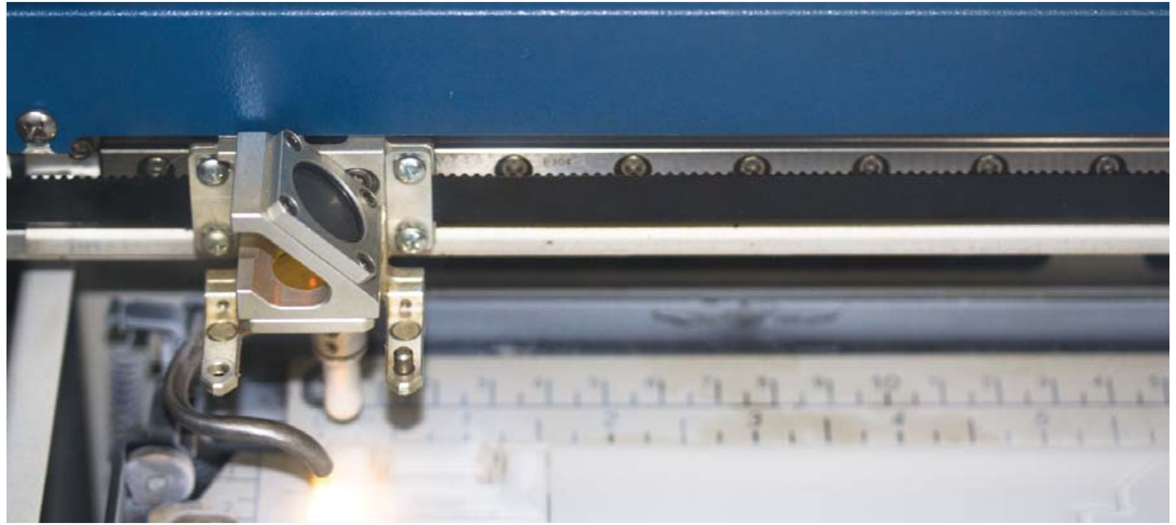
Laser Cut Like a Boss: Compliant Joints



Our laser cutter: a 60W Epilog Helix

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.

Laser Cut Like a Boss (LCLAB) is a publication created by three undergraduate research students studying mechanical engineering. We apply a design and engineering perspective toward utilizing the laser cutter as a prototyping tool for project development. Our goal is to share the laser cutting techniques and prototyping processes we've explored in hopes of informing and inspiring our audience. We'd love to hear from you! Feel free to share your feedback on our work as well as some of your own laser cutting stories.

How to use this booklet

In every issue, we feature laser cutting explorations by each member of our team. These three laser tidbits are meant as aids and inspiration techniques that can be incorporated into your prototypes during your project development process. We also take pains to think citically about and convey our own prototyping processes, detailing successes as well as failures.

Each team member has a specific take on prototyping and exploratory work which is reflected in the style of our sections. The sections are color-coded so that you may differentiate between, comment on, or adapt parts of each prototyping process to your own.

At the end of each section is a list of resources / citations that can be beneficial if you are interested in diving deeper into the topic. In the back is a place for your own notes & thoughts.

In this issue:

- **What is compliance?**
- **Materials & compliant mechanisms**
- **Mathematical models for living hinges**
- **Snap-fit design**
- **Rotary snap-fit**

Compliant Mechanisms//Everything is a spring

All materials have a natural flexibility. The ability of a material to deform and return to its original shape depends on two factors: the elastic modulus and the geometry of the piece. The elastic modulus is a quantity that describes a material's tendency to deform elastically when a force is applied to it. Compliant mechanisms use this natural flexibility to transfer an input force or displacement to another point.

