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Laser Cut Like a Boss

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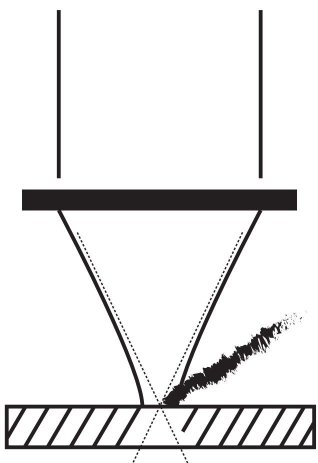
Laser Cut

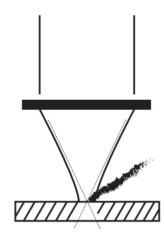
Like a Boss



CAUTION: Prototype I

The Like a Boss Philosophy

The Like a Boss philosophy is built around the central belief in the mastery of your craft, whatever you choose it to be. From blacksmithing to cooking, you are intentional with your learning and acquisition of skills— then innovative and thoughtful in your exploratory work. You may not know how to accomplish all facets of a task from the onset, but you have the confidence and collection of skills to attack the problem and execute a fitting solution.



What is this Book?

Laser Cut Like a Boss aims to aid you in bringing your project vision to life by providing informative and inspirational tips and tricks to prototyping with the laser cutter. Our goal is to help you apply design and engineering thinking toward utilizing your tool to develop your project efficiently and successfully.

How to use this book

This book is broken down into various sections:

Who Are We?

We are three undergraduate mechanical engineers in training. We work at the Design Realization Lab at Olin College in Needham, MA and have shared interests in fabrication, prototyping, and tea.

Mary Morse

Ingrid Hagen-Keith

Annie Zeng

Why Laser Cut Like a Boss?

Rapid production techniques such as 2-D laser cutters and 3-D printers are getting closer to the average consumer with each coming year. These fabrication techniques have proven to be invaluable tools for prototyping in the recent past and will only increase in importance as they become cheaper and more efficient. Although tools such as laser cutters and 3-D printers have been in existence for many years, they are still underexplored mediums of production for engineer and design applications.

Our team's shared interest at the intersection of craft, engineering, and design have led us to explore the prototyping capabilities of the laser cutter, a 2-D fabrication tool. Our goal is to share our findings with you and start a conversation around where you think the future of laser cutting fabrication will lie. Contact us, we'd love to hear your thoughts.

Reach us at:
realdesignlab@gmail.com

Laser Cutting Basics

The versatility of the laser cutter comes from its ability to machine a wide range of materials from organic woods to synthetic polymers. The energy from the raw laser beam is focused onto the surface of the material and machining is a result of the material's reaction to heat and radiation. This interaction is detailed by three major categories of laser machining: melt shearing, material vaporization, and chemical degradation.

What Does A Laser Cutter Do?

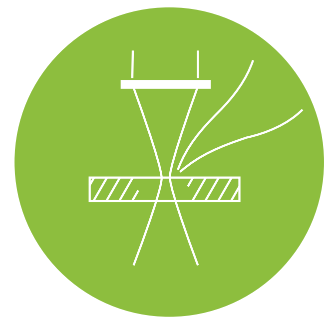
Imagine a project you would like to work on that can incorporate a laser cutter.

Design the parts using vector-creation software. Features in the drawings will dictate whether the laser cutter will cut all the way through the material or etch the surface.

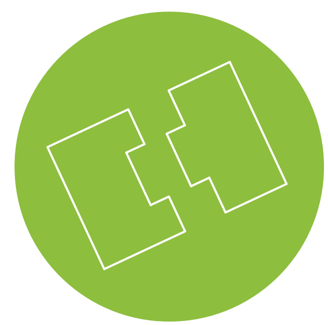
Set the cutting parameters for the cut job. Each material and job may require different settings so you will have to experiment to find the settings that you like.

Connect with the laser cutter. Remember to turn on the air assist and air filters!

Cut the parts using the laser cutter.



Realize your design!



Safety

Laser Safety

In most laser systems, the output of the high-power CO_2 laser is fully contained. However, exposure to the laser beam may cause burns and severe eye damage. Never place yourself in the path of the laser during operation.

Fire Safety

Make sure you know how to operate a nearby fire extinguisher before you execute any cut, especially with a new material. Do not ever walk away from a machine when it is executing a job because the material can catch on fire.

Fume Safety

Make sure that a ventilation system is in place to remove noxious fumes and particles resultant from the laser-material interaction. If you see or smell excessive fumes during cutting, stop the job immediately and check the air exhaust.

Note on Restricted Materials:

- Materials containing chlorine (ex. PVC) release HCL and chlorine gas when cut
- Some materials (ex. HDPE) melt horribly and catch on fire easily
- Most hobbyist laser cutters are also not rated to pierce metals
- Obtain a material safety data sheet (MSDS) to learn the hazards of processing a particular material

*** Check with your laser system manual or workshop for the specific list of restricted materials.**

Maintenance

Maintenance is one of the most significant aspects of laser cutting. A poorly kept machine and work area can reduce cut/engraving quality and increase the likelihood of a fire hazard.

Note: All WIPE-DOWN procedures should be done with a wet paper towel, Windex, or isopropyl alcohol.

Laser Bed

WIPE DOWN the periphery of the laser bed including the ruler area. Empty the crumb tray. Remove clutter around the machine to keep the area clear of combustible materials.

Optics

The external optics system can incur build-up of debris from excessive flare-ups. This can reduce the quality of the cut produced. Only clean the mirror and focus lens if you have been trained to do so. WIPE DOWN the auto-focus plunger if one exists.

Ventilation

Make sure your ventilation system is properly functioning before a job and ready to remove noxious fumes and particles. Remove visible obstructions to the exhaust airways.

*** Check with your machine shop on common maintenance practices.**

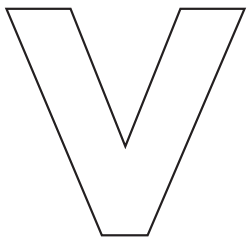
Building Intuition for Parameter Selection

The laser cutter is capable of two machining operations, vector cutting and raster engraving. Parameters as power, speed, frequency, and resolution affect the amount of energy that is delivered from the raw laser beam to the material. Although we could never provide an as comprehensive and machine specific overview as your machine manual does, this section focuses on building an intuitive understanding for each of these cutting parameters to facilitate parameter selection when machining novel materials.

Vector Cutting

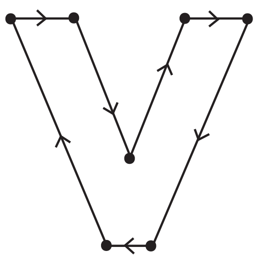
Definition: Vector cutting is a laser machining operation used to pierce or score a material, akin to a profiling operation on a milling machine.

1.



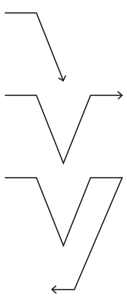
Your Cut File
Use a program to generate vector lines, which outline an object.

2.



Cut File Interpretation
Outlines are interpreted as a grid of points with a positional and directional vector associated with them. They are not seen as pixels.

3.



Laser Output
Laser follows the outline from node to node as a result of combined movement in ‘x’ and ‘y’ directions.

Very “thin” lines will vector cut instead of raster engrave. Whether the laser considers something “thin” depends on the resolution setting used to interpret the cut file and the specific laser system.

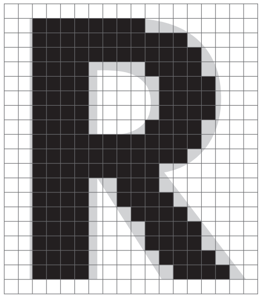
Raster Engraving

Definition: Raster engraving is a laser machining operation used to bring the thickness of the material down in depth, akin to a facing operation on a milling machine.

1.

