

# Metal Shaper Accuracy, version 1

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In the ideal case, a metal shaper could not be much simpler. A cutter moves back and forth across a surface while the table carrying this surface moves side to side<sup>2</sup>. The machine cuts a flat surface.

Life gets more interesting when you crank in a bit of reality. Nothing is ideal so the surface that is cut is not flat.

This article deals with understanding this non-ideal surface and how to measure it. It does not identify the root cause of error inside the shaper.

Picture by Neil Butterfield

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<sup>1</sup> You are free to copy and distribute this document but not change it.

<sup>2</sup> To see my shaper in action, please go to <http://www.youtube.com/watch?v=JZdbNWoySo0>

## Theory

Hold a rubber band with two hands and pulling on it. You just defined a straight line. A straight line is defined as having two end points and, as the name implies... is straight.

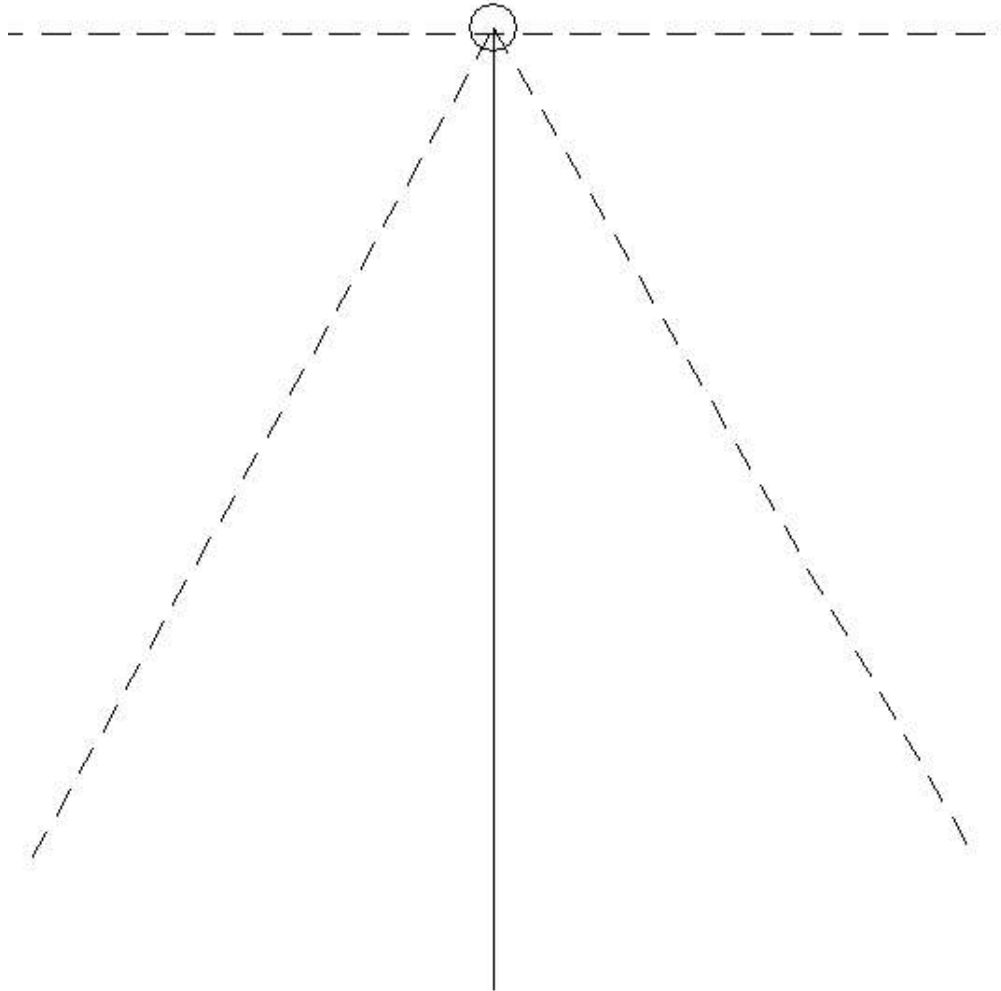


When I set points 1 and 2, I have completely defined my straight line.



This time I want you to take a plate and support it at the top two corners. The plate is free to swing.

