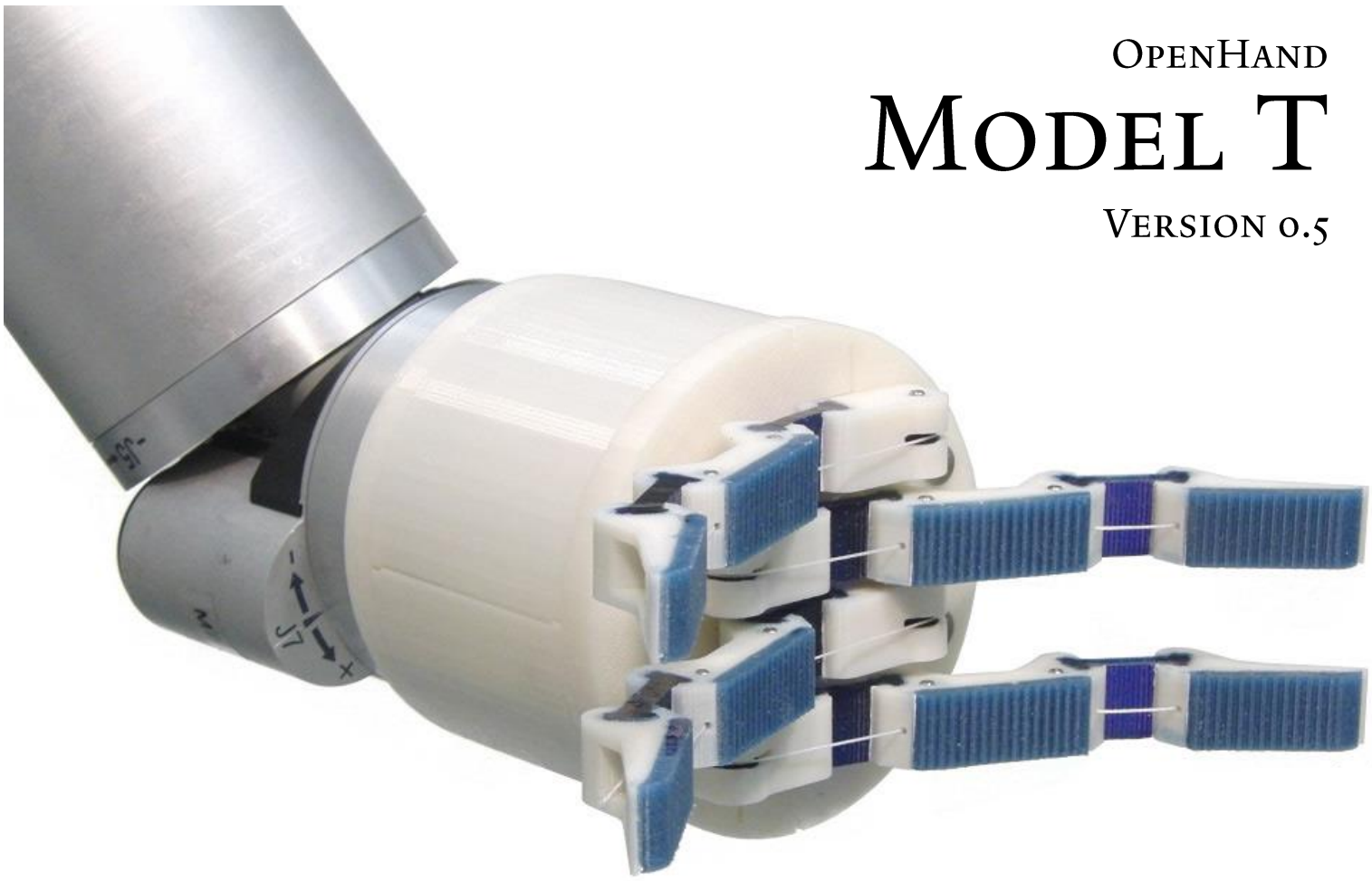
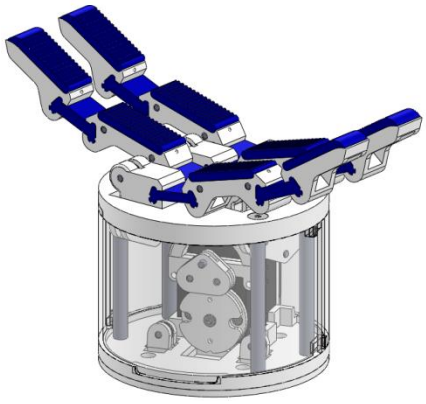


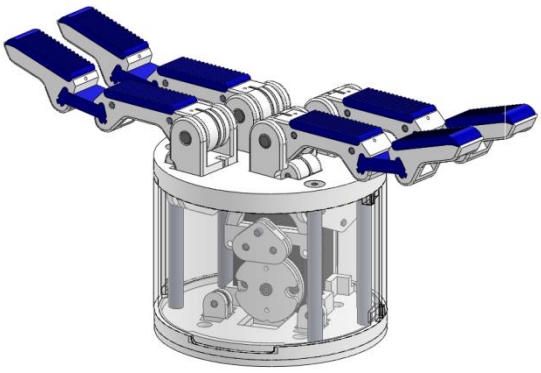
OpenHand

Model T

Version 0.5



Flexure Base



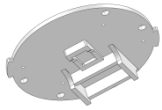
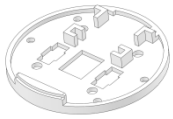
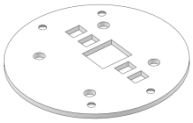
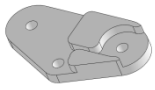
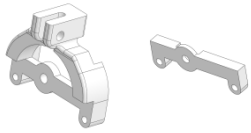
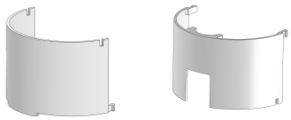
Pivot Base

Assembly Instructions

Last updated: November 11, 2013

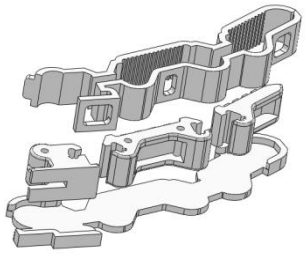
the GRAB LAB

Parts List 1/3 (Flexure Base)

Part Name	Quantity	Usage	Vendor	Preview
a1_flexure.stl	1	Top Keeper Plate	3D Print	
a2.stl	1	Top Plate	3D Print	
a3.stl	1	Bottom Plate	3D Print	
a4.stl	1	Bottom Keeper Plate	3D Print	
b1.stl	2	Drive Pulley Block	3D Print	
b2.stl	2	Routing Base Block	3D Print	
b3.stl	4	Differential Block	3D Print	
b4_a.stl, b4_b.stl	1	Servo Block	3D Print	
b5.stl	1	Servo Pulley	3D Print	
d1.stl	1	Sunon Fan Clamp*	3D Print	
d2_a.stl, d2_b.stl	1	Case Shell*	3D Print	

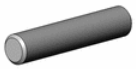
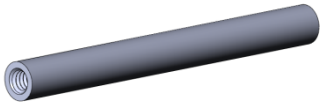
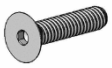
* optional

Parts List 2/3 (Flexure Base)

Part Name	Quantity	Usage	Vendor	Preview
finger_flexure_print.stl	4	Finger Molds – Breakaway	3D Print	
finger_ff_A.stl, finger_ff_B.stl, finger_ff_C.stl, shell_ff_A.stl, shell_ff_B.stl, shell_ff_C.stl	4	Finger Molds – Multi Part	3D Print	
Robotis MX-64 Dynamixel	1	Actuator	Robotis [link]	
Sunon 25x10mm 12VDC Fan	1	Cooling Fan*	Digikey [link]	
Power Pro Spectra	1	Tendon	Amazon [link]	
PMC-780 Urethane	1	Finger Joint Urethane	Smooth-On [link]	
Vytaflex 30 Urethane	1	Finger Pad Urethane	Smooth-On [link]	

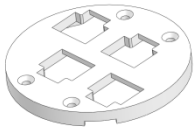
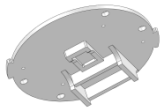
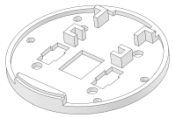
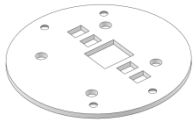
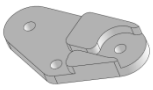
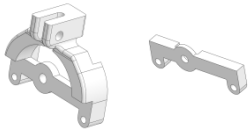
* optional

Parts List 3/3 (Flexure Base)

Part Name	Quantity	Usage	Vendor	Preview
Ø1/8”, L3/8” steel dowel pin (J1)	13	Support Pin	McMaster [98381A470]	
Ø1/8”, L5/8” steel dowel pin (J2)	12	Support Pin	McMaster [98381A472]	
Ø3/8”, Wd1/8” nylon pulley (P1)	12	Tendon Routing	McMaster [3434T31]	
Ø1/4”, L2-1/2” zinc-plated female standoff (S1)	4	Support	McMaster [92474A029]	
Socket Cap Screw 8-32, L3/4”	8	Fastener	McMaster [91253A197]	
M2.5, L7.5mm bolt	1	Fastener	Provided w/ Dynamixel	
M2, L3mm bolt	2	Fastener	McMaster [91292A003]	
2-56, L3/4” bolt/nut	2	Fastener	McMaster [92196A084]	

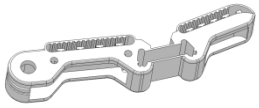
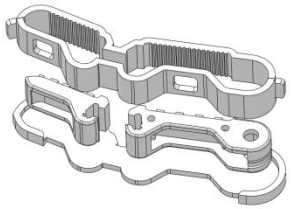
* optional

Parts List 1/3 (Pivot Base)

Part Name	Quantity	Usage	Vendor	Preview
a1_pivot.stl	1	Top Keeper Plate	3D Print	
a2.stl	1	Top Plate	3D Print	
a3.stl	1	Bottom Plate	3D Print	
a4.stl	1	Bottom Keeper Plate	3D Print	
b1.stl	2	Drive Pulley Block	3D Print	
b2.stl	2	Routing Base Block	3D Print	
b3.stl	4	Differential Block	3D Print	
b4_a.stl, b4_b.stl	1	Servo Block	3D Print	
b5.stl	1	Servo Pulley	3D Print	
c1.stl	4	Finger Pivot Base	3D Print	
d1.stl	1	Sunon Fan Clamp*	3D Print	

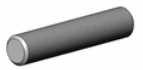
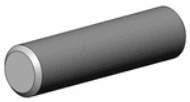
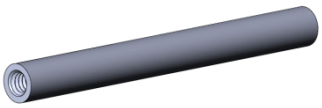
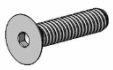
* optional

Parts List 2/3 (Pivot Base)

Part Name	Quantity	Usage	Vendor	Preview
d2_a.stl, d2_b.stl	1	Case Shell*	3D Print	
finger_pivot.stl	4	Finger Molds – Breakaway	3D Print	
finger_fp_A.stl, finger_fp_B.stl, shell_fp_A.stl, shell_fp_B.stl, shell_fp_C.stl	4	Finger Molds – Multi Part	3D Print	
Robotis MX-64 Dynamixel	1	Actuator	Robotis [link]	
Sunon 25x10mm 12VDC Fan	1	Cooling Fan*	Digikey [link]	
Power Pro Spectra	1	Tendon	Amazon [link]	
PMC-780 Urethane	1	Finger Joint Urethane	Smooth-On [link]	
Vytaflex 30 Urethane	1	Finger Pad Urethane	Smooth-On [link]	

* optional

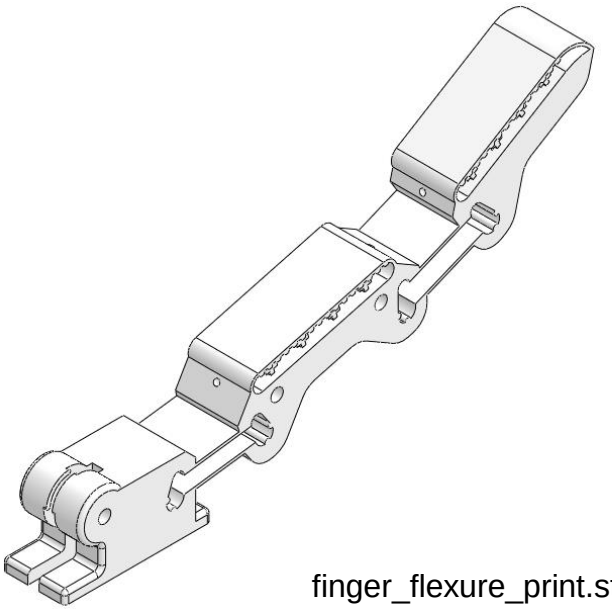
Parts List 3/3 (Pivot Base)

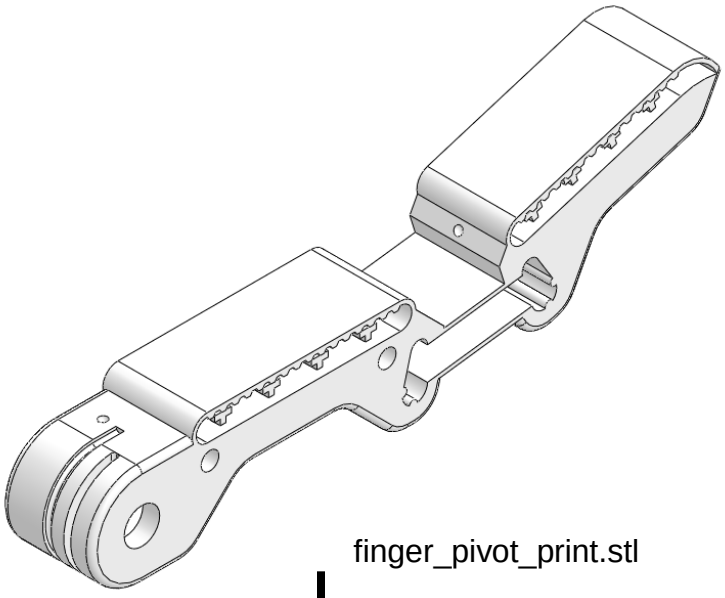
Part Name	Quantity	Usage	Vendor	Preview
Ø1/8”, L3/8” steel dowel pin (J1)	13	Support Pin	McMaster [98381A470]	
Ø1/8”, L5/8” steel dowel pin (J2)	12	Support Pin	McMaster [98381A472]	
Ø1/4”, L1” steel dowel pin (J3)	4	Joint Pin	McMaster [98381A542]	
Ø3/8”, Wd1/8” nylon pulley (P1)	12	Tendon Routing	McMaster [3434T31]	
Ø1/4”, L2-1/2” zinc-plated standoff	4	Support	McMaster [92474A029]	
Socket Cap Screw 8-32, L3/4”	8	Fastener	McMaster [91253A197]	
M2.5, L7.5mm bolt	1	Fastener	Provided w/ Dynamixel	
M2, L3mm bolt	2	Fastener	McMaster [91292A003]	
2-56, L3/4” bolt/nut	2	Fastener	McMaster [92196A084]	
Torsion Spring, Ø0.34”, 0.028” wire diameter, 180˚, left-hand wound	4	Joint Return Spring	McMaster [9271K605]	

