Triple Axis Tourbillon Build Notes

By McMaven

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1 Overview

I modeled it after a Cabestan Triple Axis Tourbillon, which they offer in several of their high-end watches. I spent many hours looking at this video https://youtu.be/Imm3mrR06tc.

Similar to the Gyrotourbillon, I tried to make the model an accurate (scaled up) version of the original Cabestan mechanism. I printed the screws to scale, then stuck a 2mm screw in their centers to hold it together. I also included Incabloc shock absorbers by printing clear red 'jewels', and working snap rings to hold them in place.

Here is some information on how Incabloc shock absorbers in a modern mechanical watch, if you're interested: https://youtu.be/FakIAZxcDII.

This model is about 140mm in diameter. I power it with a 2 Amp USB power supply.

And a real-time video. https://youtu.be/Imm3mrR06tc

2 Parts list

Here are the parts that I used. You can use hex socket or Philips head screws, your choice. I paid about $1 a piece for all the ball bearings on eBay or Amazon.

Some of the “2mm” steel shafts that I’ve picked up on eBay or Amazon have been slightly oversized, just enough so the bearings won’t fit on to them. Look for a slip fit of the shaft in the bearing. DON’T force the bearings on the shaft. I tried and jammed the bearings, making them useless. My solution was to order from another vendor. Maybe you will get lucky the first time.

2.1 Summary

(9) 2x5x2.5mm ball bearings

(4) 0.3125x0.5x0.15625in ball bearings

(~60mm) 2mm shafts

(9) M2x4 flat head screw

(1) M2x6 flat head screw

(43) M2x8 flat head screw

(4) M2x12 flat head screw

(1) M2x4 hex socket cap head

(10) M2.5x4 button head screw

(4) M2.5x8 flat head screw

(1) Arduino Uno

(1) 28BYJ-48, 5 Volt Stepper Motor with driver board.

(3) 7x3/32 inch Rubber bands

(1) 2A USB Power Supply

(1) USB B to A cable.

2.2 Details

2x5x2.5mm ball bearings

- 2 for the L1 Fork
- 2 for the L1 Escape Wheel
- 2 for the Balance Wheel
- 2 for L2 Idler gear 28T M1
- 1 for Stepper Pully

.3125x.5x.15625in ball bearings

- 1 for the L2 Frame Upper and L1 Upper Bearing Mount
- 1 for the L2 Frame Lower and L1 Frame Lower
- 1 for the L3 Frame 2 and L2 Lower Frame
- 1 for the L3 Frame 2 and L2 Lower Frame

2mm shaft

- 10.5mm long for the L1 Fork 5
- 18mm long for the L1 Escape Wheel
- 26mm long for the L1 Balance Shaft

3 Components

The following images identify where the parts go in each layer.

I used *Screw 8mm* and *Screw 9mm* parts to simulate the screw tops on the original mechanism. In most cases I ran a M2x4 mm flat head screw through them and the parts that they needed to connect together (e.g. the *L1 Frame Upper* and *L1 Frame Lower*, or the *L1 Frame Lower* to the *L1 Bridge* and the *L1 Lower Escape Bridge*), and used *Screw Seat 8mm* parts as a 'nut' to screw them into. In some cases I used a real M2 nut (rather than a Screw Seat 8mm part) and covered the nut with a *Screw Seat 8mm nut* part. I didn't use glue on the Screw Seat 8mm nut parts because they were a press fit.

3.1 L1

I press fit the L1 Balance Wheel to the L1 Balance Shaft, and the L1 Balance Spring to the L1 Balance Wheel.

Don't forget the 2x1mm Bearing Spacers for the fork and escape wheel. You might have to file the Fork Bearing Spacers a little to get them to fit.

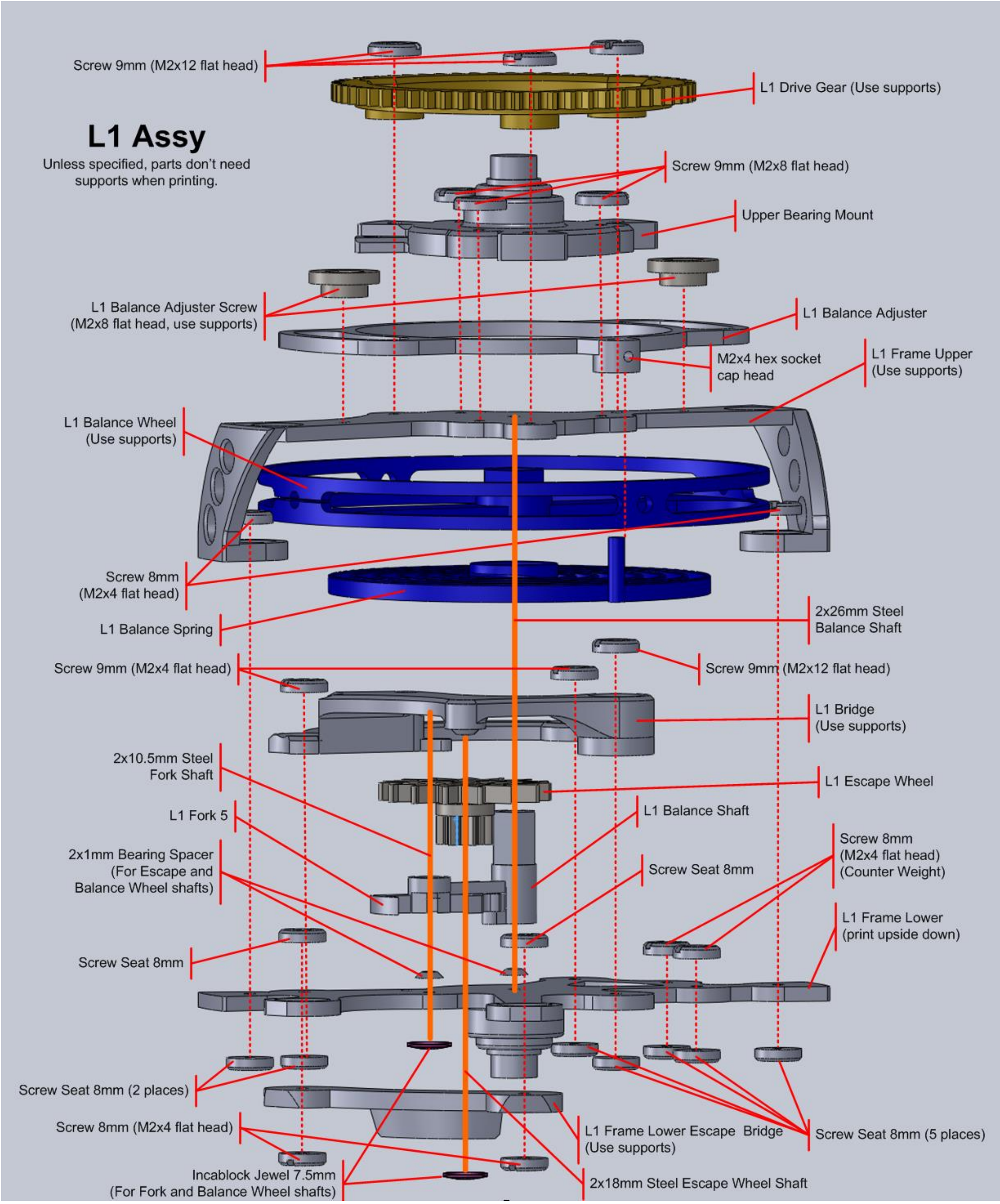
Glue the 7.5mm Incabloc Jewels to keep the 2mm *L1 Fork* and *L1 Escape Wheel* shafts from falling out.