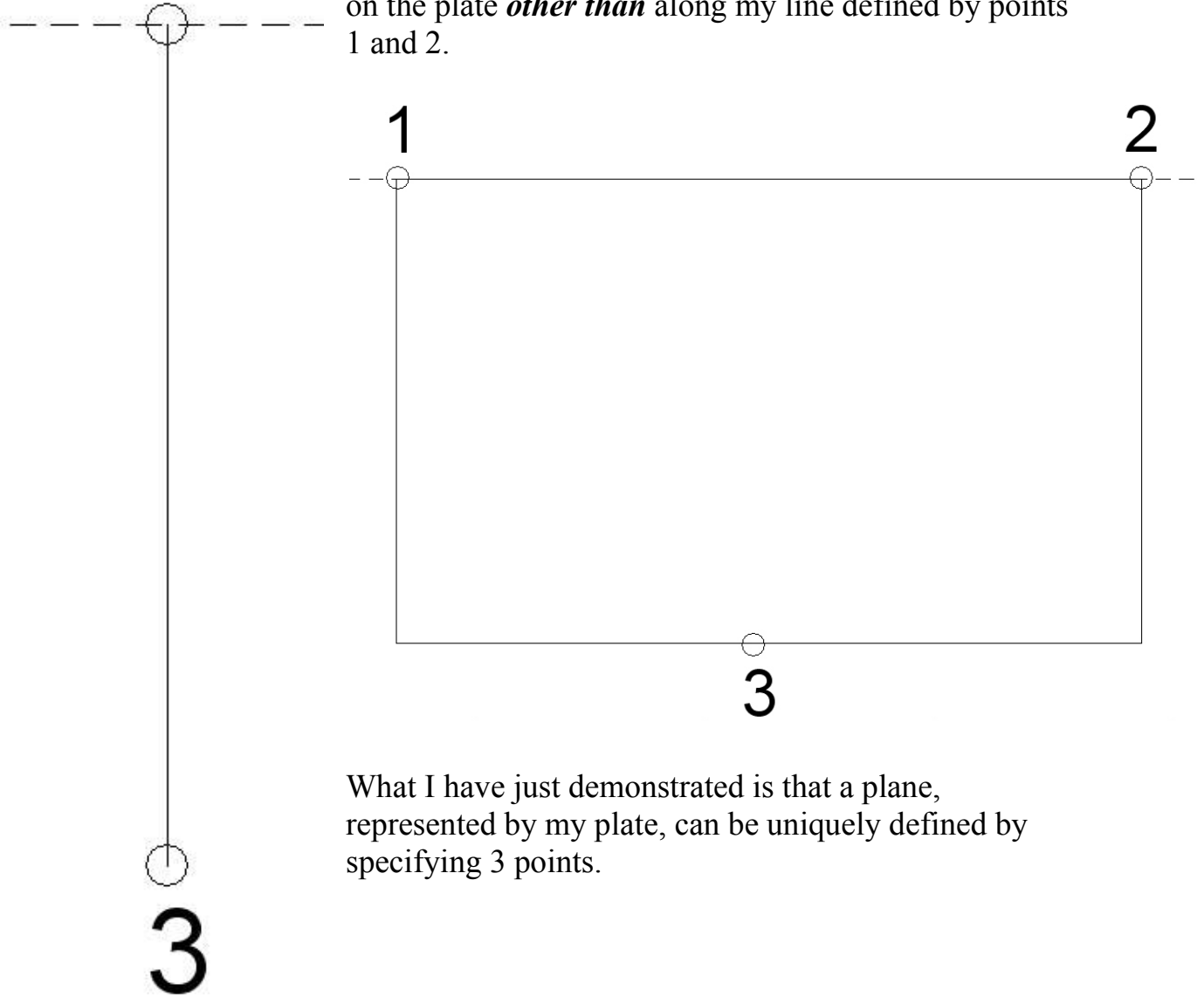
# 1,2



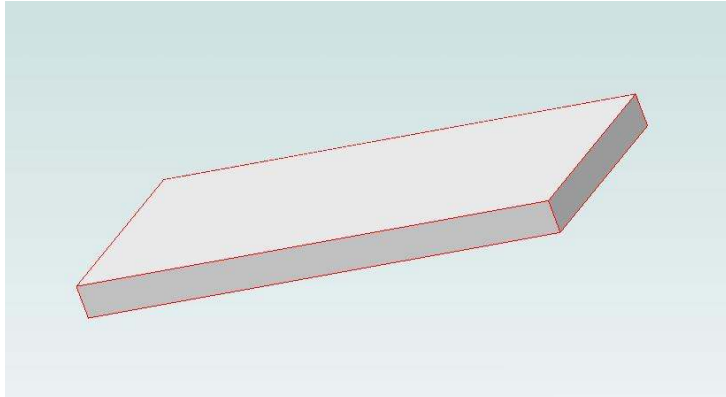
Here is an end view of our plate. My pivot points (1 and 2) are at the top and the plate can swing forward and back.

1,2

I can stop this swinging by locking the bottom of the plate at the point marked 3. In fact, my plate will be locked into this position as long as point 3 is somewhere on the plate *other than* along my line defined by points 1 and 2.

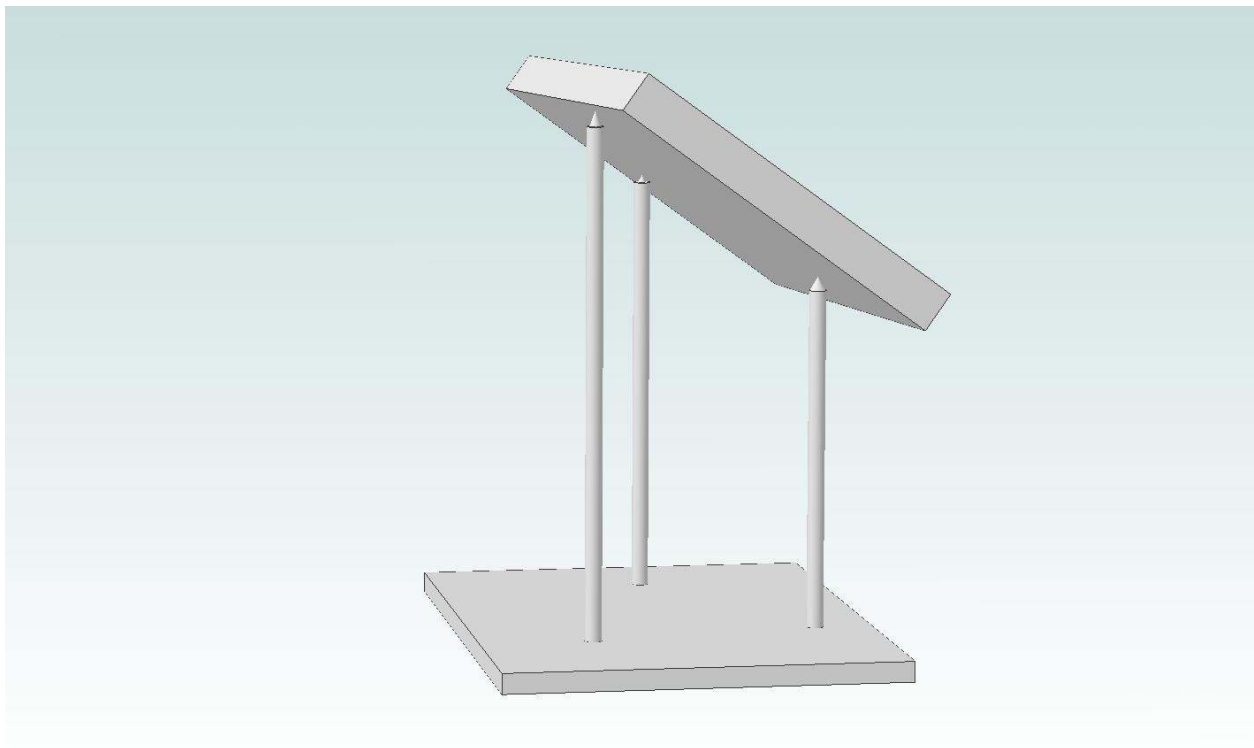


What I have just demonstrated is that a plane, represented by my plate, can be uniquely defined by specifying 3 points.

