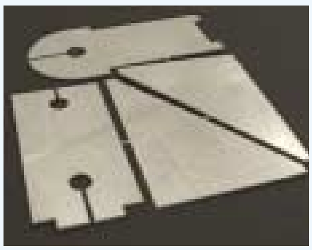
# THE ENGINEERS' GUIDE TO DESIGNING ABRASIVE WATERJET PARTS:

This is intended to give some tips for Engineers who are not experts in abrasivejet machining, but may be designing parts for Abrasivejet Machining. Hopefully, some of the tips and ideas presented here will save you time, effort, and money.



***Above: A couple of typical parts. Notice secondary machining (Left), and tabs used to hold pieces (Right).***

Quick Tips:

- You can machine virtually any 2D shape.
- For cheaper / faster parts: avoid sharp corners, or tight radii.
- Avoid tiny holes in thick materials.
- Use AutoCad Release 12 ASCII DXF files for best luck in transfering files.
- Your final part will be no more accurate than the CAD drawing you start with.
- Brittle materials and laminates require special attention.
- Different machines & job shops have different specialties and capabilities.

## The gritty details:

• You can cut virtually any 2 dimensional shape, however there are quirks of the abrasivejet that if you understand, you can design your parts to be made faster, stronger, to higher precision, and cheaper than if you just ask your local waterjet shop to "make this part".

## Materials you can machine:

- Abrasivejets can machine virtually any material: You can even machine material after it has been heat treated. This means that you can pre-heat treat the material, then cut it to shape! Typically, the difference between cutting material before heat treat vs after is negligible to an abrasivejet.
  Take advantage of this, if you can.
- Yes: Abrasivejets are great for exotic materials like Inconel, Hastalloy, Titanium, etc. But don't forget that they are also a great choice for less exotic materials such as mild steel or aluminum.

## Limitations to the shape:

- The minimum inside radius an abrasivejet can cut is about 0.015 in. on most machines. Higher power machines may require a minimum radius of up to 0.030 in. Smaller radii such as 0.01 in. can be machined with special nozzles.
- You can make a hole that is as small as the diameter of the nozzle. This means 0.030 in. to 0.060 in. However, in thicker materials, the tolerance on such holes becomes increasingly difficult to maintain.

***Above: SeaCatch™. All flat parts were machined on an abrasivejet.***

## How can I optimize my design so that it is machined quickly?

The best way to do this, is to understand the main factors that affect cutting speed. These are:

- Cutting horsepower of the pump / nozzle combination being used
- Material that you wish to machine
- Thickness of the material you wish to machine
- Geometry of the part
- Type of pierce
- Desired surface finish and tolerance

Let's discuss these in more detail...

***Cutting horsepower:*** Simply put, the more horsepower that makes it to the nozzle, the faster you will cut. This is described in more detail elsewhere on our web site, such as in the FAQ page, and the Buyers Guide. However, a faster cut does not necessarily translate into a cheaper part. Much like a dragster can go 300+ mph in the 1/4 mile, it can be cheaper to take my Honda, but only go 60. Therefore, from the engineer's point of view, I would not care so much about the equipment being used as much as the quote you are given.

***Material:*** As one might expect, each material has a different speed at which it likes to be machined. However, these speeds are hardly at all related to the speeds that other "traditional" machines would use. For example, Hastalloy, Inconel, Hardened tool steel, and Titanium all are fairly difficult to machine on most other machinery. However, with an abrasivejet, all of the above materials machine at close to the same speed as mild steel. In fact, titanium even cuts faster!