The inner and outer hex's at the center of the *L1 Balance Wheel* required a little bit of filing to get it to press fit on to the *L1 Balance Spring* and the *L1 Balance Shaft*.

Press 2 2x5x2.5mm ball bearings into each end of the *L1 Balance Shaft*, *L1 Fork 5*, and *L1 Escape Wheel* parts.

Two of the *Screw 8mm*/*Screw Seat 8mm* combinations marked "Counter Weight" are cosmetic. I think they were used to as counter weights on the original device. I used 8mm long screws and stacked 2 extra *Screw 8mm* parts to make them look more 'massive'. The end of the L1 Assy with the Escape Wheel and Fork is definitely heavier, but because this is motor driven it doesn't matter.

Figure 1: L1 Assembly Components (Side)



3.2 L2

Press 2x5x2.5mm ball bearings into each end of the *L2 Idler Gear 28T M1* part.

Press 0.3125x0.5x0.15625in ball bearings into the *L2 Frame Upper* and the *L2 Frame Lower* parts.

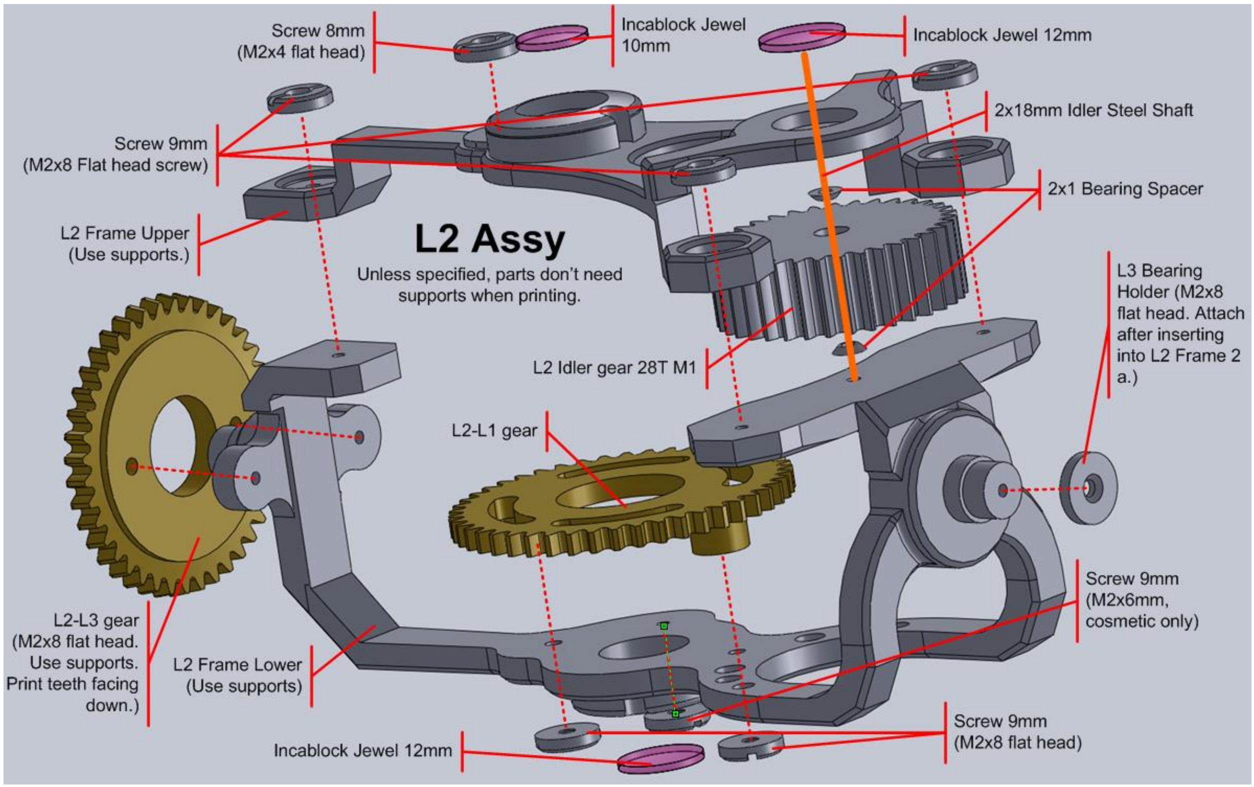
Don't screw in the L2-L1 gear until you are ready to add the L1 Assy to the L2 Assy.

