# Manual for Tube Mitering

*In Loving Memory of Sam Calisch, 2013-2013*

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# Contents

# 1 Motivation

Recently, there has been a rise in the number of local, small-operation framebuilders as mass manufacturing of bicycles has moved overseas. Cannondale's last frame with "Made in USA" was completed in 2010, spurring the onset of these low-volume companies such as Firefly and Geekhouse in Massachusetts, MAP, Calfee, and LOW Bicycles in California to name a few. Framebuilding is an art akin to blacksmithing. One does not simply 'make a bicycle frame' as one would make a cake. Many builders offer apprenticeships similar to Japanese sword-making, and some shops offer season-long workshops where customers build their own bike alongside an experienced builder. While there are exceptions, framebuilding is a skill set that takes years to acquire, let alone perfect. We are motivated to create completely custom bicycle frames at a fraction of the cost, time, and required knowledge currently required. We will achieve this goal by substituting traditional methods for modern technology.

Figure 1: Badass Samurai

# 2 Background

## 2.1 Framebuilding

### 2.1.1 Lugged Frames

The use of lugs requires less accurate mitering than a mitered frame. Companies like Look pioneered using carbon fiber tubes with aluminum, steel, or chromoly lugs. Lugs can be cast or hand-made. Lugs are usually brazed with flux and silver braze. This technology dates to bicycles made in the late $19^{\text{th}}$ century.

Figure 2: Toptube to headtube lug

### 2.1.2 Non-Lugged Frames

Fillet brazing is a popular choice in the modern market, whereas lugged frames are now more a thing of the past. This operation involves mitering tubes perfectly given a geometry, and TIG welded at their joints. Materials included Chromoly, Aluminum, Titanium, and Stainless Steel. This process produces a clean-looking frameset, free of the 'heavy' aesthetic that lugs yield.

### 2.1.3 Tubesets

Tubes are known as "straight-gauge", "single-butted", "double-butted", "triple-butted", and "quad-butted". Firstly, the outer diameter does not change, but the wall thickness is variable between each type of tube. Unbutted tubes are of equal thickness throughout. Single-butted tubes are thicker at one end while the other end is consistent with the midsection. Double-butted tubes are equally thicker at the ends. Triple-butted tubes are thicker at one end than the other, and neither end is consistent with the midsection. quad-butted tubes are differing thickness at the ends and thinner in the midsection. This comes into play with cutting tubes, as different thicknesses are necessary for certain joints.

### 2.1.4 Time Intensity

A handmade bicycle frame, from geometric conception to finished product, can take anywhere from days to months to create. This depends on the craftsman or craftswoman, the complexity of the bicycle, and the uniqueness of the build. A company usually will have a production workflow and a custom workflow. A skilled builder may be able to fashion one hundred or more custom frames per year, while a production line may create tens of thousands. Mass manufacturing, of course, sacrifices both uniqueness and attention to detail of the product.

## 2.2 Technology

### 2.2.1 Software

Several Python scripts begin a workflow starting with a geometric frame concept and ending with MetaBeam compatible files (.lmc). From a novice's perspective, the script utilizes Otherlab's custom GUI and meshing platform. Points are assigned to build a basic geometry, rays are created from that set of points to create tubes, and points are created around those rays for mitering operations. To ensure a good fit between tubes, a 'min' operation is performed to account for the thickness of the tubes constrained by the perpendicular cutting of the laser beam.

### 2.2.2 Hardware

The laser used for research and development of this project is a Coherent MetaBeam 1mW 670nm laser with a pallet size of $4'$x$8'$. For our purposes, the pallet is replaced with a custom rotary pallet. Similar to a lathe operation, the rotary stage has one drive chuck and a 'live center'. This machine is powerful enough to cut inch-thick steel, and with the correct power, feed, and assist gas settings can cut delicate features in most metals. These qualities are important when cutting the features required for precise tube mitering. The rotary stage, with accompanying firmware, allow the y translation to become a rotational degree of freedom instead. Combined with the x-axis mobility, the laser is able to cut tube miters.

# 3 Workflow

## 3.1 Obtaining Geometry

Professional cyclists and die-hard amateurs pay hundreds of dollars to have a professional 'fit'. This is accomplished by riding a stationary bicycle with adjustable tubes to achieve a, theoretically, perfect bike geometry per specified riding habits and body geometry. Once this step is complete, a bike geometry CAD model is formed (Figure 3). This process can take hours to complete.