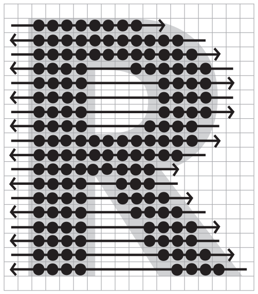
Your Cut File
Object has a fill.

2.



Cut File Interpretation
A map of pixels is created.

3.



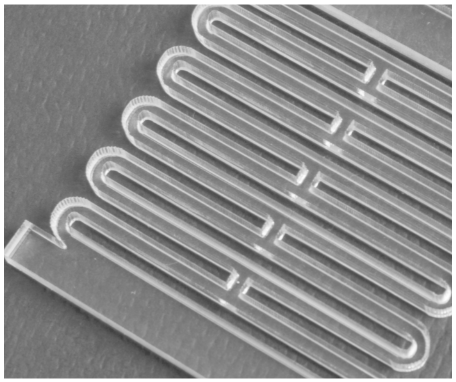
Laser Output
The laser head scans back and forth in ‘x’ direction, reversing direction every time. The resolution determines where the laser ‘sees’ a black dot and therefore fires. Increasing the resolution will also increase the cut time. The raster setting is meant for marking, not cutting.

A Material Specific Comparison

With an understanding of the differences between the cut file interpretation and laser output of vector cutting and raster engraving, let's look at a material-specific (cast acrylic) application of the two operations.

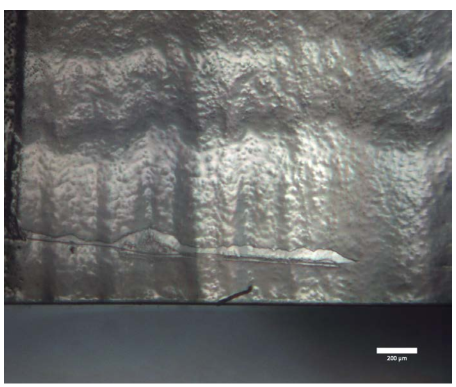
Vector Cutting

Macro



A vector line pierces material and outlines and object.

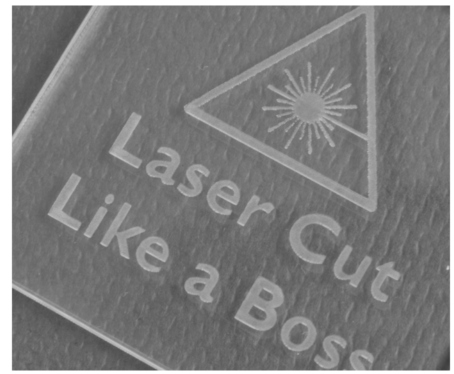
Micro



This is the side view of a vector-cut edge taken at 5X magnification on an optical microscope. The laser removes material along the entire edge of this piece of cast acrylic.

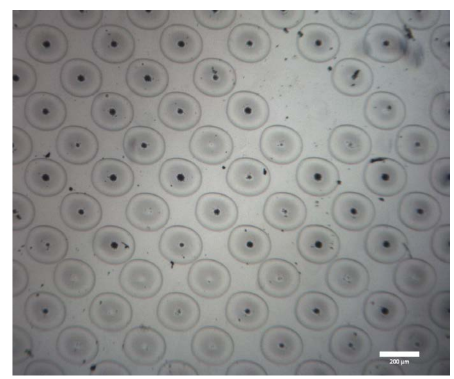
Raster Engraving

Macro



Rastering takes off the surface of a material. This operation is ideal for engraving images or text.

Micro



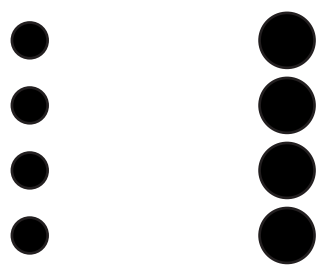
The dot pattern of a raster engraved image is shown here. The laser removes surface material only and reflects the dot pattern of the image and laser DPI settings.

Laser Cutting as an Energy Transfer Method

A laser cutter is an energy transfer method that can be used to melt, vaporize, or degrade a material. You can vary how long energy is transferred to a section of a material (speed), how much energy is transferred to a section (power), and the spacing of the energy transfer to the material (frequency or resolution for vector cuts and raster engraving, respectively). There are other ways to vary energy transfer but these are the most central to laser cutting. When cutting a new material, understanding the effects of these parameters as well as the material properties will help you narrow down an optimal setting with greater ease.

Power

Definition: Power indicates the rate at which energy is transferred in the laser beam. Power is measured in W, and it is often displayed as a percentage (%) of maximum power. Maximum power differs for each model and laser system.



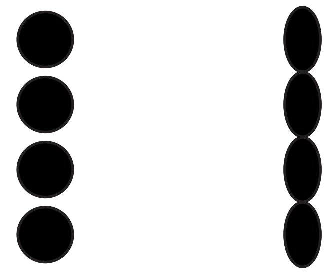
Low Power High Power

- Lower power applies less energy per pulse on the material.

- Higher power applies more energy per pulse on the material.
- In general higher power means deeper cuts than lower power.

Speed

Definition: Speed indicates how fast the laser head moves. It is measured in units of distance/time and is often expressed as a percentage (%) of the maximum speed. Maximum speed differs for each model and laser system.



Low Speed High Speed

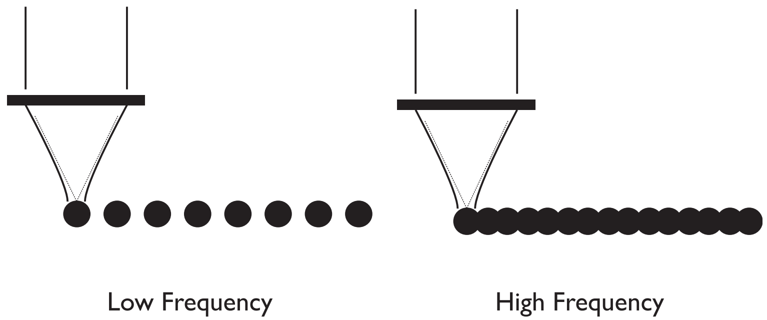
- Lower speed allows more time for the laser beam to dwell on a particular spot which means more energy is transferred to the material.
- In raster engraving, lower speed gives more time for the material to cool between consecutive passes of the laser head.

- As speed increases the amount of energy transferred to a specific area on the material decreases because one laser pulse is spread out over a larger area and also has less time to dwell on the area.
- To reduce charring and thermal damage, increase the speed so that the air assist can quickly access the recently cut zones.

Vector Cutting

Frequency

Definition: While vector cutting, frequency indicates the number of pulses fired per second or per inch of travel depending on the laser system (measured in pulses/second, PPS, & Hz or pulses/inch, PPI).



- Lower frequency means less heat is applied to the material per inch
- There is less overlap between pulses
- Lower frequency reduces melting and charring because less heat is applied
- Lower frequency results in a serrated edge or perforated cut

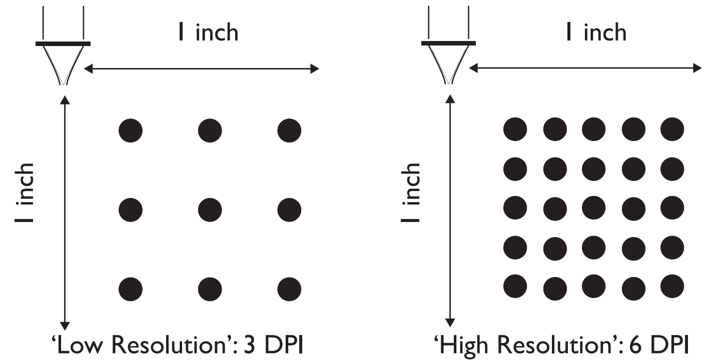
- The higher the frequency, the denser the dots on each path, and therefore the more dense the energy applied on the material.
- Higher frequency decrease the amount of energy in each pulse if all other settings are held constant because total energy allotted is divided evenly amongst each pulse.
- Higher frequency is great for melting materials to a polished look

Both resolution and frequency are similar in that both are concerned with the number of pulses fired in an area. The major difference between the two is that resolution determines the quality of the image clarity or an area of a shape that is rastered, while frequency determines the quality of a line.