Slip the L2-L1 gear under the *L1 Frame Lower Escape Bridge*, press the L1 Assembly into the *L2 Frame Lower* part 0.3125x0.5x0.15625in ball bearings, then screw the *L2-L1 gear* to the *L2 Frame Lower* part.

The shafts for the 0.3125x0.5x0.15625in ball bearings at either end of the *L2 Frame Lower* part will need some filing to get a snug slip fit for the bearings.

The *L3 Bearing Holder* is not screwed on until after the L2 Assy is added to the L3 Assy.

Figure 2: L2 Assembly Components



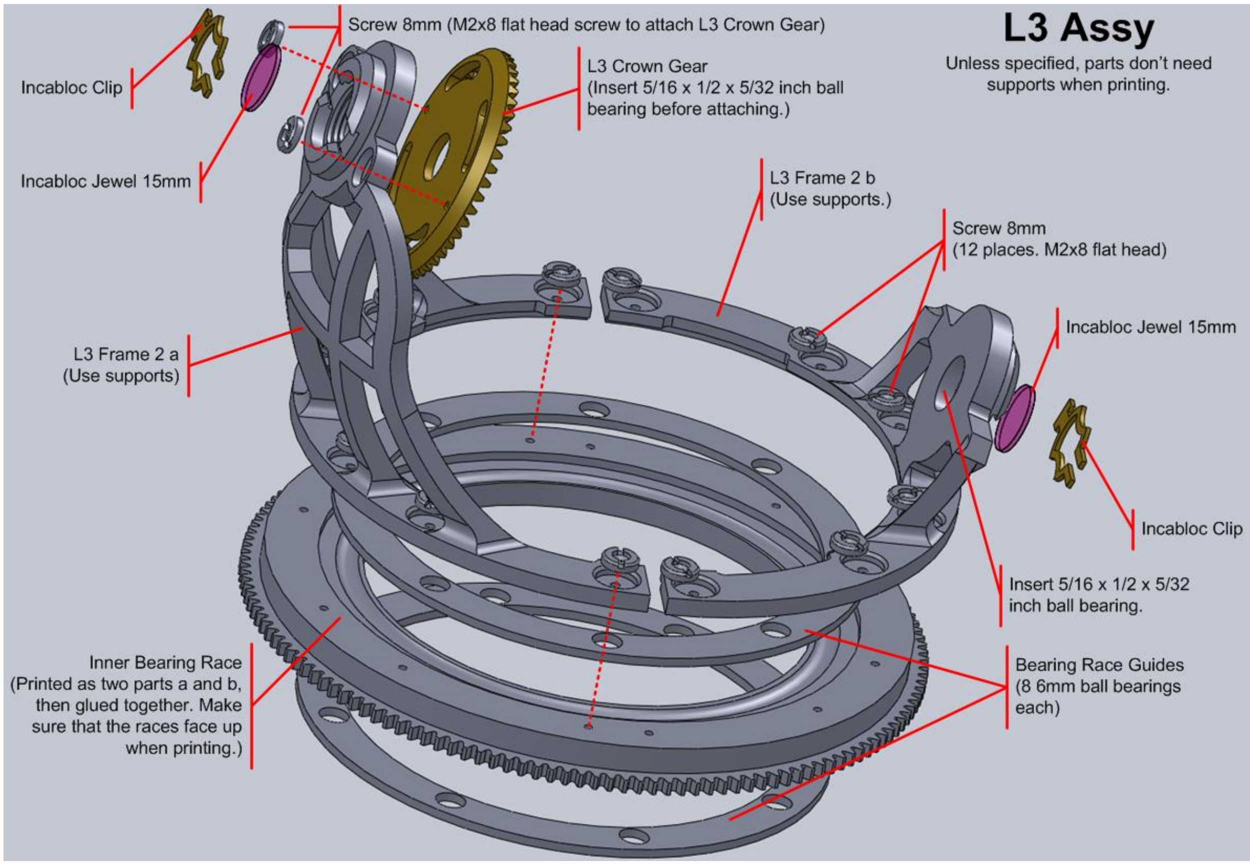
3.3 L3

The *L3 Base*, *L3 Upper Bearing Holder*, and the Left and Right *L3 Upper Bearing Supports* are printed with supports.

The only thing special about assembling the L3 components is that the Left and Right *L3 Upper Bearing Supports* need to be cleaned up and glued together.

The Stepper Pinion is a press fit.

Figure 3: L3 Assembly Components



Press 0.3125x0.5x0.15625in ball bearings into the *L3 Frame 2 a* and the *L2 Frame 2 b* parts.

Before you insert the L3 Assy to the *L3 Frame 2 a* ball bearing, attach the *L3 Crown Gear*. The *L3 Crown Gear* holds the *L3 Frame 2 a* ball bearing in place. Now insert the L3 Assy, and attach the *L3 Bearing Holder* (see Figure 2). The *L3 Bearing Holder* prevents the L2 Assy from pulling out of the ball bearing. Using the *L3 Frame 2 a* ball bearing like this allows it to act as a thrust bearing (as well as a ball bearing), holding the *L2 Idler gear* against the L3 Crown Gear, preventing any teeth from slipping.

After adding the *L3 Bearing Holder,* press in the Incablock Jewel and snap in the Incablock Clip. I needed to file the ends of the Incablock Clip to get it to snap into place.

