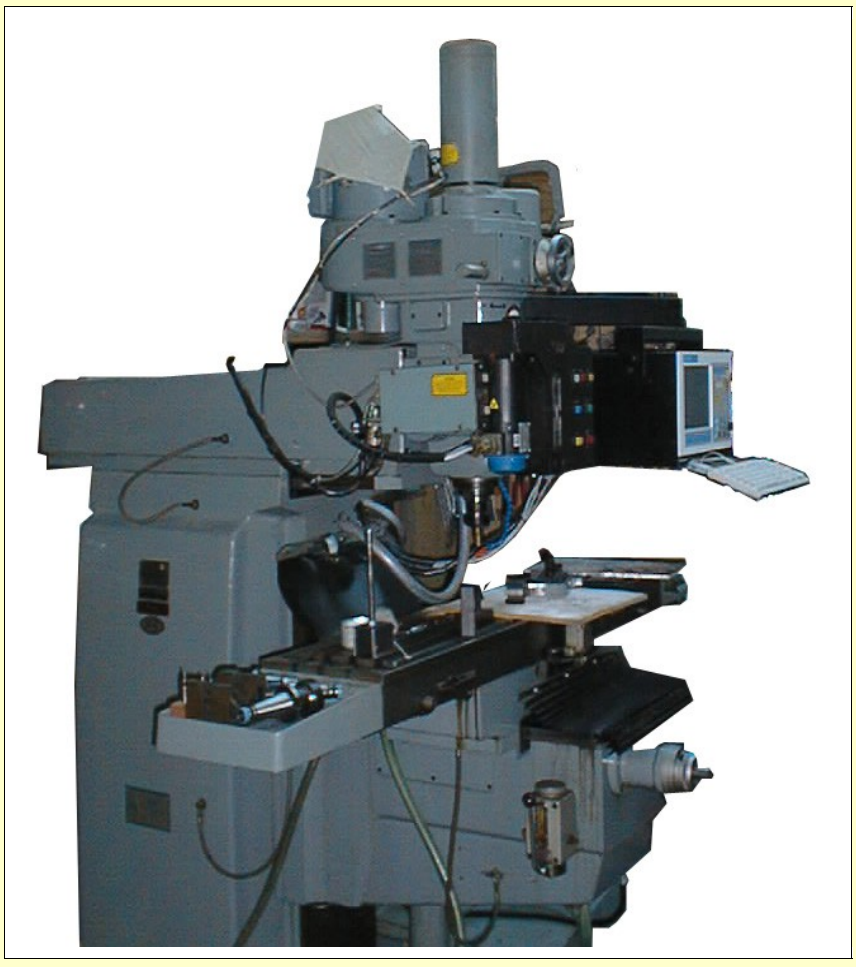
COST EFFECTIVE DESIGN

FOR

3-AXIS MILLING MACHINES



INTRODUCTION

I have been using a 3-axis milling machine for many years now and have found on many occasions that a few minor modifications to the designs that I am presented with can make a significant change to the cost of production.

This document has been written to help designers reduce the time taken and the material wasted when machining a part. This directly translates into cost savings. While mainly directed at parts made on a 3-axis mill, the general principles apply to most machining operations.

Commonly used Cutters

Square end Cutter

The majority of work done on a milling machine uses a square end cutter. This is for cutting slots, holes, faces and ledges.

Ball End Cutter

Ball end cutters are normally used for compound curve machining e.g. a hemisphere. In most cases using a ball end cutter requires small steps across and small steps down, often a step that is less than 10% of the cutter diameter. These small steps are necessary to give a smooth blended surface.

TOLERANCES

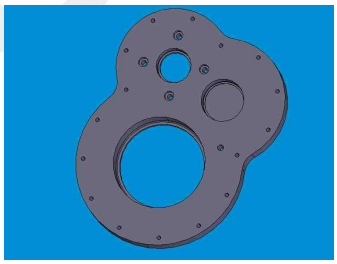
Part Fits

Specifying inside measurements and outside measurements to the same dimension means they will not fit. Tool and machine flex causes holes, pockets and internal machining to be slightly undersize while machining the outside of a solid will result in the item being fractionally over size. Fractions count and what was meant to be a slide fit may now be a press fit.