* optional

Part Preparation

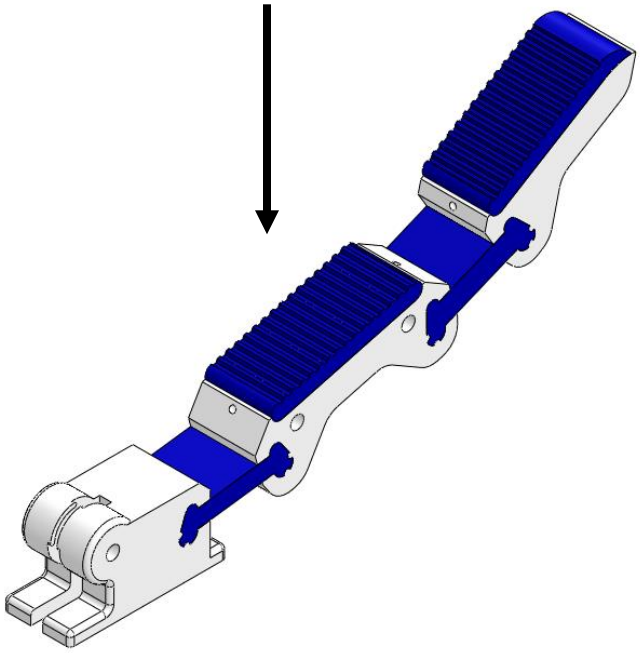
FINGER MOLDING

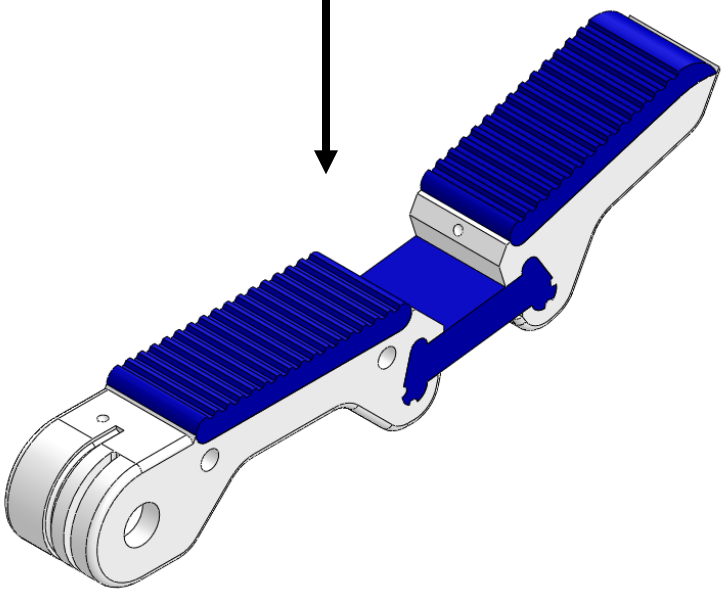


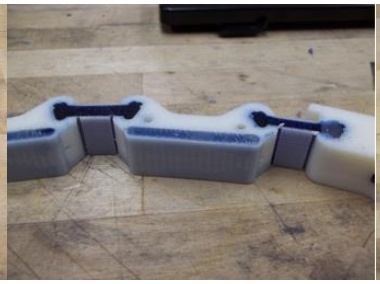


finger_flexure_print.stl

finger_pivot_print.stl



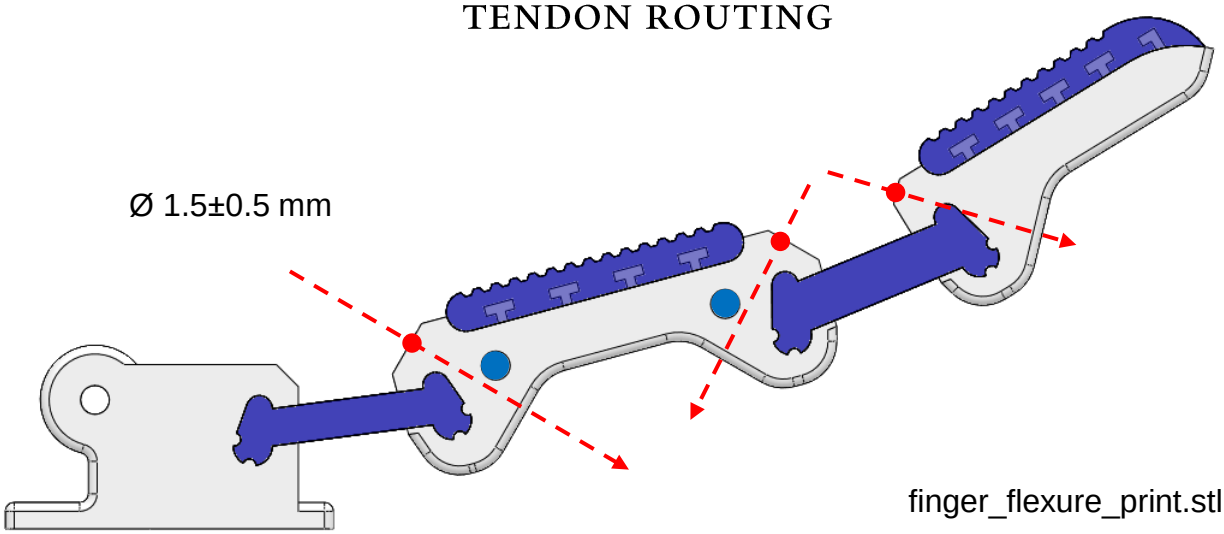




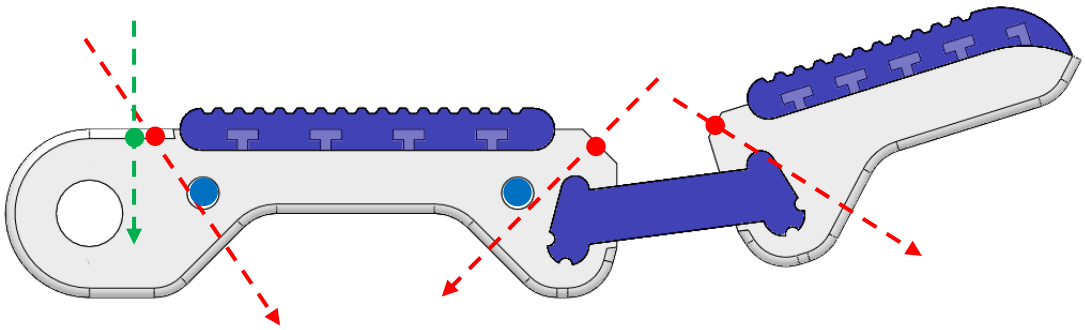
Consult DDM (Dieless Deposition Manufacturing) guide for further details on pouring/preparing the joints and pads for fingers

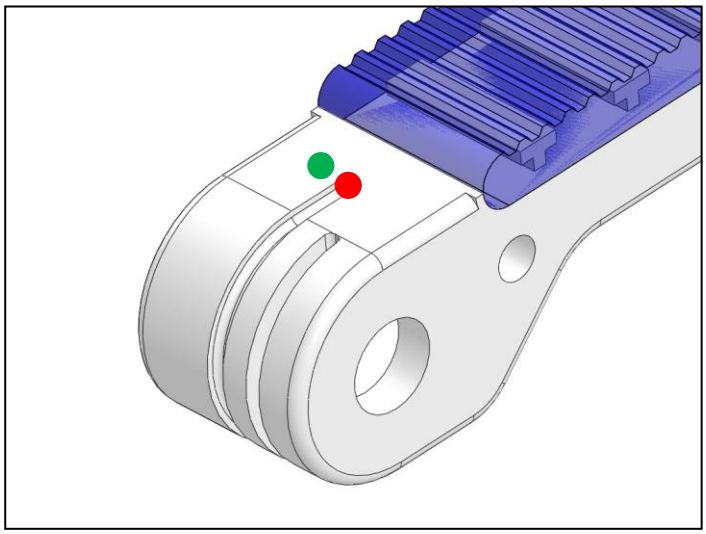
Part Preparation

TENDON ROUTING



finger_flexure_print.stl (x4)



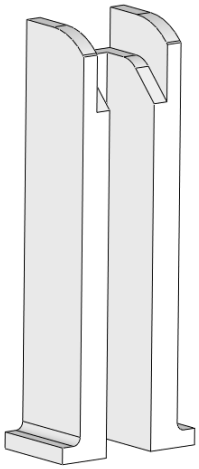


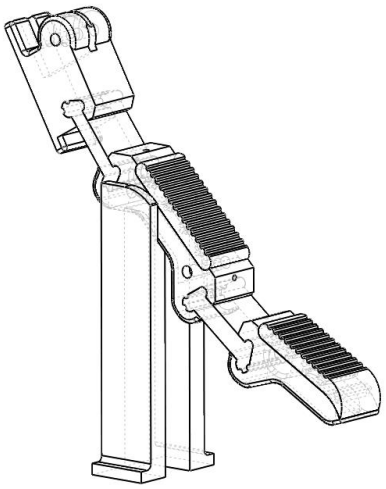
finger_pivot_print.stl (x4)

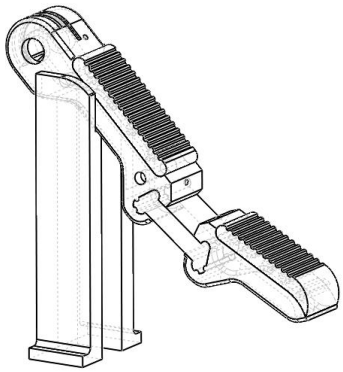
Drill tendon routing holes such that tendon will run tangent to inserted pin. Minimize contact between tendon and ABS but ensure that tendon runs freely. For the pivot base design, the fingers also have a torsional spring mounting hole to be drilled as shown.

Part Preparation

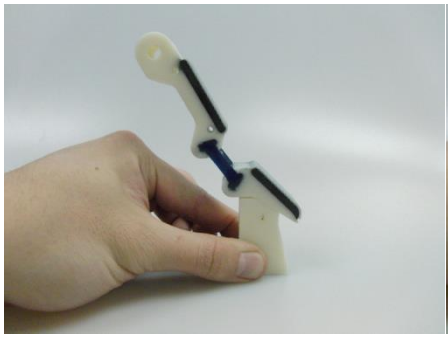
tendon routing (2/2)

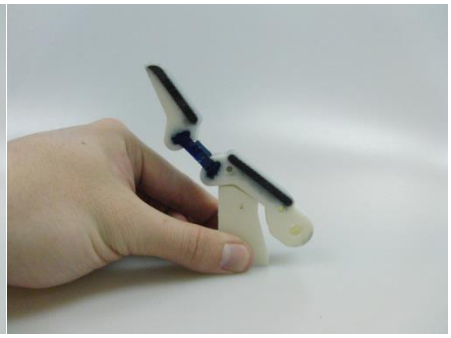


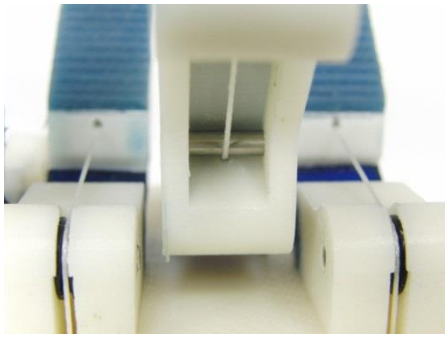


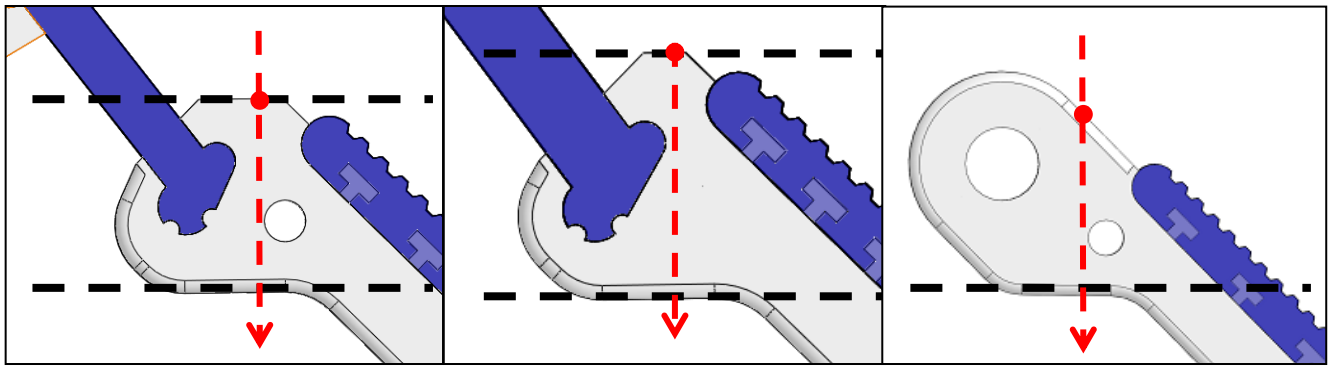


helper_jig.stl





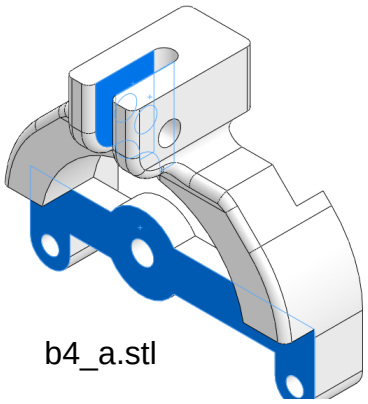




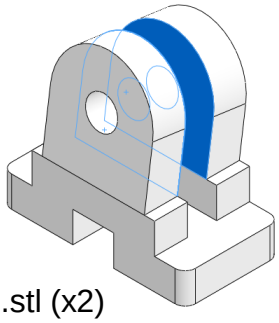
Use *helper_jig.stl* to aid in positioning and orientation during drilling if desired. Routing holes should be drilled perpendicular to hole surface. The fingers are designed such that for each routing hole, there is at least one feature surface that is perpendicular to the direction of drilling, as shown above. It is ideal to minimize the diameter of the tendon routing holes if possible.

Part Preparation

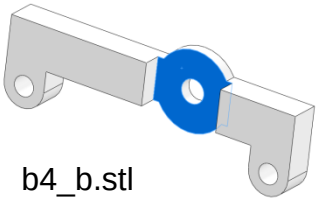
SURFACE FILING/DEBURRING



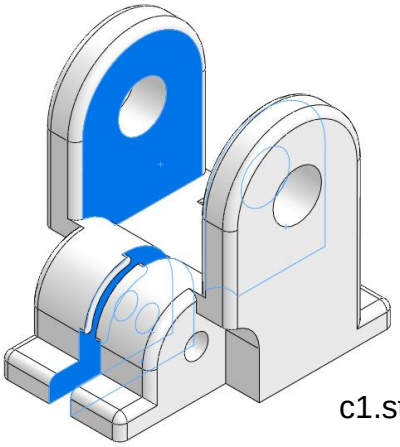
b4_a.stl



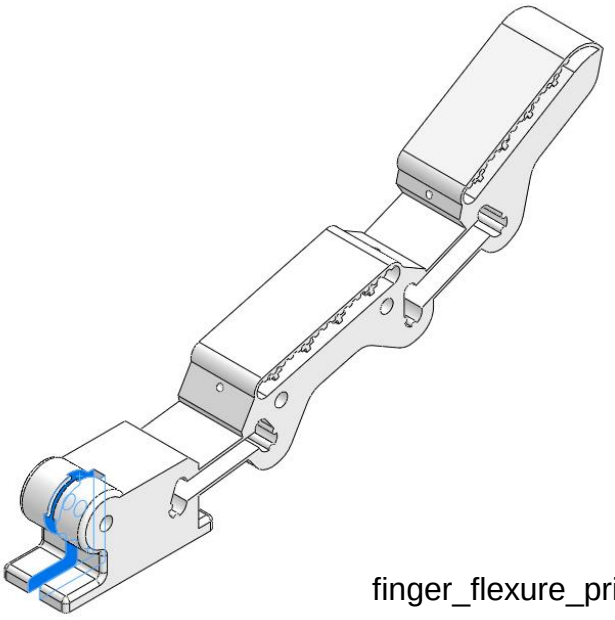
b2.stl (x2)



b4_b.stl



c1.stl (x4)

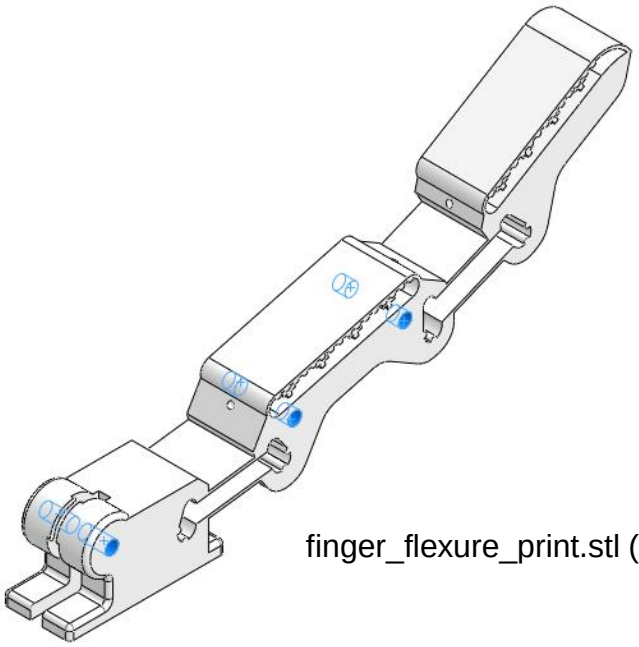


finger_flexure_print.stl (x4)

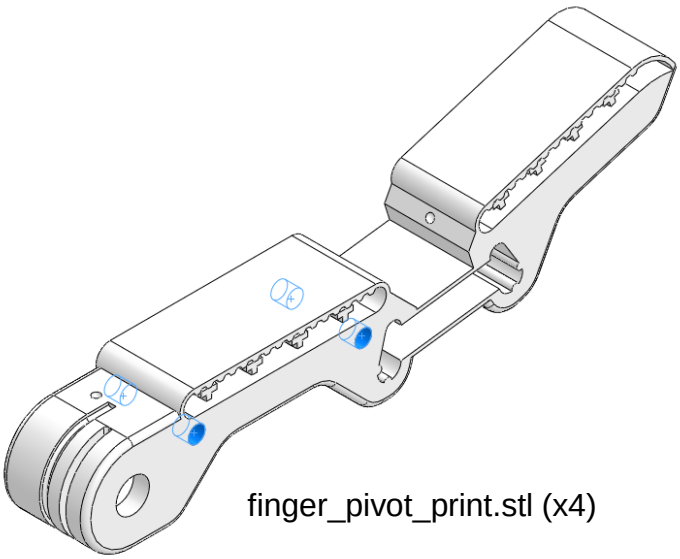
File down and deburr bearing surfaces as indicated above. Ensure that no support material remains, if applicable. Complementary piece (ie. pulley, finger) should slide in freely. The parameter "*print Free*" in the CAD parameters file can also be adjusted to avoid this step. The default printing tolerances are calibrated to a Stratasys FDM printer.