The 6mm ball bearings and the Bearing Race Guides are not used until you add L3 Assy to the Base Assy.

Use 12 Screw 8mm parts and 12 M2x8 flat head screws to attach the *L3 Frame 2* and *L3 Frame 2 b* parts to the *Inner Bearing Race*.

3.3.1 Choice of Drive Mechanism: Pulley or Gear

In my original design, the L3 assembly was gear driven, which is still illustrated in the Figure 3 above. Gear drive worked fine for the Gyrotourbillon design, but I was having lots of problems finding the correct stepper speed for this Triple design. Too fast and the whole thing would bind up, and too slow, it would intermittently stop. A friend suggested using a rubber band, which led to the version that you see in the video.

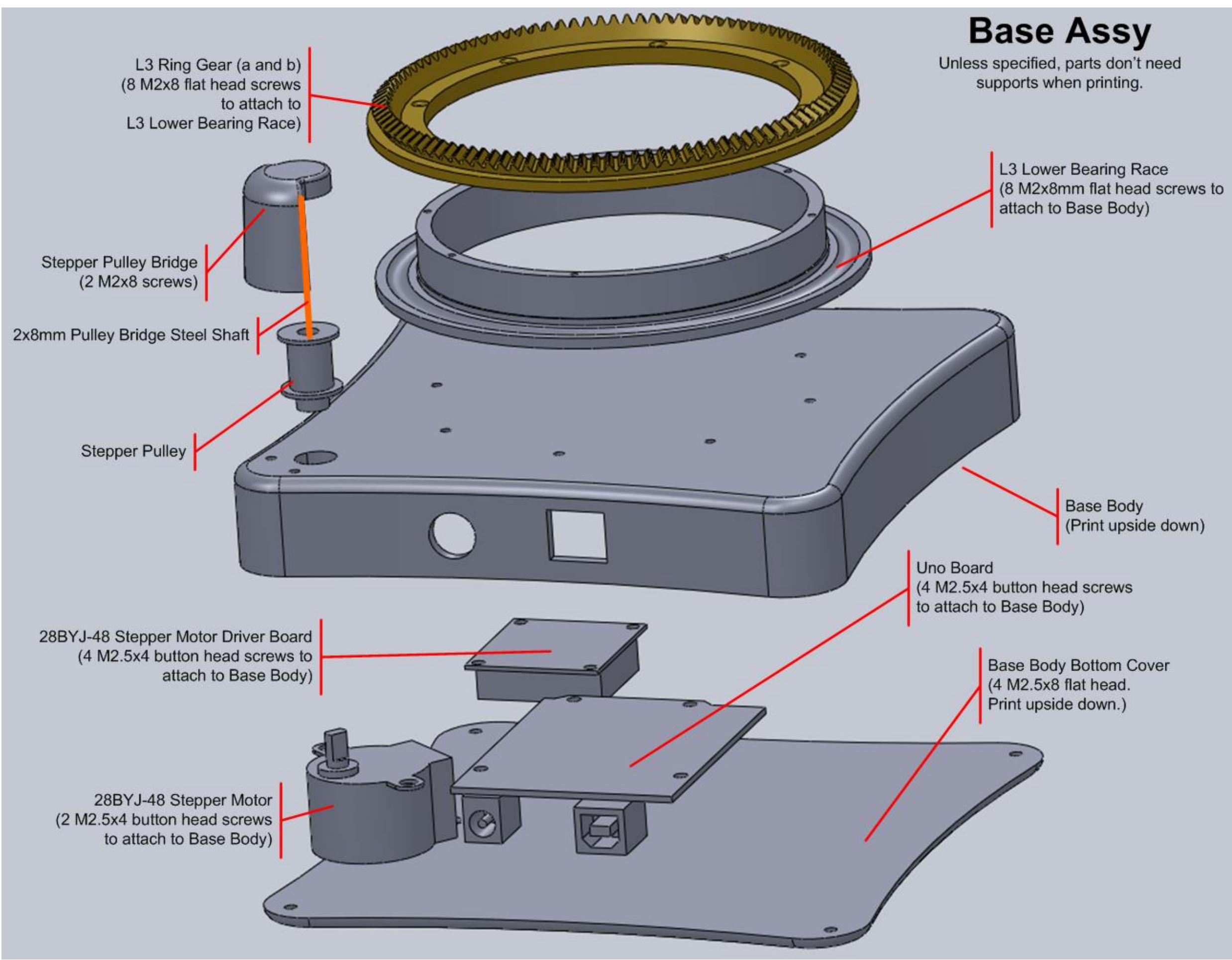
I would recommend using the Pulley/rubber band approach. That is, print the *L3 Inner Bearing Race 2a.STL*, *L3 Inner Bearing Race 2b.STL*, and *Stepper Pulley.STL* files. However, the *L3 Inner Bearing Race a.STL*, *L3 Inner Bearing Race b.STL*, and *Stepper Pinion.STL* files are included if you want to experiment with a gear driven design.

My argument being that the rubber bands provide two benefits. 1) The stepper can be set at a slightly higher speed than necessary, and the rubber bands will slip on the pulley if it is not the perfect speed for the movement, and 2) the rubber bands provide a constant tension, which works well with a movement that periodically locks its position while the balance wheel swings back and forth. If you turn the L3 turntable manually, you can feel the intermittent motion that gets transmitted to it by the escape wheel movement. The rubber bands stretch while the L3 rotation is locked, and contract when the escape wheel turns. Basically acting like a weight would, in weight driven design.

3.4 Base

The *L3 Ring Gear* is printed in two parts, *L3 Ring Gear a* and *L3 Ring Gear b*. This allows the bearing race (on the bottom of the gear) and the gear teeth (top) to be printed without supports. Glue them together with some 'Acrylic Cement' (see section 8.1). This stuff is super volatile and works in seconds. So make sure you are ready to align the parts before you apply the glue.