As a rule of thumb plus or minus 0.05mm is a standard tolerance for a 3 axis milling machine.

Part dimensions

Overly strict dimensioning costs money, lots of money. If you specify the centre distance between two bearing pockets as 287mm+/-0.01mm (as in the drawing to the right) you will require aerospace precision machining with temperature controlled machine, tooling and environment.



You have created a very expensive thermometer as shown in the table below

Expansion Coefficient table

Acrylic	63
Aluminium	24
Brass	18
Mild steel	12
304 Stainless	17
Invar	1.2

Worked example for Aluminium

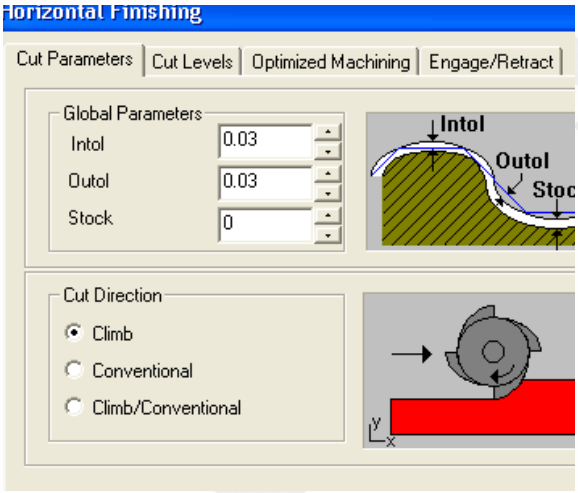
Length mm	Expansion Coefficient K	Temperature Change ºC	Resulting Length Change mm
287	24	10	0.06

Cutter vs size of parts

This is a trap that many designers never think about. If you specify curves, recesses, slots, gaps etc to exact numbers (eg 5mm) it is probable that the machinist will have to fake the tool dimensions to get a 5 mm cutter (standard cutters are made in 1mm increments) to machine the slot. This varies between CAM programmes but most of them have a tolerance in the programme which will be set to "adequate" by the machinist.

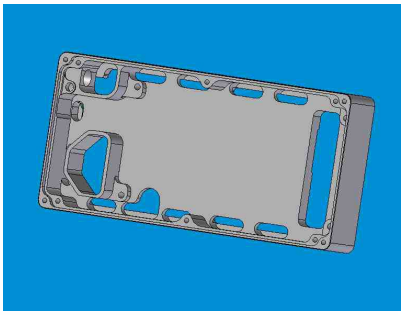
This picture shows a machine set at 0.03mm tolerance on the curves

This means the program may refuse to feed a 5mm cutter into a 5mm slot. Make the slot 5.1mm and there is no problem. Why would you not use the next size down? Because the next smaller standard size is 4mm which is slower as the cutter cannot cut as wide or as deep, and it is volume, not area of material, that you are removing.



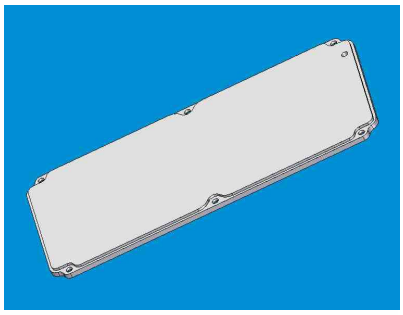
Standardize your cutter / drill size

If all the holes are 3.0mm and one is 2.0mm that is a tool change that takes time and that costs money.



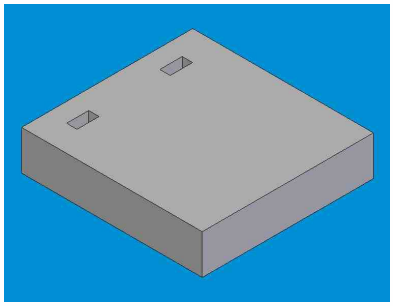
Face cuts vs all over cuts

You need to think if all the work can be done in one plane as the cheapest machining methods are 2D single flat plane such as plasma, water jet or laser cutter. After that is 3D CNC milling, then 4 axis then 5 axis then rapid prototyping.



