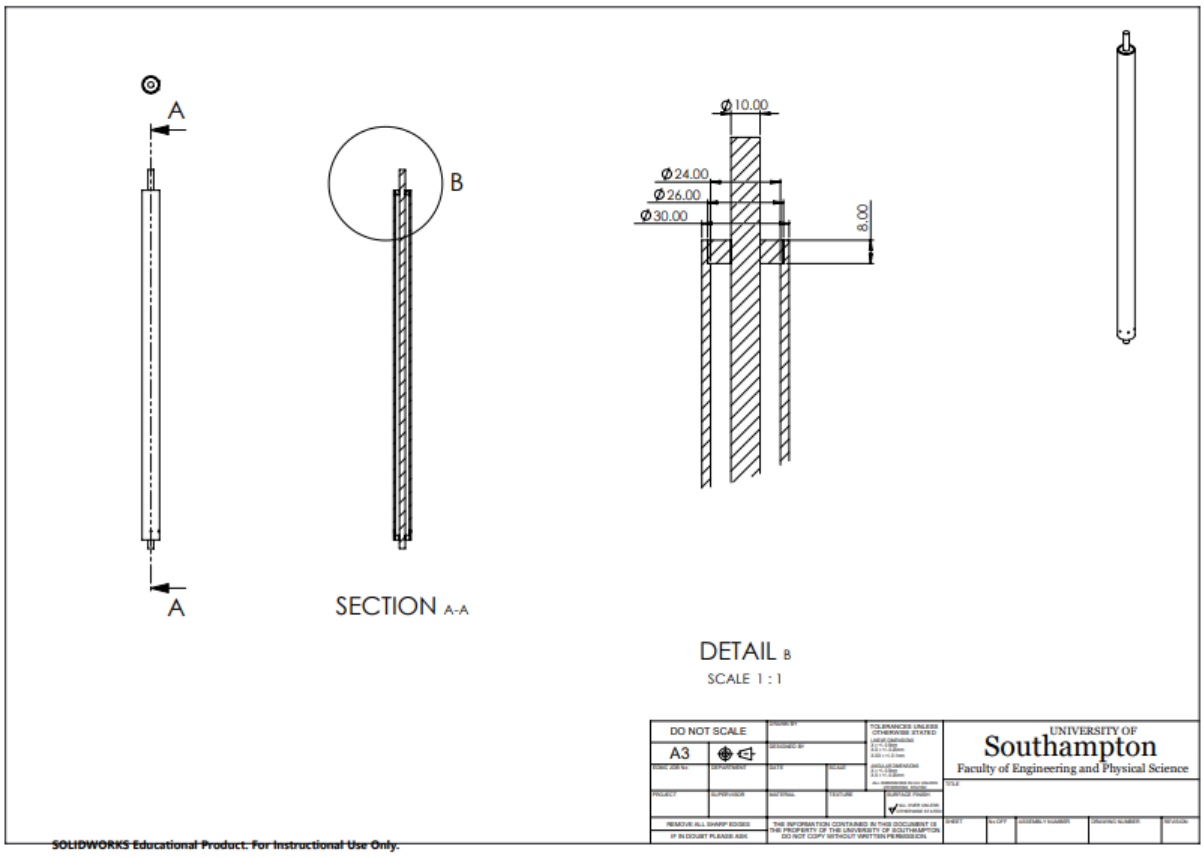
Metric Calibrations (SI)

Calibration	Fx,Fy	Fz	Tx,Ty	Tz	Fx,Fy	Fz	Tx,Ty	Tz
SI-12-0.12	12 N	17 N	120 Nmm	120 Nmm	1/320 N	1/320 N	1/64 Nmm	1/64 Nmm
SI-25-0.25	25 N	35 N	250 Nmm	250 Nmm	1/160 N	1/160 N	1/32 Nmm	1/32 Nmm
SI-50-0.5	50 N	70 N	500 Nmm	500 Nmm	1/80 N	1/80 N	1/16 Nmm	1/16 Nmm
	SENSING RANGES				RESOLUTION			

Task 10:

'If alignment bearings don't stay in the outer shaft with a pressure fit, add an additional method of retention.'