Figure 4: Base Assembly Components



Screw the *L3 Lower Bearing Race* to the *Base Body* with eight M8x8 flat head screws. Then lay a Bearing Race Guide on the *L3 Lower Bearing Race* and add eight 6mm ball bearings. Now rest the L3 Assy on the ball bearings, lay the second Bearing Race Guide on top of the *L3 Inner Bearing Race*, and add another eight 6mm ball bearings. Finally add the L3 Ring gear and screw it to the *L3 Lower Bearing Race*. The L3 Assy should spin freely on top of the base.

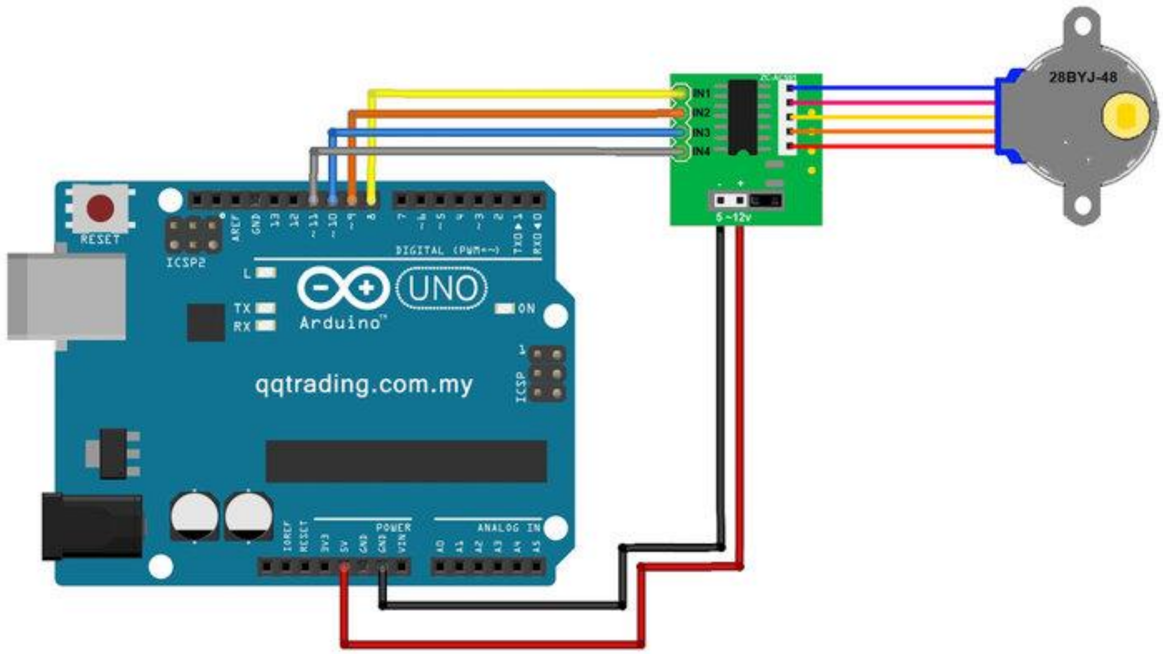
I redesigned and reprinted the *L3 Inner Bearing Race* a couple of times. Sometimes the L3 Assy would spin freely with the L3 Ring Gear screwed on tightly, and other times it would bind a little and I needed to relax the screws a little.

After attaching the stepper motor to the Base Body, press on the Stepper Pulley and add the belt (rubber bands). Finally attach the Stepper Pulley Bridge.

4 The Stepper Motor

The stepper is a 28BYJ-48. It is a very low cost motor that is used in 1,000,000's of products.

Here is the wiring that I used. The source that I used for the stepper and the driver board is below.



I used the stepper.ino and stepper_settings.ino sketch files from https://dronebotworkshop.com.

The stepper_settings sketch is be used to determine the optimum speed that the stepper should rotate at. For me the magic 'SPEED' number was 218, with the STEP_PER_REV = 64 and the step size was -2. Once you know the speed, you can hardcode the value into the stepper.ino file. With the stepper.ino code loaded the stepper starts turning at the selected 'SPEED' as soon as you plug in the USB cable.

Note: the +5V pin on the Ardunio is connected to the +5V USB connector Pin through a FET. The FET can easily handle the current that the stepper needs. The 3.3V pin on the Uno is connected to the +5V USB connector Pin through a regulator, that can only source about 150ma, so DON'T connect the stepper driver power to the 3.3V pin. Besides the stepper driver board requires at least 5V to work. I drive it off a 2Amp USB wall charger, and so far I have had good results.

The USB ports on my laptop couldn't source enough power when the stepper driver power wires were connected to the Uno, and it wouldn't boot. In this case, I attached a separate 5V supply to the stepper driver board.

5 Sources

For the screws I used ones that I had left over from previous projects. So I don't have any screw sources that I specifically used for this project. I started off with assortments of 2 and 2.5 mm (4 to 10 mm long), flat head, cap head, and hex Socket Head Cap screws and had to order another 100 from ebay, when I get low on a particular size.

From the following ebay page, you can order 2 or 2M, black or steel, cap, button or flat head screws in 4-30mm lengths for under $2 for 50. If you search, you will find a similar page for 2.5M screws.

https://www.ebay.com/itm/50X-M2-M3-M4-M5-Hex-Socket-Allen-Head-Screw-Bolt-Self-locking-Nylock-Nut-Locknut-/162286993963?var=&hash=item25c90f022b

Below are the links to some of the parts that I did order for this project.