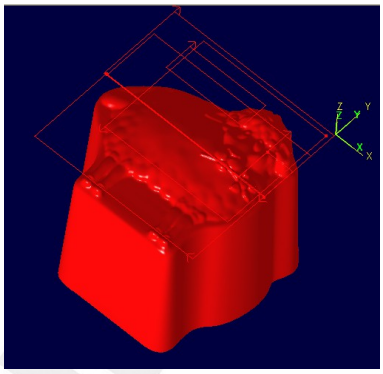
Square internal corners

This can be done with small cutters, slotters and hand work, but it is slow and it is expensive.



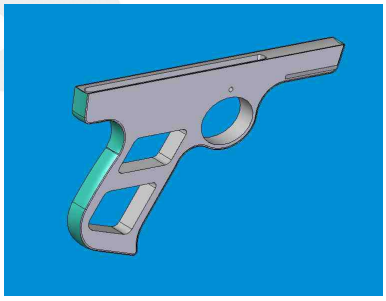
Small sections

These cost as fine detail means small cutters, moving slowly, removing tiny amounts of material.

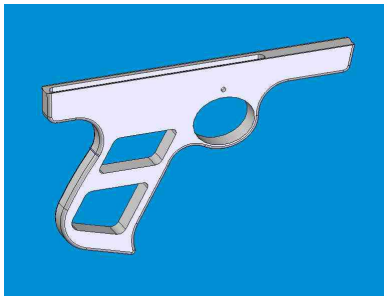


Compound curves

These cost as they require very fine cuts at fine stepovers. The green sections on the paintball gun to the right are compound curves.

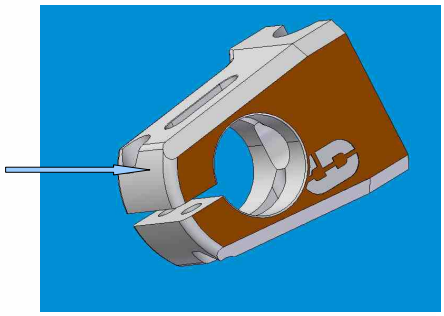


Changing to a simple chamfer using a chamfer cutter means now the paintball gun is simpler and faster to manufacture.



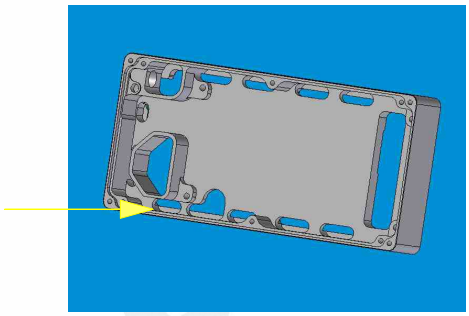
Chamfer cutters are cheap compared to milling compound curves with a ball end cutter

Contour milling is expensive as it takes more time. The blend between the 45 deg chamfer and the curved front profile had to be machined with a ball end cutter with fine steps. This was due to the choice of non standard angles and radiuses in the design.



Deep narrow sections

This is costly as long reach cutters are required. Vibration and flexing means the cutter travel speed must be drastically slowed. Time is money.



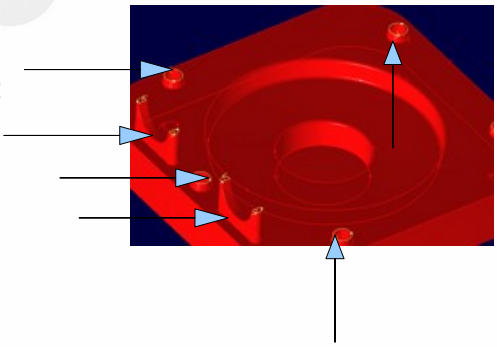
Thin sections

Vibration when using high rates of metal removal over thin sections in a job give a terrible finish unless cut very slowly, once again time is money. A thin sections acts like a resonating drum.