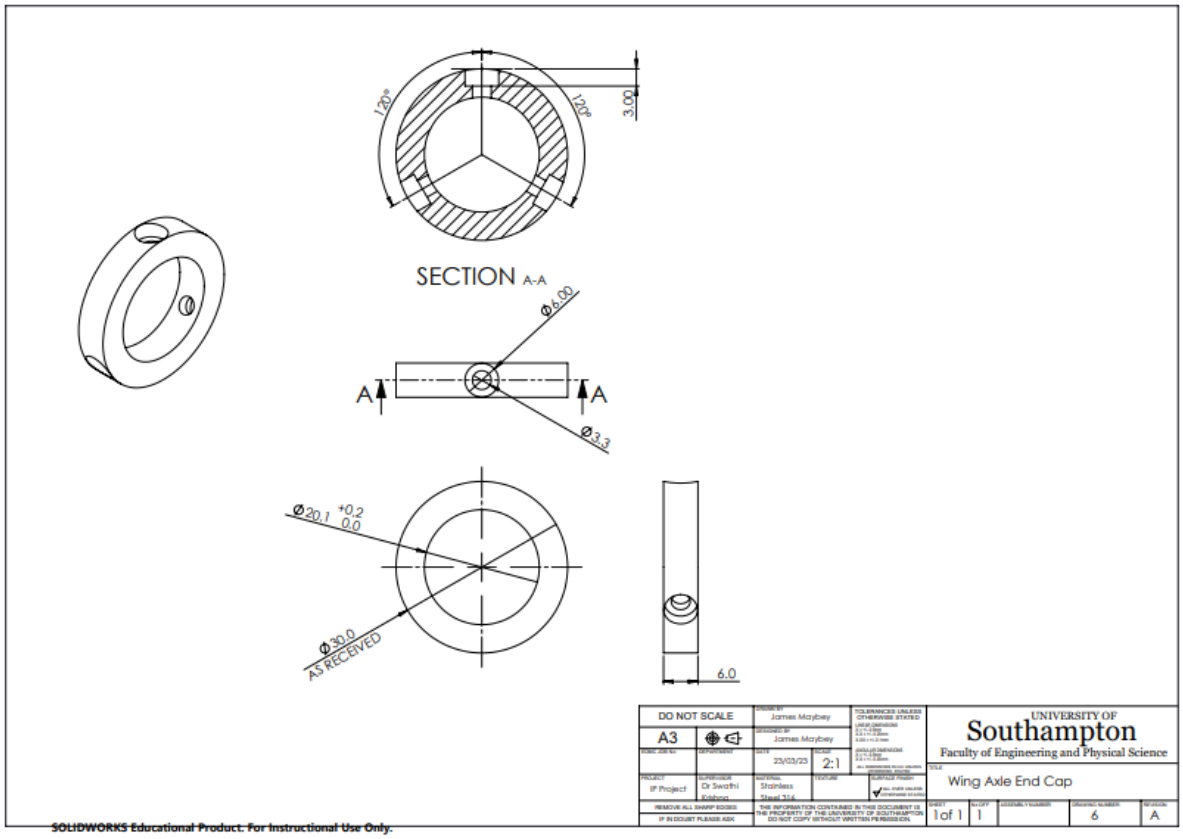
During the testing stage, if the bearings are seen to become lose or drop from the outershaft, additional retention methods may be required. Bearings shown in diagram below. Both shaft inner diameter and bearing outer diameter are 26mm. Minor work may be required to adjust the ease of installing the bearings.



Task 11:

'Where deemed applicable and possible add countersinks if time permits.'

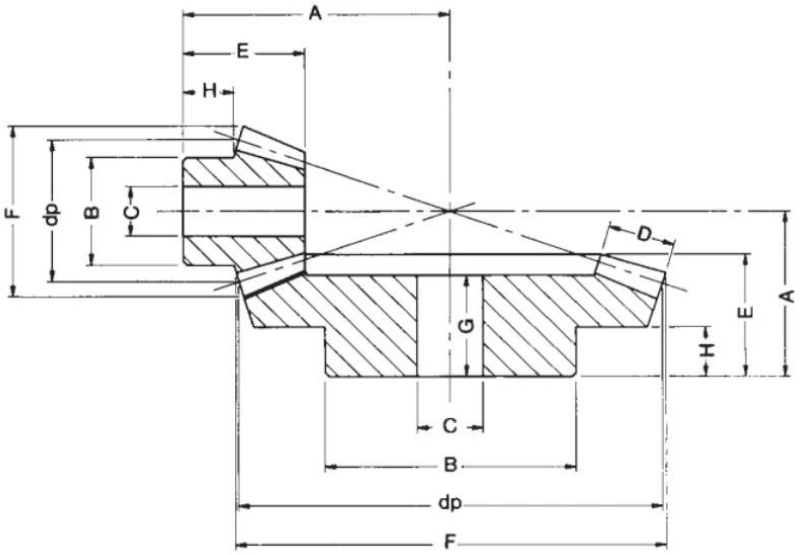
Countersinks can be added to components if size and material width permits, e.g axle retention ring.