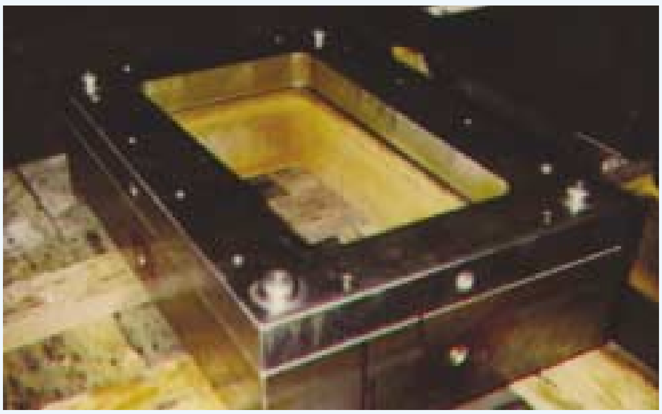
***Material Thickness:*** Cutting speed is an exponential function of material thicknesses. This can be represented roughly by the following, where the "exponent" is 1.15:

Cutting Speed ~ 1 / (Thickness^1.15)

**In other words:**

"The speed of cutting is proportional to the One over the Thickness raised to the power of 1.15 in.

This means parts under 0.5 in. thick will machine quite quickly, while parts >1 in. thick are much slower. Over 2 in. thick, and many shapes are not practical, unless you are roughing out the part, or you can't do it any other way.



***Above: 5 in. thick slug machined from the center of a very heavy chunk of steel by CTI . Not something you would typically do with an abrasivejet, but it can be done. This part took around 9 hours! Generally speaking, it is better to stick to <2.0 in. in thickness. Notice the use of rounded corners to speed things up.***

• For more info on cutting speeds, be sure to download the Waterjet Web Reference Abrasivejet Feed Rate Calculator . This calculator will give you a good idea of how thickness effects speed, as well as the cutting rates for various materials. Note, however, that because cutting speed is also a function of the geometry of the part, this calculator is only good for linear speeds.

***Geometry of the part:*** Simply put: Avoid sharp corners to speed things up. There is nothing wrong with wanting a sharp corner, but if you don't need one, don't ask for one! Tight curves will also slow the process down. This is especially true of inside corners.

The sharper the corner, the more the machine must slow down in order to maintain tolerance. Therefore, if you want to make the part quickly (cheaply), then avoid sharp corners. On internal corners, you will not only cut the part faster, but you may also be able to hold tighter tolerances.

All sharp corners will slow the cutting processes down. On thin parts, this is not very important, but on thicker parts the effect is huge.

Sharp inside corners are hard to hold tolerance in. Some controllers are better than others at this, but expect lower tolerances in inside corners from any machine.

Sharp outside corners make it hurt more when you drop the part on your foot, especially if it is heavy. However, sharp outside corners are sometimes faster than radii, if the path is optimized for them. When you get a quote, let them know if outside corners have to be sharp or round, or if it does not matter. If it does not matter, then the operator can use whichever type of corner will be fastest for their controller. Most likely that will be a rounded corner, but it may be square.

Fillet inside corners with the largest radius that you can.

***Type of pierce:*** It takes time to pierce the material. If you have lots of room inside of the scrap material (i.e. the "slug" that is removed from a hole), then faster pierce techniques can be used. If you have tiny holes, then slower pierce methods must be used in order to fit.

***Number of pierces:*** On/Off transitions take additional time and cause fatigue on high pressure components from the pressure fluxuations in the lines. Therefore, expect to be charged more if you have a lot of on/off transitions in your parts. (If it were me, I would probably charge you an extra $0.01 to $0.05 per hole.)

***Desired surface finish and tolerance:*** The smoother the surface finish you want, the longer you have to wait for it. Smooth surface finish is obtained by slowing down the cutting rate. Higher tolerance parts also take longer to machine for similar reasons. Do not specify a higher tolerance or surface finish than you really need.

While it is true that high tolerance parts are typically machined at a slower rate than low tolerance parts, it is not true that the slower you go, the higher the tolerance you get. In fact, after a point, if you go slower, you simply get more taper, and thus less precision. There is an optimal speed for each material and thickness that gives you the best tolerance.

***Stacking materials:*** You can often cut many parts at once by stacking thin materials. This can result in big increases in productivity, such as 150 percent to 300 percent or more. However, there is diminishing returns if the total stack height exceeds 1/4 to 1/2 in.

If your part has a lot of corners, then stacking the material will be less advantageous when compared to a part that has few corners. (Your optimum total stack height will be less.) This is because the jet needs to slow down for corners, and when you increase the stack thickness, it has to slow down extra for the corners.