Over Location of parts

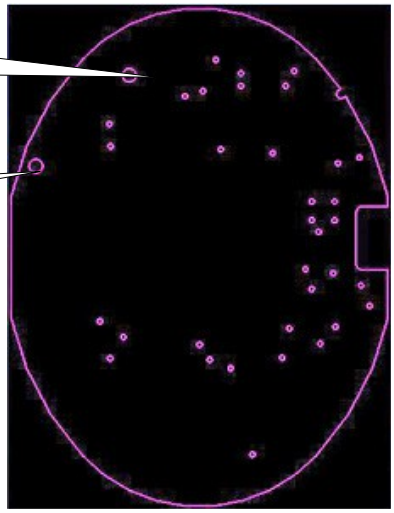
The two clamping C shapes and one peg are more than sufficient to to locate the part in the other half of the assembly. The extra pegs are redundant features. An even better solution would have been a lip fitting into a rim round the outside of the part

Locating holes drilled and reamed with a dowel fitted will 99 times out of 100 be cheaper than a machined peg and socket.



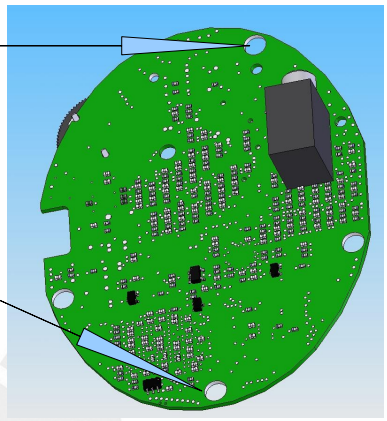
Poor Practice

The two locating holes are so close together any flex or slight movement round the locating pegs causes magnified location errors at the other end of the piece.



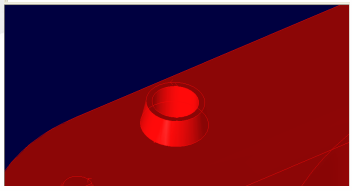
Good Practice

Two location points are sufficient if widely spaced as in this example as long as the holes are a tight slip fit over the locating pins.



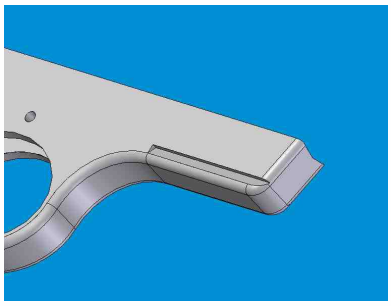
Test sample vs the production mould

A sample model may be easy to machine but if care is not taken it may be very very difficult to machine in the negative for a mould. The locating peg to the right illustrates a prototype that was made to evaluate a design for injection moulding. The mould for this part would have needed very deep narrow pockets that would be hard to machine as well as difficult for an injection moulding machine to fill.



Non standard tapers

This costs as either special tools are required or the tapers have to be machined with multiple fine passes. Standard 45 or 60 degree counter sinks and dovetail cutters are your friends.



Dovetail

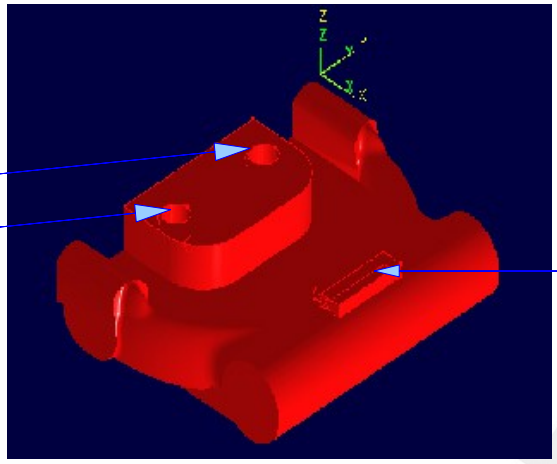
Example of Standard Dovetail Cutter

Surface finish

Getting a polished finish from a milling machine on a curved surface can be done but it is expensive (many passes with very small step overs). Can the item be power sanded and or polished after machining more cost effectively?

Tabs, Lugs, Bolt holes

The cost of making a part is always reduced if it is designed so that it can be easily held firmly. i.e. Parallel flat surfaces, locating holes, clamping tabs that can be cut off and finished last, holes that allow bolting the part firmly to the mill bed. Indicate to the machinist if these features are present. Do not add locating features if you have not consulted the machinist. Your idea of a good locating detail may be useless for the machine being used and will add to the machining time for no value.