Raster Engraving

Resolution

Definition: While raster engraving, resolution indicates the density of pulses (measured in dots per inch, DPI). Resolution can also be thought of as the image density.



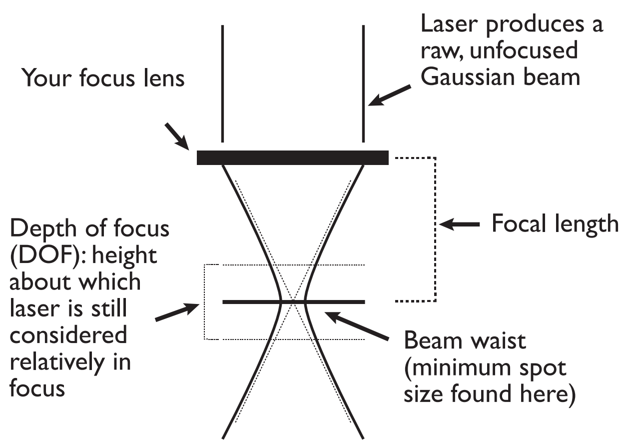
- Lower resolution means faster cut time
- Great for doing drafts for a job; coarse images

- Higher resolutions give clearer and more detailed the prints.
- Since each pulse applies the same amount of energy regardless of resolution settings, higher resolutions deliver energy at a higher density than lower resolutions. At particularly high resolutions, the dots machined overlap meaning most of the image is printed twice, making for a darker, deeper image.

Recap: Laser Cutting as an Energy Transfer Method

A laser cutter is an energy transfer method that can be used to melt, vaporize, or degrade a material. The main parameters, speed, power, frequency, and resolution determine the amount of energy applied to the material. After a set of parameters are chosen, for optimal energy transfer and the highest energy density (energy per area) possible, your laser beam must be in focus on your material. Manual or autofocus options exists for a range of laser systems.

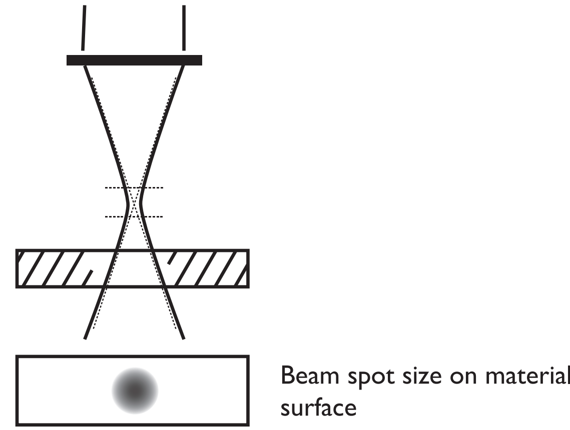
Focusing the Raw Beam



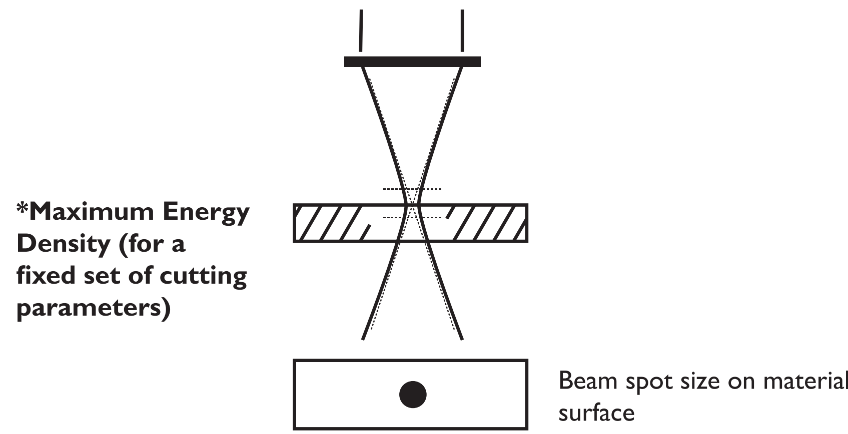
The wavelength of the CO_2 laser, 10.6 micrometers, sets the limit for the minimum spot size achievable.

The raw beam from the laser tube is propagated and focused via a lens and mirror setup. The focus lens in the laser head concentrates the beam down to a minimum spot size found at a focal length's distance from the lens. The energy density of the beam (energy per area) is determined by the energy supplied by the laser and the area of the focused spot size. A smaller spot size (when the beam is in focus), results in a higher energy density.

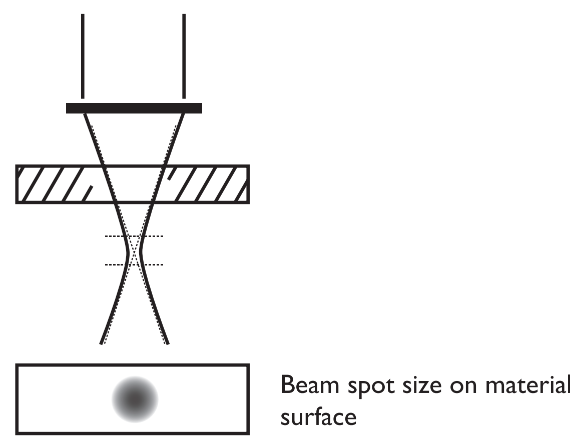
1. Beam is focused above the material.



2. Beam is focused on the surface of the material.



3. Beam is focused below the material.



Laser-Material Interaction

The versatility of the laser cutter comes from its ability to machine a wide range of materials from organic woods to synthetic polymers. The energy from the raw laser beam is focused onto the surface of the material and machining is a result of the material's reaction to heat and radiation. This interaction is detailed by three major categories of laser machining: melt shearing, material vaporization, and chemical degradation.

Laser-Material Interaction

There are three main types of laser machining (material removal methods):

Melt Shearing

Many polymers are cut through the process of melt shearing. Essentially, the laser creates a molten pool of material which is continually blown away by the air jet. It is important to note that cut quality is affected by the way this molten material leaves the cut zone. If one is rastering or vector engraving, the molten material will be blown away to the sides of the cut where it will resolidify. If one is cutting all the way through a piece, then the molten material will be blow out of the bottom of the cut. Even in this case, it is not possible to remove all of the melt, so some material will resolidify along the edge. The turbulence of the air jet disturbs the material as it is cooling and creates a rippled texture along the cut edges.

In theory, this process involves a simple change of phase from solid to liquid. In reality however, some chemical change does occur. This means that in a chemical sense the makeup of the cut edge is slightly different than the rest of the material

Common materials machined via melt shearing include most thermoplastics as nylon, PP, and PETG.

Material Vaporization

The only material commonly cut by vaporization is acrylic. The laser beam acts to melt and then vaporize the material, which leaves as a gas. The air jet on the laser head acts to blow away the gas which is generally flammable. The molten material is not entirely vaporized causing some of it to remain on the cut edge giving a similar rippled appearance as that which was discussed for melt shearing. In general, the cut edge is very smooth and has a high quality finish.

Common materials machined via material vaporization include POM (Delrin) and PMMA (acrylic).

Chemical Degradation

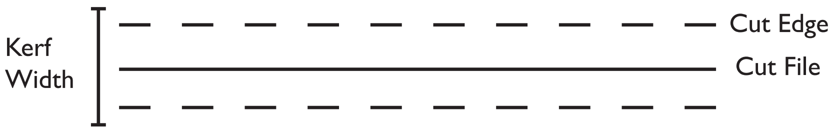
The laser beam acts to break chemical bonds in a material. For many materials this process takes the form of localized burning. This process tends to be slower and high energy because of the large amount of activation energy it takes to initiate these chemical reactions. This process yields a flat and smooth cut edge that usually has a layer of residual carbon dust.