In this issue, we'll share 3 examples of laser cut compliant mechanisms:

Cantilever Snap-Fit Joint

Rotary Snap-Fit Joint

Lattice Hinge

MATERIAL AND DESIGN CONSIDERATIONS FOR COMPLIANT MECHANISMS

ELASTIC MODULUS AND YIELD STRENGTH

Each material has a unique elastic modulus and yield strength. The elastic modulus of a material is the tendency of a particular material to deform along an axis. The elastic modulus is a measure of stress (force over a given area) over strain (extension over original length) and therefore has pressure units (GPa in the table). A smaller value indicates that the material is more flexible/compliant.

The yield strength of a material is the stress at which a material begins to deform plastically (i.e. it will not return to its original configuration). It is a measure of stress and is therefore given in pressure units (GPa in the table). If a material deforms plastically, it is no longer considered compliant.

Remember that the elastic modulus is a proportion of stress over strain so don't fret when the elastic modulus of a material is greater than the yield strength.

When selecting a material, look for a proportionally low elastic modulus and high yield strength.

Ultimately, you need to experiment to get an intuitive sense.

Material	Elastic Modulus (GPa)	Yield Strength (GPa)
Acrylic	3.2	0.072
Delrin	1.5	0.099
MDF	4	0.02
Rubber	0.01-0.1	0.001-0.007
Wood (along the grain)		
Douglas Fir	13	0.03-0.05
Oak	11	0.05-0.1
Pine	9	0.05-0.1

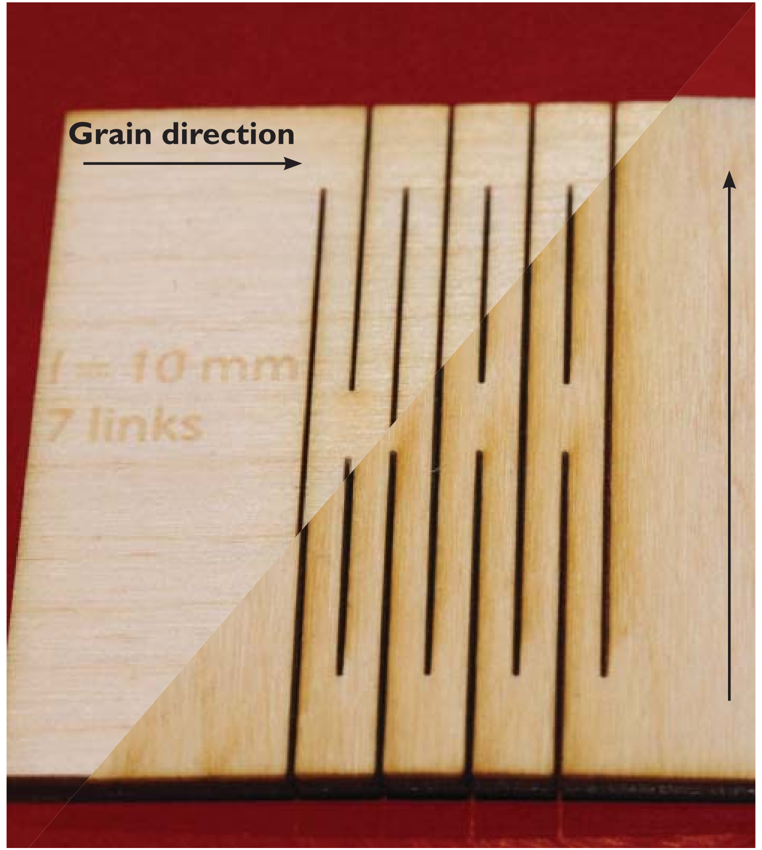
Note that a structure has a certain stiffness (think spring coefficient for a metal spring in a pen) which is determined by the structure's material **and** geometry.

When creating a compliant mechanism, you will want to keep the elastic modulus comparatively low and the yield strength high. You'll want to optimize the geometry by testing.

We should also point out that not all materials have identical behavior in all directions. Some materials have a grain that affects its behavior.