Copying an existing part

It may save money if the part as well as the drawings /solid model is available to the machinist. There can be features in the part that the machinist can use saving time and hence money.

Plunge vs Edge entry

Plunging a cutter is hard on it and reduces tool life, ramping in is better but slows down the machining. If the tool can enter from the edge of the work this is much better and saves time.

CUTTING PARTS FROM STOCK

Pieces fitting into stock

The size of the part times the number of parts is not the size of the stock. There has to be a tool allowance and the machinist may opt for a big fast cutter so the gaps between the units are large or if the material is expensive the machinist may opt for a small cutter taking more time but saving material. The stock may also have to support the part. The size of the stock may also be larger to allow for holding the part.

Configuration of stock

If a material is only available as round bar there will be a large amount of unexpected wastage if it has been assumed the part will be machined from flat or bar stock. If this hasn't been allowed for in the design the cost may be much higher than expected.

Stock Size

Stock may only be available in certain sizes. Ie minimum of a full length, sold by the metre, etc. This can make a significant difference to costs of a job. Examples are, having to buy 1m of some plastics in rod form, aluminium only available in full lengths or half sheets. There can be minimum order quantities, for example specific stiffness castable urethane rubbers only come in 5 litre pack sizes

Supply of Material

If you are supplying material ask the machinist to check the quantities and to explain how they have arrived at this. Some machine shops much prefer customers to supply stock as it eliminates a cost but usually only if they can specify and check the material on delivery.

Material finish ex supplier.

Stock from suppliers cut for a small job is often gouged or scarred on the face as it is usually from another off cut. Insignificant to the materials supplier but possibly a major problem for the finished part if there is no allowance for a skim / facing cut. Never assume supplied material will be flat or to a correct thickness tolerance. Suppliers often state nominal size and can supply an imperial equivalent to a metric size and visa versa. If flatness is not specified to the supplier plate and bar stock can often be bowed. An example was a 450mm square of aluminium 8mm thick that came from the supplier with a 2mm bow across one diagonal.

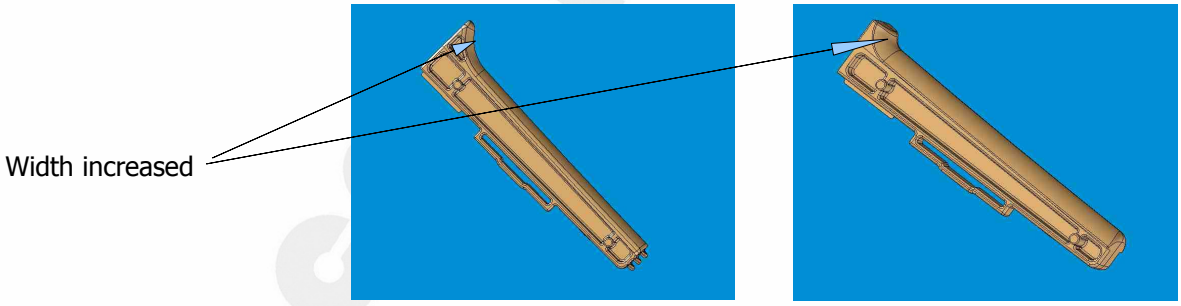
SMALL CHANGES / BIG PROBLEMS

Making the part a little larger

Increasing all the dimensions, for instance by 25%, will increase machining time as the surface area increases by 95%. This is now a major change.

Make the part only slightly different in one dimension

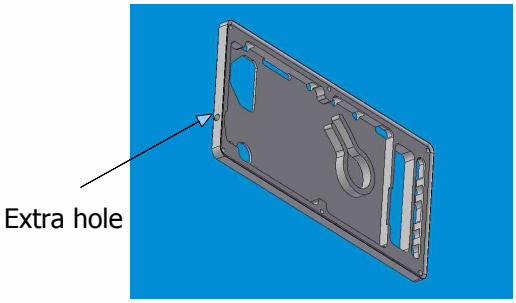
If the size of the part is changed, the stock may no longer be big enough.



Extras

"I've added a couple of holes, I hope that's not a problem".