There is also some extra time needed in set-up when stacking materials, to insure the parts will not float away, etc., when cutting.

***"Un-stacking" thick parts:*** If you need a part cut that is 2 in. thick, it will be much faster to cut 4 1/2 in. thick parts, then stack them together. This can save you a lot of money, if your design considerations will allow you to do it.

***Stacking dissimilar materials:***
It is possible to cut materials that are of different composition that are glued to each other. For example, a cover plate made from plastic that has a foam backing on it. Glue the foam to the plastic first, then cut them both together as a unit. This can save production time, and insure the parts line up perfectly.

***Brittle materials:***

***Above: Dragons cut from Black Granite, Bullet-proof glass, and Marble.***

Some brittle materials may crack on piercing. If your unsure about the particular brittle material that you have, ask your job shop for advice, or call the technical support number of one of the abrasive waterjet manufacturers. You may ask your job shop to do some test cutting before providing you with a quote. Here are some pointers:

- Consider cutting from the side of the material, to avoid piercing. This will make it much less likely that the part might crack during the pierce.
- Choose a job shop that has equipment that can pierce at low pressure. This also can prevent cracking on the pierce.
- Sorry, you cannot cut tempered glass, but you can cut virtually any other form of glass, even bullet-proof.
- Expect to pay a little bit more for the added effort and risk of cutting brittle material.

***Laminated materials:*** Laminated materials may want to delaminate when pierced, and sometimes even when cut. As with brittle materials, you may want to ask your job shop for advice. Here are some pointers:

- If you have the choice, choose materials that are strongly bonded.
- Consider cutting from the side of the material to avoid piercing
- Choose a job shop that has equipment that can pierce at low pressure.
- In some cases, you may have to cut at lower pressures also.
- In some worst cases, you may have to pre drill start holes, but this is fairly rare.

***Making tiny parts:***
It is possible to make very small parts of fairly fine detail. Specialized nozzles allow for narrow kerf widths such as 0.020 in. When cutting parts that are smaller than 1 inch in size, special considerations need to be made to ensure the parts will not fall into the tank. Leaving a small tab on the material to hold it in place is a common method for this. Also cutting on top of “waterjet brick” or other dense surface helps prevent parts from falling into the tank.

***When cutting any “special” material:***
Try to give your job shop some scrap material that they can do some test cutting on.

***Tolerancing:***
• Provide extra information on your drawing to indicate which areas are high tolerance, or require better surface finish, and which areas can be “roughed out”.

• If your tolerances are less than 0.010 in., then really consider what tolerances are needed. If you need +/-0.003 in., but you call out +/-0.001 in., then a lot of unnecessary set up and work will be performed to squeeze the extra 0.002 in. of tolerance.

• Ask your Job shop what kind of tolerances they feel comfortable not only with respect to the material and part shape, but also in regards to thicknesses you intend to cut. Some machines and operators are fairly comfortable with +/- 0.002 in., while others may not be able to do better than +/-0.020 in. It all depends on the equipment used, what you are cutting, and the experience of the operator.

- Probably all waterjet job shops can do +/-0.1 in.
- Most waterjet job shops can do +/-0.01 in.
- Waterjet job shops with modern controllers and equipment can usually do +/-0.005 in.
- Waterjet job shops with modern controllers, precision equipment, and experienced operators can sometimes achieve +/-0.002 in. for many parts.
- A few waterjet shops can do better than +/-0.002”, but it requires precision equipment, a good abrasivejet controller, an experienced operator, and only if the part geometry, material and thickness are favorable.
- Better than +/-0.001” is also possible under the right conditions, but I would not count on it.

• Repeatability when cutting the same part multiple times is usually quite excellent.

***Design for taper:***
• Parts cut on an abrasivejet will often exhibit a few thousandths of an inch of taper. Usually this is one of the biggest factors in determining the final tolerance of the part when cutting high precision parts.
• Use taper to your advantage: For example, If you are cutting gears, then cut every other gear upside down. Then, when they mesh together, the tapers will cancel each other out. This can also be useful when embedding two parts into each other, such as when doing marble inlays.