Part Preparation

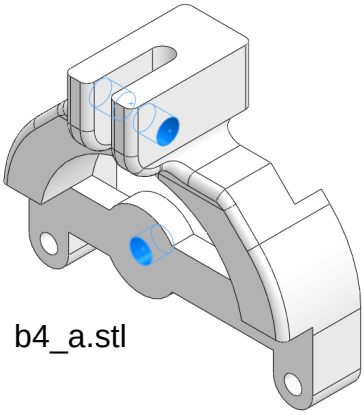
reaming (1/8" pin holes)



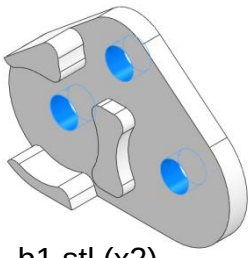
finger_flexure_print.stl (x4)



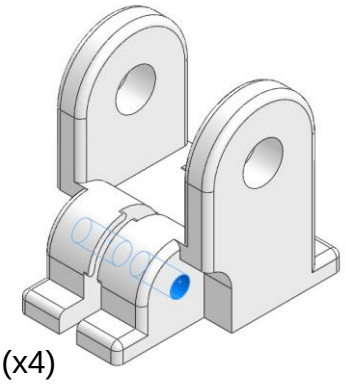
finger_pivot_print.stl (x4)



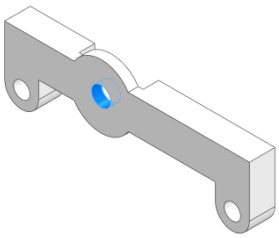
b4_a.stl



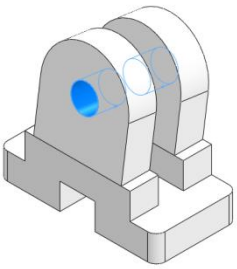
b1.stl (x2)



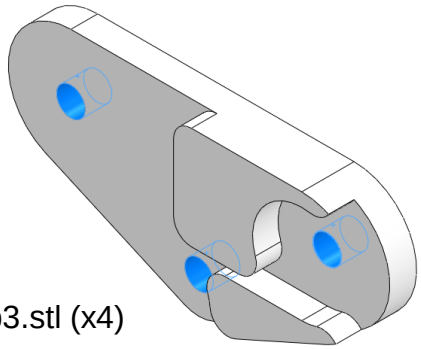
c1.stl (x4)



b4_b.stl



b2.stl (x2)

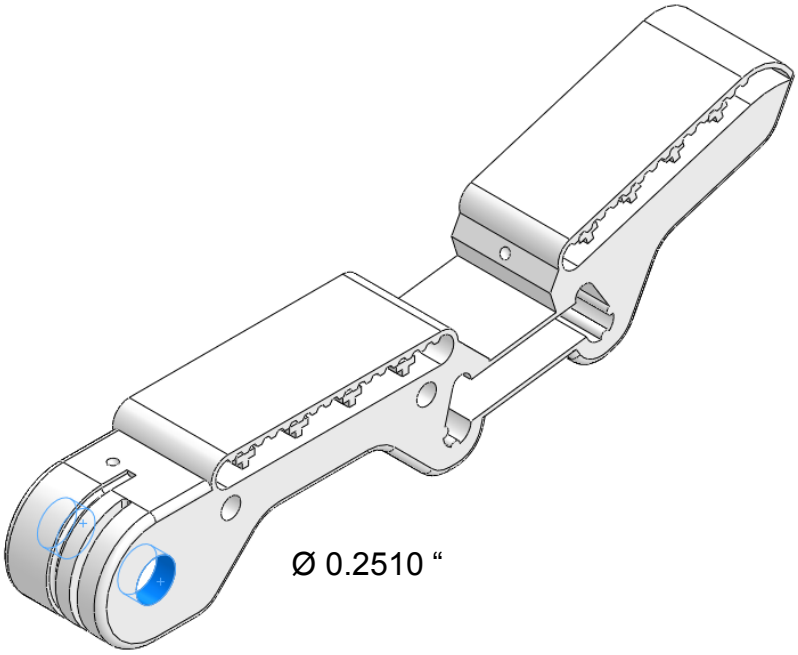


b3.stl (x4)

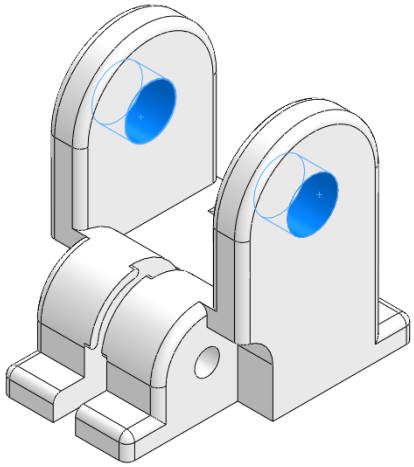
Use Ø0.1240" reamer to prepare pin holes as indicated above. This step can be skipped in lieu of precise 3D printer calibration and parameter selection, but manual reaming is the recommended approach.

Part Preparation

reaming (pivot bases)



finger_pivot_print.stl (x4)



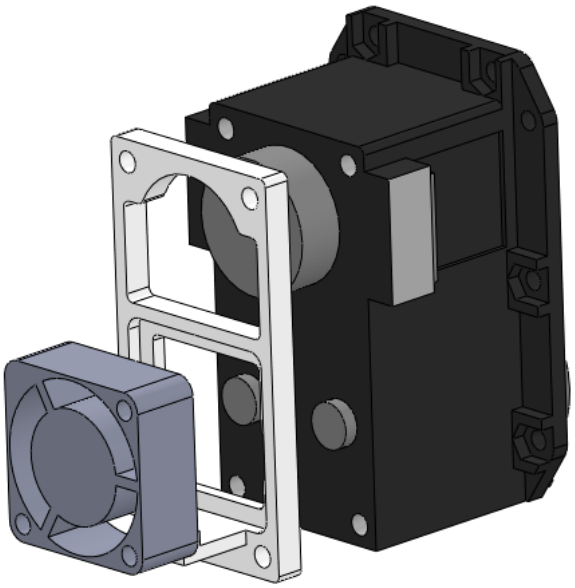
c1.stl (x4)

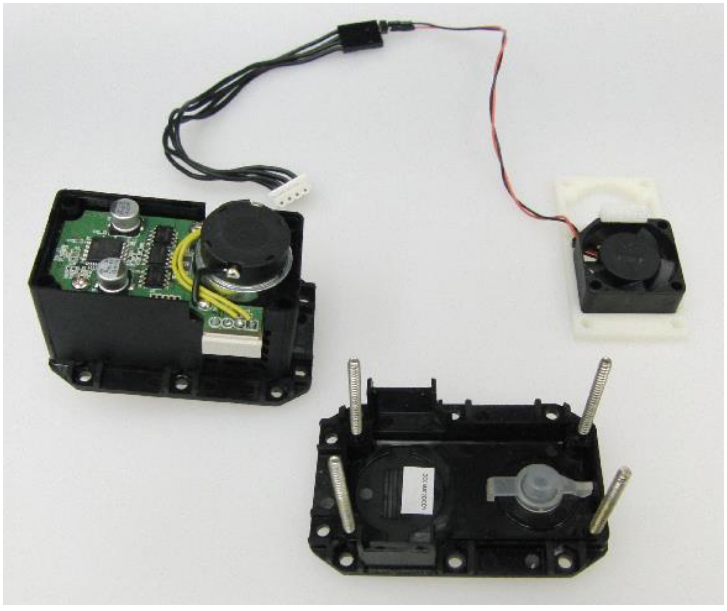
Use Ø0.2490” reamer to prepare pin holes on pivot bases *c1.stl*, and Ø0.2510” reamer to prepare pin holes on the corresponding fingers *finger_pivot.stl.* Finger should spin freely and loosely on a Ø0.25” steel pin. The steel pin should fit tightly in part *c1.stl* with no slip.

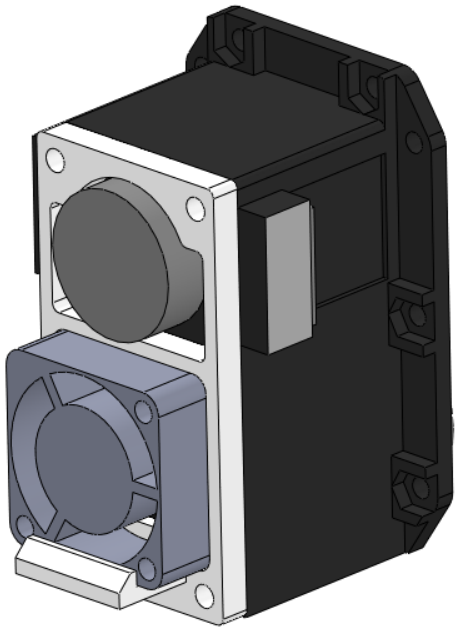
ASSEMBLY

BLOCK_ACTUATOR

Parts	
Dynamixel MX-64	
d1.stl	
Sunon 12VDC fan	





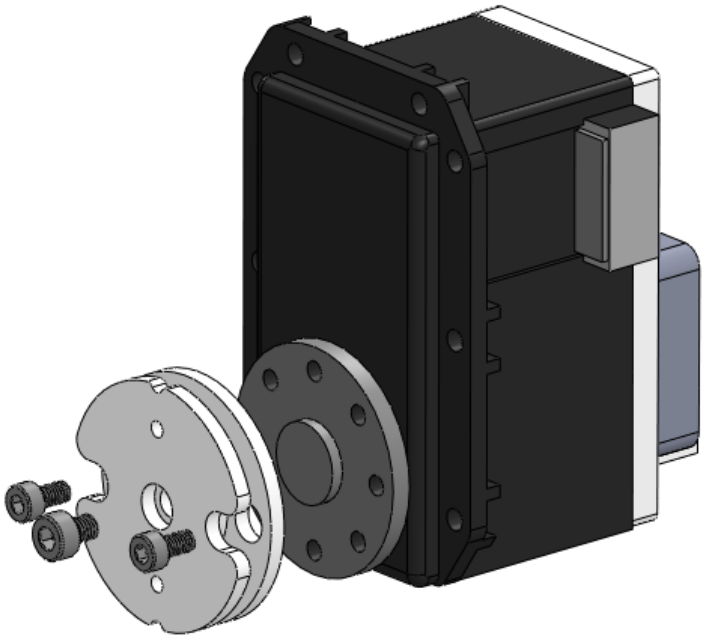


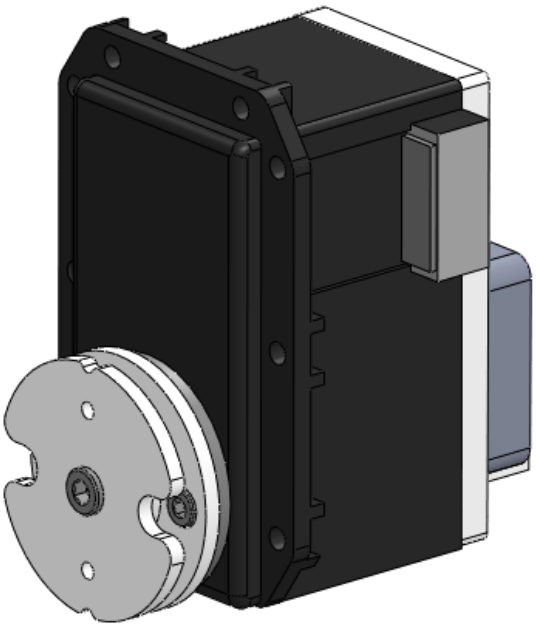
Remove back of Dynamixel MX-64 and replace with fan clamp *d1.stl*. Sunon fan snaps into place onto *d1.stl*. Use same 4 existing screws to attach clamp frame *d1.stl* to servo. Skip this step if fan implementation is not desired.

Assembly

BLOCK_ACTUATOR

Parts	
Sub-assembly from step 7	
b5.stl	
M2.5, L7.5mm bolt	
M2, L3mm bolt	

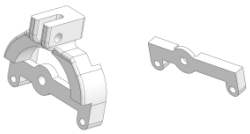


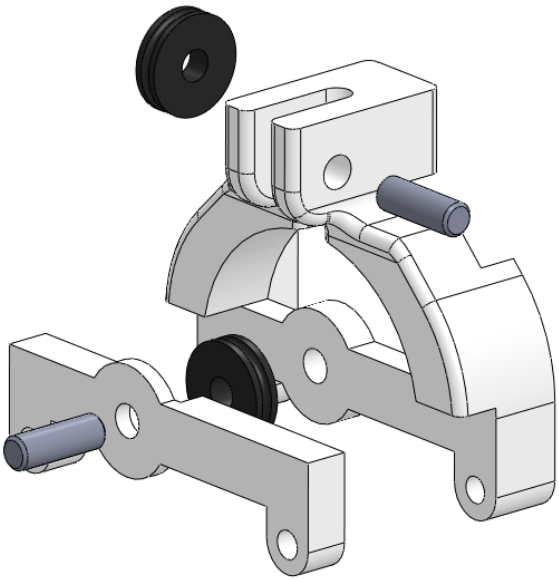


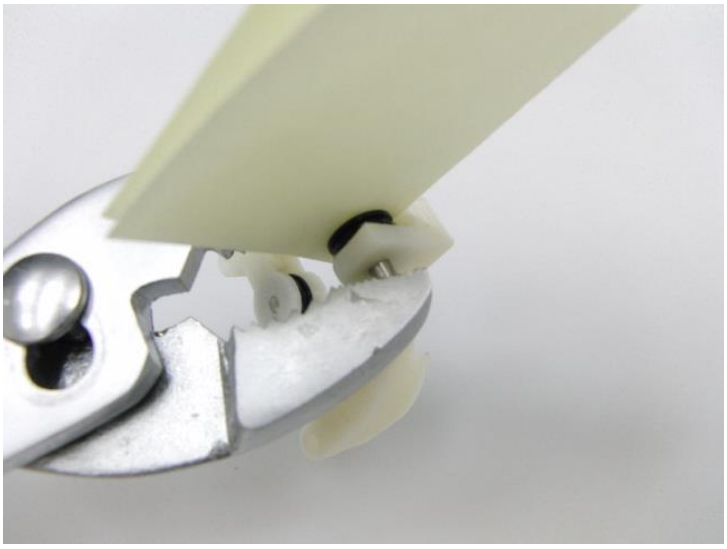
Assemble main drive pulley onto actuator block sub-assembly as shown. M2 bolts should not interfere with servo rotation after assembly.