MATERIAL AND DESIGN CONSIDERATIONS FOR COMPLIANT MECHANISMS

EFFECT OF GRAIN ON COMPLIANCE

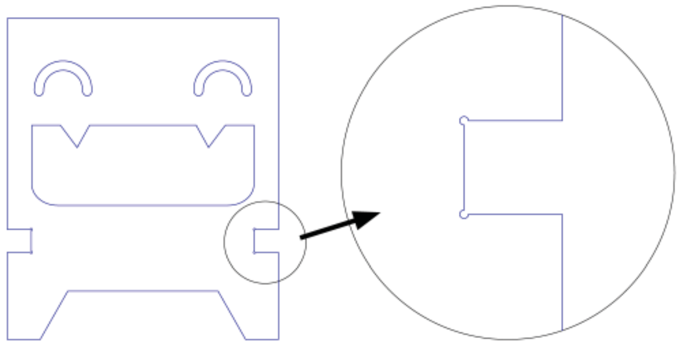


Grain direction has an effect on strength. This becomes particularly important when creating a compliant mechanism. Compliance works best when the cuts are along the grain (as seen in the right partition of the image). When cut against the grains, they acts as shear planes and the piece is less flexible and more likely to fail. It is also important to consider the ply of your material. Consider which is most dominant for your joint's case (e.g. where is the greatest deflection, which layer is thickest, etc).

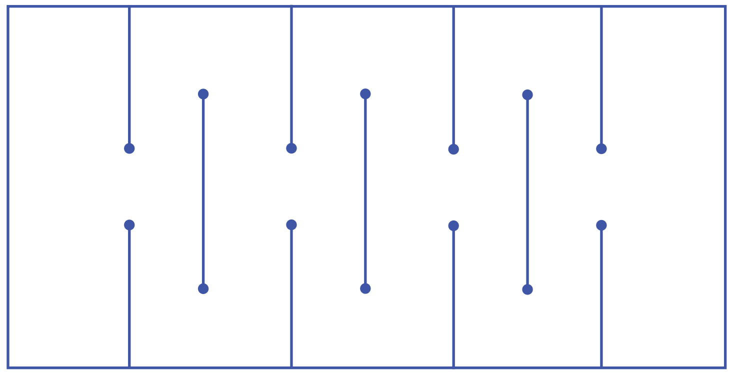
MATERIAL AND DESIGN CONSIDERATIONS FOR COMPLIANT MECHANISMS

STRESS-RELIEF TECHNIQUES IN COMPLIANT MECHANISM

Certain geometries are particularly susceptible to stress concentrations. Compliance enflames the issues. Note that certain materials, such as acrylic, are far less forgiving with stress concentrations.There are various methods to reduce these stress concentrations and this is just a sample of techniques:



At corners, add small stress-reliefs.These can be quite small or more dramatic.



For lattice hinges, it is helpful to include stress-reliefs at the ends of cuts.

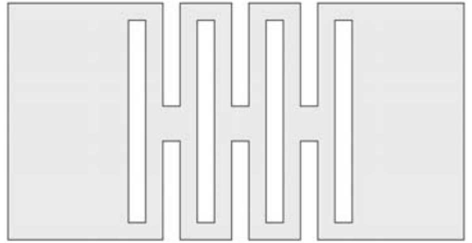
Lattice Hinge

written by Mary Morse

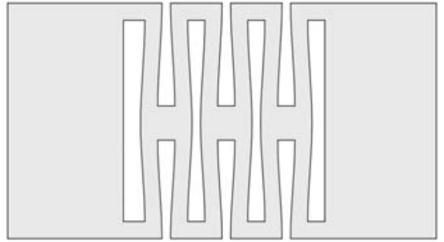
Lattice Hinge

This hinge is a part of the Magical Star Machine by Jasper Nance. View it here: https://www.flickr.com/photos/nebarnix/9935576084/in/set-72157600222539663