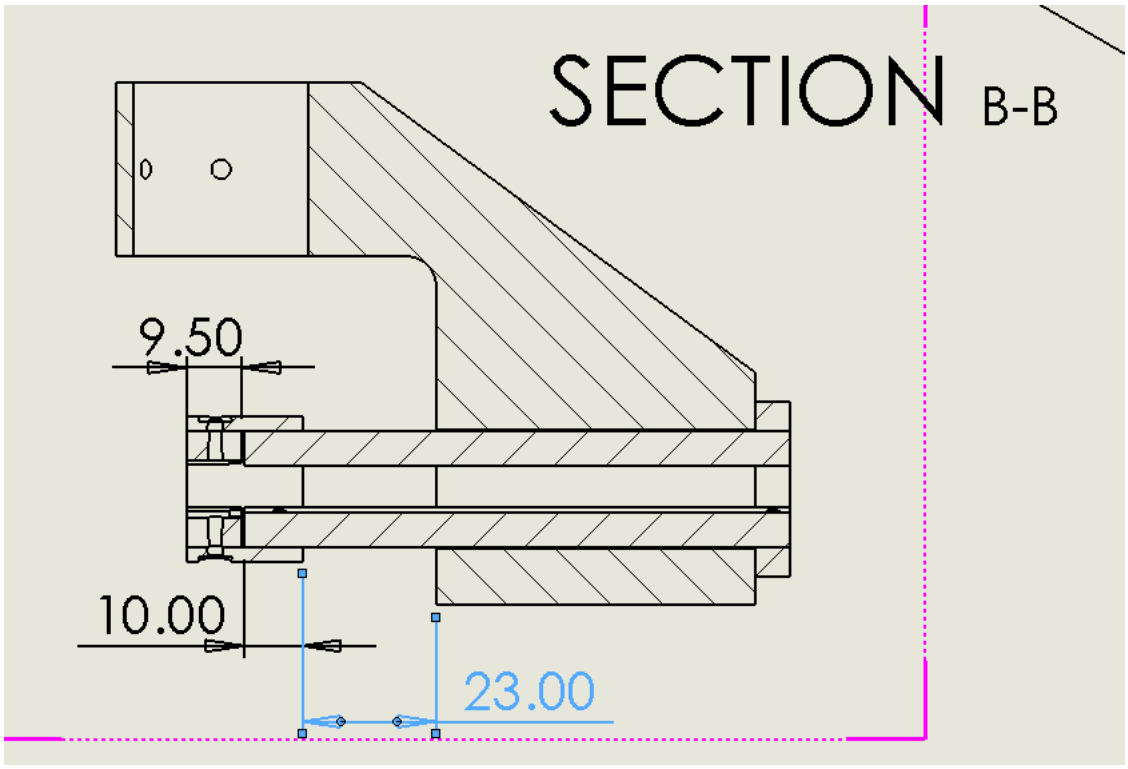
WARNING: With the inner bore increased to 21mm by the EDMC, the remaining material is reduced for counterbore depth

Task 12:

'During assembly it may be found the 'Axle coupler/sleeve' needs to be machined to a shorter length if the bevel gear and coupler interact.'



(G)	25.2	24.7



Design currently leaves 23mm space for 24.7mm long gear (Measurement specified by manufacturers site, Not measured from received component).

There are 3 options to change this:

- **Machine the Gears front face (where the teeth are) back, however make sure to try not to interfere with gear meshing**
- **Machine the coupler back however this will start to near the 3x M3 clearance holes**
- **Produce a new, longer, axle that will increase this space (Simplest fix but most effort and cost)**

Task 13:

'Make the jaw couplers support axial load'

I was made aware that there was a way to further manufacture onto the jaw coupler to allow the coupler to support load axially (to not pull apart at the rubber spacer). I am unsure whether this will be required as the attached driving gear will fall against the 2nd gear and this may permit operation.

I am not sure how this change to the coupler is done as I never got round to investigating myself but I believe I was instructed to speak to Building 185 Technician Sam Harper.

Task 13:

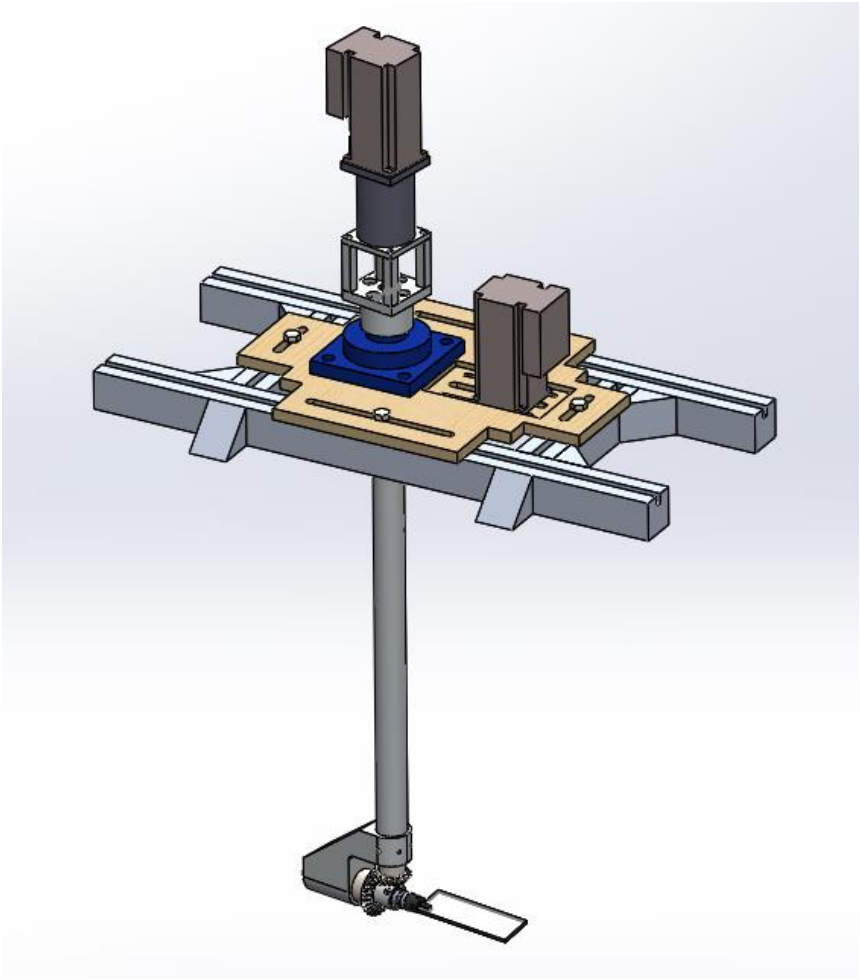
‘14. Add set screw to small pulley/ make shaft extension+coupler’