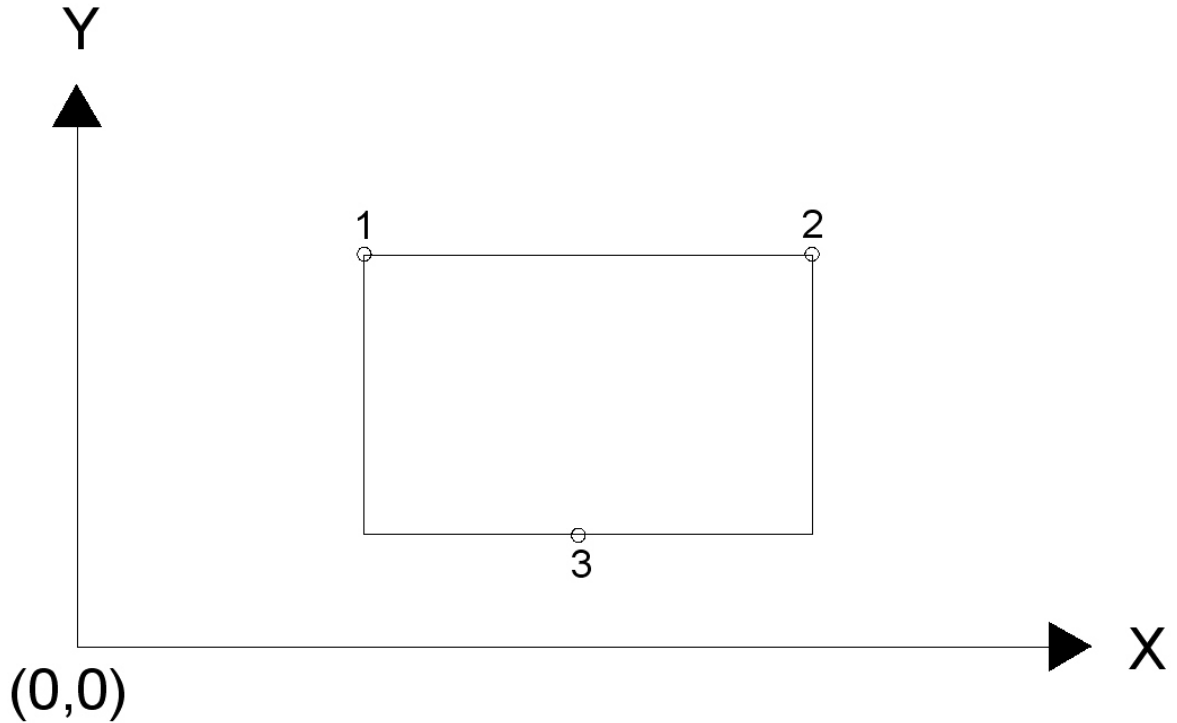


A plane is a 2 dimensional object. By giving it some thickness I have a flat plate floating in 3 dimensional space. I now have a plane on the top of this plate and a parallel plane at the bottom of the plate.

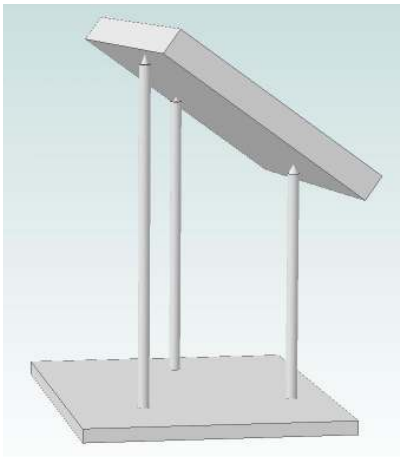
Imagine driving 3 nails into a board and turning the board so the nails point up. Regardless of the height of these nails above the board, you can place a plane on top and it will not rock.



My plate is now fixed in 3D space.



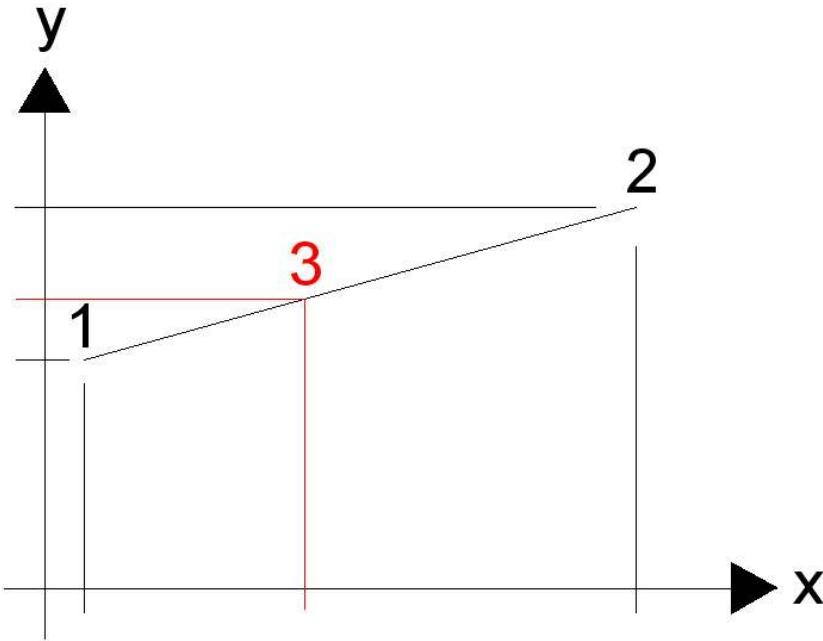
Imagine my base plate resting on a table which has an X and Y axis drawn on it. I can define a distance from the (0,0) point to the bottom of each nail.