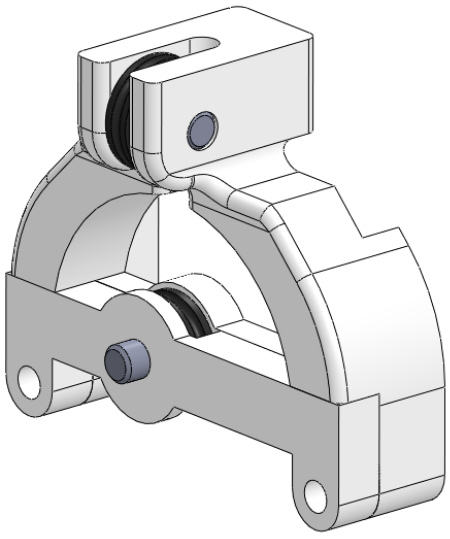
Assembly

BLOCK_ACTUATOR

Parts	
Pulley P1 (x2)	
L3/8" pin J1 (x2)	
b4_a.stl, b4_b.stl	



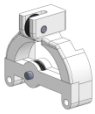


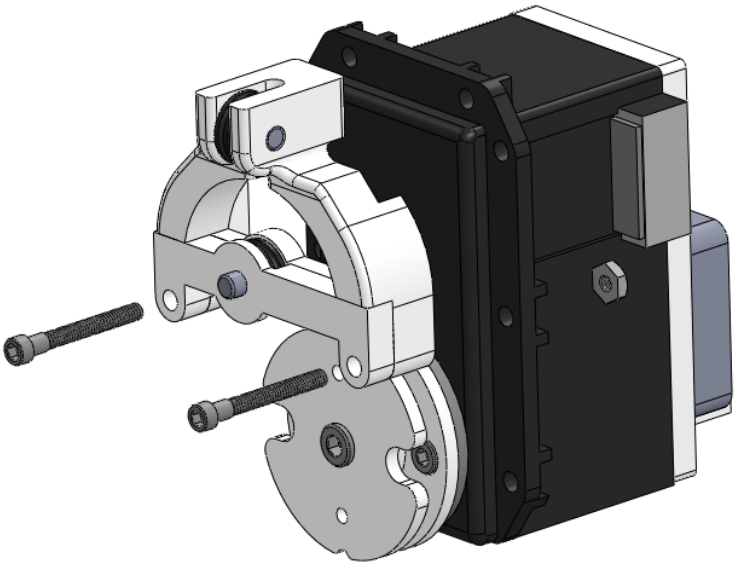


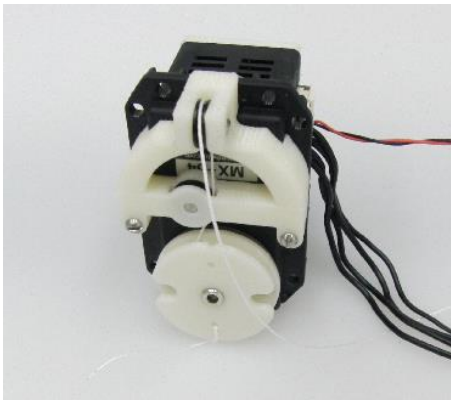
Assemble re-routing sub-assembly as shown above. It is suggested that a paper shim is used when press-fitting the top pin to ensure that the pulley is not pinched during assembly. Both pulleys should spin freely after assembly.

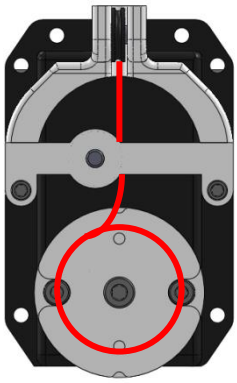
ASSEMBLY

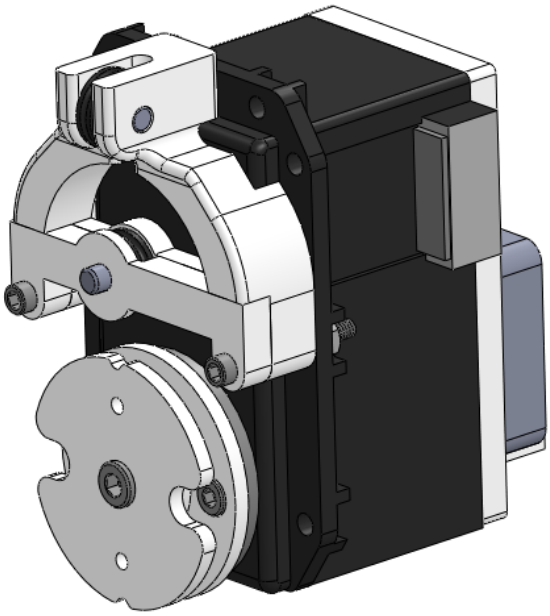
BLOCK_ACTUATOR

Parts	
Motor sub-assembly from step 8	
Tendon-routing sub-assembly from step 9	
2-56 L3/4” machine bolt/nut (x2)	
Spectra Tendon ~8in (~200mm)	







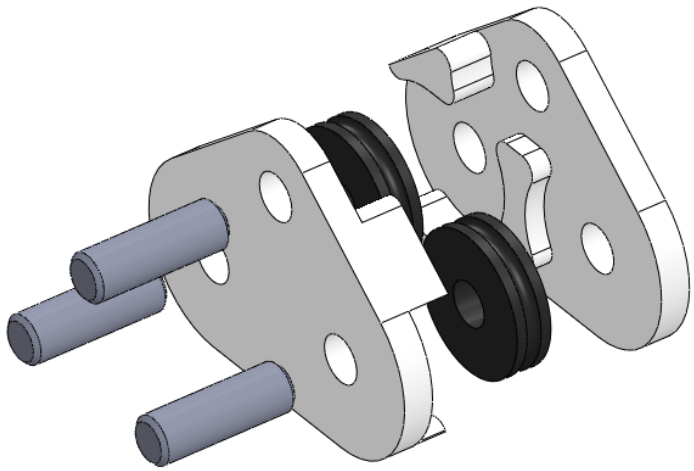


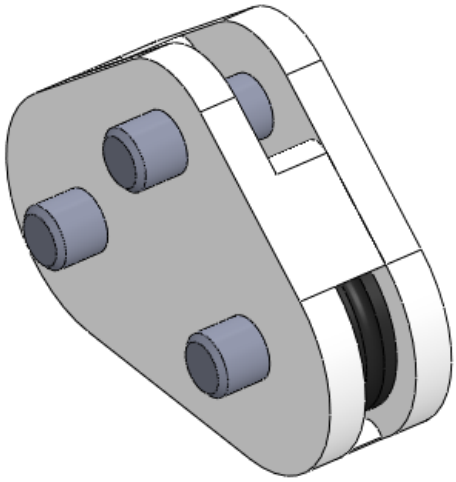
Finish assembling block actuator sub-assembly as shown above. Any bolt/nut pairing of size in close approximation to 2-56 can also be used here. Spectra tendon should be secured to the pulley at one of the two anchor holes (we use a no-slip, improved clinch knot) and wound clockwise, then up and through the pulleys in the sub-assembly from step 9.

ASSEMBLY

PULLEY BLOCKS

Parts	
b1.stl (x2)	
Pulley P1 (x2)	
L3/8” pin J1 (x3)	



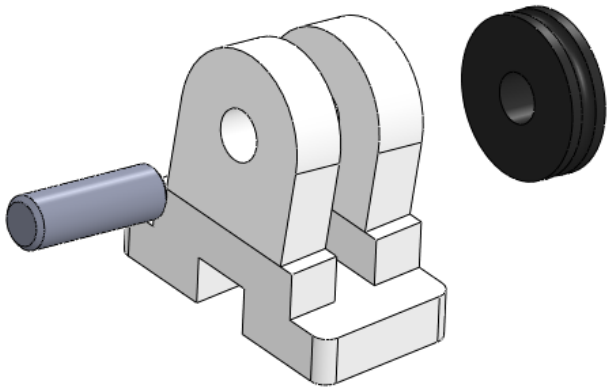


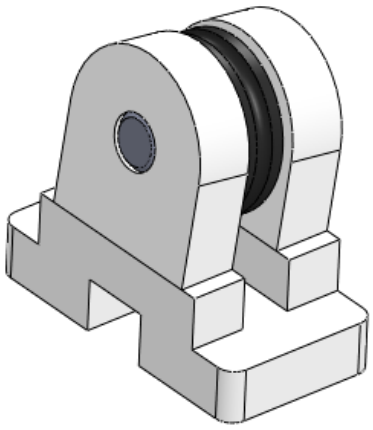
Assemble the drive pulley block as shown above. Shorter steel pins can be used if desired, but pins must be longer than overall thickness of drive pulley sub-assembly. This sub-assembly should be attached to the other end of the Spectra tendon from step 10 with a no-slip knot.

ASSEMBLY

PULLEY BLOCKS

Parts
b2.stl (x2)
Pulley P1 (x2)
L3/8” pin J1 (x2)





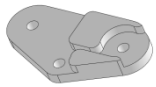
x2

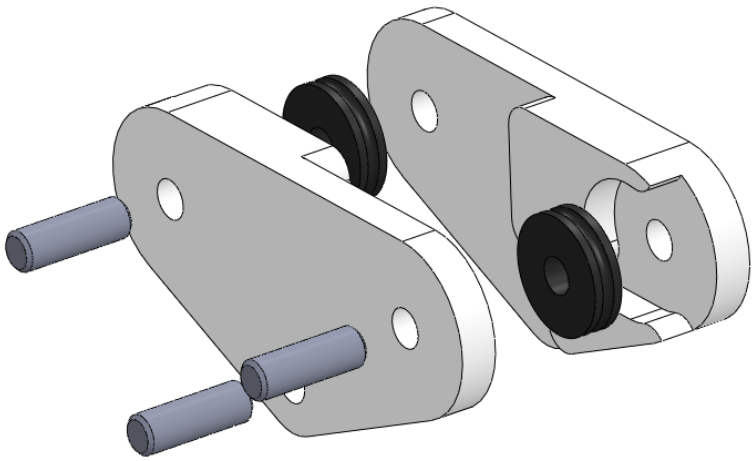
Assemble the sets of pulley blocks as shown above. Ensure that all pulleys can spin freely. Use a paper shim during assembly with *b2.stl* as done in step 9 to avoid pinching.

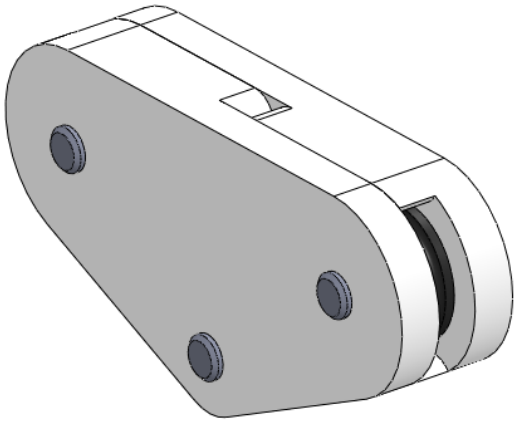
ASSEMBLY

PULLEY BLOCKS

Parts
b3.stl (x3)
Pulley P1 (x4)
L3/8” pin J1 (x6)





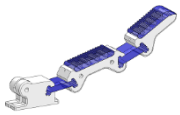
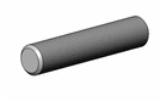


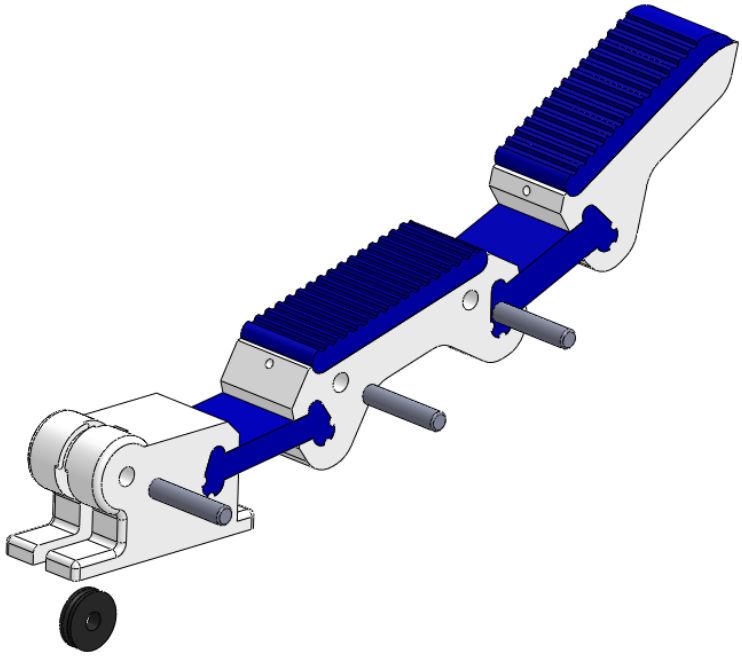
x2

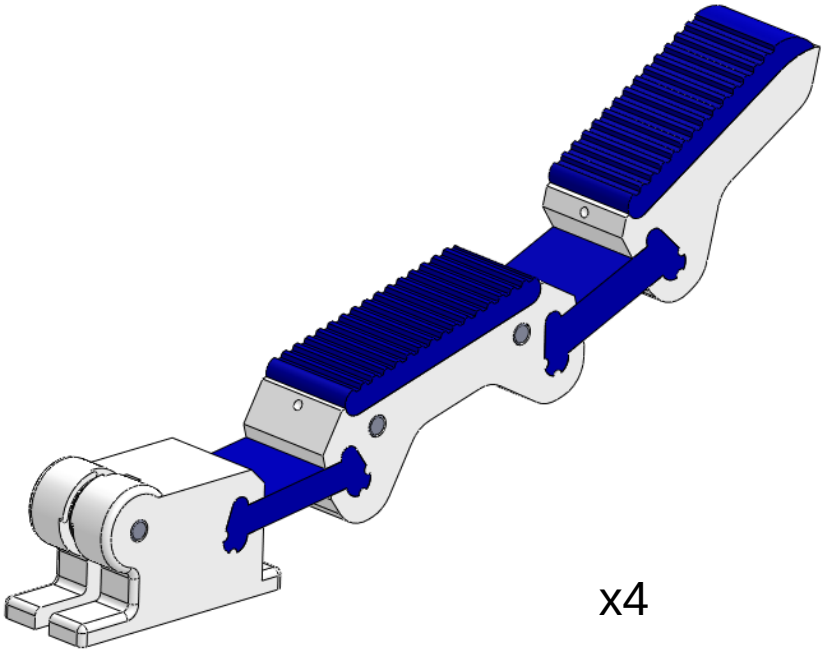
Assemble 2 sets of differential pulley blocks as shown above.