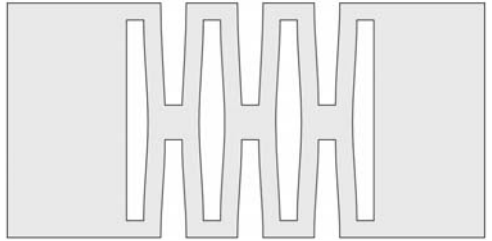
A lattice hinge creates a flexible area in a piece of flat stock by removing material so that it can bend and stretch. Lattice hinges are made up of tiny beams linked together. Each beam twists a little bit and when these little twists add together, they create a big twist in the material. This allows material to be very flexible. The images below demonstrate the effect in terms of compression and tension.



Basic Lattice Hinge



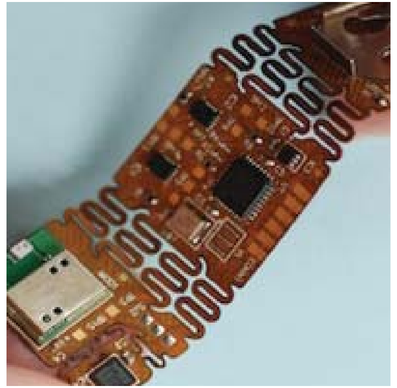
Compression



Tension

Diagrams from http://www.deferredprocrastination.co.uk/blog/2011/laser-cut-lattice-living-hinges/

Applications and Variations



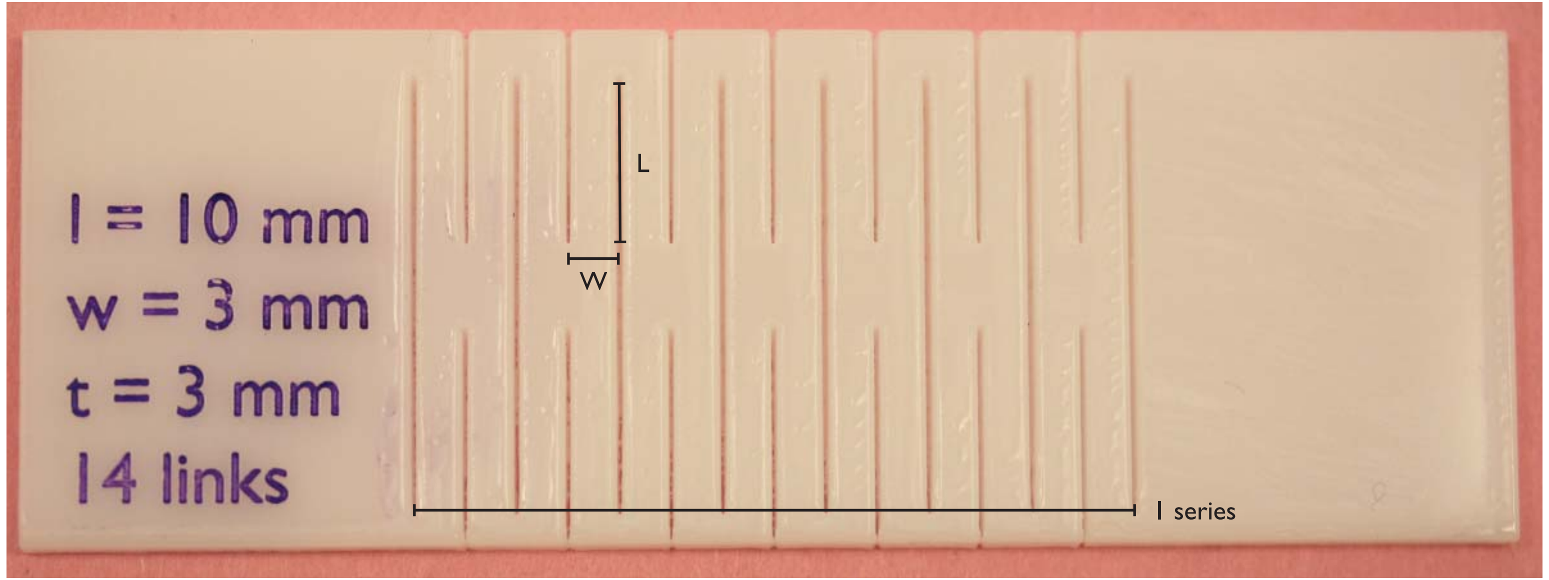
Infinite Corridor Technology created flexible, wearable circuits by adding serpentine cuts to their PCBs. These operate the same way as a lattice hinge. http://ict-flex.com/applications/limberboard/