**Use the abrasivejet to locate holes, even high precision holes.**

• The abrasivejet can be used to cut holes that will be reamed out or tapped later.

Use the abrasivejet to rough out tough materials

• You can save your other tools by "roughing out" the near net shape, to then do the finishing work in another process. However, many abrasivejets are precice enough that you may want to take the part "as is", right out of the machine.

***Fixturing:***

Abrasivejets can be used as the primary machining operation, or to do secondary machining on existing parts. Either way, you will have to find some way to hold the material in place.

Typically, most parts are machined from plate. In this case, you simply need to weigh down the plate, to keep it from floating, and fixture it from the sides to prevent sideways motion. It is nice to have a little extra material to hold on to for this reason.

***Specifying material to be machined:*** Consider supplying your material to the job shop in sheet sizes that are convenient for them to work with. This means:

- If you can, let the job shop cut the outside parimeter of the part. It is easier to cut the parimeter of the part than have to locate internal features on an existing part where the parimeter has already been machined.
- This is because if you cut the inside and outside on the same machine, there is no chance of them loosing tolerance as you move to another machine.
- Find out what size machine the job shop has, and send them material that will fit. Most shops can take larger material, and feed it through the machine, but larger material is awkward to work with.
- Avoid material that is highly warped, or contains internal stresses. While such materials can be machined, your tolerances will suffer, and it is more work to deal with.

***Maintain compatibility with your Waterjet Job shops equipment & programming system:***

- If you farm out a lot of parts to a specific vendor, then you may be able to save some money by programming the parts in your own facility. Some vendors will appreciate this, while others will not. Ask.
- Talk with your vendor, and consider getting a copy of the waterjet software that your job shop is using, and output your own tool paths. Some manufacturers of Abrasivejet machining centers will give you copies of their programming system for free. You may also be able to use your favorite CAD/CAM package to output the tool paths. For example MasterCam, or whatever you happen to have. Check with your vendor.

***Use compatible file types to exchange your CAD data:***

DXF is undeniably the most common file type for exchanging 2D CAD data. Unfortunately, due to the hundreds of different "flavors" of DXF, you may run into conversion problems between CAD / CAM systems. Here are some pointers to avoid headaches or incompatibilities:

- AutoCad Release 12 DXF files are compatible with almost everybody. AutoCAD 13, 14, and 2000 are "iffy".
- Avoid "binary" dxf files, as virtually nobody supports these.
- Before saving as a DXF, "Explode" all entities that define the geometry of the part. ("Explode" is a command in many CAD systems, although it may be called other things like "ungroup", "convert to curves", etc.)
- You may find that your CAD system does not allow you to "Save" as a DXF. Most likely, there is another command such as "Export " or "dxfout " that will do the job.
- Use simple lines and arcs whenever possible.
- If you have trouble reading a file after it was emailed, then try using PK-ZIP to "zip" it up before emailing it. Oddly enough, some email programs will actually alter the DXF in transit, thinking it is simply text that it can format as it likes. (Older versions of Netscape do this, and possibly others.)
- Provide a print, with dimensions, so the programmer can check the file conversion against known geometry and dimensions. I recommend that you draw two concentric squares on each drawing. The outer square should have a dimension of 1 in. x 1 in., and the inside square should have a dimension of 1cm by 1cm. That way who ever you give the drawing to can quickly see if the drawing is properly scaled by simply measuring the edge of one of the squares. This will prevent mistakes such as cutting a part that is 25.4 times too big due to some metric conversion problem.

**Tip:** If the file will eventually end up on an OMAX system, then you can use the "Layers" in your CAD system to specify cutting quality (Layer 0 is for heads down traverse, 1-5 are Qualities 1-5, 6 is "etch", 7 is "scribe", 8 is "water only", 9 is for leads, 10 is for "heads up traverse", and 11 is for "Minimum Taper". Click link on the site for what the Waterjet Web Reference Glossary says about "Quality".