Assembly

FLEXURE-BASE FINGERS

Parts	
Flexure-base Finger (x4)	
Pulley P1 (x4)	
L5/8” pin J2 (x12)	





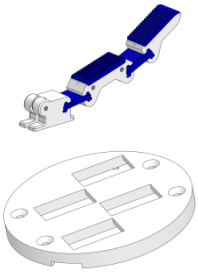
x4

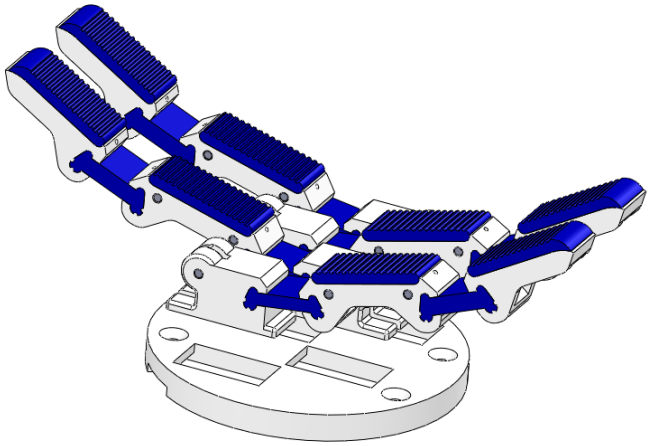
For pivot-base fingers, skip to step 18. Use a shim as done in steps 9 and 12 to ensure that nylon pulley spins freely at finger base

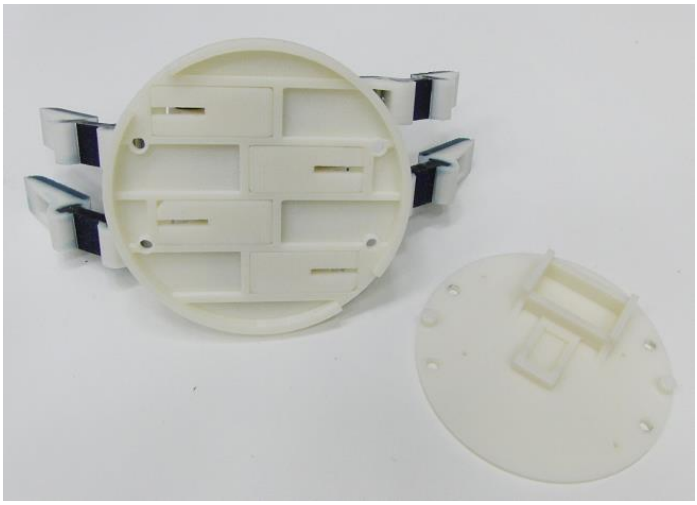
Assembly

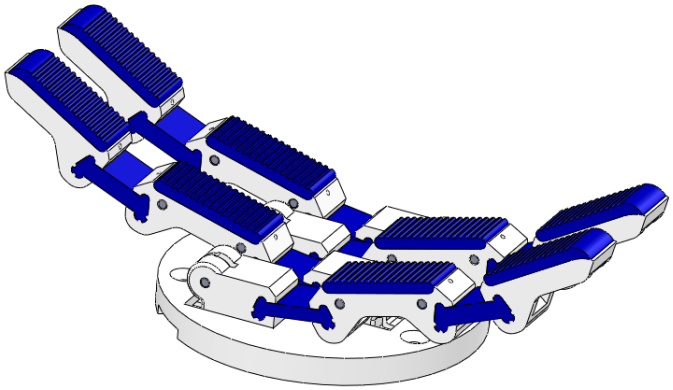
FLEXURE-BASE FINGERS TOP

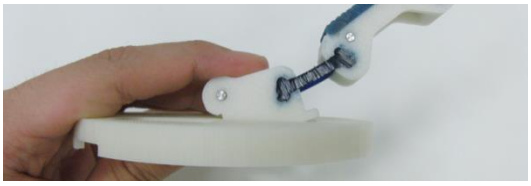
Parts
Finger sub-assembly from step 14 (x4)
a1_flexure.stl

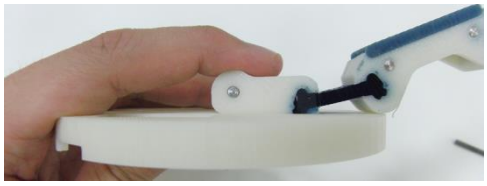


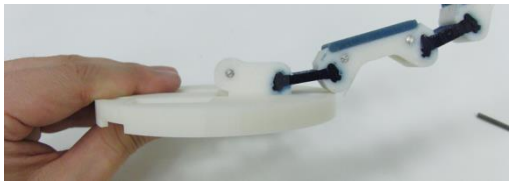


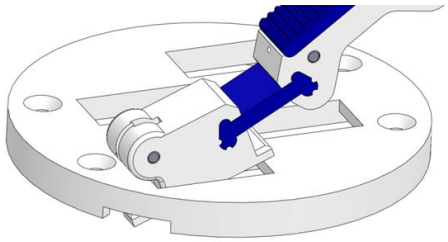


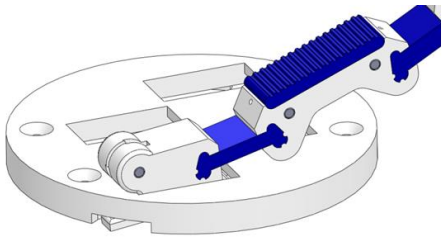


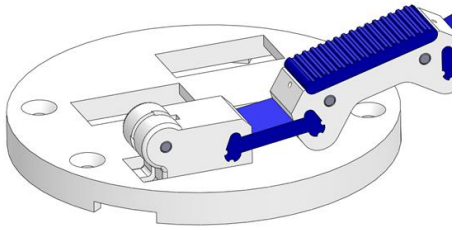








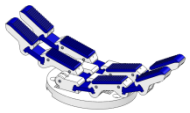
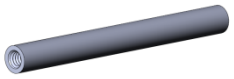
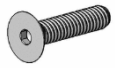


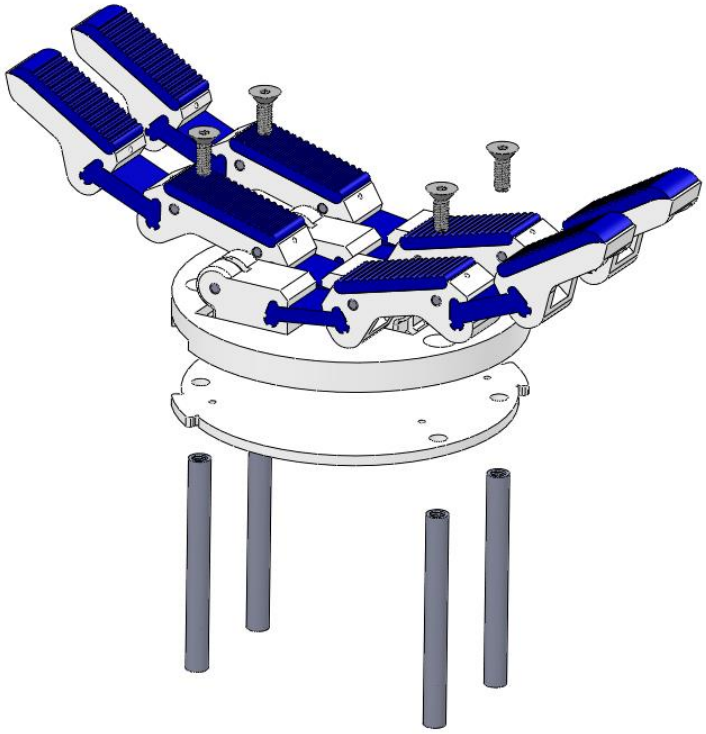


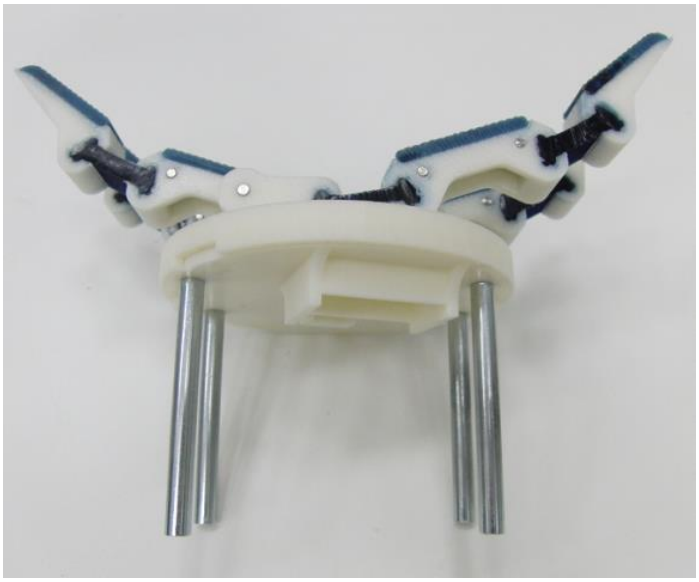
Insert fingers into top plate from above as illustrated in the figures. Fingers are inserted in at an angle and then tilted up into place. Finger base should lie flush with plate *a2.stl*

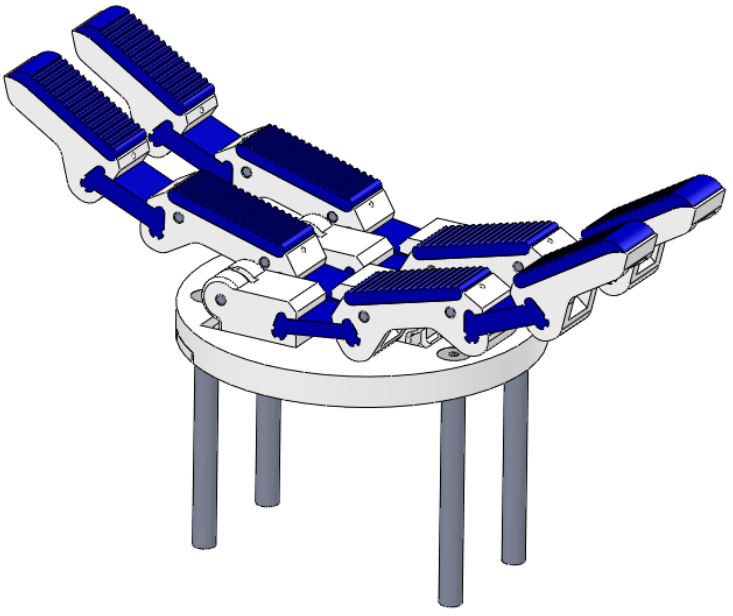
Assembly

FLEXURE-BASE FINGERS TOP

Parts	
Sub-assembly from step 15	
a2.stl	
Female standoffs S1 (x4)	
8-32 Socket Cap Screws (x4)	



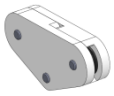


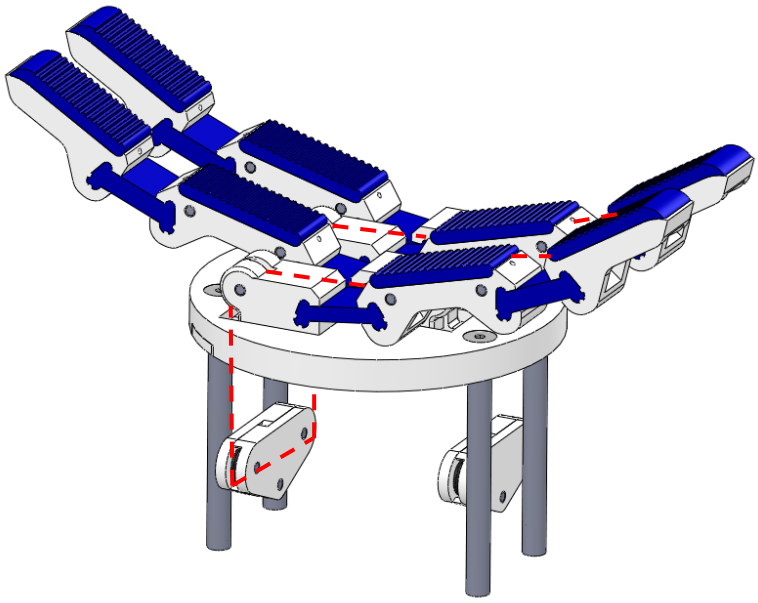


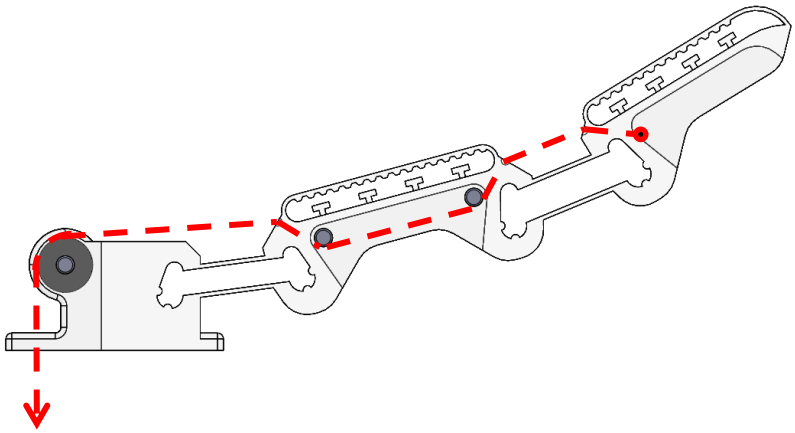
Use socket cap screws and standoffs to fully assemble the top flexure-base sub-assembly. Plates *a1_flexure.stl* and *a2.stl* should sandwich and immobilize the finger bases

Assembly

FLEXURE-BASE FINGERS TOP

Parts	
Sub-assembly from step 16	
Sub-assembly from step 13 (x2)	
Spectra Tendon ~8in (200mm) (x2)	



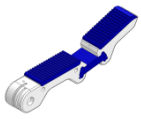


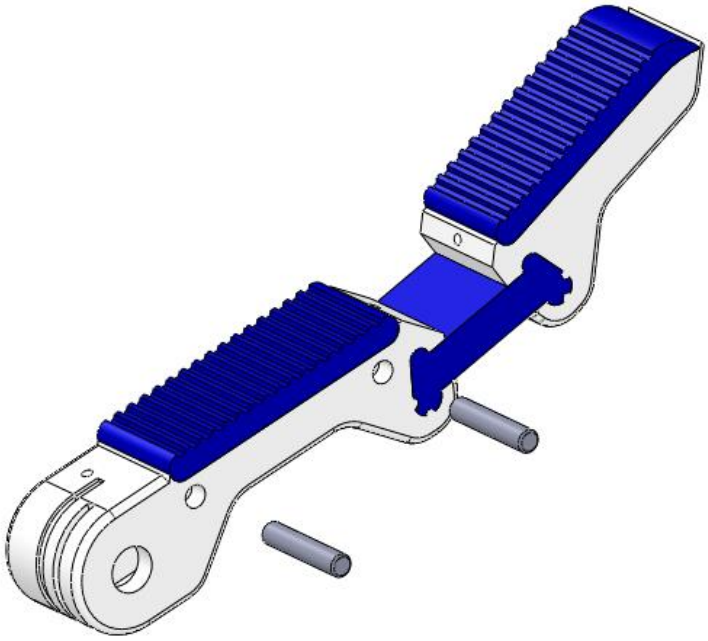
Each tendon runs from the back of the fingertip, down through the finger base, across the differential block from step 13, and back up through to the tip of the finger on the same side.

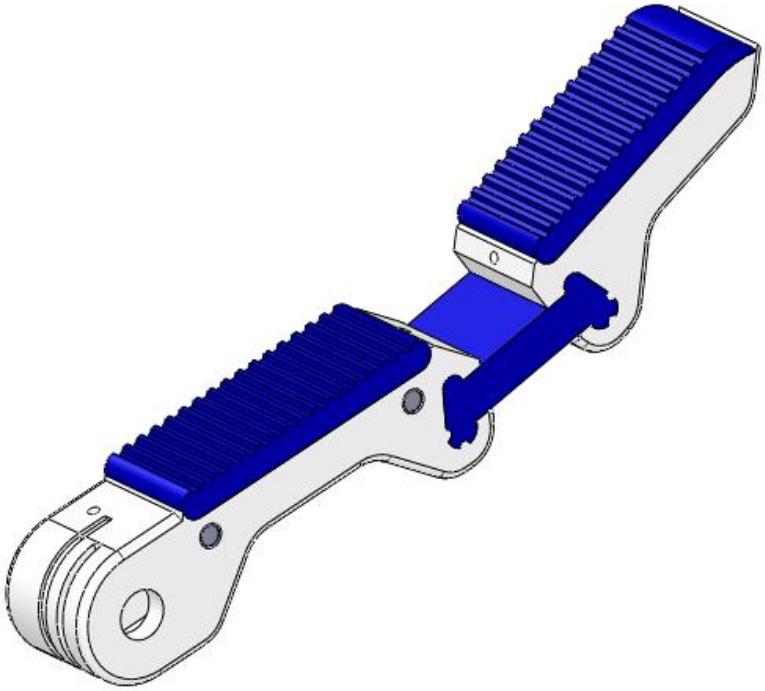
Use tendon to affix differential sub-assembly blocks to the sub-assembly made in the last step. Tendon length should be set such that it is taut when the fingers are at rest. Tendon tied off to small nut at back of finger.