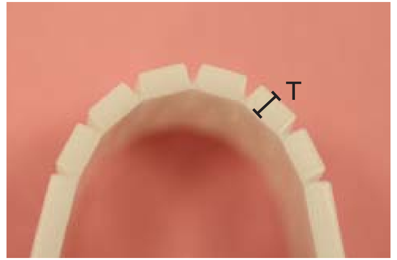
This lattice hinge has circles cut at the end of each slot to relieve stress concentrations that tend to occur at sharp corners.
This project was lasercut at Danger!Awesome: http://www.dangerawesome.co/portfolio/mobius-strip/

Michael Harwood used a large lattice hinge to create a flexible clutch. https://www.flickr.com/photos/miwood/6846121269/

A variety of patterns can be used to add flexibility to your material. This one was created by students at Massey University in New Zealand. Check out the project here: http://www.instructables.com/id/Kerf-Table-Lamp/

Lattice Hinge Anatomy



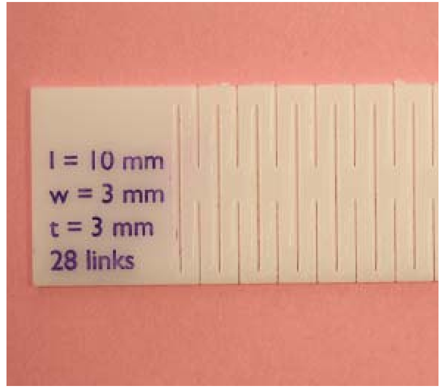


L - length of linkage
W - width of linkage
T - material thickness
N - number of links in series
Θ - total bend angle

Hinge Design

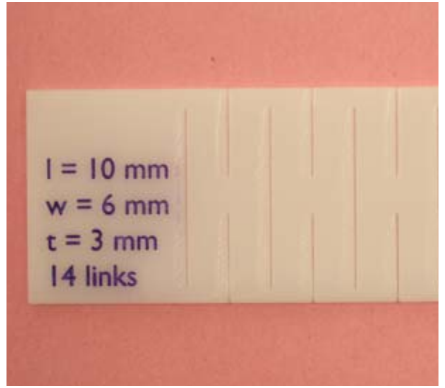
Length of Links Doubled

Spring Stiffness: ↓
Θmax: ↑



Number of Links Doubled

Spring Stiffness: same
Θ max: ↑



Width of Links Doubled

Spring Stiffness: ↑
Θ max: ↓

These conclusions are drawn from a mathematical model of the mechanics of the living hinge.

If you want a more quantitative approach to hinge design, check out this derivation:

http://deferredprocrastination.co.uk/blog/2011/laser-cut-lattice-living-hinges/.