Due to the bolts that hold the flange bearing in place, the pulley may need to be positioned lower on the outer shaft. To achieve correct alignment, the small pulley may need to be fixed to another shaft that couples to the motor. The motor has 6.35mm output shaft diameter whilst the pulley has a 6.5mm drilled bore.

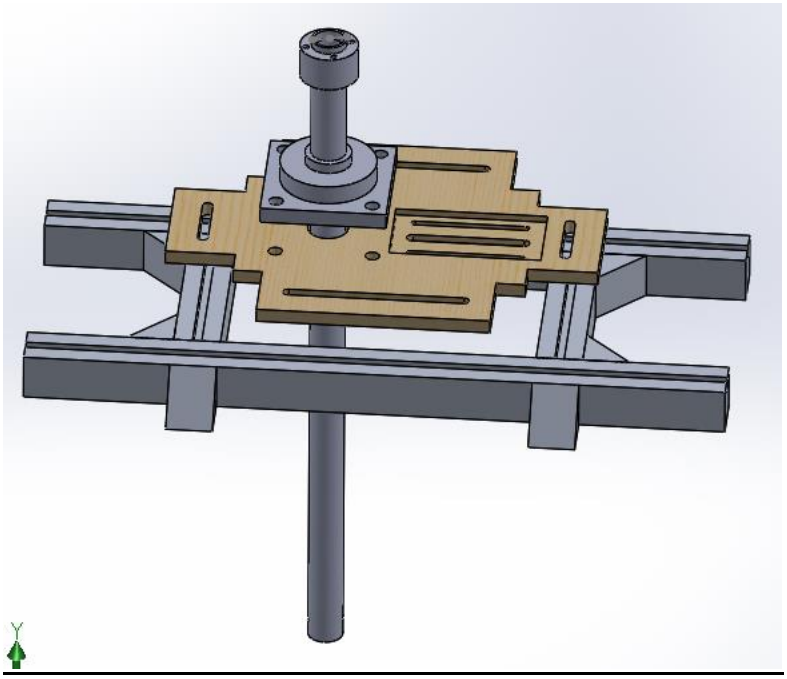
By adding a 1 or 2mm set screw to the neck of the small (12-tooth) pulley, it can be fixed to a 6.5mm shaft and then coupled to the motor. This Coupler will need to be bought or made.

Assembly:

Step No.	Step	Components involved	Instructions
1	Fix the outer shaft	Welded outer shaft subassembly, Mounting frame, Plywood mounting board, Flange bearing	Fix the flange bearing to the board and the board to the frame with M10 and M8 bolts, then push the outer shaft through the bearing and tighten set screws.
2	Insert inner shaft and bearings	Inner shaft, alignment bearings x2, outer shaft	Push the inner shaft down the outer shaft and place the alignment bearings over the inner shaft and into the ends of the outer shaft
3	Fix the pulley system	Large pulley, small pulley, locking bush, pulley belt, stepper motor	Slide the large pulley and bush onto the outer shaft from underneath and tighten the set screws to fix, then place motor onto the board and use set screw to fix the small pulley onto the shaft, then use 4 M4 machine screws to bolt the motor into position whilst tightening the belt in place.
4	Fix the second motor	Gearbox, motor, gearbox plate, outer shaft plate, standoffs x4, Ruland jaw coupler	Bolt the shaft plate onto the welded sleeve on the top of the outer shaft using 4 M6 bolts, then secure the 4 standoffs to this plate with 4 more M6 bolts, secure the motor to the gearbox using 4 M5 machine screws and then bolt the gearbox to its plate with 4 M5 bolts, this plate can then lastly be secured to the standoffs with M6 bolts at the same time the Ruland jaw coupler is aligned and fixed to the inner shaft and gearbox output
5	Create the gear sub assembly	Mechanism block, retention ring, Nano17, sensor back plate, 21mm bore gear, wing axle, coupling sleeve	Firstly, pass the sensor through the retention ring, mechanism block, 21mm bore gear, and coupling sleeve. Then slot the back plate over the sensors wire and fix the backplate to the back of the sensor with M2 screws, then slot the wing axle over the wire and slide into place. Then using M3 screws, fix the sleeve to the back plate and wing axle, then slot the wing axle through the gear and mechanism block and fix to the retention ring with M3s, finally tighten the 24-tooth gear's set screw to fix into the wing axle.
6	Fix the wing to the sensor	Wing adapter, wing plate	Glue the wing plate into position in the adapter, then screw the adapter onto the sensor using M2 screws
7	Fix the gear sub assembly onto the outer shaft	16-tooth driving gear	Putting the driving gear into its final position next to the driven gear allows for the assembly to be slid onto the bottom of the outer shaft and the inner shaft can pass into the driving gear whilst the outer shaft stays in the mechanism block, the set screw can then be tightened, fixing the gear, and the 4 M3 machine screws can be used to fix the mechanism block onto the outer shaft
8	Mount the apparatus	Testing environment	The mounting frame can then be fixed to the existing frame above the tanks using right-angled brackets
9	Fix the electronics	Wire connections, signal converter (serial adapter)	The wiring can then be implemented, from power source to motors and from signal generator to the converters and then also to the motors. The sensor wire can also then be connected into the reading device, signal converters can be screwed onto the wooden board for fixing if space permits.