Common materials machined via chemical degradation include wood, MDF, and silicon rubber.

Note: Not all materials fit squarely into one of these processes. To understand how a material will respond to laser light it is necessary to know what it is made of. For example, opaque acrylic is made with fillers that typically burn when subjected to laser light. This means that the acrylic will have its usual high quality cut edge accompanied by white soot left over from the burnt filler material.

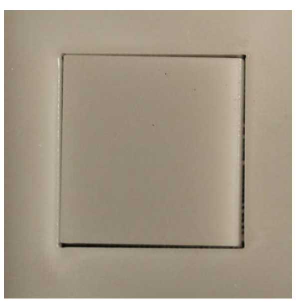
Kerf

Defined: Kerf is the width of the cut made by the laser. It changes the finished size of your cut piece.

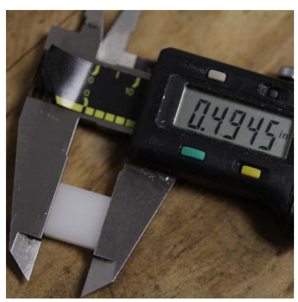


How to deal with kerf (a kerf test)

The laser kerf can be different across materials for a variety of reasons ranging from the pressure on the air assist to the method by which the laser removes the material. For this reason, if you are trying to make a precision cut or get a close fit between two pieces, you must take the kerf into account and alter your cut file accordingly. The best method of approach is to do a kerf test on a sample piece to understand the tolerances that you will be working with. The kerf is also a factor in the minimum width of objects that you can laser cut on a material in order to still preserve the integrity of the piece.



Cut a test square



Measure the square piece and the hole it left behind in the stock

The kerf width can be measured as the difference between the outer and inner measurements taken. Compensating for kerf is easy. Just add or subtract half the kerf width from the edges of your cut file.

Material Profiles

Following are profiles for some commonly laser machined materials. A discussion of the material, its main applications, and its laser machining and mechanical properties are presented.

Cardboard

+ ***Material is*** *wood composite*
+ ***Available at*** *Uline, McMaster-Carr, Thomasnet, Georgia Pacific & International Paper*
+ ***Varies by*** *flute size and thickness*
+ ***Available as*** *corrugated sheets and rolls*

What is this material?

Cardboard is a composite material made up of layers of corrugated paperboard (the medium) and outer layers of flat paperboard (the linerboards). It is typically referred to as corrugated fiberboard in the manufacturing industry.

Main Applications

The main use of corrugated cardboard is in packaging and shipping. The fluted layer allows corrugated cardboard to deform elastically in response to loads applied to the package, protecting the contents inside from harm. Recently, it has also become a popular prototyping material. Since corrugated cardboard is so widely used in the shipping industry, anyone who has ever ordered a package or bought a large appliance has the material available to them. Corrugated cardboard is easily manipulated using common household tools like a box knife or scissors. This means that rough mock ups of bigger projects which require more complex machining and expensive materials can be made quickly and easily for proof of concept.

Thermal Properties

Wood fibers have a flashpoint that is much lower (about 420°C) than their melting temperature (about 3500°C). For this reason, corrugated cardboard is cut by chemical degradation. Essentially, the laser produces a localized fire on the surface of the material which produces CO_2, water, and carbon dust, which are then blown away by air assist.

Thermal Properties	**Value**
Thermal conductivity (W/m K)	0.21
Ignition point (degrees Celsius)	427
Specific Heat Capacity (kJ/kg K)	1.4

Mechanical Properties	**Value (MPa)**
Tensile modulus against grain	863
Tensile modulus with grain	555
Bending modulus against grain	844
Bending modulus with grain	605

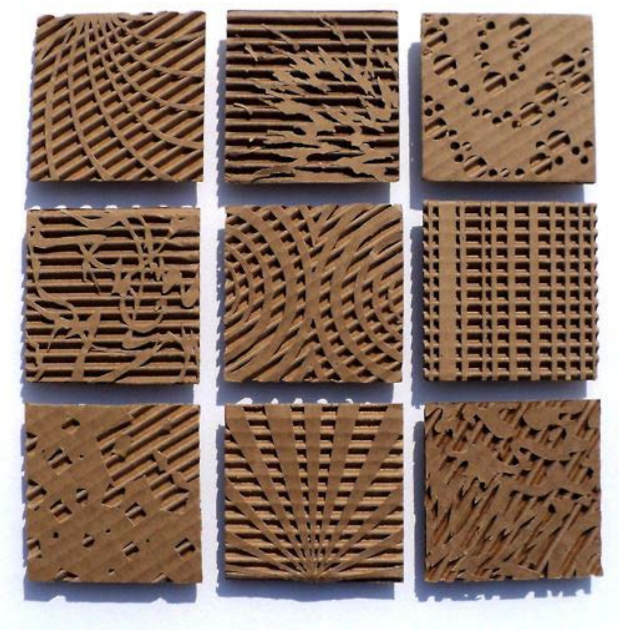
Mechanical Properties

Corrugated cardboard is essentially composed of tiny wood fibers and a matrix of resin or starch to hold it all together. Typically these bonds are relatively weak. Thus, the force required to break these bonds will be relatively low by mechanical and chemical means. If the matrix used is starch, the material should dissolve in water. Since the glue used to hold the layers of corrugated cardboard together is typically made of starch, it should also dissolve easily.

Corrugated cardboard is anisotropic in nature. It can resist higher tension and bending forces parallel to the direction of the flutes. Corrugated cardboard that is made with multiple fluted layers is sometimes produced with the grain running in different directions to counteract this anisotropy.

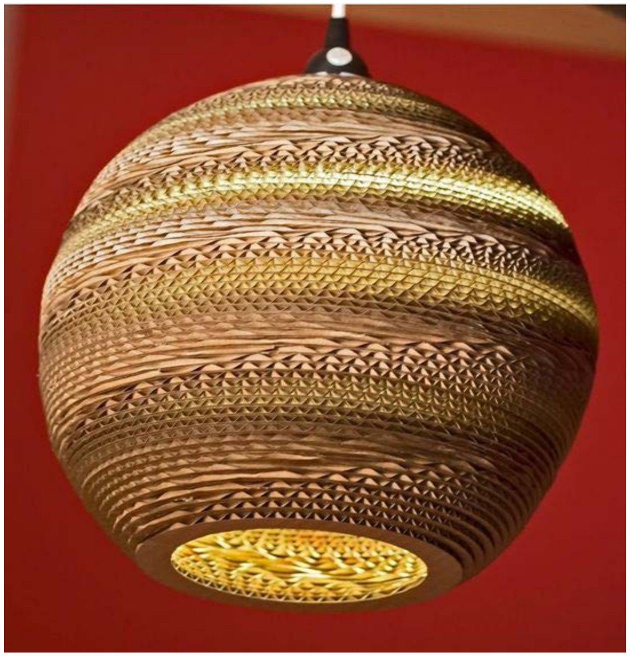
Cardboard

Trade Secrets: Cardboard Relief



The precision of the laser enables the user to cut through individual layers of corrugated cardboard. With careful experimentation, one can find settings which cut through the top layer of corrugated cardboard only. This way you can vector cut a pattern out of the top layer of the corrugated cardboard, then selectively peel away certain parts. Take care when cutting shapes with a radius smaller that the width of the grain of the corrugated cardboard as desired parts may fall away if they aren't located precisely on the corrugated cardboard. Wetting the top surface of the corrugated cardboard may make peeling it away cleaner and easier. When peeled away dry, the material has a tendency to tear and leave small pieces that make the finished product look messy.