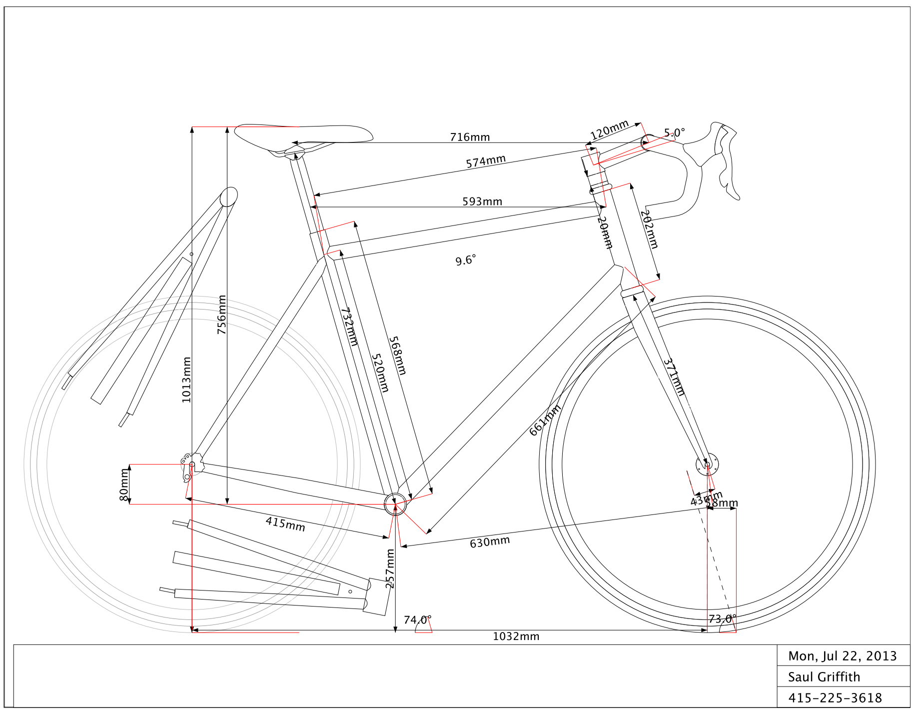


Figure 3: A basic bike CAD model

Some argue that fit is overwhelmingly subjective depending on the situation in which you are riding, thus constantly changing. Most mass manufacturers only take into account 'stack' and 'reach' to devise a finite number of sizes. After a purchase, you are able to adjust your fit through stems, saddle height, handlebars, and seat post height. our approach would be work with a happy medium. Given a set of rider's characteristics and measurements, we would design a unique geometry for their riding situation.

#### 3.1.1 Critical Measurements

To ensure a proper fit, we need to find the rider's inseam, shoulder width, arm length, height, weight, and riding purpose. From these measurements a geometry can be devised to perfectly match the rider's needs.

### 3.2 Using ./tubes

Tubes is the Python-powered GUI to input design parameters. Accompanying scripts are 'bike_parts', 'write_lmc' and 'TubeScene'[1], which create geometries used in tubes, create .lmc files, and definitions for trimming meshes, respectively. This document assume you have access to the git repository "other" and are familiar with Terminal. First, we need to create the frame. In the 'frames' directory, create a text file with a descriptive name of your bike. Then, navigate to the tubes script and run the ./ command.

#### 3.2.1 Inputting Geometry

Next, we need to design the geometry. At the moment, all frames are diamond-style (double-triangle, traditional) framesets. Scroll down to the 'io' tab and click on your file in the list, then run the Open command. As you peruse the GUI, you will notice there are many options. From a typical bike CAD drawing, you can usually find *most* of the parameters listed under the 'main geometry' tab, and your tube set parameters will be known and should be inputted to the 'tubes' tab.

Most is not all, however. The main caveat here is the 'bb-to-bottom-head-tube-x' and 'bb-to-bottom-head-tube-y' fields. Based on your CAD drawing, you maybe be able to do rough trigonometry to estimate these values, however for now just guess and we will confirm them later.