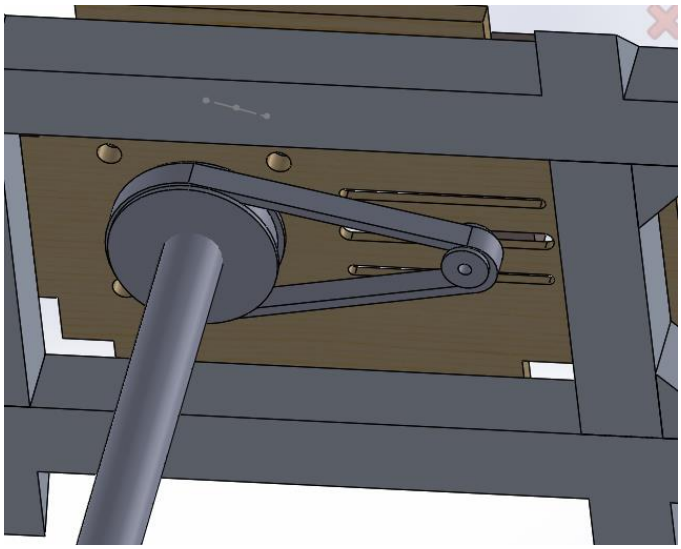


Step 1:

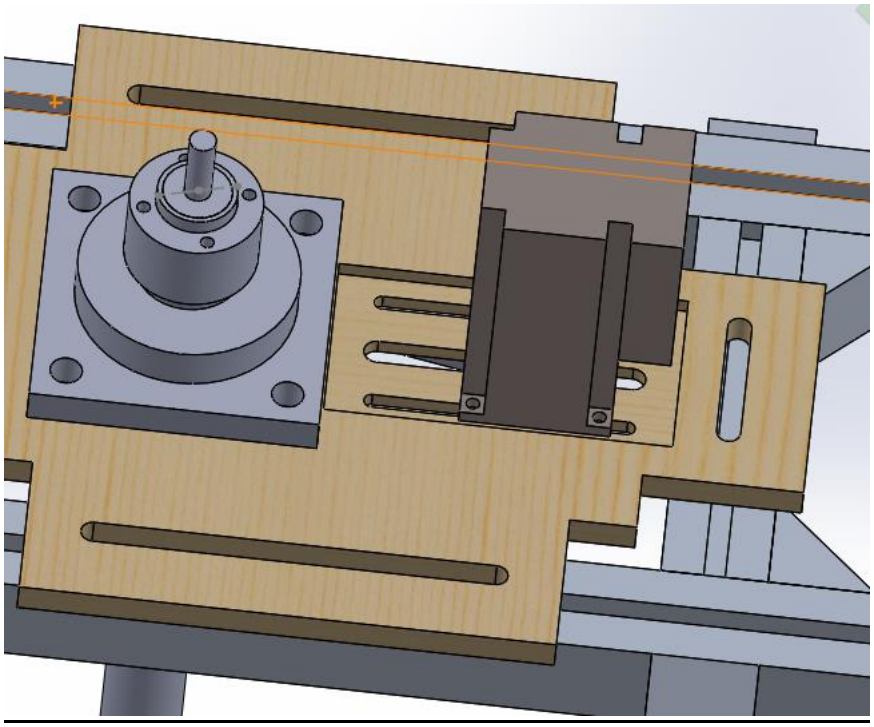


Step 2:

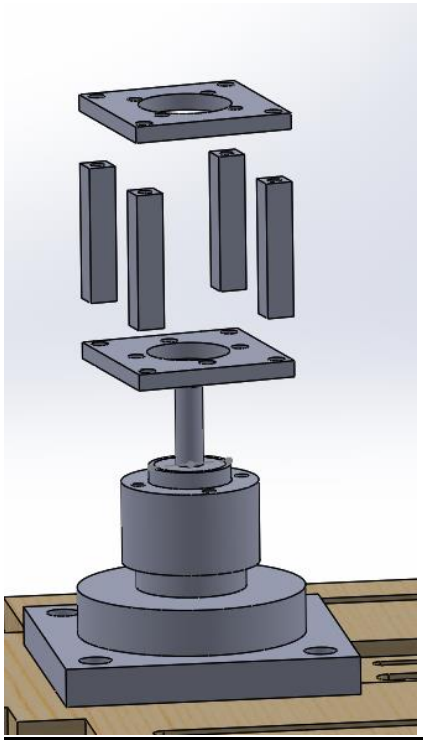
Step 3:

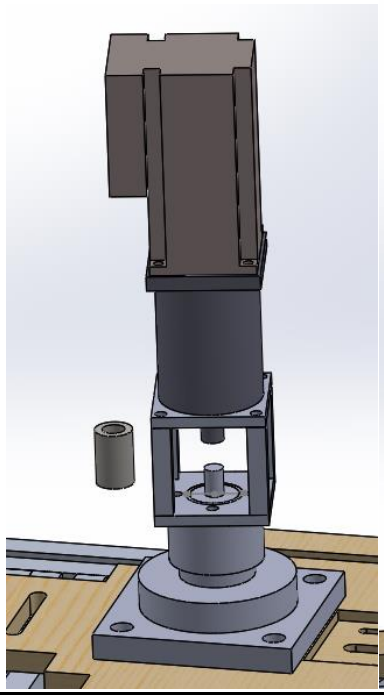


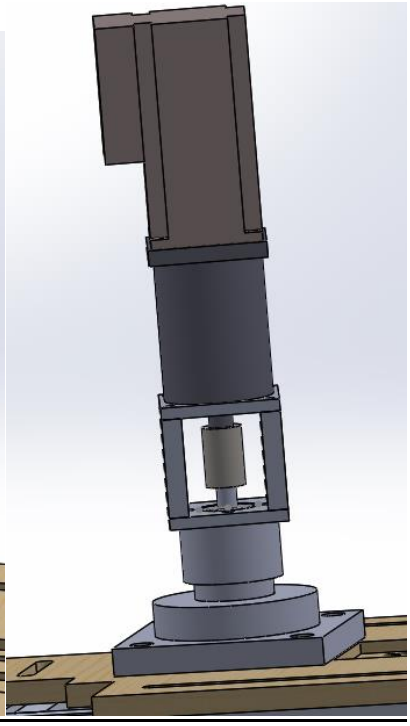
This step does not show the additional shaft/coupler that will likely be needed. Image shows how belt is close to the flange bearing mounting holes.



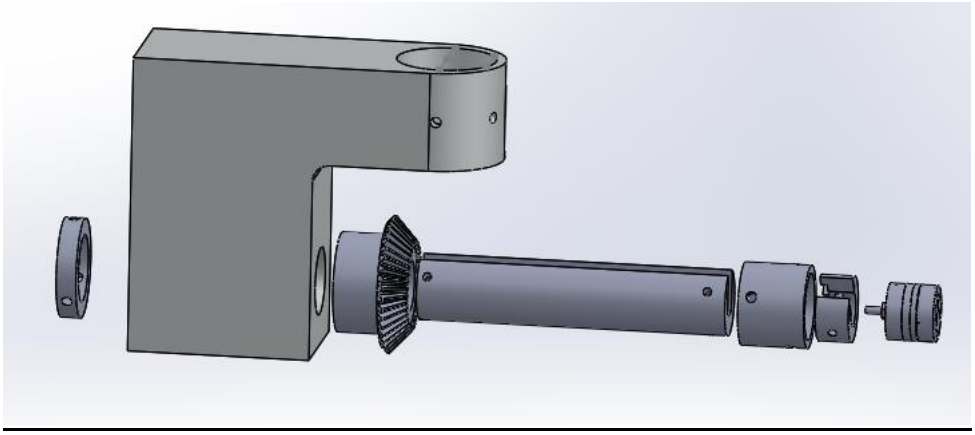
Step 4:





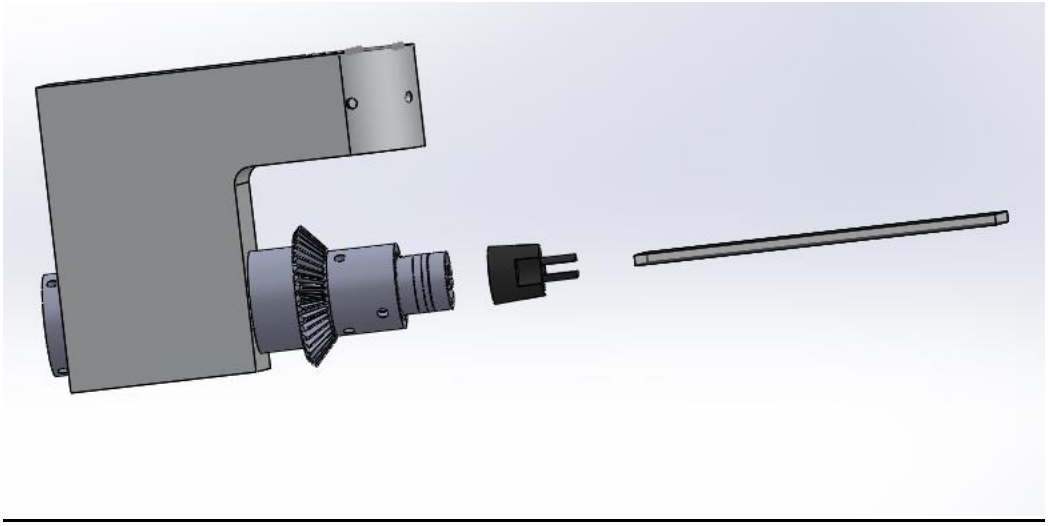


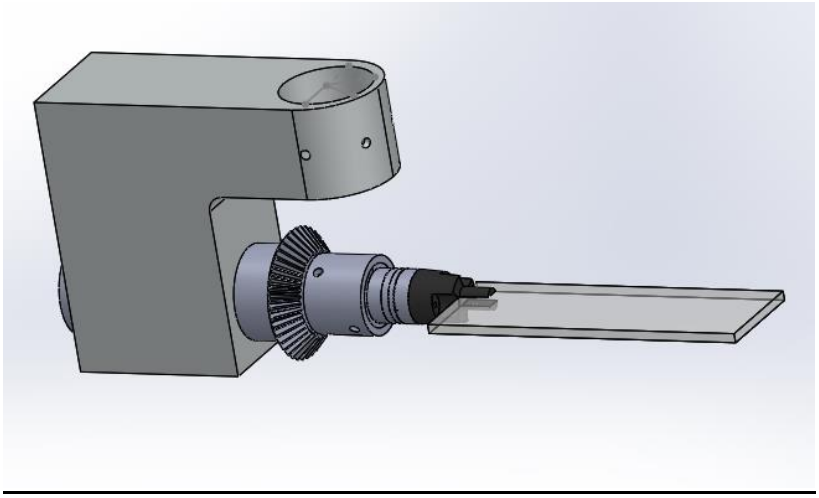
Step 5:



Due to the sensors axial cable, it will need to pass through the bores of the end ring, aluminium block,24-tooth gear, and coupler

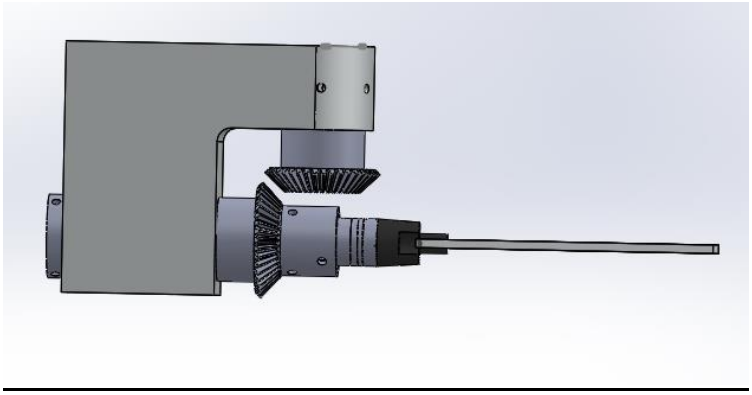
Step 6:



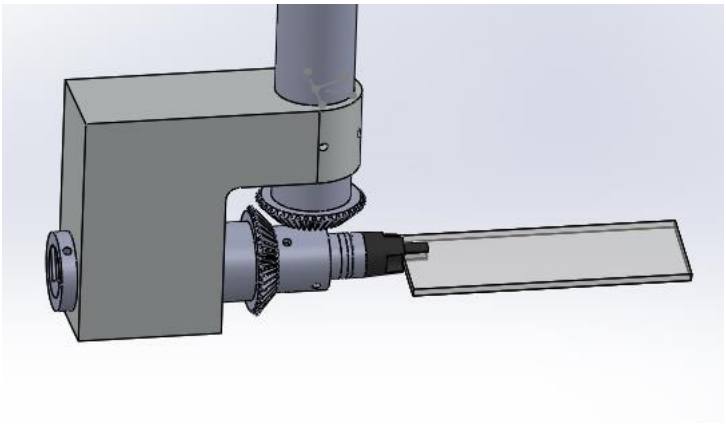


(Gears not accurate – shown gear corresponds to 24-tooth gear)