Then I can measure the height of each nail which tells me the Z axis value. The tip of each nail will therefore have a unique (X,Y,Z) value which must be in contact with the bottom plane of the plate.

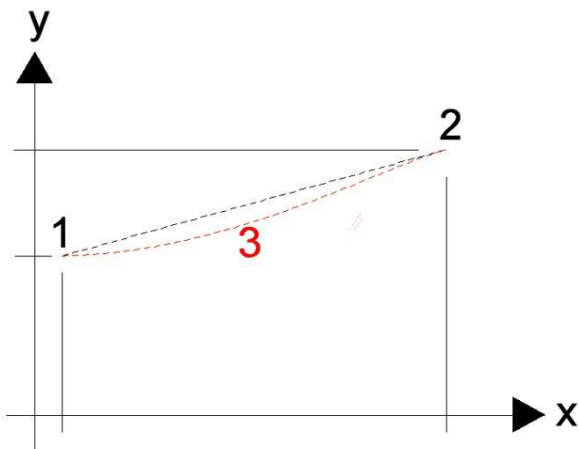
The take home message here is that if I have a plane with 3 known points, I have completely defined its location in 3D space.

To see the value of this statement, let's return to 2D space.



I have a straight line which passes through the points 1 and 2. The XY location of these points is known. If you give me the XY coordinates of a third point, I can verify if it is on the line.

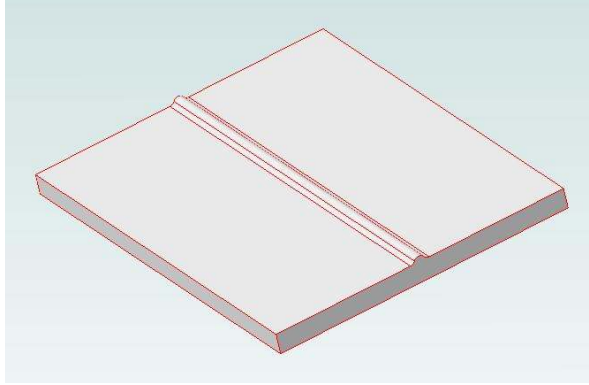
My goal here is to convince you that it is possible to verify this third point is on the line, not to burry you in math.



The converse is also true. If this third point really was on the line along with points 1 and 2, then I would have to conclude that the line was not straight.

The same is true in my 3D case. You give me 3 points and I can define a plane. Give me a fourth point and if it does not lie on this plane, then I just proved that I don't have a plane.

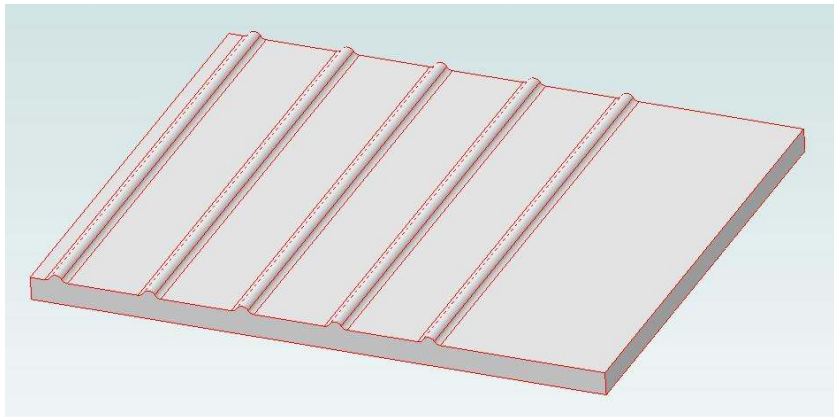
So by taking 4 points, I can test if a surface is not a plane. However, just because I find 4 points on a surface, it does not prove that it is a plane. Maybe I missed the high or low spot.



Say my plate has a ridge through it. This new surface is no longer a plane.

No matter where I place my 3 points, I cannot fully define this surface. In other words, if I am trying to verify if this surface is a plane, I just have to take one measurement on this ridge plus three off of the ridge and I will know it is not flat.

But note that I might accidentally pick three points that don't hit the ridge. In that case I would be fooled into thinking I have a plane. Such is the danger of trying to prove something is true. I can really only prove that it is not true.