Assembly

PIVOT-BASE FINGERS

Parts	
Pivot-base Finger (x4)	
L5/8” pin J2 (x8)	

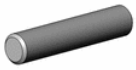


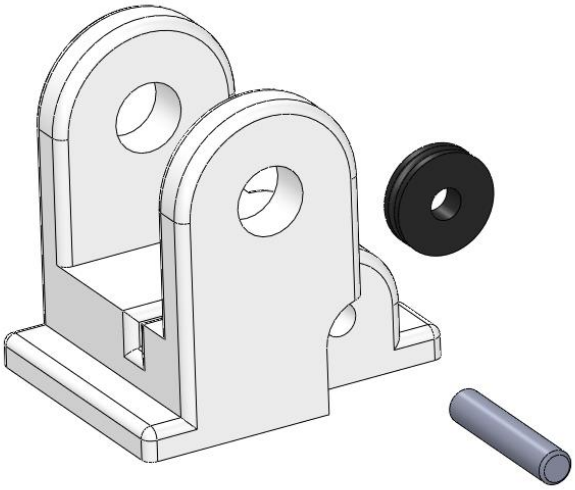


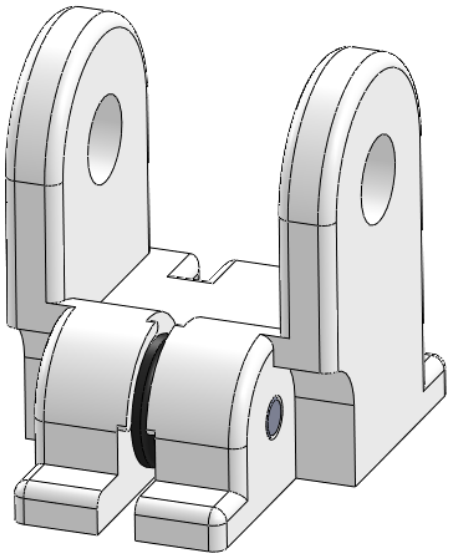
Assemble re-routing pins to fingers as shown in figures above.

Assembly

PIVOT-BASE FINGERS

Parts	
c1.stl (x2)	
Pulley P1 (x2)	
L5/8” pin J2 (x2)	

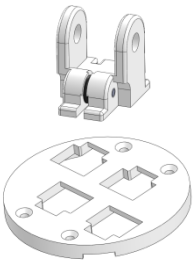


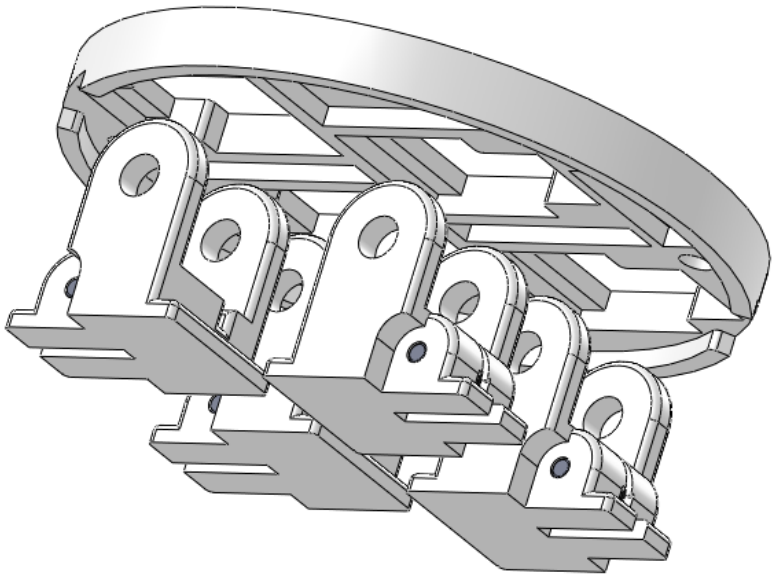


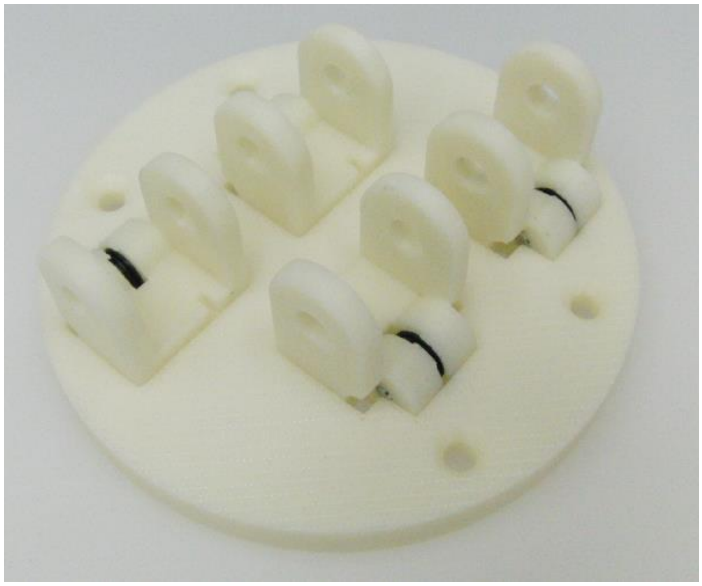
Assemble pivot base sub-assembly as shown. Use shim when press-fitting the pin and pulley to ensure that the pulley spins freely after assembly.

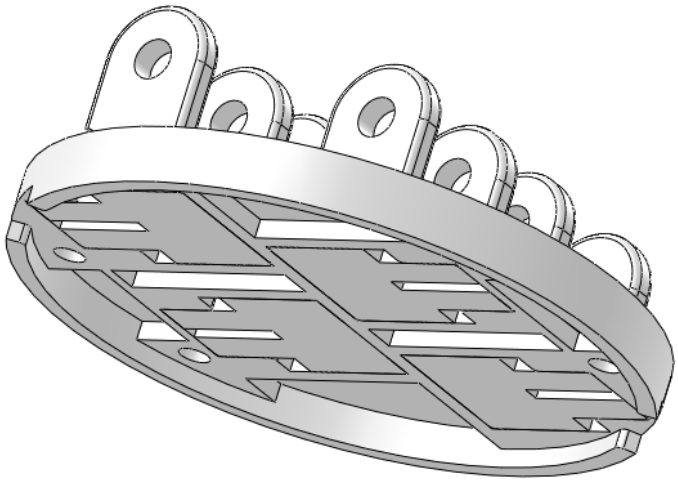
Assembly

PIVOT-BASE FINGERS TOP

Parts	
Sub-assembly from step 19 (x4)	
a1_pivot.stl	



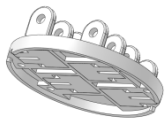
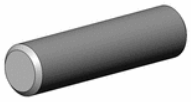


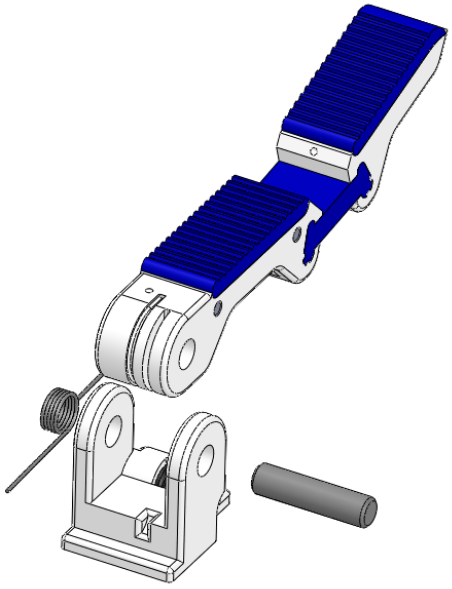


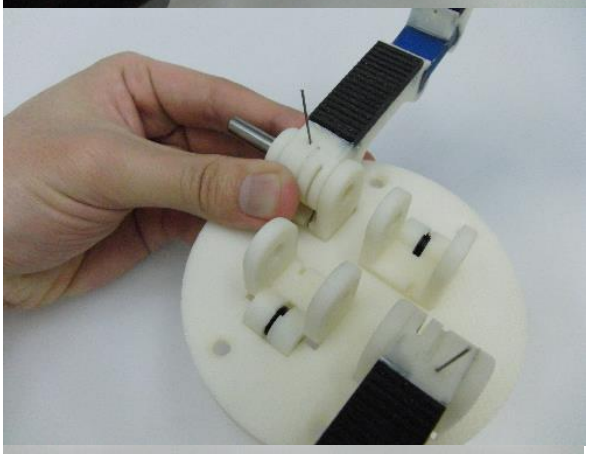
Assemble top pivot base plate as shown above. The bottoms of the finger pivot bases should fit flush with the top plate. The interior sides of *a1_pivot*.stl may need to be filed down for a proper fit.

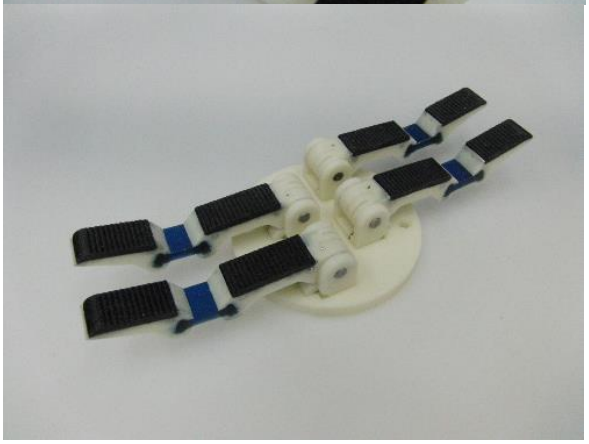
ASSEMBLY

PIVOT-BASE FINGERS TOP

Parts	
Sub-assembly from step 20	
Pivot-base finger sub-assemblies from step 18	
L1” pin J3 (x4)	
Torsion Spring (x4)	





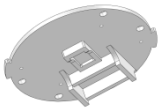
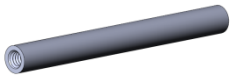
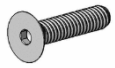


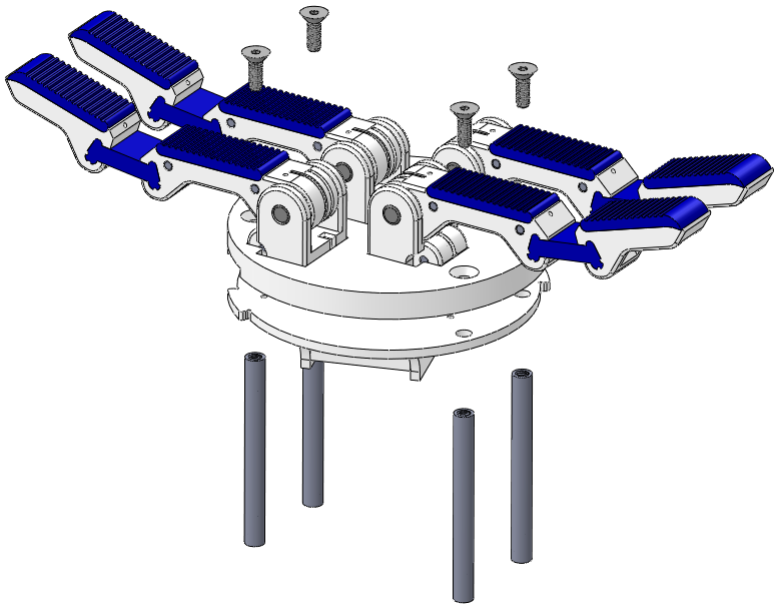
Assemble fingers onto top plate as shown above. Ends of torsion spring align with opening on finger and slot in finger base. It’s easiest to align/position the spring first and then press the joint pin J3 through the pivot base *c1.stl* and the finger base.

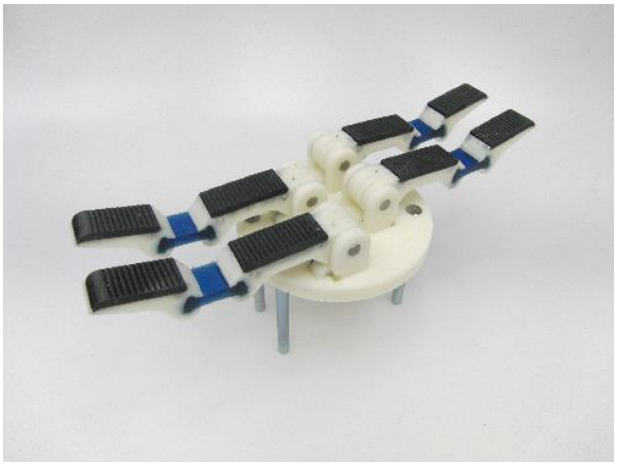
Cut off excess torsion spring ends when done. Ensure that the fingers rotate without friction.

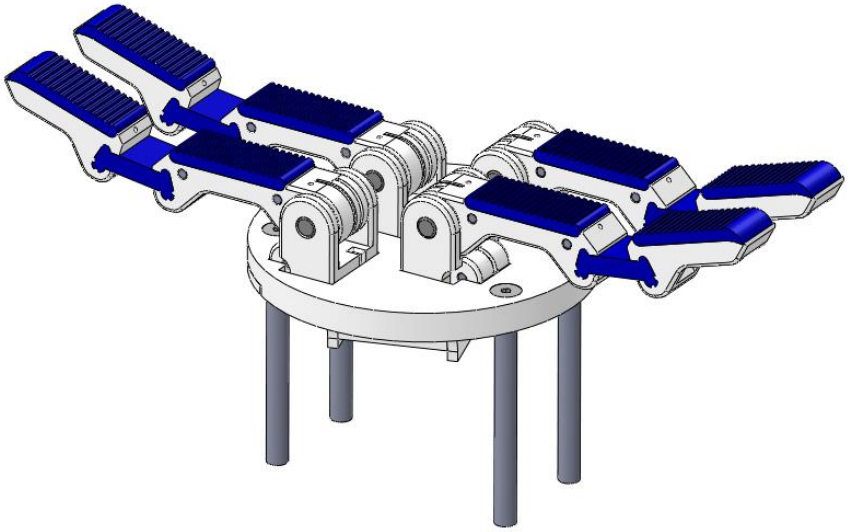
Assembly

PIVOT-BASE FINGERS TOP

Parts	
Sub-assembly from step 21	
a2.stl	
Female standoffs S1 (x4)	
8-32 Socket Cap Screws (x4)	



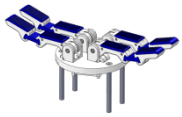
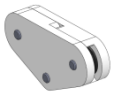