[1] TubeScene is actually a C++ file

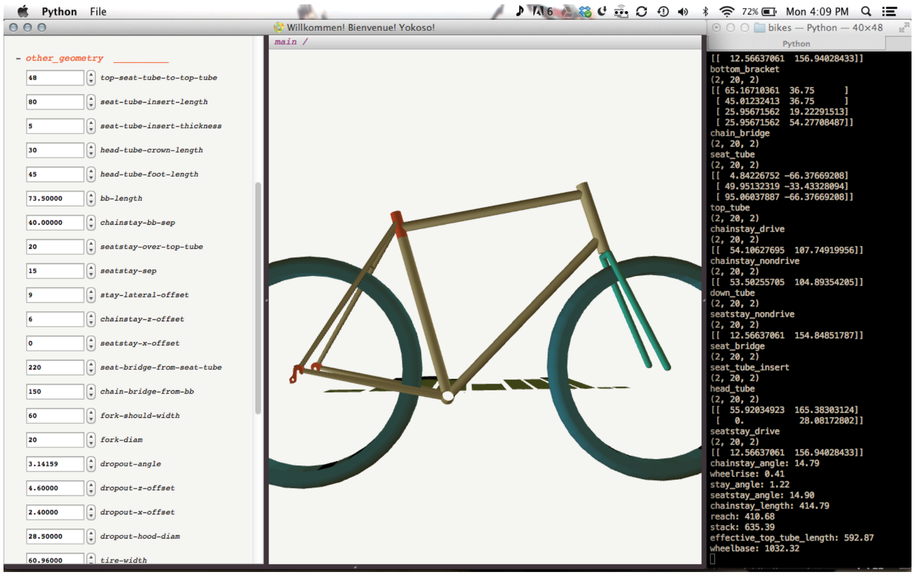


Figure 4: A simple caption

### 3.2.2 Measure Twice, Cut Once

Now, use the Save command and the Export commands to save your work. Then, use the 'Display Alternate Measurements' command. In Terminal, not-before-seen geometric quantities will show up. Chainstay length, a value usually given on the CAD drawing, should match given your 'horizontal chain stay length' value in the GUI. Check the wheelbase against the value on the drawing. 'Wheelrise' should be zero, meaning the geometry ensures both wheels are level with the ground. Adjust the 'bb-to-head-tube' values to make wheelrise zero. Check the other quantities and adjust as necessary. This will take several tries, and being within a millimeter is adequate.

### 3.2.3 Exporting .lmc Files

Once you are satisfied with the bike's geometry, use the export command and save commands to retain your changes. This command writes .lmc files to the directory within 'bikes' appropriately name 'lmc'. This creates a single cut file for the down tube, seat tube, head tube, top tube. There are three files for the chain stays and seat stays, drive and non-drive for each. These will be explained in the next section. Move the appropriate files to the laser cutter computer for cutting. Typically, you need everything except the bottom bracket shell and the seat/chain bridges. We do not cut the shell and as of now, we are not cutting the bridges on the laser[2].

## 3.3 Working with the .lmc file format

### 3.3.1 Editing .lmc Files

Once you are on the laser cutter station, make sure you have the correct .lmc files for the geometry. This is critical throughout the operation: single-, double-, and triple-check after every step. The workflow is unforgiving. Keep your wits about you and make sure you do not lose your place. Create the necessary directories to keep your files straight. I recommend compressing the entire 'lmc' folder from your local machine and extracting to a timestamped directory on the laser computer. Next,

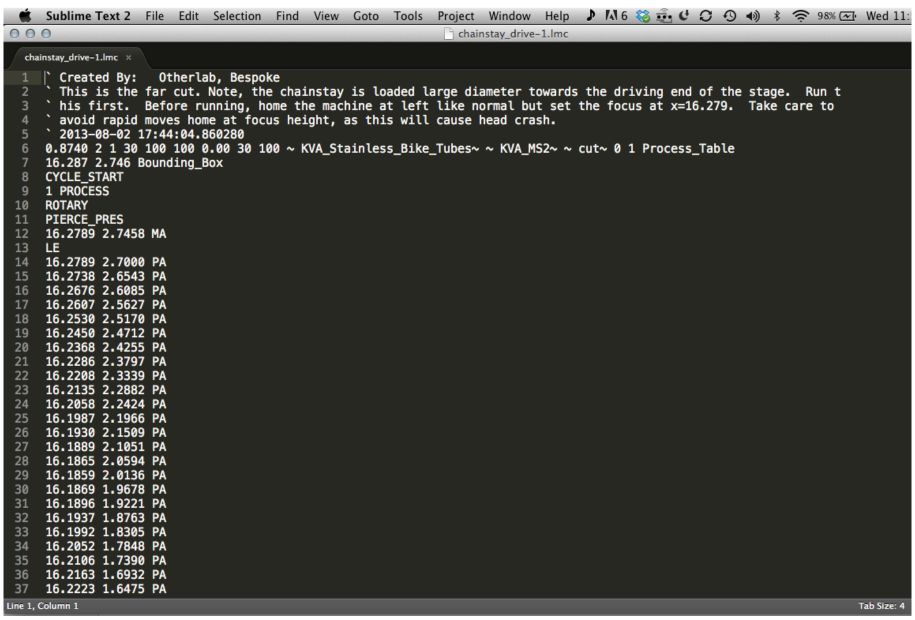


Figure 5: Viewing correct lmc file output from tubes in Sublime Text 2

devise a plan and lay out your blank tubes in the order you wish to cut them. Open the lmc files in a text editor[3] to check them. What you are looking for is a ROTARY command after each PROCESS command, a lack of an 'AF' command (autofocus),