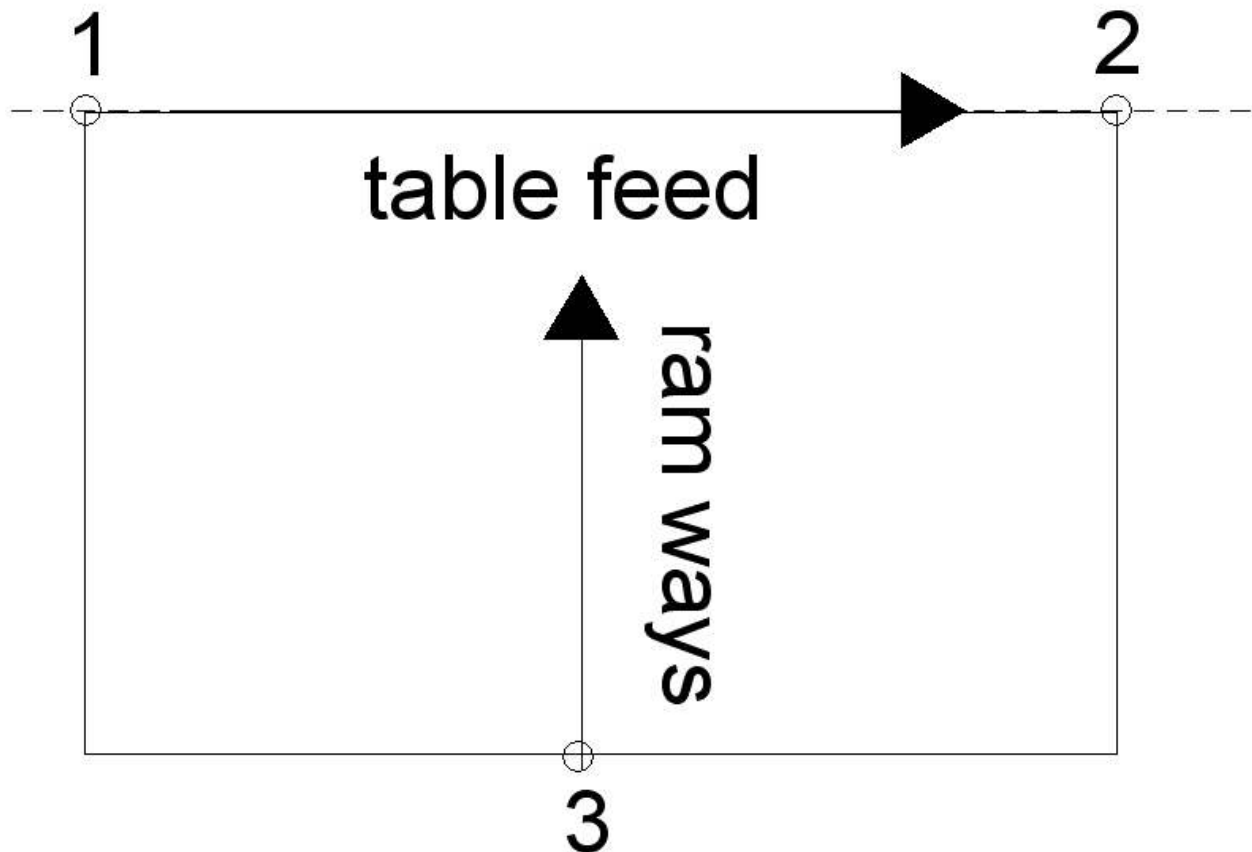
I might have a surface with many of these ridges. If the ridges are all of the same height, I could choose to place a flat bar on the surface and verify that the peaks of these ridges define a plane. It all depends on what you are trying to prove.

The ability to take readings over the surface of a test surface and use them to verify alignment is key to evaluating the shaper.



## Back to the Shaper

Everything about accuracy of the shaper can be gleaned from looking at the surface that it cuts.



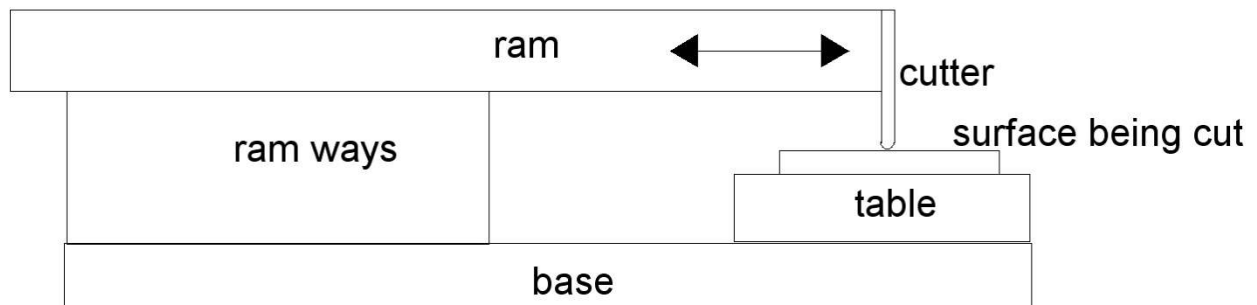
Here is my plane defined by 3 points. If everything is ideal, I will be able to select two points along the table feed axis. A third point will be on the ram ways axis. My metal shaper will then cut a perfect plane.

The goal here is to see how much deviation we get from this ideal case.

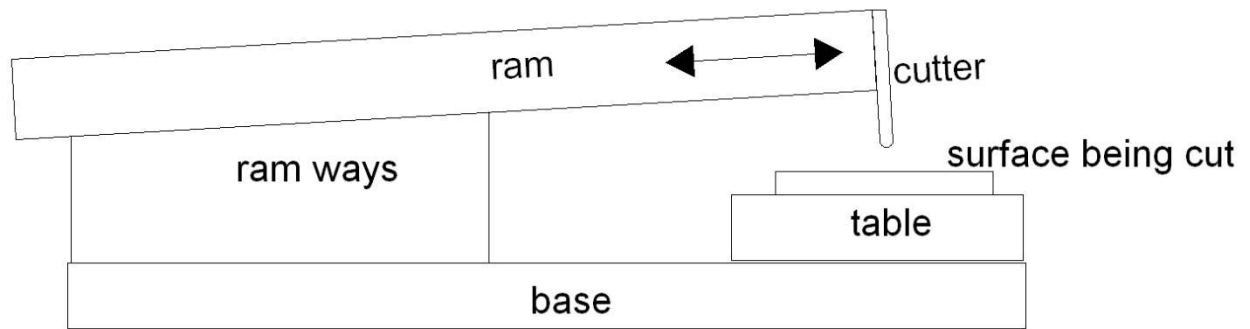
Remember what the shaper looks like?



Consider this simplified diagram.