Trade Secrets: Variation in Fluting Orientation



In applications where the fluting of the cardboard is visible, the orientation of the cut edge changes the appearance of the material. This can be manipulated to create effects of texture or to render images on a surface.

Delrin

+ ***Material is a*** *thermoplastic*
+***Available at*** McMaster-Carr
+***Varies by*** *thickness from 0.010”-4”*
+***Available as*** *black and white sheets and circular bars*

What is this material?

Delrin is a thermoplastic polyacetal material. Polyacetals come in various forms (determined by their molecular structure). Delrin is a polyacetal homopolymer formed from pure formaldehyde molecules.

Main Applications

Delrin is a great engineering material. It has a high stiffness and high toughness. It has low friction, low water absorption, and a high resistance to scratching and scuffing. This makes it a fantastic material in industry and for laser cutting. In industry, it is often used to create small gears, ball bearings, ski fasteners, knife handles, joint clips, zippers, instrument picks, and insulin pens. In the laser cutting world, vector and raster cutting of precision parts in Delrin have been very well explored.

Delrin, however, is one of the more expensive laser cuttable thermoplastics. You cannot use adhesives with Delrin and it is always opaque, limiting its aesthetic possibilities. As a result, we suggest that Delrin is used as a “final product” material for engineering designs that are very well planned.

Thermal Properties

Delrin cuts by vaporization as the ignition temperature is low. Delrin’s fatigue resistance is affected by the material’s thermal conductivity (ability to transfer heat). Since the material has a relatively low thermal conductivity, the material does not generate a lot of heat when stressed overtime, resulting in a high fatigue resistance.

Thermal Properties	Value
Thermal conductivity (W/m K)	0.4
Ignition point (degrees Celsius)	320
Specific Heat Capacity (kJ/kg K)	0.35

Mechanical Properties	Value (MPa)
Tensile modulus	2800
Flexural modulus	758
Coefficient of Friction	0.2

Mechanical Properties

The material is particularly tough because it has a balance of crystalline and amorphous regions. The polyacetal chains form lamellae (crystalline sections) and have occasional, amorphous (formless) regions in its polymer structure. The crystalline regions of the material make it strong while the amorphous regions allow the material to bend. This ensures that cracking in Delrin does not occur (like in acrylic). For Delrin, the orientation of the part with respect to its extrusion direction has a negligible effect.

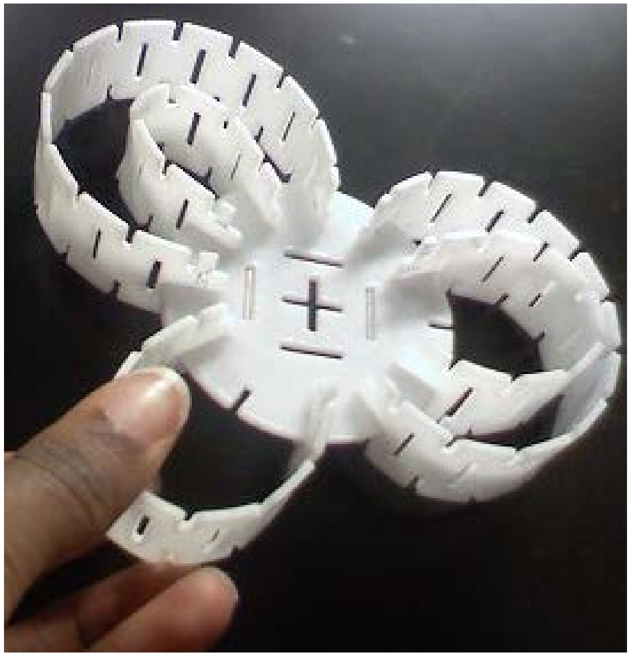
Delrin has a low coefficient of friction because of the flexible stacking of the polyacetal chains. This, combined with even extrusion, results in a superiorly smooth material.

Delrin

Trade Secrets: Synthetic Raster Contrast

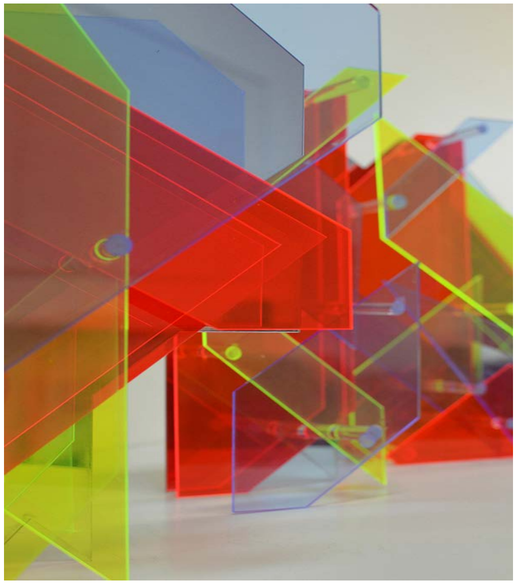
When you raster white Delrin, the rastered image is white. But you can create "synthetic" contrast. After rastering a design, blot the area with a dry erase marker and let it wick into the Delrin. Once it seeps long enough, wipe away the excess to reveal your design. Make sure to do some prototyping with this technique.

Trade Secrets: Creating Rough Edges



To create a rougher finish, this maker changed the frequency of her laser cutter to create a more jagged surface that could grab hold of a surface.

Acrylic (PMMA)



+ ***Material is a*** *thermoplastic*
+***Available at*** McMaster-Carr, Lucite International, Plaskolite, J. Freeman
+***Varies by*** *color and transparency*
+***Available as*** *mirrored, cast, extruded and many others*

What is this material?

Poly(methyl methacrylate), known commonly as acrylic, is a transparent thermoplastic polymer. Acrylic is a choice material for laser cutting due to the ease with which it is laser machined.

Main Applications

Some desirable qualities of PMMA include high light transmission and the aesthetic appeal of transparency. PMMA is widely used for illuminated as well as non-illuminated display signs. Trophies and memorabilia often use cast acrylic as the base material due to the high visual contrast produced by engraving the material. Furthermore, acrylic is often used as a shatterproof glass substitute. It is more weather resistant than other plastics as polystyrene and polyethylene and therefore often found in outdoor applications.

Thermal Properties

Acrylic is laser machined via material vaporization. This is in contrast to most other thermoplastics which are cut by melt shearing due to acrylic's relatively low vaporization point. When heated above the glass transition temperature (about 100°C), PMMA becomes rubbery, a state which extends for about 60°C. Raising the temperature above this point causes decomposition. Thermal degradation of PMMA occurs at 300-400°C.

Thermal Properties	**Value**
Thermal conductivity (W/m K)	0.2
Ignition point (degrees Celsius)	560
Specific Heat Capacity (kJ/kg K)	1.47

Mechanical Properties	**Value (MPa)**
Tensile modulus	3200
Flexural modulus	3000
Coefficient of Friction	

Mechanical Properties

Poly(methyl methacrylate) is derived from the polymerization of methyl acrylate. Most commercial acrylics are amorphous, linear polymers with a wide range of molecular weights. The difference in molecular weight determines the amount of entanglement of polymer chains; a high molecular weight contributes to extensive chain entanglement and therefore a more rigid material. However, the syndiotactic nature of acrylic polymers (orientation of side chains are alternating in space) does not enable the polymers chains to pack so closely as to form a crystalline material.

Manufacturing variations between cast and extruded acrylics result in sheets with different mechanical properties. Casting produces a homogenous (polymer chain orientation is random) material with similar properties in all directions. On the other hand, extrusion aligns polymer chains, resulting in a heterogeneous sheet with properties which vary depending on the extrusion direction. The polymer is often stronger in the direction parallel to the molecular orientation. When cast acrylic is annealed in its heating cycle, it reduces the amount of residual stresses in the polymer as compared to its extruded counterpart.