Uno Board

https://www.amazon.com/gp/product/B01EWOE0UU/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1

Kit of 5 28BYJ-48 steppers and driver boards for $12.50. They were cheap, and now I have plenty for future projects.

https://www.amazon.com/gp/product/B076KDFSGT/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1

HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Transparent Red https://www.amazon.com/gp/product/B00M0CS68E/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&psc=1

HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Black

https://www.amazon.com/HATCHBOX-3D-Filament-Dimensional-Accuracy/dp/B00J0ECR5I/ref=sr_1_3?crid=1BC7W0DI20WIY&keywords=hatchbox+pla+1.75+Black&qid=1557296623&s=gateway&sprefix=Hatchbox%2Caps%2C205&sr=8-3

HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Silver

https://www.amazon.com/gp/product/B00MEZEEJ2/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1

HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Gold

https://www.amazon.com/HATCHBOX-3D-Filament-Dimensional-Accuracy/dp/B00MEZEFVO/ref=sr_1_2?keywords=hatchbox+pla+1.75+Gold&qid=1557296671&s=gateway&sr=8-2

10pcs 2x5x2.5mm MR52-ZZ Precision Ball Bearings Chrome Steel, Metal Shield

https://www.amazon.com/gp/product/B00TVPSCVO/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1

10 Pack - R1810-ZZ (5/16 x 1/2 x 5/32 inch) Ball Bearing

https://www.amazon.com/gp/product/B00GGQ54Q2/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1

6mm (0.236") Precision Chrome Steel Bearing Balls G25 (100 PCS)

https://www.amazon.com/PGN-0-236-Precision-Chrome-Bearing/dp/B07DKSN46T/ref=sr_1_2_sspa?keywords=6mm+ball+bearing&qid=1557296488&s=gateway&sr=8-2-spons&psc=1

Guillow 7x3/32" Rubber Bands

https://www.amazon.com/Pack-10-Rubber-Bands-Accessories/dp/B0006OBI3I

6 Escape Wheel

The trick to aligning the balance spring is to position the balance wheel so the Balance Wheel Post, that engages with the Fork Pins, is pointing directly at the center of the Fork shaft. I refer to this position as the 'natural center position' of the Balance Wheel. And the Fork Center Pin should be pointing directly at the center of the Balance Wheel Shaft. See Figure 5.

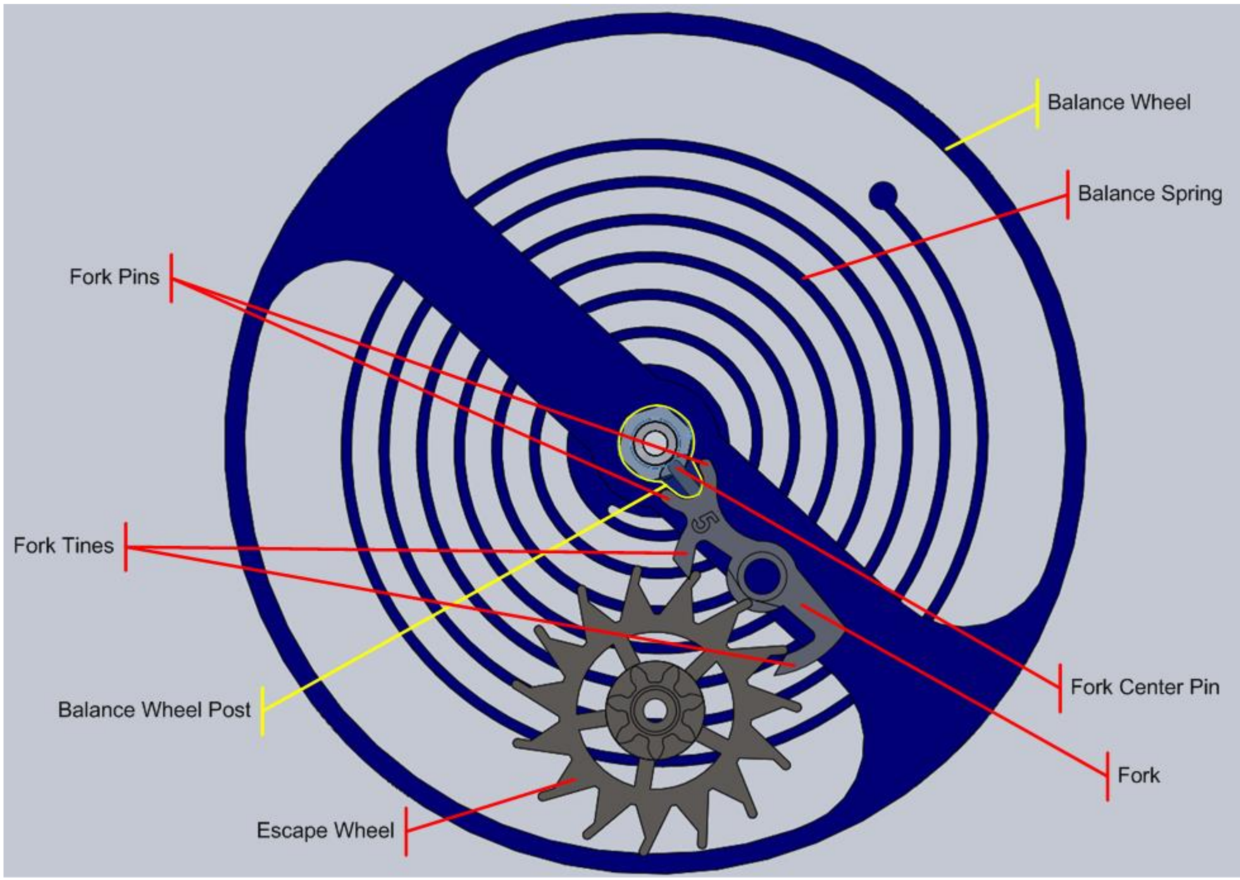
Then with the Balance Spring rotated to the position where it drops into the Balance Spring Adjuster mount on the L1 Frame 3, push the hex center of the Balance Spring onto the hex of the Balance Wheel. Then push the hex center of the Balance Wheel onto the hex of the Balance Shaft Note, you may have to file the hex's before you start to make this a snug slip fit. I didn't glue the Balance Shaft or the Balance Spring to the Balance Wheel, because the Balance Spring is the part most likely to fail, and I wanted to be able to easily replace it.