[2]The tubing is very thick for these structural elements, so a good cut is difficult to obtain. This may be a possibility for future improvement

[3]Notepad++ seems to be popular for PC, Sublime Text is also a good option

and the correct tube diameter as the first the number in each process line. The tubes script should produce a perfect lmc output. However, it is good to know what is going on under the hood in order to test a material, thickness, feed, power, etc. To do so, you can create an lmc file in the LaserLink software and edit it manually to make it rotary-compatible.

**UPDATE 8/12/2013**

We are in the process of working out the kinks in the system with Matthew Bye. We need to determine the correct form for the lmc files so the laser keeps its home when entering and exiting rotary mode. This is essential to cut multi-process files. Putting ROTARY before each process is most likely incorrect. The ROTARY command should only be called once per file and should communicate ROTARY mode throughout a multi-process job.

**UPDATE 8/16/2013**

Place the rotary command only one time after each process command. Each time you end a job the machine will be reset to x-y mode. Each job will start at the current position when entering the rotary mode. You have to establish the start position before the job starts. This should be improved in the future so you can find a absolute home on the rotary axis. This would require a home sensor routine. The home position will be constant in one job. If you end the job in a random spot and start a new job this will be the new home. If you place a 0 0 ma at the end of each job it would go back to the same zero. This will allow you to run multiple jobs on one tube if desired. This need to be changed too.

## 3.4 Cutting

### 3.4.1 Preparing the Laser

If the flat pallet is in place, switch it with the rotary pallet. Use the small cube magnets to trip the Hall Effect sensors. This will allow the laser to think that the longer pallet is in place which simplifies the operation. Watch for the red LEDs to know where to place the magnets.

### 3.4.2 Setting Tubes for Cutting

Now you are ready to cut a tube. Fixture the tube using the aluminum chuck jigs. Make sure the butted end of the single-butted tubes are on the drive side, as this is how the lmc files are generated in the script. On the drive side, apply aluminum tape tightly to the circumference of the tubing, overlapping onto the chuck jigs. This

Figure 6: The LEDs are not illuminated here because the laser is turned off. The magnets are the small silver cubes below the red wire. This is looking from the backside of the machine. Placing them on top of the sensor will trip them.

secures the tube to prevent slipping when torque is transferred from the motor[4]. The free end will spin on it's own.

#### 3.4.3 Beam Control Panel

Open the Beam Control Panel, and let the machine find its home by following its instructions. To jog around, use the arrow keys or the arrows in the panel. Clicking "Fast" will toggle quick movement. Use the 'Up' and 'Down' keys to raise and lower the pallet, respectively. Make sure the focus offset is set with the precision 1" block and the homemade feeler gauge (16 gauge steel piece). This is done by going to the 'Setup' tab and finding 'Set focus offset', then entering '0.0'. **Make sure** the laser is over a flat piece of stock like cardboard or plywood for this operation. Then, move

[4] At the time of this writing, this is our temporary fix after experimentation. Perhaps someone will figure out a more elegant solution.

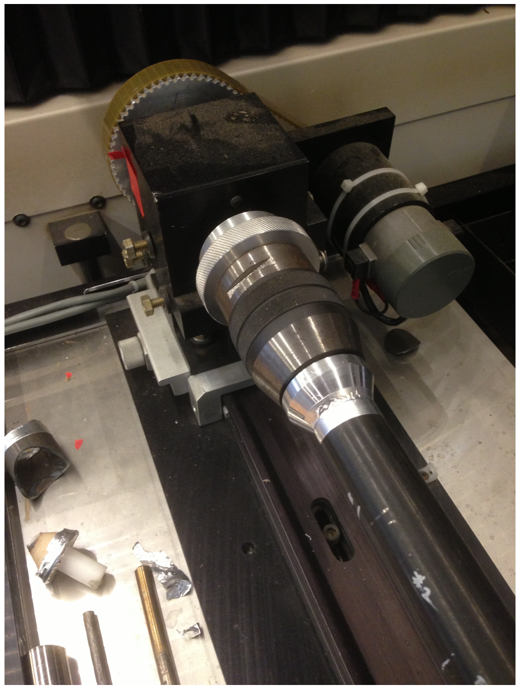

Figure 7: Use a strip of aluminum tape to secure the tube to the chuck jig (two usually does the trick).

the laser to the left-hand, drive-side chuck to home (close to the jig). Bring the bed up close to the guide laser. Look up towards the nozzle, and use the reflection of the guide laser from the tube itself to align the laser in the y direction. Set the home position. Then, use the feeler gauge against the nozzle and tube. Set the focus, and make sure the control panel reads “focus set”.