Acrylic (PMMA)

Trade Secrets: Engraving Cast Acrylic

Engraving acrylic on the underside of the material allows the image to be seen through the thickness of the piece. Mirror your graphic in your cut file to produce the correct final engraving.

When engraving graphics which span large areas, the fine, horizontal lines of engraving can cause the final image to look coarse. Lower the laser bed, and shift the piece from the optimum focus level by just the slightest bit so that the spot size of the laser is increased and the raster strokes are overlapping to achieve a smoother, blending effect.

Trade Secrets: Engraving Mirrored Acrylic

Single surface mirrored acrylics come with a reflective side and an opaque backing on the opposite surface. When engraving mirrored acrylic, a double image will occur if engraving on the reflective surface (you can engrave on the back side instead). When vector cutting mirrored acrylic, cut with the mirrored surface up and don't worry about the laser reflecting off of the material because it will be absorbed by the acrylic first.

This laser engraved wedding invitation by decadentdesigns on Etsy showcases the double image effect of engraved mirrored acrylic.

Joinery Techniques

In this section we'll share a few joints that we've created on the laser cutter. Each joint will appear alongside example projects as well as cut file geometry so that you can use these in your own projects.

Gallery

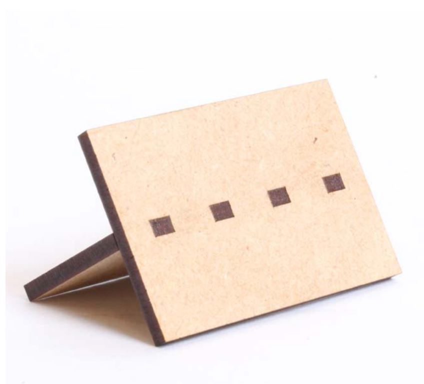
Cogged Scarf

Dado

Dovetail

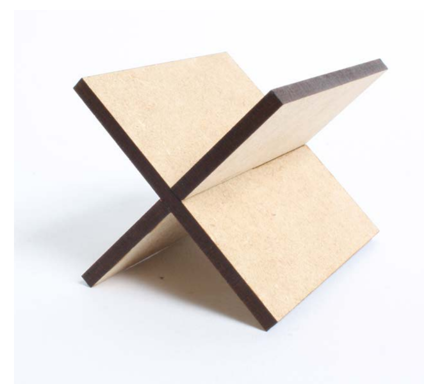
Finger

Keyed Mortise and Tenon



Mortise and Tenon

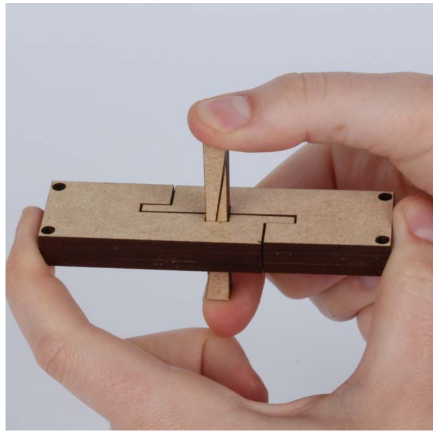
Planar Dovetail



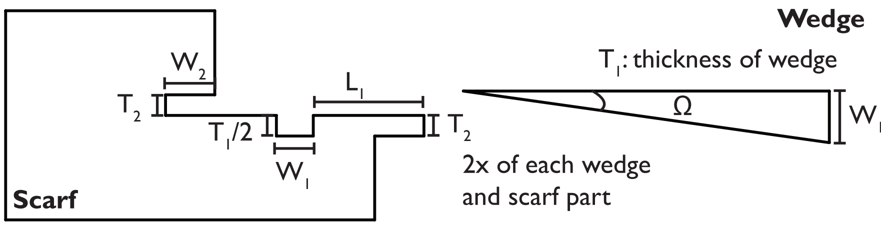
Slot

Cogged Scarf

A scarf joint is unique because the joining angle is not 90 or 180°. The angled joining surface exposes a large area for interlocking. The cogged scarf is a special variation of the scarf joint which has additional fortification against tensile and shear stress as a result of the cog.



Joint Design



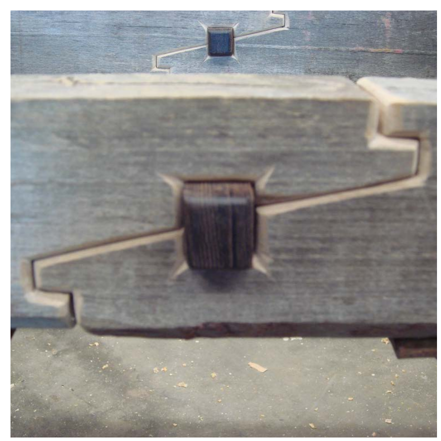
Parameter	Importance
W_1, T_1	Ensure that these complementary parameters on the wedge and scarf form a snug fit to limit motion
T_2, W_2	Increasing T_2 and W_2 gives the joint greater resistance to planar bending
L_1	Increasing the length of this surface area reduces shear and twist between the two scarf parts

This particular design of the cogged scarf joint takes advantage of the variable width of folding wedges. The taper angle, Ω, along with the length of the wedge adjusts the snugness of fit when the complementary wedges are inserted.

Applications

This joint has two cogs for extra support against tension.

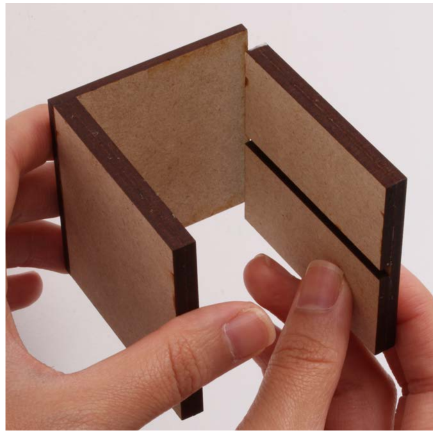
This joint is highlighted by the use of two different woods.



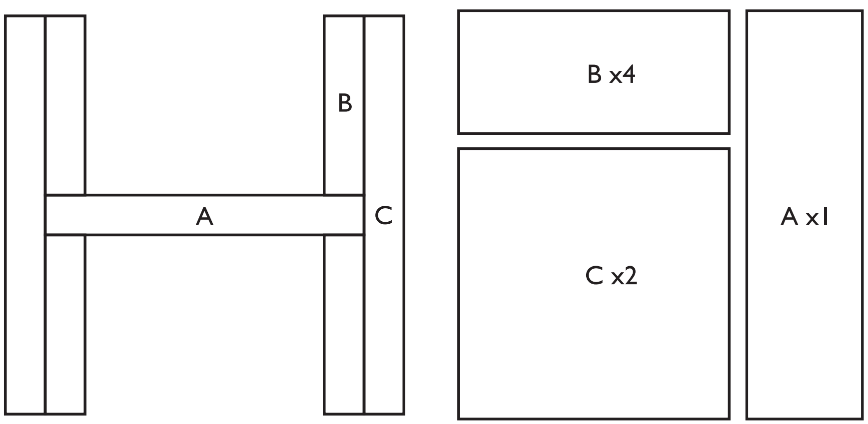
Scarf Joints can be made at an angle, or parallel to the edges of the piece.

Dado

The layered dado is a highly useful and versatile joint that is easily fabricated using the laser cutter. It is often used in shelving.



Joint Design



Parameter	Importance
A	This member forms a shelf and slides into the gap left in the B and C members.
B	These members should be glued onto C such that it leaves a gap that is about the thickness of A.
C	This member needs to at least tall enough to cover the gap left for A. It must also be wide enough to run the full length of B.