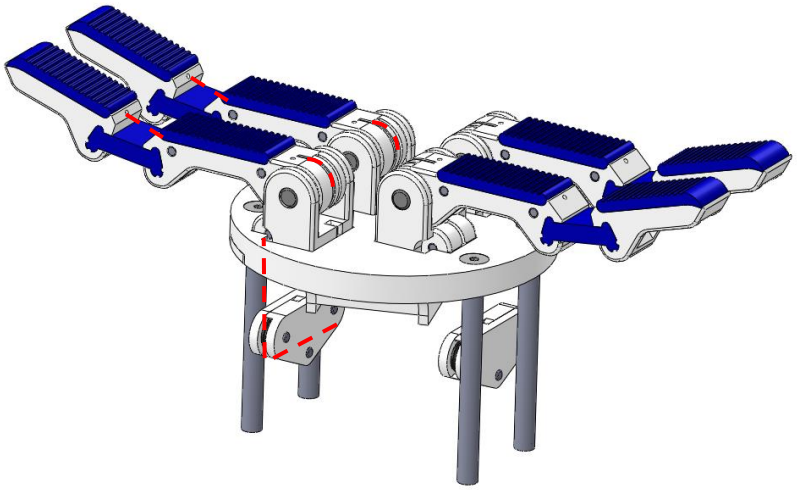


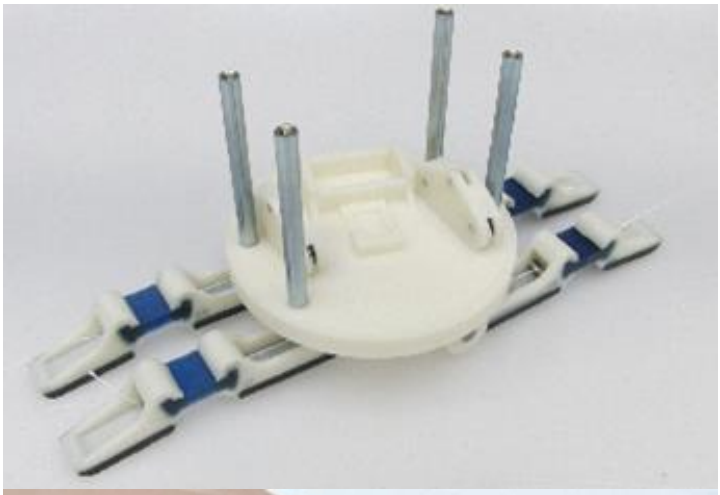
Use socket cap screws and standoffs to fully assemble the top flexure-base sub-assembly. Plates *a1_pivot.stl* and *a2.stl* should sandwich and immobilize the finger bases

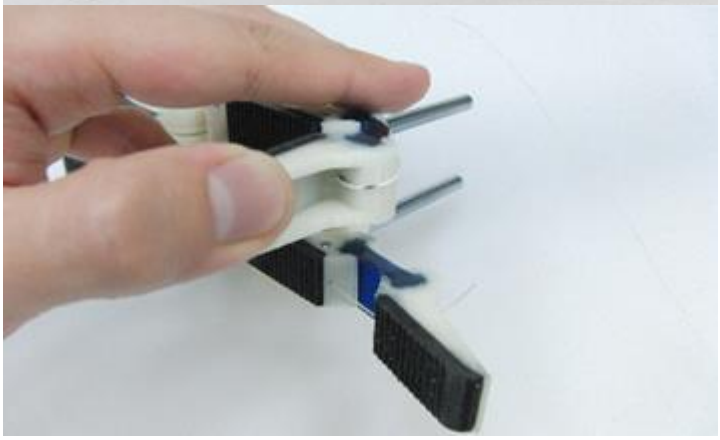
ASSEMBLY

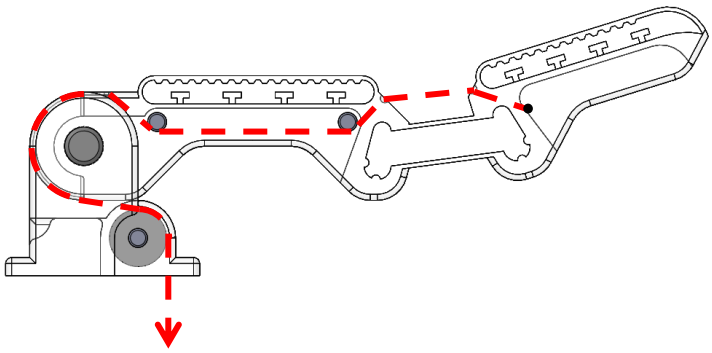
PIVOT-BASE FINGERS TOP

Parts	
Sub-assembly from step 22	
Sub-assembly from step 13 (x2)	
Spectra Tendon ~8in (200mm) (x2)	





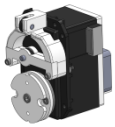
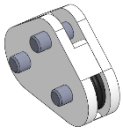


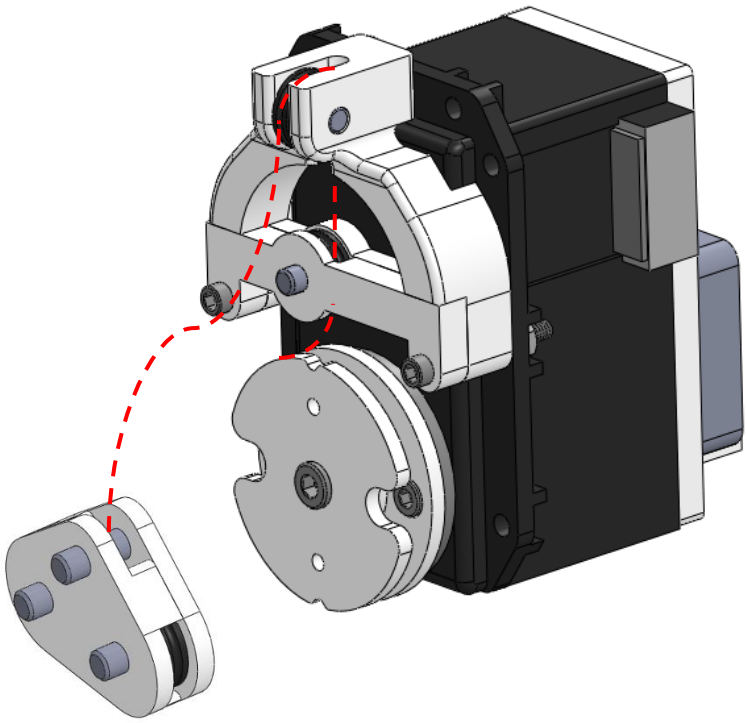


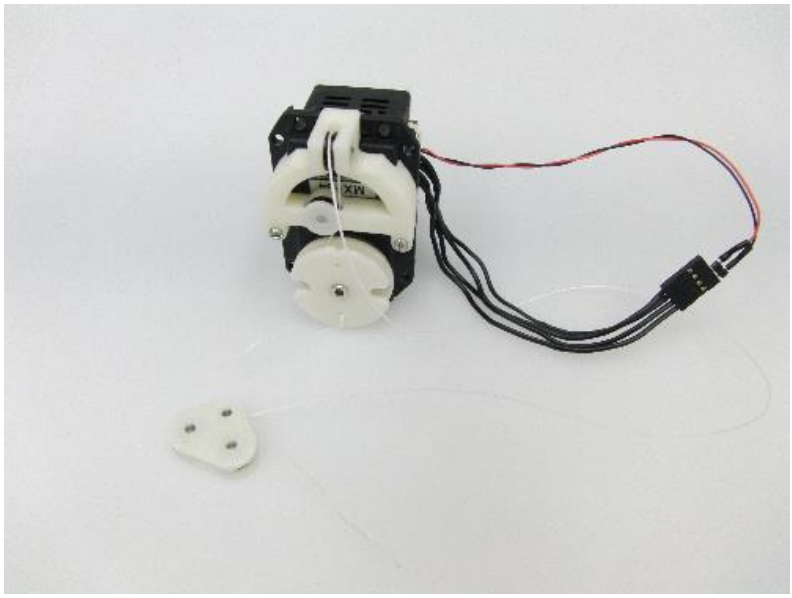
Use tendon to affix differential sub-assembly blocks to the sub-assembly made in the last step. Tendon length should be set such that it is taut when the fingers are at rest. Tendon tied off to small nut at back of finger.

ASSEMBLY

FINAL TENDON ROUTING

Parts	
Sub-assembly from step 10	
Sub-assembly from step 11	

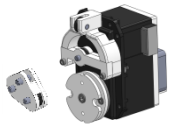
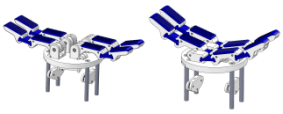
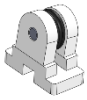




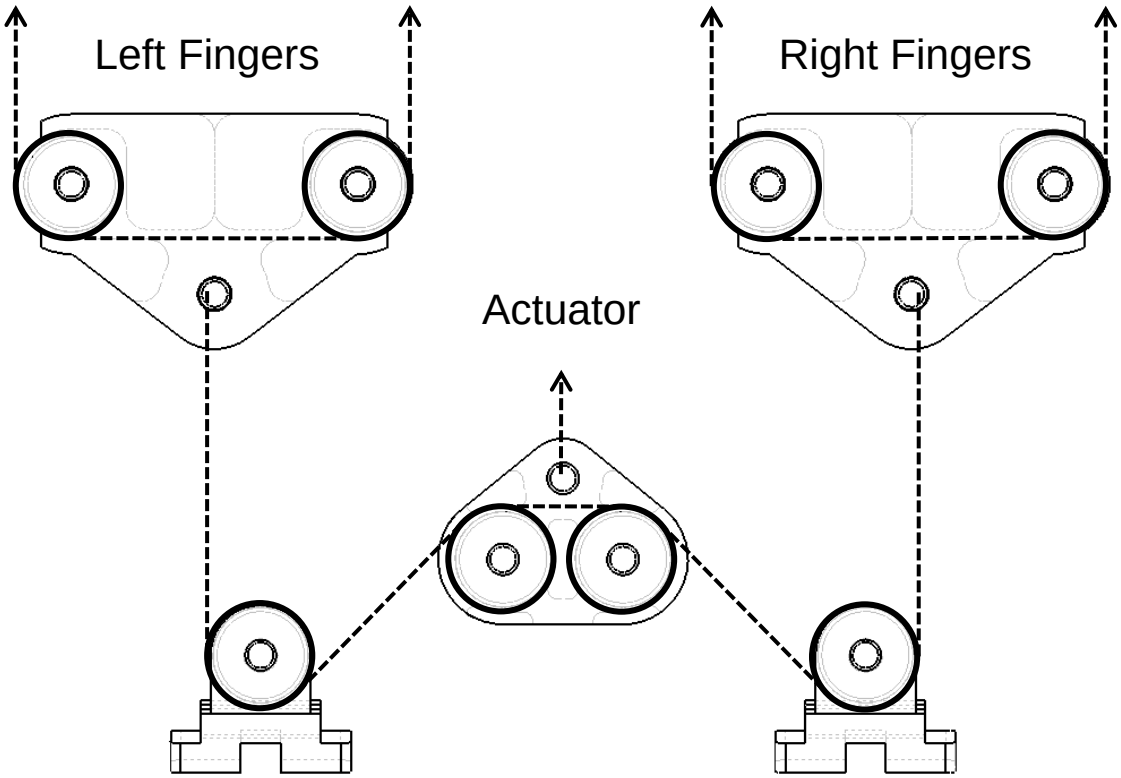
Attach drive pulley block to the actuator block with Spectra tendon. Tendon should tie off on topmost pin in sub-assembly from step 11 and main drive pulley. The improved clinch knot is suggested as a no-slip knot in this situation. Do not worry about zero-ing the tendon at this step.

ASSEMBLY

FINAL TENDON ROUTING

Parts	
Sub-assembly from step 24	
Sub-assembly from step 17 (for Flexure-base design) or step 23 (for pivot-base design)	
Sub-assembly from step 12 (x2)	
Spectra Tendon ~8in (200mm)	

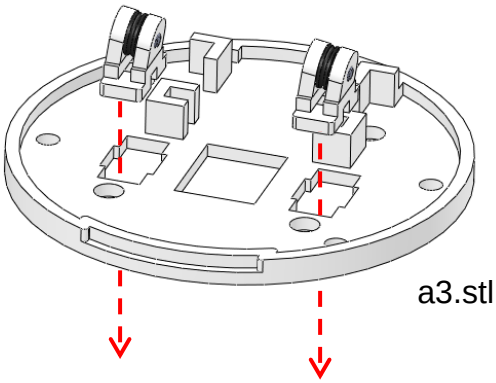
Transmission Diagram

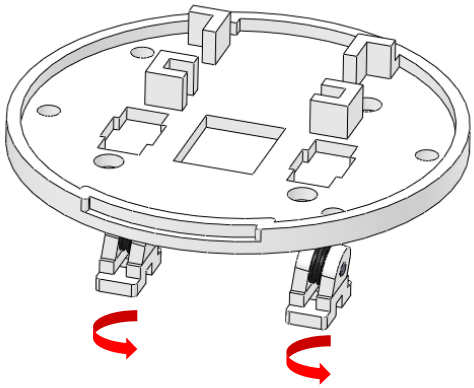


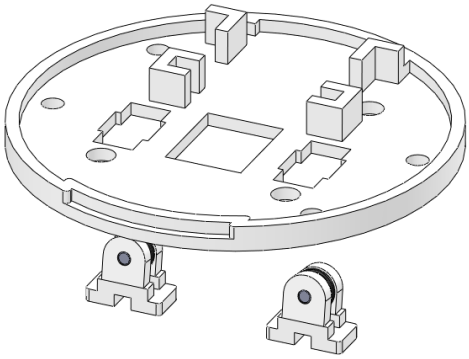
Final tendon runs between the differential blocks from step 13 and through the pulley blocks from step 12 and main drive block from step 11. The tendon length is approximately 14cm (5.5”) between the two termination points. This tendon will be taut once the hand is fully assembled, and the fingers are at rest.