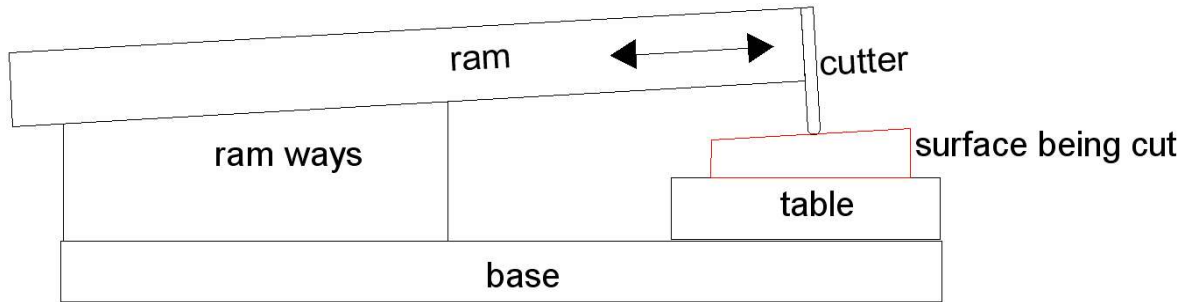


I have a base which supports the entire machine. On the left end I have my ram ways which both support the ram and enable it to slide left and right. The ram supports the cutter. As the ram moves left and right, the cutter moves across the surface being cut. After one left/right cycle of the ram, I get a groove in the surface being cut. If the ram moves parallel to the base, then the cutter will form a groove that is parallel to the base.

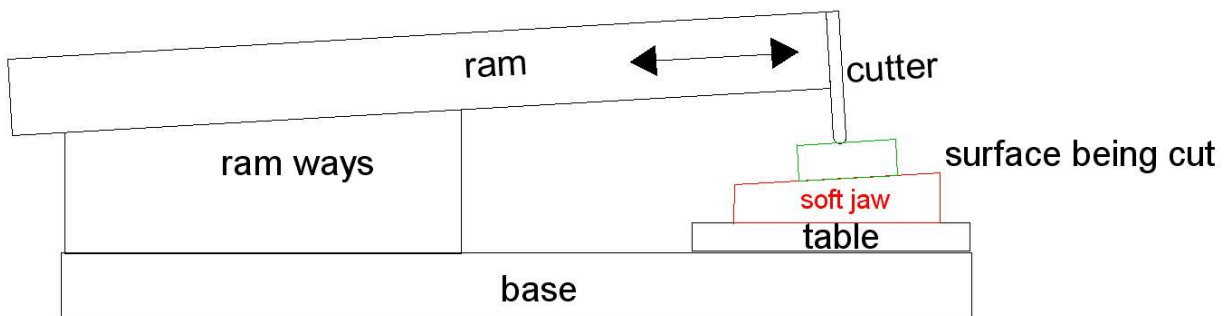


If the ram is not parallel to the base, then the surface being cut will not be parallel to the base. The cool thing here is, that can be OK.

Enter the concept of soft jaws.



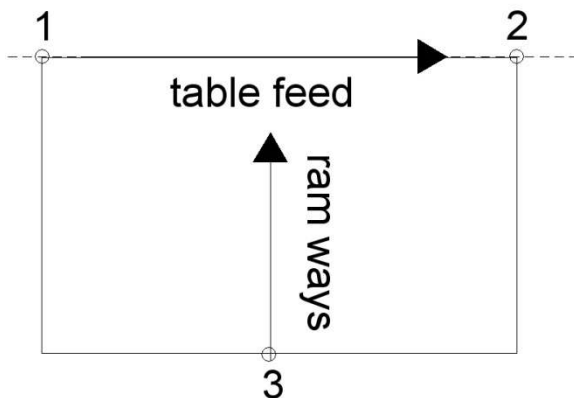
The surface that I do cut with my out of square ram will be parallel to my ram ways. I really do not care if I'm parallel to the base.



If I first cut a reference surface, it will be aligned with the ram ways. Call this my soft jaws. Then I can put my surface being cut on top of the soft jaw and it will be cut square.

So consistent misalignment of the ram with respect to the base should not be an issue.

What *is* a killer is if this misalignment is not consistent. If the ram's orientation with respect to the base varies over time, then the soft jaw cannot cancel the error.



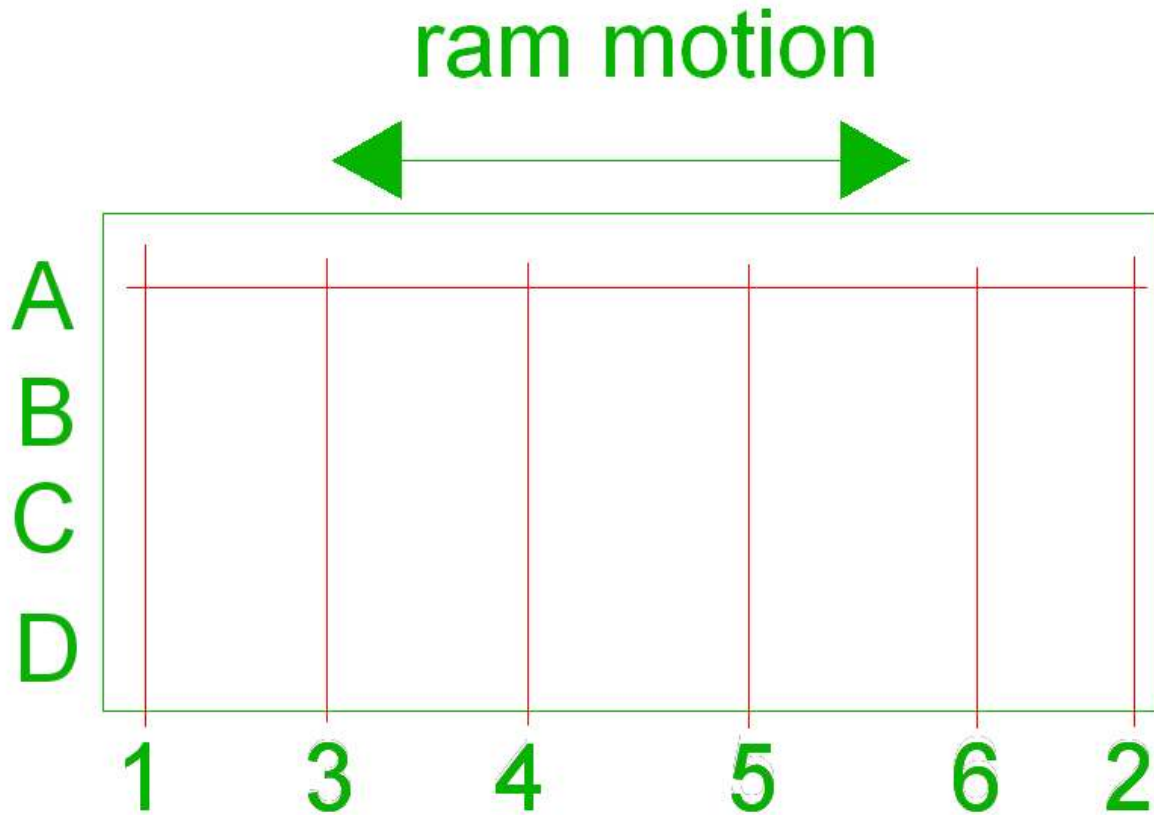
This gets us to the first test: verifying that the ram moves along a straight line.