It may not be but if it is on another face, a new jig may be required complete with extra set up and take down time.



"We've changed to 2.5mm threads from some that were 3mm I hope that's not a problem".

It is, tapping speed drops as this is a more fragile drill and tap size, plus another tool change is required.

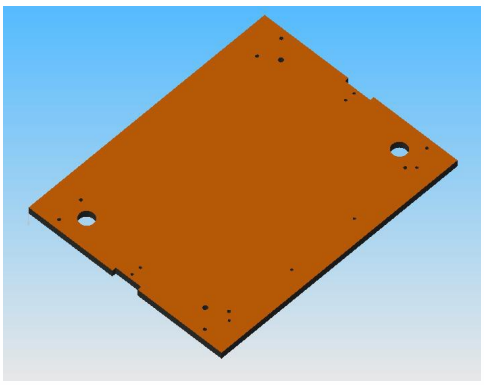
Make the part slightly smaller

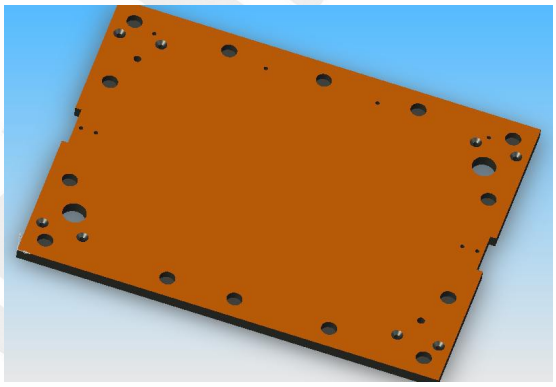
If the cutter being used won't fit into the now smaller area as the area has shrunk, a smaller cutter will be needed which will be slower. Time = money.

SUPPLYING THE SOLID MODEL AND FILES

Tiny errors can cause major problems

Never assume it won't make a difference.



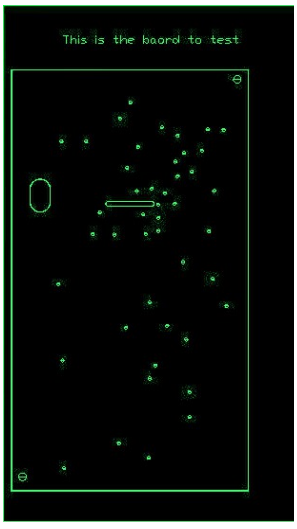


If locating holes are specified as symmetrical but in the solid model are out by 0.2mm, when the part is flipped to machine the back everything is offset by 0.4mm and nothing will line up as in the above pictures. It is strongly recommended a dimensioned drawing as a PDF with tolerances and specific instructions is sent with any solid model. Solid models are fast, and up to date CAM programs handle them well, but it is much harder to see errors compared to a dimensioned drawing.

Dimensioned file format

Check what the machine shop uses.

For 2D work dxf's are standard.



For 3D work IGES, STL, STEP are industry standard.

Sending a native file (ie a file straight from Solid Works, Pro Engineer, AutoCad, Alibre, Rhino etc) might be OK, however many small machine shops don't have all the standard CAD packages or expensive software converters.

COURTESY

Mistakes

If you make a mistake or the design is changed, expect to be charged for tools and materials already used or bought for the job. A good shop stands by its work, don't abuse that.

Panics

If you call urgency, be prompt yourself, calling at 2pm saying "hold the job we are on way with new material and a change" and not arriving until 6pm when a machine shop is busy has cost them 4 production machine hours. Your time is NOT more valuable than the machinists. Calling a panic and then not collecting the job for 2 weeks is similarly rude.

Scrap

Left over materials are usually not returned. If you require this make sure this is understood up front with the machine shop and that you will be paying to have it returned or will collect.

Changes

Once an order number is issued for a part, changes will be at the customers cost. Reworking quotes, changing machine code, resizing materials etc all takes time and time is money.

Number of parts

Telling the machine shop this is the "first of 400" probably will not get a discount on the first test prototype. . Getting a quote on 4 then switching to 1 will not give you the same unit cost. The cost of raising the quote, set up etc is now carried by one part and not spread over 4.