When I was testing my L1 Assembly, the Balance Wheel was regularly hanging at the same angle. Using the L1 Balance Spring Adjuster to rotate the Balance Spring so that the 'natural center position' of the Balance was better aligned with the Fork shaft, and it made the problem go away.

After connecting the balance spring to the balance wheel and the tourbillon frame, the balance wheel tab should point directly at the fork, when the balance wheel is at rest. See Figure 5.

It doesn't really matter what angle the Balance wheel is at, relative to the *L1 Balance Spring* and the *L1 Balance Shaft*. But the *L1 Balance Spring* to *L1 Balance Shaft* relationship is critical.

Figure 5: Balance Wheel to Fork Alignment



Note: The Balance Shaft is 'transparent' in the drawing to allow the Fork Center Pin to be visible. From this point of view, the Balance Wheel Post will normally hide it.

6.1 Getting it to Tick

This is the most critical part of the design. It is made easier if you have printer that generates accurate prints. With my printer, I needed to drill out the all parts so the shafts spun freely, but I did not need to file any of the parts.

There are 4 parts involved, the Balance Wheel, the Balance Wheel Spring, the Fork, and the Escape Wheel. The names in this section refer to Figure 5.

- Make sure that any surfaces that contact between the Balance Wheel, Fork, and Escape Wheel are free of burrs, bumps, or any other printing artifacts that may cause a surface not to be smooth. If not, then some filing or scraping with a knife may be necessary to smooth the parts.
- Make sure that the Balance Wheel, Fork, and Escape Wheel each rotate freely when installed by themselves. The Wheels should spin easily, and the Fork should flop back and forth as the assembly is rotated.
  I ran a 2.5mm drill through the Fork and Escape Wheel shaft holes, and a 3.5mm drill through the Escape Wheel shaft hole to ensure that any printing artifacts were cleared out of the cavities.

    - Note: Run the drill backwards in plastic at first, otherwise it may auger in at some weird angle and ruin the part. Once the drill is running smoothly backwards, reverse it to clear out the plastic shards.
- All bearings need to fully seated, so that their top surface is flush with the respective part. You may need to pop them out and scratch out underneath them with a knife.
- With just the Fork and Escape Wheel installed:
    - Turning the Escape Wheel backwards (clockwise in Figure 5), should cause the Fork to snap back and forth easily.
    - And turning it counterclockwise should cause it snag against a Fork Tine. If the Fork snaps back and forth a little, it is OK. But if it never snags the Balance wheel when rotated counterclockwise, then the Fork Tines may be too short.
- With just the Balance Wheel and Fork installed (No balance Spring), spinning the Balance Wheel back and forth should cleanly engage the Fork. If there is any sign of a snag, or slowing down, then inspect where the two parts are rubbing, and file the offending part lightly. It is easy to take off too much. If you do, just print another part, and start again.
- Depending on the direction the Balance Wheel is spinning, one of the Fork Pins and the Fork Center Pin should slide along the surface of the Balance Wheel shaft, but not touch so much that they slow the Balance Wheel down. The two contact points formed by the Fork Pin and the Fork Center Pin act to hold the Fork at an angle where its Tines can snag/block an Escape Wheel tooth.
    - When the Balance wheel is rotated in the opposite direction, the Balance Spring Post engages with the Fork Pins to swing the Fork in to its opposite position. The swinging action of the Fork causes the Escape Wheel to advance one tooth, and engage with the opposite Fork Tine.
    - If there is any binding when the Fork swings, you will need to file the Center Pin a little shorter.
- When all the parts are assembled, a *very light amount of torque* on the Escape Wheel in the counterclockwise direction should cause the fork to swing, and the Balance wheel to rotate. Continuing to put torque on the Escape Wheel will cause the Fork to move to its opposite position when the Balance Wheel swings back, due to the Balance Spring. As long as you put consistent, light torque on the Escape Wheel, the assembly should continue to tick.

7 STL Files

Unless noted, I used a .2mm first layer and all other layers were 1.5mm.

I also set the Perimeter Vertical Shell count to 3. I used the default settings for all the support options.

Sub-Assy	File Name	Quan.	Support material	Color	Notes
L1	L1 Drive Gear	1	Yes	Gold	Layer 1 components
	L1 Upper Bearing Mount	1	No	Silver	
	L1 Balance Adjuster	1	No	Silver	
	L1 Balance Adjuster Screw	2	Yes	Silver	
	L1 Frame Upper	1	Yes	Silver	
	L1 Frame Lower	1	Yes	Silver	
	L1 Balance Wheel	1	Yes	Red	
	L1 Balance Spring	1	No	Red	
	L1 Balance Wheel	1	Yes	Red	
	L1 Balance Spring	1	No	Red	
	L1 Bridge	1	Yes	Silver	
	L1 Frame Lower Escape Bridge	1	Yes	Silver	
	L1 Balance Shaft	1	Yes	Silver	
	L1 Escape Wheel	1	No	Silver	
	L1 Fork 5	1	Yes	Silver	
	2x1 Bearing Spacer	4	No	Silver	
	7.5mm Incabloc Jewel	2	No	Transparent Red	Used 0.7 layers for this part to provide smoothest surface.
L2	L2 Frame Upper	1	Yes	Black	
	L2 Frame Lower	1	Yes	Black	
	L2 Idler gear 28T M1	1	No	Silver	
	L2-L3 gear	1	Yes	Gold	
	L2-L1 gear	1	No	Gold	
	L3 Bearing Holder	1	No	Silver	
	10mm Incabloc Jewel	1	No	Transparent Red	Used 0.7 layers for this part to provide smoothest surface.
	12mm Incabloc Jewel	2	No	Transparent Red	Used 0.7 layers for this part to provide smoothest surface.
L3	L3 Frame 2 a	1	Yes	Silver	
	L3 Frame 2 b	1	Yes	Silver	
	L3 Crown Gear	1	No	Gold	
	L3 Bearing Race Guide	2	No	Don’t care	
	L3 Bearing Race Inner a	1	No	Silver	
	L3 Bearing Race Inner b	1	No	Silver	
	15mm Incabloc Jewel	2	No	Transparent Red	Used 0.7 layers for this part to provide smoothest surface.
	Incabloc Clip	2	No	Gold	