My test block must be flat on the bottom so that it does not contribute error.

I could cut my soft jaw and then cut a test block on top. Any variation in thickness of the test block would tell me how much the ram movement diverged from an ideal line.

An easier way to run this test is to just put the flat bottom test block in the shaper's vise and cut the top surface. Then use math to determine if the top surface is consistent with a ram ways that is true.

I will do this second method.

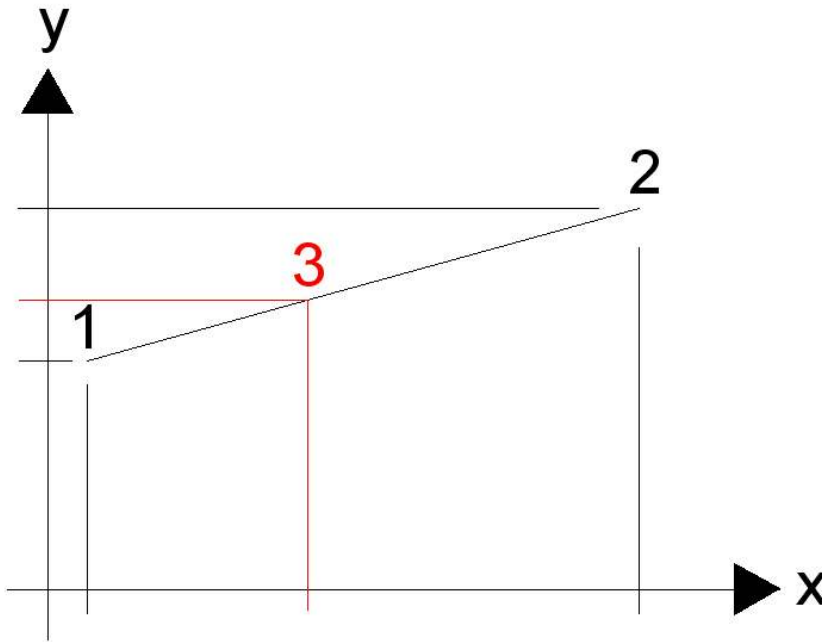


I am looking down on the cut surface of my test block. The bottom had been previously cut dead flat on another machine. A mill or lathe can do it.

I want to measure the thickness of the test block along the red horizontal line marked "A". Readings are needed at points 1 through 6. I also must measure the distance between each of these points along line A.

We are measuring a 3D object but by sticking with readings along line A, it is an approximation to a 2D line.

Remember this? The only difference is that “x” is the distance across the face of the cut surface and “y” is the thickness of the block at each point.



Our readings should define a line. Readings 1 and 2 are the furthest apart so I will use them to define my straight line. Then I will test to see how far points 3 through 6 are from this line.

I will not burden you with the math, but along with this article is a spread sheet that will take your data and tell you how close your ram movement is

to a straight line. For you math geeks, the derivation is in the appendix.

After you open the spreadsheet for testing the ram’s linearity, notice that the 6 points match the figure present in the spreadsheet. Record the thickness at each point and the distance that point is from point number 1.

The last column is the error – the difference between the actual thickness at this point and the expected thickness if the point was on the line.

Points 1 and 2 define the equation so will not have any error. The error seen with points 3 through 6 tell you all about ram motion error.

If these values make you happy, then move on to the next test. If they made you sad, take apart your ram ways and ram plate to see why this motion is not following a straight line. That procedure might be addressed in another article.

Here is the data I collected:

<u>point</u>	<u>thickness</u>	<u>distance</u> <u>from point</u> <u>1</u>	<u>error</u>	
1	0.86675	0.000	n/a	
2	0.86590	2.100	0	<- a check
3	0.86730	0.500	-0.001	
4	0.86730	0.900	-0.001	
5	0.86710	1.300	-0.001	
6	0.86720	1.700	-0.001	