***Avoid mistakes, by making good CAD files to begin with:***

- Draw your part to scale. Use a scale of 1:1, or else when the part is made, it may be off by whatever weirdo scale you drew it in. It is no problem for the programmer to scale the part, but they have to know ahead of time that this is needed. This might not be caught until after the part was made; therefore, just draw it to scale to start with.
- Keep your drawings clean. Remember, your CAD drawing will be turned into a tool path eventually. Therefore, if you have lines on top of lines, or other crap in your drawing, it will make it difficult for the programmer to turn it into a tool path, especially if their CAD / CAM system does not have good automatic "cleaning" functionality.
- Make sure your drawing matches your dimensions: If you draw a circle that is 5.3 in., but then put a dimension on it that says it is 5.0 in., it will still be cut at 5.3 in. Therefore, draw it the size you want it, so it gets cut that way.
- In the file you supply to your vendor, Include only the stuff that you want cut to avoid confusion.
- Ask your vendor what kind of file they prefer to get.

***Bidding:*** This web site is probably your best resource for this. Contact several job shops in your area. Note that each job shop has their own strengths and weaknesses. Some are better at long production runs of the same part over and over, while others are better at short runs, cheap prototyping, or high precision.

- They may charge you quite a bit more money per hour for



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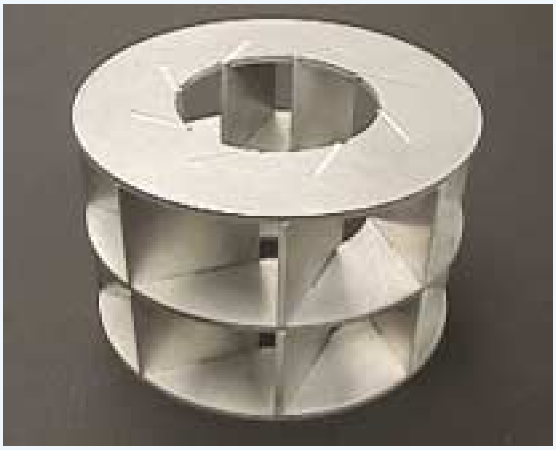
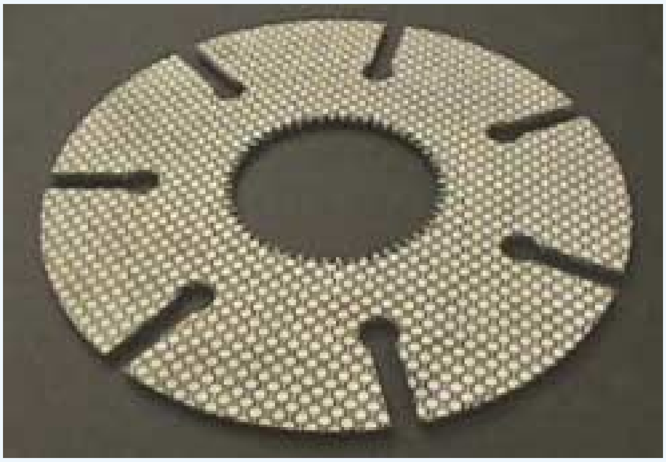
abrasivejet machine time, than they would for time on other machines. However you will probably also get more parts per hour for an overall savings.

- Also, consider contacting manufacturers of waterjet equipment, to see what shops they recommend in your area. The listings on this web site represent only a tiny fraction of the actual shops that are out there.

**Be creative!**

- You are not limited in shape or material. Cut curves in glass. Square holes in titanium, use thin webbing to replace springs.





***Above: (A) 3D part. (B) Friction plate with texture etched & profile cut with abrasive and (C) Titanium Cheese slicer.***

***Above: Brass spring.***

# Try to do what has never been done before!

***Consider buying your own machine:***

Several waterjets are designed to be precision, low cost, and capable of "just in time" manufacturing or rapid prototyping. This makes them great tools for engineers who like to tinker, and prefer to wait for minutes instead of days to get a part.

***The information from this story was submitted by Omax Corp of Kent, Washington. For more information visit www.omax.com or www.waterjets.org.***■

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