<u>Step 7:</u>

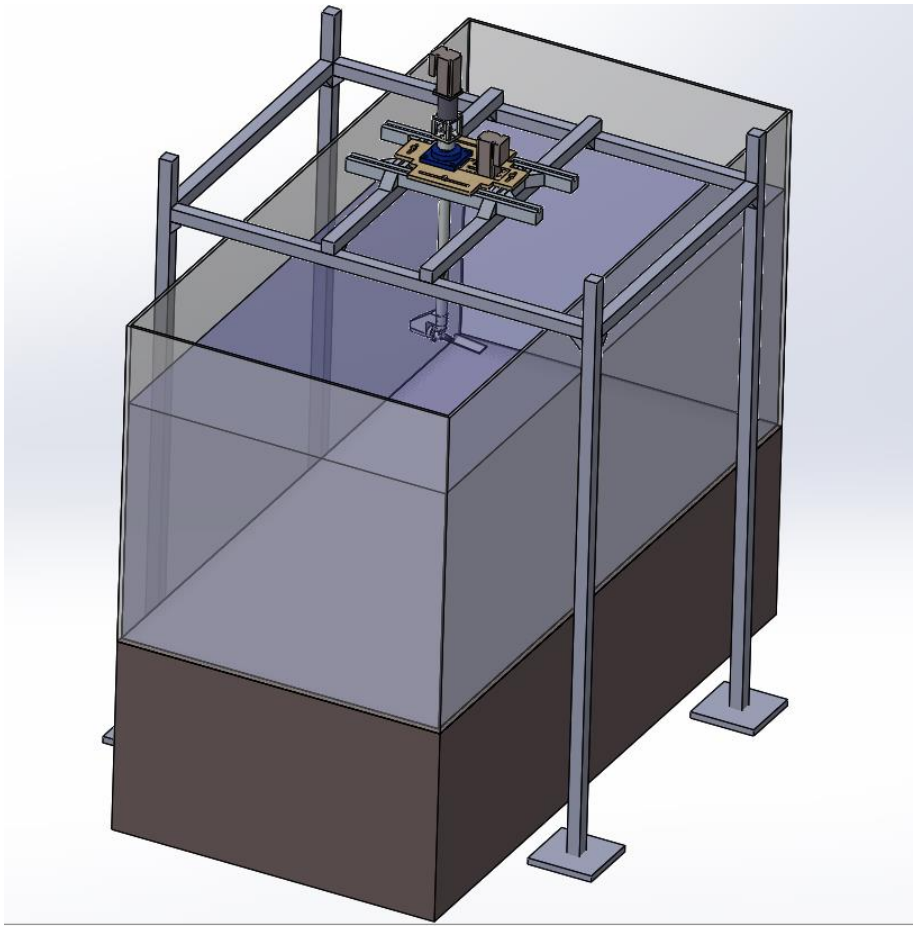


(Gears not accurate – New gear in photo corresponds to 16-tooth gear)



Slide both parts pre-positioned up onto the bottom of the outer and inner shaft

Step 8:



Step 9:

Fix Electronics

More Useful links:

https://www.applied-motion.com/s/product/detail/01t5i000000xylkAAA?name=STM23S-3RE-NEMA-23-Integrated-Drive-Motor-w-Encoder – Stepper motor

https://simplybearings.co.uk/shop/p20194084/P12-5M-15F-5mm-Pitch-12-Tooth-Flanged-HTD-Type-Steel-Timing-Pulley-for-15mm-Wide-Belts/product_info.html - small pulley

https://simplybearings.co.uk/shop/p671275/HTD425-15-85-Major-Brand-Synchronous-Belt-15mm-Wide-5mm-Pitch-85-Teeth/product_info.html - Pulley belt

https://simplybearings.co.uk/shop/p20193090/TL48-5M-15F-5mm-Pitch-48-Tooth-Flanged-HTD-Type-Steel-Taper-Bore-Timing-Pulley-for-15mm-Wide-Belts/product_info.html - large pulley

https://simplybearings.co.uk/shop/p552040/1210-30-Tapered-Locking-Bush-with-30mm-Bore/product_info.html -large pulley locking bush

https://uk.rs-online.com/web/p/ball-bearings/6189991 - ball bearing

https://bepltd.com/products/2-mod-1-5-ratio-16-24-teeth-precision-bevel-gears-steel-en8 - bevel gear pair

https://uk.rs-online.com/web/p/bearing-units/7508784 - flange bearing

https://uk.rs-online.com/web/p/flexible-couplings/4231775 - 12mm gearbox jaw for coupling

https://uk.rs-online.com/web/p/flexible-couplings/7019155 - coupling rubber spacer

https://uk.rs-online.com/web/p/flexible-couplings/4231769 - 10mm inner shaft jaw for coupling

https://motioncontrolproducts.com/media/productattach/r/e/re-planetary-gearbox.pdf - gearbox dimensions (RE55 model for Nema 23)

https://www.ati-ia.com/products/ft/ft_models.aspx?id=Nano17+IP65%2fIP68 – ATI Nano17 IP68 Web page (useful documents for sensor found here)

https://uk.rs-online.com/web/p/standoffs/1768297 - Metal female-female standoffs (unsure if these are the exact ones)

https://www.mouser.co.uk/ProductDetail/Connective-Peripherals/ES-U-3001-M?qs=jotIDw4kbYV9GiEaKLbLDA%3D%3D – Serial adapter/data converter, Data sheet can be found here