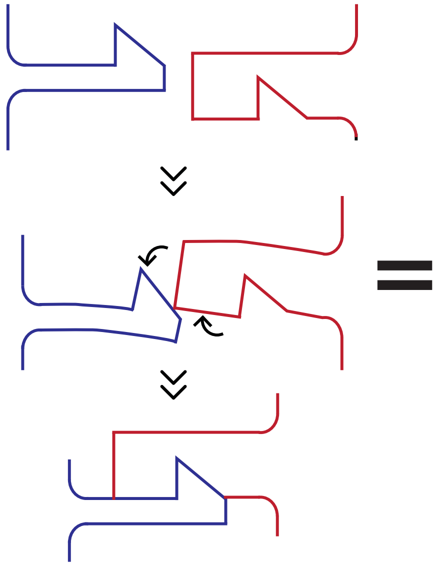
Cantilever Snap-fit

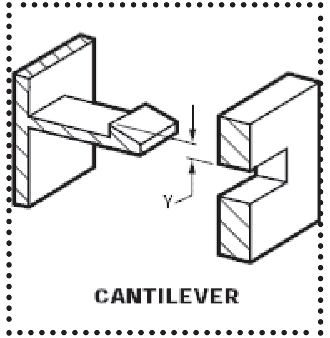
written by Ingrid Hagen-Keith

CANTILEVER SNAP-FIT JOINTS

A snap-fit joint is a compliant mechanism that works by briefly deflecting a protruding component so that it catches in a depression in another component. A common example of snap-fit joints is the ends of K'nex toys.

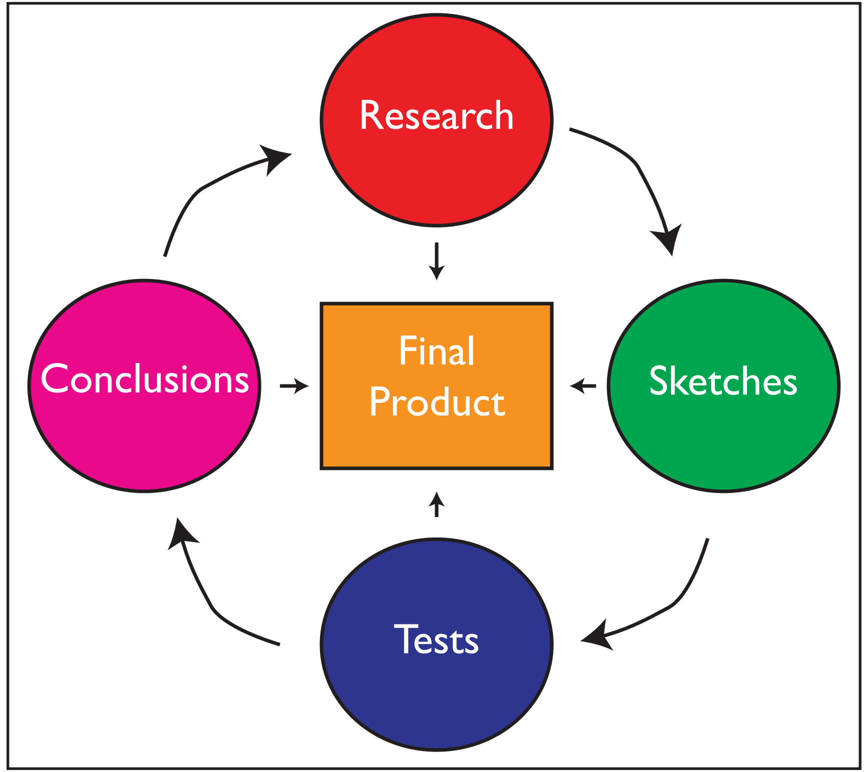
I decided to explore cantilever snap-fit joints. A cantilever is a beam that is anchored on one end. Cantilever snap-fit joints are very good for creating perpendicular planes with your laser cut parts. Below are some examples from plastics:





CANTILEVER SNAP-FIT JOINT

MY PROTOTYPING PROCESS



My prototyping process was very iterative for this joint. I started with researching what already existed and then moving on to sketches and tests. In each test, I identified a parameter that I wanted to examine (see geometry pages) and then was able to make useable conclusions. All of these activities increased my understanding of the joint.