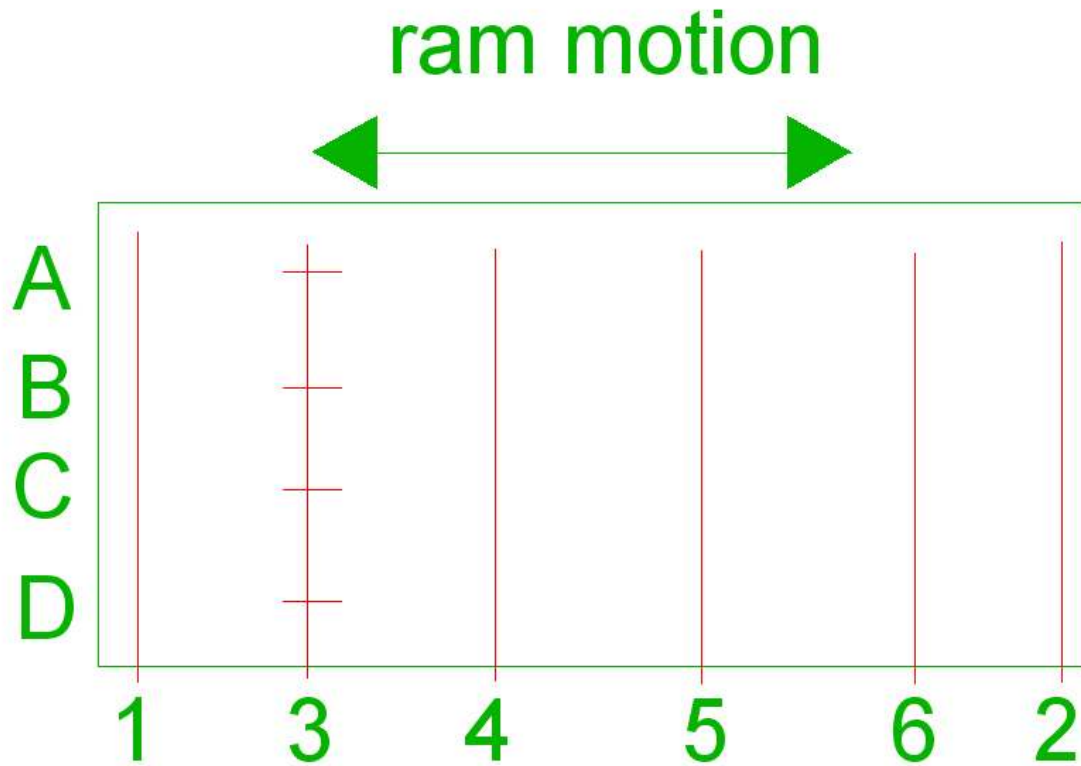
m        -0.0004  
b        0.86675

Note that point 2's thickness data is an furthest from all of the other data points. If I used point 6 as the end point rather than point 2, the error comes out to zero. Which data points to keep and which to drop can be somewhat of an art form. I will leave it as is and accept an error of -0.001".

The slope of the line, m, is -0.0004". Do not put much stock in this number. It would be canceled by soft jaws anyway. All that counts here is the deviation from a straight line.

Our second test uses the same test block: verifying that the table moves along a straight line.

The concepts are the same, just the direction has changed by 90°.



I need to collect thickness data along points A through D on at least one of these lines. Since my last point 1 was a bit odd, I will run my tests along line 3.

Table Movement Linearity Test

<u>point</u>	<u>thickness</u>	<u>distance</u> <u>from point A</u>	<u>error</u>
A	0.86930	0.000	n/a
B	0.87240	0.200	0.000
C	0.87445	0.400	0.001
D	0.87885	0.600	0.000 <- a check

m      0.015912  
b      0.869303



There is one thing fishy here and another that is interesting. The fishy bit is that my thickness at point A is 0.86930". But this is the same point as in my last test where I measured 0.86730". Those should be the same value. I'll have to recheck my measurements.

The interesting bit is the slope,  $m$ , which is 0.0159" per inch. That is a very large number. My soft jaws will cancel it but I think I will still figure out why it is so high. Something is not set square. But again, the only number that matters is the error column. My table is out of linearity by at most 0.001" which is comparable to the ram's error.

As the shaper now stands with my first batch of measurement, I can expect to cut a plane within  $\pm 0.001$ " assuming I use soft jaws to cancel the static error in the ram and table. Not bad for a homemade shaper! And I'm just starting to tune it up.

I welcome your comments and questions.

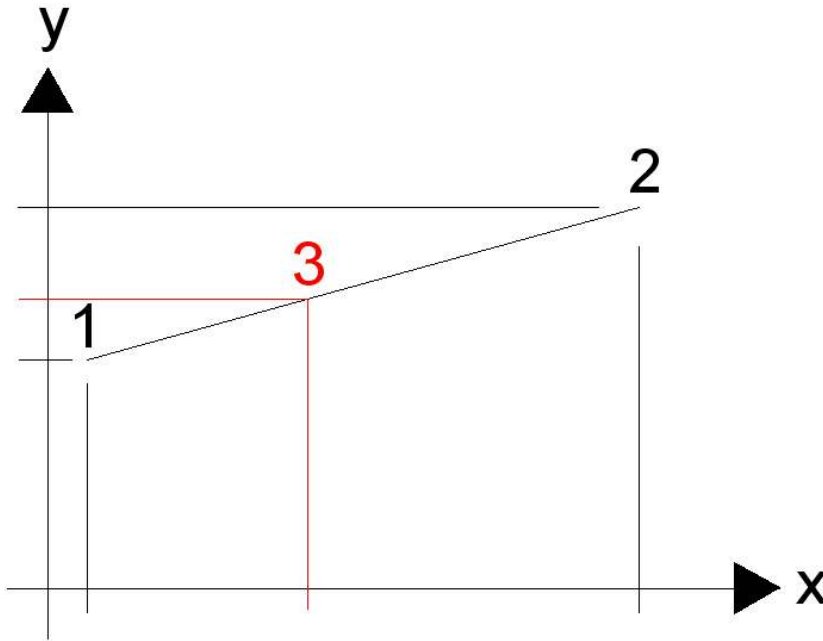
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## Appendix



Given two points, I can define a line. The basic equation is

$$y = mx + b \quad (\text{equation 1})$$

Given  $(x_1, y_1)$  and  $(x_2, y_2)$ , I can find the slope,  $m$ , and the intercept  $b$ .

$$y_1 = mx_1 + b \quad (\text{equation 2})$$

$$y_2 = mx_2 + b \quad (\text{equation 3})$$

Subtract equation 3 from

equation 2 and get

$$y_1 - y_2 = m(x_1 - x_2) + b - b \quad (\text{equation 4})$$

this gives me

$$m = \frac{(y_1 - y_2)}{(x_1 - x_2)} \quad (\text{equation 5})$$

I can then plug equation 5 into equation 2 and solve for  $b$

$$y_1 = \frac{(y_1 - y_2)}{(x_1 - x_2)}x_1 + b$$

so

$$b = y_1 - \frac{(y_1 - y_2)}{(x_1 - x_2)}x_1 \quad (\text{equation 6})$$

Once I know  $m$  and  $b$ , I can plug in known values of  $x$  and calculate the expected value of  $y$ . Any difference will be called error.