Applications

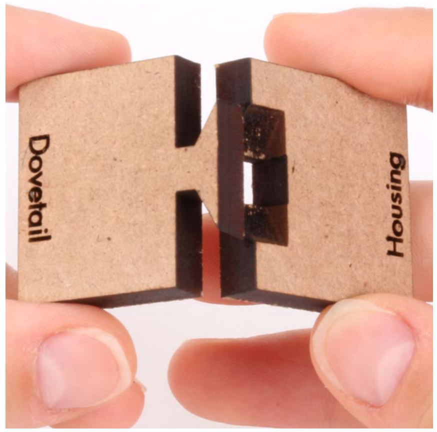
The slot is used on the glasses case a compact way close the case.

The slot can be layered in varying ways to create a flat top as in the box's top (by Perera and Quinlavin).

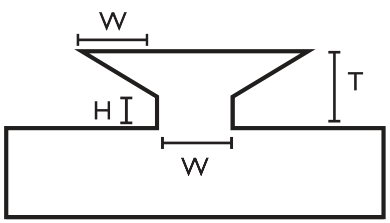
Zeng and Hagen-Keith used the configuration for slot joints described in this guide.

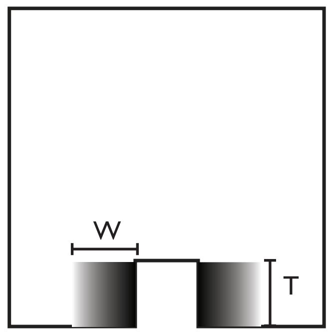
Dovetail

A dovetail joint is useful for holding two pieces of material together in perpendicular planes. The tapered dovetail is stronger than joints like the finger joint because the angled shape prevents pieces from sliding apart easily.



Joint Design





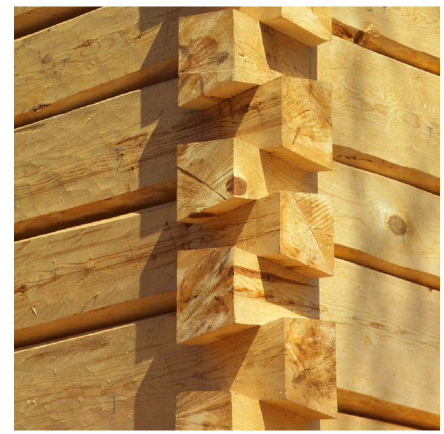
Parameter	Importance
T	Thickness of the material used
W	Unit width of the dovetail
H	Height of stand off

This joint takes advantage of some advanced rastering techniques on the laser cutter. It uses a mode where the laser will vary the power output according to a grayscale gradient. Lighter shades use less power, while darker shades use more.

Applications

This joint is quite visually pleasing and is often used in woodworking for drawers, boxes and other perpendicular faces.

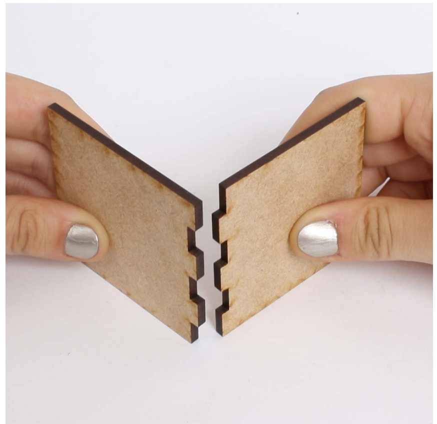
This joint is quite strong and can used to support a lot of compressive loading.



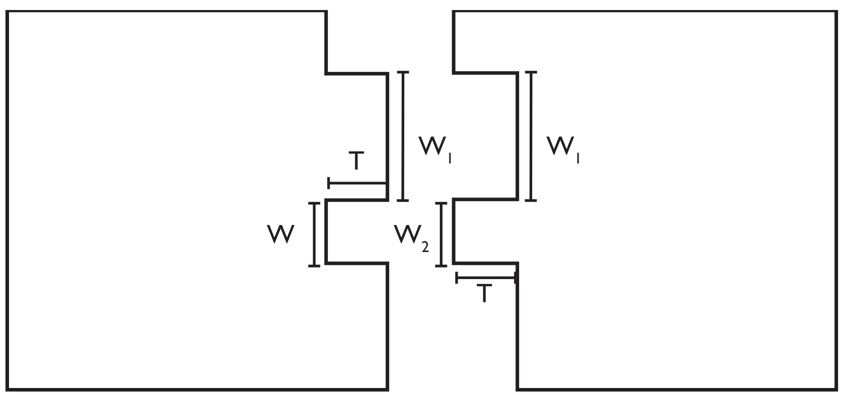
The dovetail joint can be used to create angles between parts that are not quite perpendicular by playing with the angles.

Finger Joint

A finger joint (also a box joint) is used to interlock pieces at a border. The design is simple involving only sets of complementary rectangular cuts. This design can be made more structurally sound by including glue. It is a strong design and adds to the aesthetic of the piece.



Joint Design



Parameter	Importance
T	This represents the depth of the finger. If you want to create a finger joint at 90° angle, this should be the thickness of the material you are using.
W_1, W_2	This measurement on each finger should match up with the corresponding gap that it fits in on the other side of the joint.

Applications

This castle made by students at the Olin College of Engineering utilizes numerous finger joints.

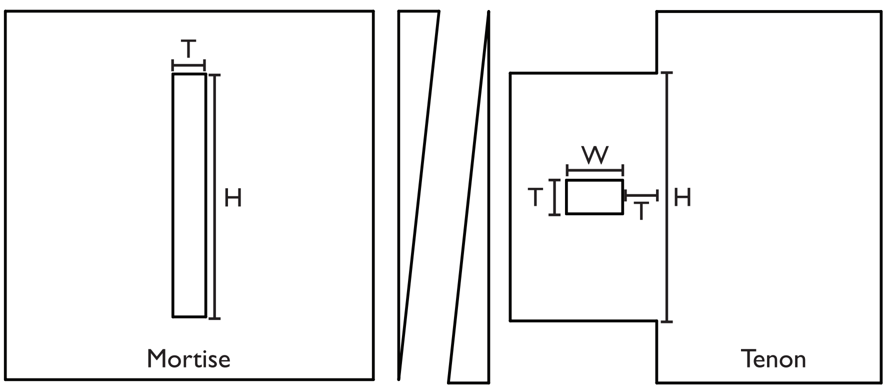
This finger joint by s. krushchen is laser cut from Baltic birch.

This joint can be modified to be different shapes for any aesthetic style.

Keyed Mortise & Tenon

A keyed mortise and tenon is a common variation on the mortise and tenon joint. In this version, the tenon protrudes from the end and has a slot for a wedge. The wedge reinforces the joint against tension and makes the use of glue unnecessary.

Joint Design

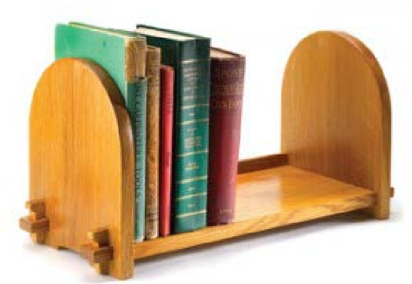


Parameters	Importance
H	Height of the mortise, the tenon needs to be about the same size.
T	Thickness of the material being used
W	Width of the slot through the tenon. The wedges need to be about this width to create a tight fit.

Applications

Mortise and tenon joints can be seen on furniture where a joint needs to be strong but also easy to deconstruct.

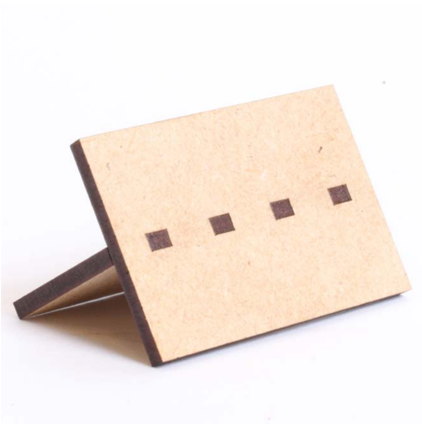
This is another typical application of the keyed mortise and tenon.