#### 3.4.4 Process Settings

The feed, power, and pressure settings depend on the thickness and type of the material being cut. Here is a table with empirically determined settings

| Material | Power | Feed | Pressure |
|---|---|---|---|
| KVA Stainless | 80 | 30 | 60 |
| Paragon Titanium | 100 | 20 | 60 |
| 4130 Chromoly | 80 | 50 | 60 |
| Cardboard | 50 | 500 | 5 |

# 4 Time Intensity

We have determined an estimate of the time involved in making a bicycle frame using this novel workflow.

| Task | Time Spent |
|---|---|
| Make geometry | X |
| Cut Tubes | Y |
| Weld Frame | Z |

# 5 Cost

Here is a list of costs

| Item | Cost |
|---|---|
| Make geometry | X |
| Cut Tubes | Y |
| Weld Frame | Z |

# 6 Future

## 6.1 With current technology

### 6.1.1 Ovalized Tubes

The ability to cut ovalized tubes allows greater flexibility in frame building. With ovalized tube mitering, more complex frames can be created with oversized tubing, teardrop down tubes, etc. More importantly, ovalized chain stays can be mitered. Most chain stays are oval for greater strength, and are more popular aesthetically.

To test this, we would try to use the METAL option when cutting, in order to employ the capacitive sensing head on the Coherent. This should work theoretically, but needs to be tested.

### 6.1.2 Forks

This is early in the prototyping phase, but eventually stainless steel forks should be built into the software and cut along with the frame components. For now, aftermarket forks are fitted to the custom frames. Many riders purchasing a high-end stainless bicycle will opt for carbon fiber forks regardless, however, some might choose a completely custom stainless frameset.

We hope that this software will be further implemented to easily output more complex tube arrangements. When this is possible, we can create more elegant designs with more robust features, like bladed forks.

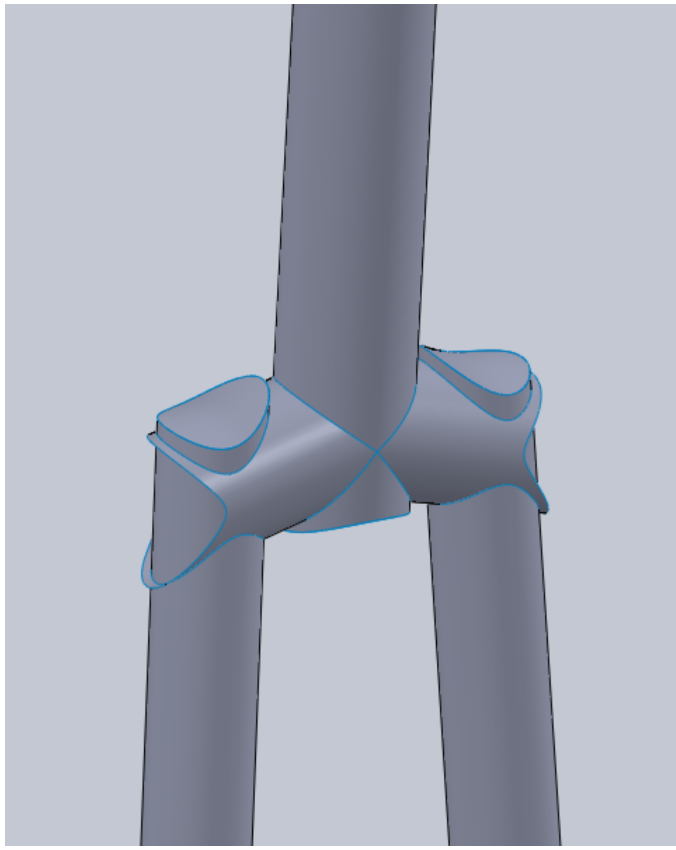

Figure 8: CAD model of fork made from varying tube diameters.

### 6.2 Dream Machine

The end goal of this project is to produce a stand-alone, fully-optimized tube mitering workflow. Initially applied to diamond-style bicycle frames, it could be adapted in software to accommodate any tubular structure. This machine would presumably have 4 axes: horizontal, rotational, vertical, and a planar spindle tilt of $\pm 30°$. A currently available model is BLM Group's model LT823D for non-orthogonal cutting.

Our goal is to create a comparable machine with a much smaller footprint and top-level software at a fraction of the cost.