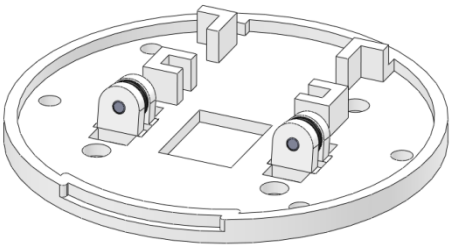
Assembly

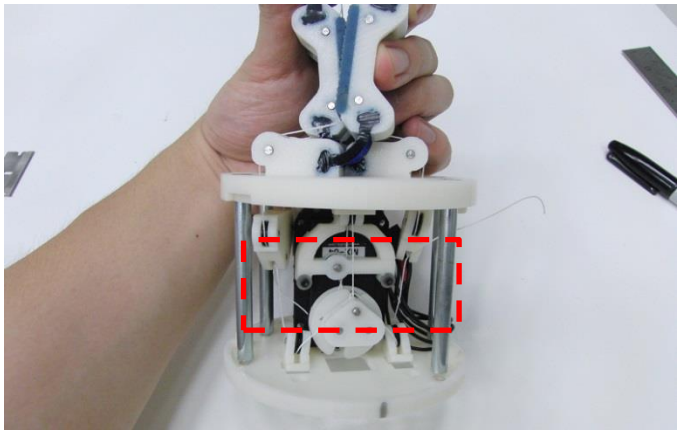
FINAL TENDON ROUTING

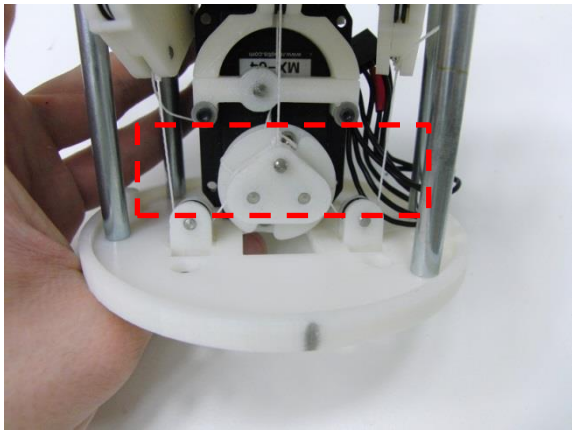










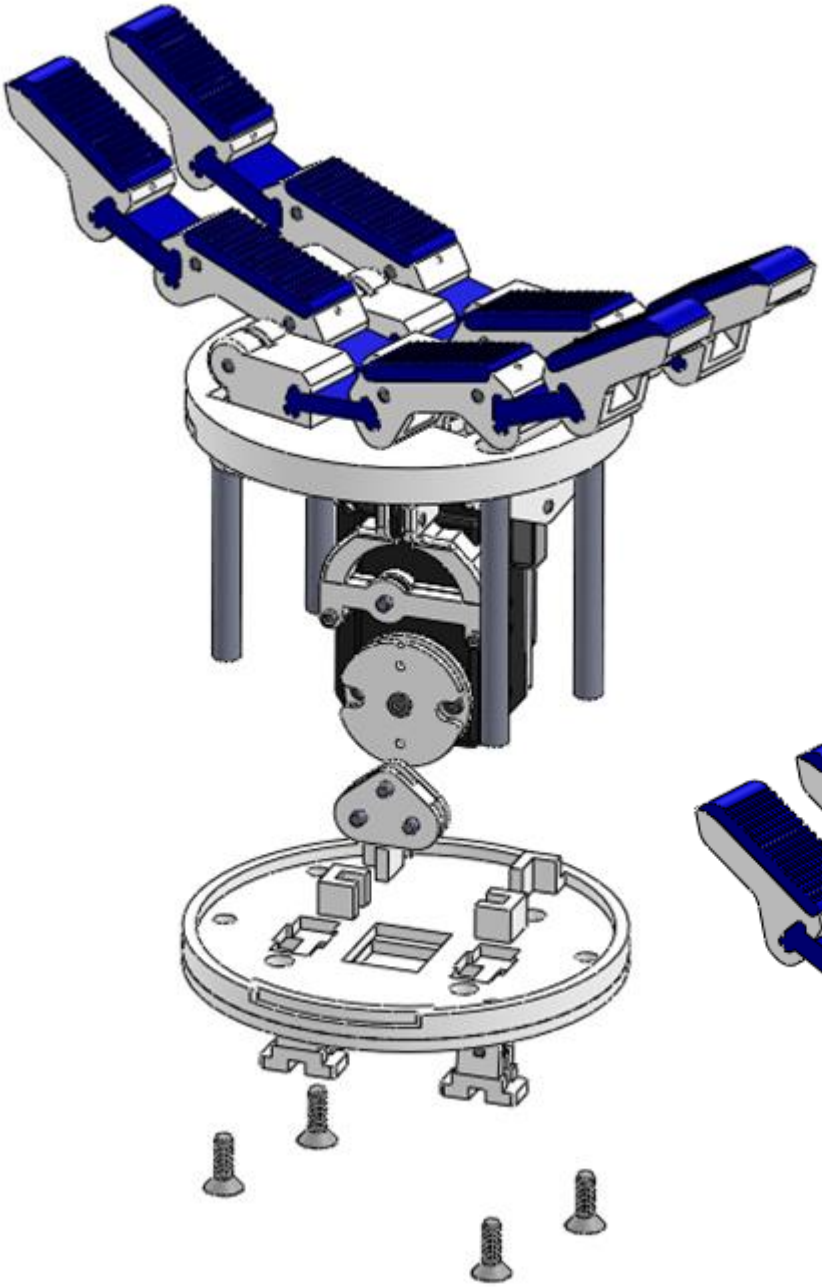


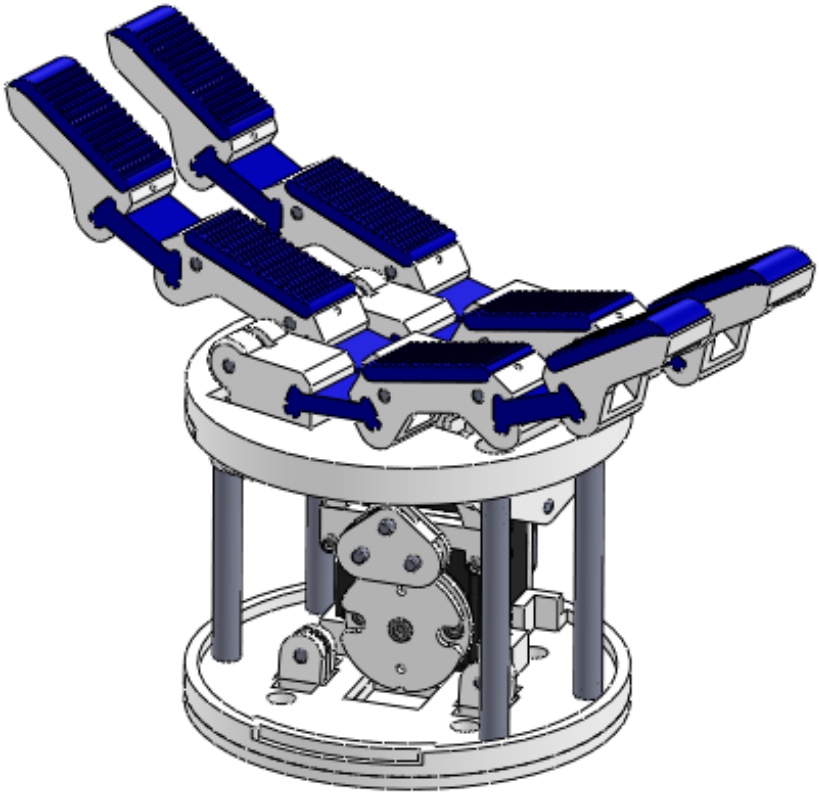
Note that the base pulley blocks can be inserted into the bottom base from above, as shown above. This may help in the process of achieving the appropriate tendon length between the differential blocks.

Bend the fingers in order to generate slack in the tendon.

Assembly

Final Assembly – Flexure Base

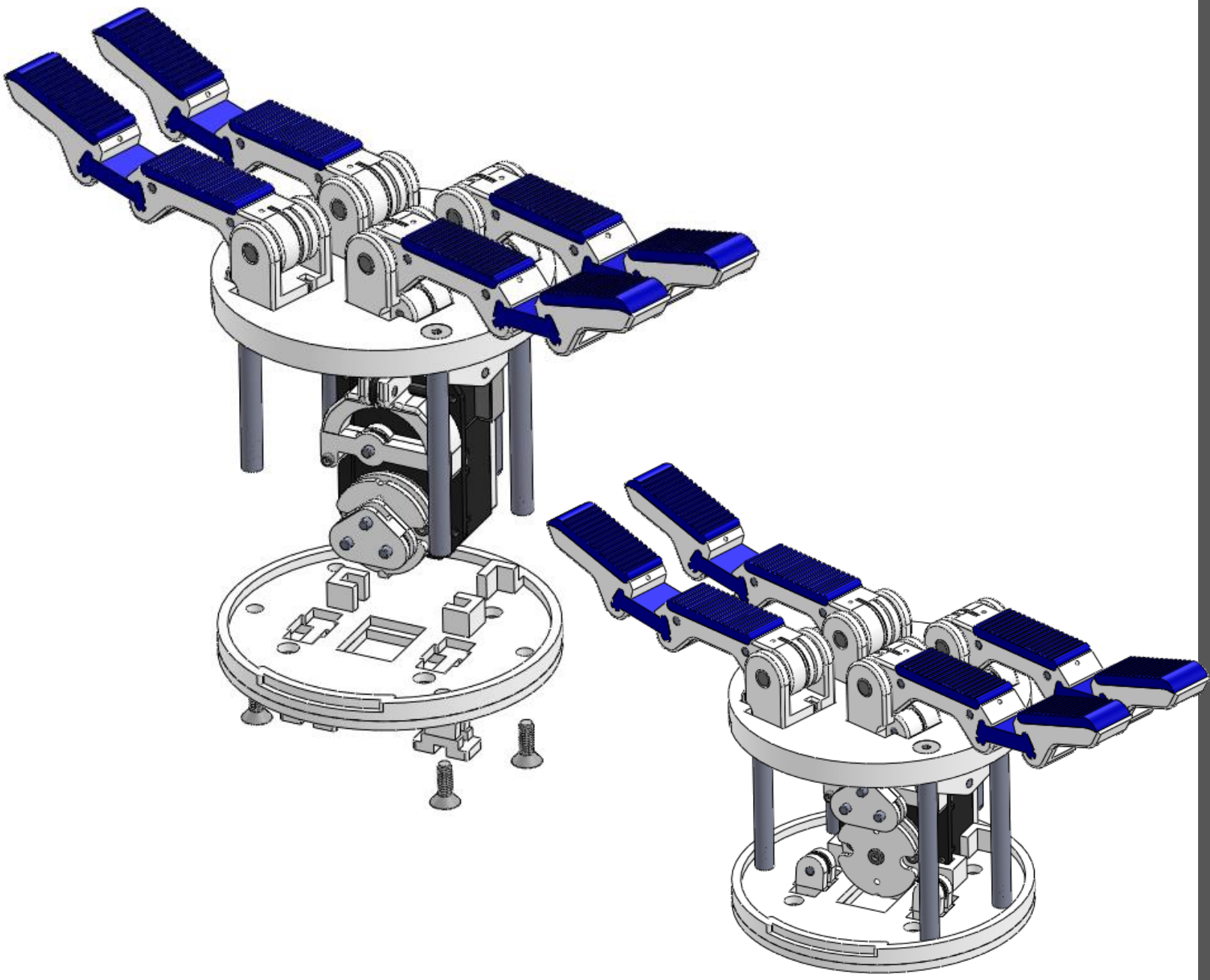




Use remaining socket screws to clamp the entire assembly together in place. The actuator block sub-assembly from step 10 should fit snugly

Assembly

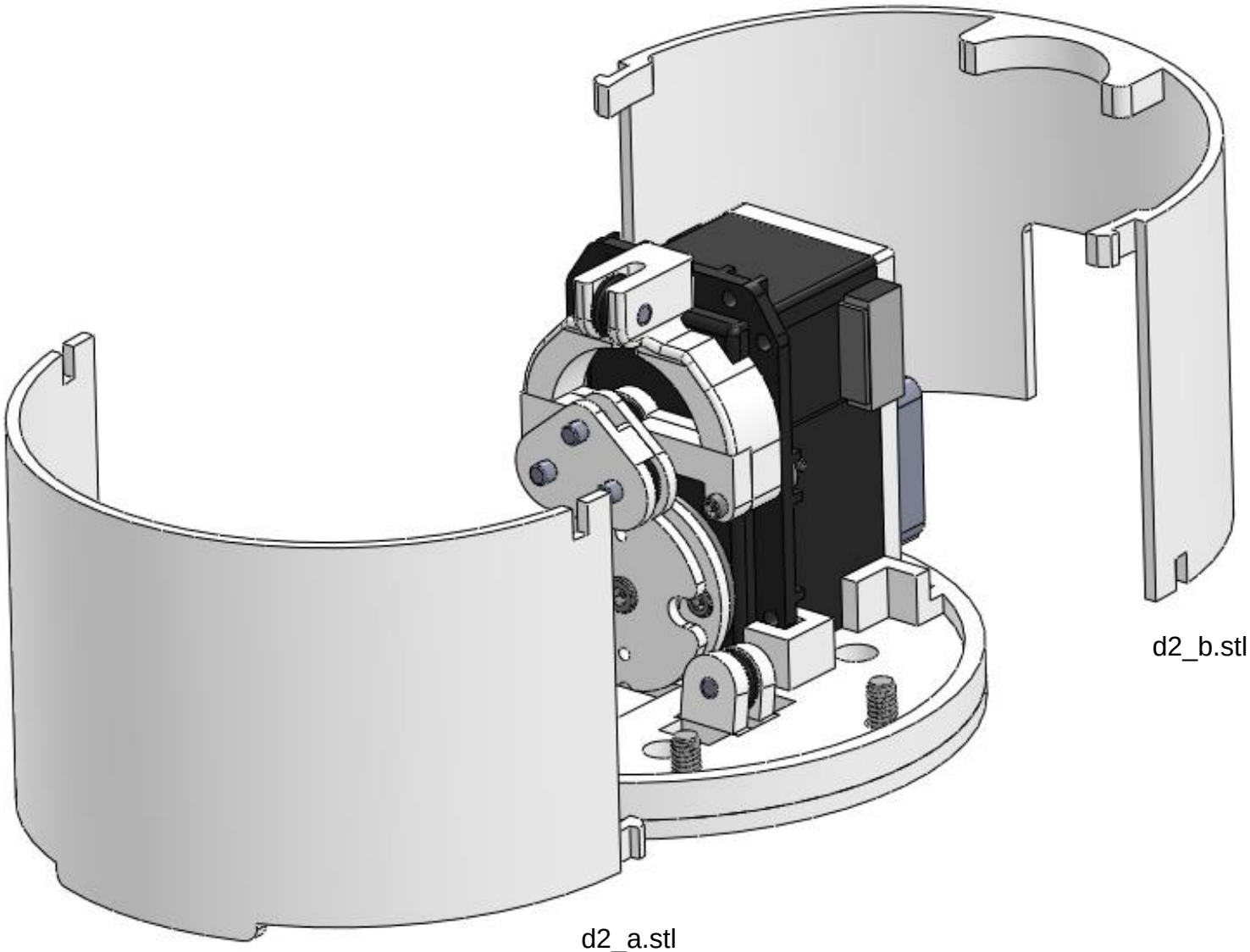
Final Assembly – Pivot Base



Use remaining socket screws to clamp the entire assembly together in place. The actuator block sub-assembly from step 10 should fit snugly

Assembly

Final Assembly – Shell



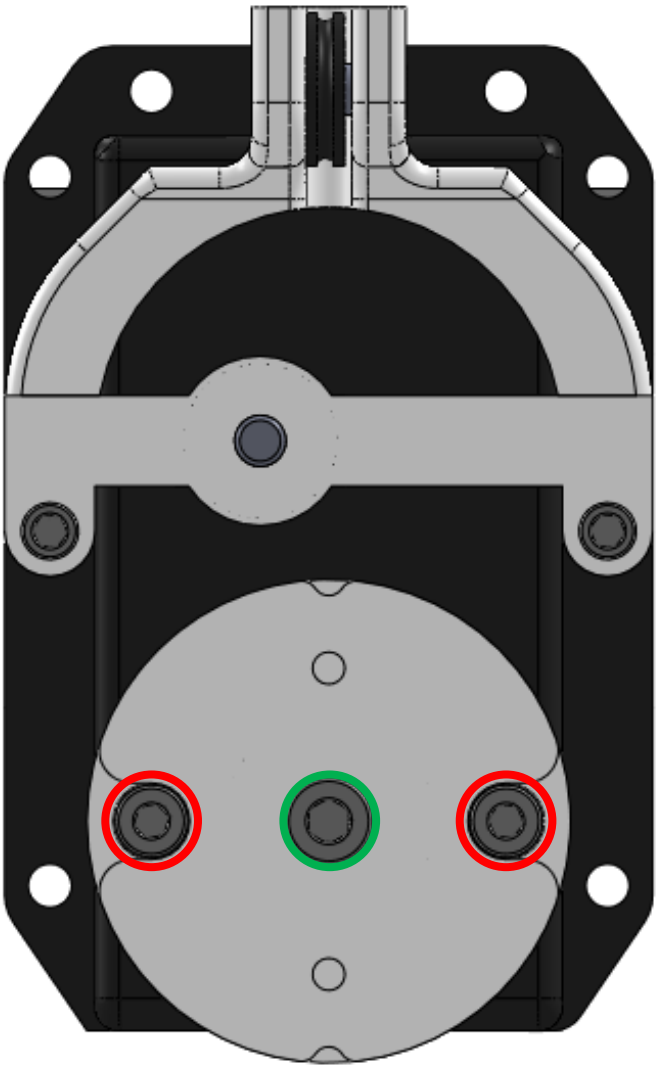
d2_b.stl

d2_a.stl

Optional shell snaps together from two sides, as shown above. It may help to pre-loosen either the top or bottom set of socket screws to allow the shells to slide together more easily.

Post-Assembly

SERVO ZERO-ING



1. Remove the M2 bolts from the servo pulley
2. Loosen, but do not remove, the central M2.5 bolt, such that the servo pulley can spin freely
3. Connect the Dynamixel and (in position mode) move it to its zero encoder position
4. By hand, turn the servo pulley until the tendon between the pulley and the main drive block is as taut as possible
5. Re-attach the M2 bolts and tighten the servo pulley

Consult the main documentation for suggested software and control methodologies.

You may need to adjust tendon lengths (especially the tendon running between the differential pulley blocks) to optimize operation.