RESEARCH

INDUSTRY USES

I first looked to the examples of snap-fit joints that already existed and are widely used in industry. I found some great resources (see the back of this section for more). I used the following examples to inform and inspire my exploration of the cantilever snap fit:

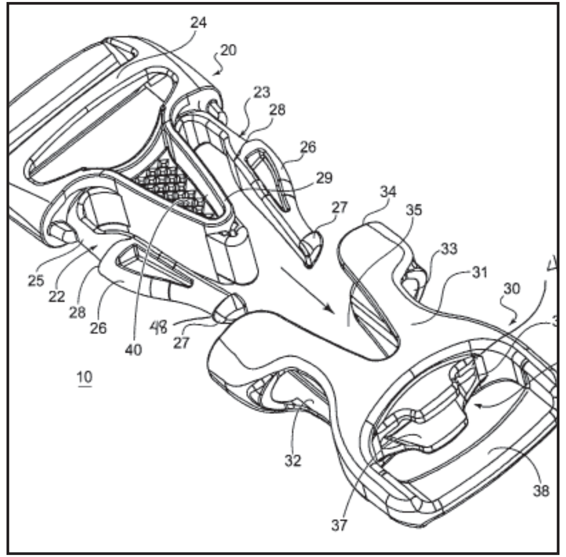


Fig. 1: The most common use of cantilever snap-fit joints is in snap-lock buckles like the one above.

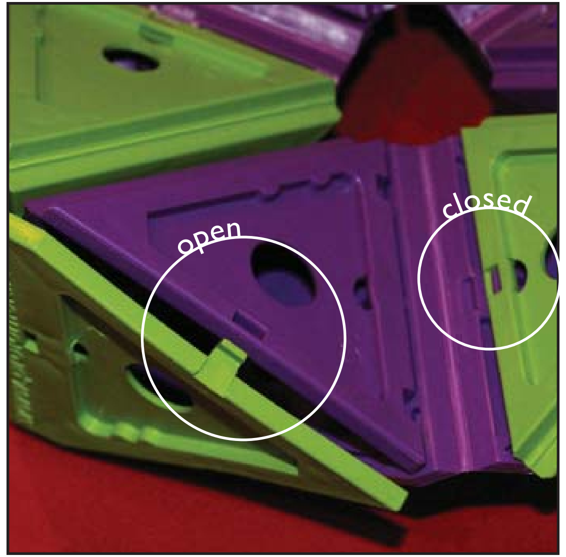
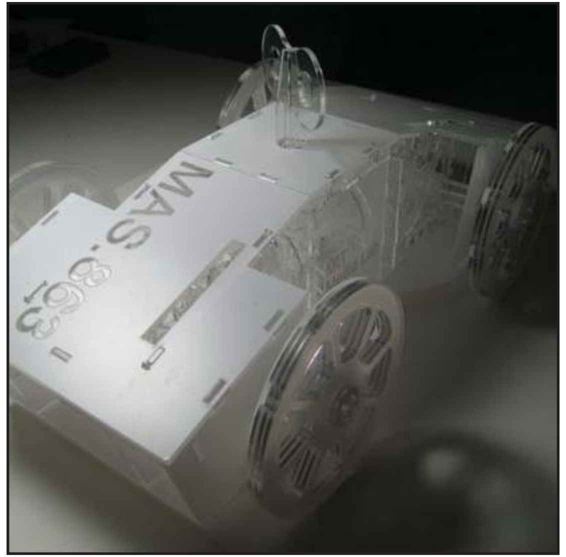


Fig. 2: We have a toy in the lab from Protomold (if you are interested in plastics you should check them out) that includes snap-fit joints! I got to play with them which is a great way to learn for me.