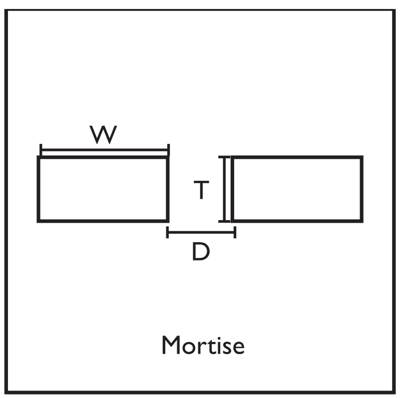
This mortise and tenon uses a decorative wedge for an aesthetic effect.

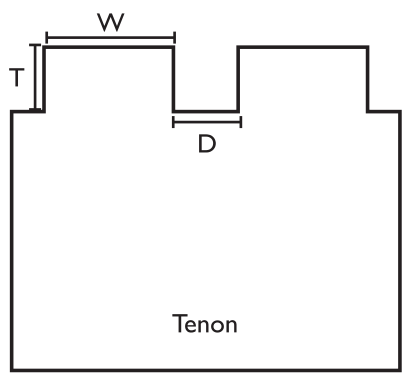
Mortise & Tenon

A mortise and tenon is used to attach to pieces of material along perpendicular planes. The finger-like tenons slip into the mortise openings. With a snug fit this joint can be very strong, but is not easy to disassemble.



Joint Design





Parameters	Importance
T	Thickness of the material being used
W	This is the width of the tenon, it should match the width of the mortise.
D	Distance between each tenon.

Applications

This joint can be used to create partitions in a box. Note that in the toolbox by Steven Mattern, finger joints were used on the outside edges while mortise and tenon joint were used to create the non-corner partitions between the helicopter, car, and backhoe.

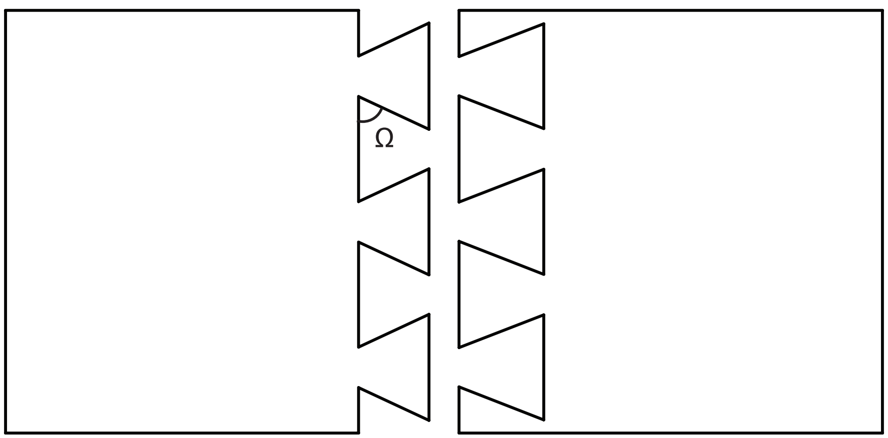
The model rocking chair pictured here uses a single mortise and tenon on the ends of each of the arm rests.

Mortise and Tenon Joints hold the front panels of this box in place (Morse and Sutantio).

Planar Dovetail

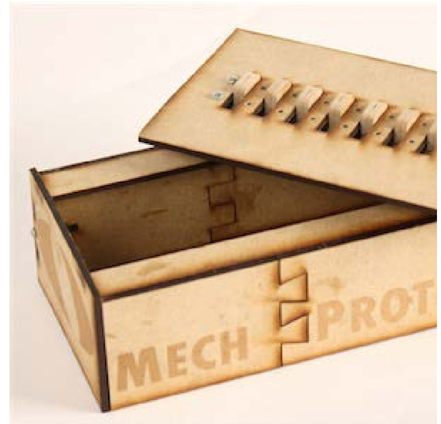
The dovetail joint is a way to join two elements in a plane. It is easy to assemble but requires more consideration when cutting due to the challenge of making a snug fit.

Joint Design



Parameters	Importance
Ω	Making the angle of the dovetail smaller will help the joint to resist tension forces

Applications



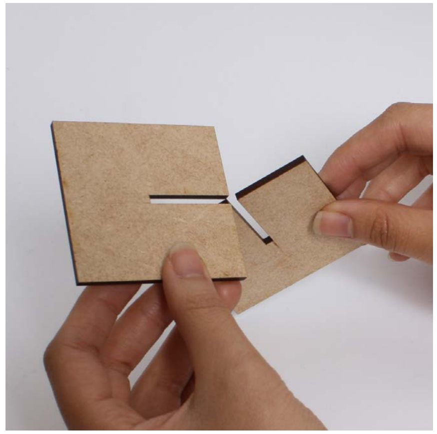
This use of a dovetail joint is mostly aesthetic, but it demonstrates how a dovetail could be used to join two pieces of flat material. It could be especially useful when making something that is larger than the capacity of the laser cutter (by Holzgrafe and O'Toole).

This chair uses a dovetail to join the seat to the legs in an aesthetically pleasing way. The joint isn't cut all the way through the leg in order to support the seat.

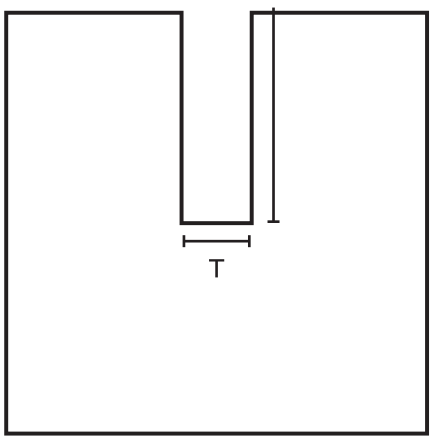
The bowl pictured here is made from laminated scrap wood and uses the dovetail as an aesthetically pleasing way of joining individual pieces.

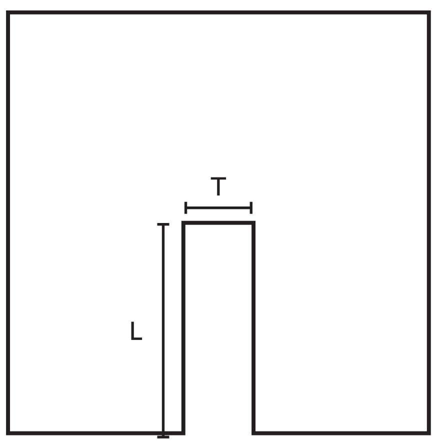
Slot Joint

A slot joint is used to join two pieces of material along perpendicular planes. This type of joint is valuable for it's simple construction; no extra fasteners are required.



Joint Design



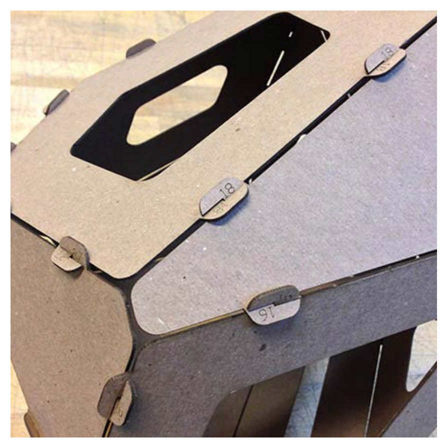


Parameter	Importance
T	Thickness of the material used
L	Consider how far you want the material to extend past the joint.

Applications

This lamp uses slot joints and curved geometry to create a 3D shape for planar materials.

The simple construction of slot joints also makes it an ideal choice for modular building blocks.



This project used slot joints to hold different pieces together along their edges. You'll also notice, that none of the joints pictured here are perpendicular. To change the angle created by the joint, the width of the slot must be increased slightly.

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Finger Joint

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Notes and Sketches

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