Sub-Assy	File Name	Quan.	Support material	Color	Notes
Base	L3 Ring Gear	1	No	Gold	
	L3 Lower Bearing Race	1	No	Silver	
	L3 Ring Gear a	1	No	Silver	
	L3 Ring Gear b	1	No	Silver	
	Base Body	1	No	Black	
	Base Body Bottom Cover	1	No	Black	
	Stepper Pulley	1	Yes	Black	
	Stepper Pulley Bridge	1	Yes	Black	
Other	Screw 9mm	14	No	Silver	
	Screw 8mm	20	No	Silver	
	Screw Seat 8mm	9	No	Silver	
	Screw Seat 8mm nut		No	Silver	Option to using *Screw Seat 8mm*.

8 Other Stuff

8.1 Some notes on gluing PLA…

I purchased the Bottle Applicator and Acrylic Cement (also called 'Acrylic Solvent') from Tap Plastics.

Bottle Applicator:
https://www.tapplastics.com/product/supplies_tools/plastic_tools_supplies/hypo_type_solvent_cement_applicator/409

Acrylic Cement:

https://www.tapplastics.com/product/repair_products/plastic_adhesives/tap_acrylic_cement/130

The web page says that the Acrylic Cement is for INDUSTRIAL USE ONLY. This is because it is made up of Methylene Chloride (75-09-2), Trichloroethylene (79-01-6) and Methyl Methacrylate Monomer (80-62-6). ONLY use in a well ventilated area!!! Not only does it smell bad, but inhaling it can hurt you. So treat it with respect. Fortunately a little of it goes a long way, so the fumes from tiny drops are minimal. And don't forget that it is also flammable!

This is probably the most volatile stuff I've ever used. When it comes to evaporation, it makes alcohol look like motor oil. There was an 1/8 inch of it in the bottom of the applicator and it was gone the next day. And this was with the syringe top tightly screwed on, and the cap on it. Also, after 4 months of sitting the garage a 4 oz. container of the stuff that was almost full when I put it on the shelf, was empty! I found that the seal on the container is junk. After tightening as hard as I could, I could tip the container and the stuff would still drip out. My solution, which has worked pretty well, was to store the Cement container in a coffee can with a plastic cap. My theory was that, even with the leaky Cement container, the solvent vapor pressure would equalize inside the coffee can, and slow the evaporation process. But hold the coffee can away from you when you open it, otherwise you will get an eye watering whiff of the stuff.

To fill the Bottle Applicator, just squeeze some air out of it, then stick the syringe into the bottle. It takes a minute, but the stuff will be sucked into the bottle. I found that I never needed very much. An 1/8th of an inch in the bottle, will go a long way. Besides anything you leave in the applicator will evaporate away within a day.

With all this said, a friend said that Acetone was just as effective a cement for PLA. Being a cheapskate, I will try it as soon as my current supply of Acrylic Cement is gone.

Also…

When using this Cement with the Bottle Applicator, its volatility comes into play. Normally you tip the Applicator and give it a squeeze to get a single drop of cement to come out, then relax your grip to cause an additional glue to be sucked back up the syringe. But because this stuff is so volatile, the heat from your fingers causes it to expand, so instead of a single drop, the expansion of the cement inside the bottle causes it to start dripping immediately. Even if you stop squeezing. This will flood your print with glue if the syringe is against it and make a mess. I found the best way to get a single drop was to hold the tip above a piece of cardboard, quickly tilt it to get a drop to come out, then tilt it back immediately, but no so much that the cement reaches the end of the syringe inside the bottle. The ‘tilt back’ causes the drop of cement to slide back to the working end of the syringe, without additional drips landing on your work. Note; this only works if there is just a little solvent in the bottle.

8.2 Design Issues

I posted my second L2-Frame design. For the first one I only had the 3 center columns, and the Idler Gear would slip as it went around because the torque forced the teeth apart. In the design that I posted, I added the extra side braces, and changed the size of the frame from 4x4mm to 5x5mm. This helped but didn't completely solve the problem the gears would still slip occasionally when the idler was at the top of the

9 Release Notes

Date	Notes
5/7/19	Initial release.
5/8/19	I posted the Stepper Pulley, Stepper Pulley Bridge, L3 Ring Gear a and L3 Ring Gear b STLs, and renamed the 'L2 Balance Spring Adjuster' STL to 'L1 Balance Spring Adjuster' so the name matches the documentation. I also updated the Build Notes PDF accordingly. I was concerned that using supports would make the bearing race too rough, so the L3 Ring Gear is printed as two parts (a and b), then glued together so you don't have to use supports.
5/19/19	I posted the pulley versions of the L3 Inner Bearing Race (L3 Inner Bearing Race 2a,STL and L3 Inner Bearing Race 2b.STL) and the Stepper Pinion.STL file. Refer to section 3.3.1 for more information.
5/24/19	Added L2 Idler gear 28T M1 to STL Files section.