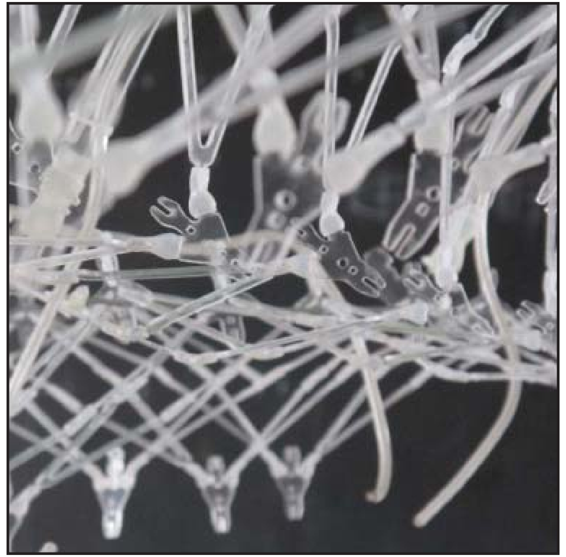
RESEARCH

LASER-CUT EXAMPLES

After looking through various industry resources, I decided to examine the snap-fit joint presense in laser cutting. I found some awesome examples that inspired me and demonstrated how creative you can be when combining joint techniques.

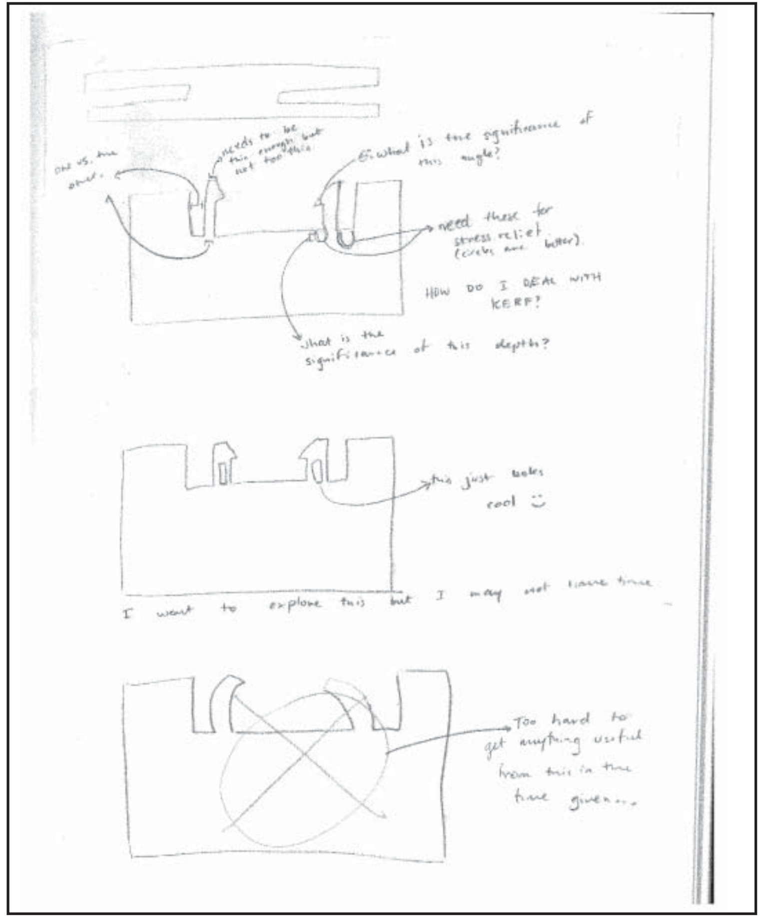


I found a project by Dimitris Papanikolaou from the MIT Fab Lab that was the bomb-diggity! It had snap-fit joints everywhere! Check it out here: *http://fab.cba.mit.edu/classes/MIT/863.10/people/dimitris.papanikolaou/Assignment_2.html*



This photo was posted for a Digital Crafting Workshop focused on snap-fit joints and really caught my eye. It creates a compliant web when everything is snapped together: art and craft.

SKETCHES



Armed with my knowledge, I started sketching. To the left is one of my first sketches. I played around with three ideas and ultimately decided to explore two. Since this was such a big category, I knew I had to narrow my focus. So I decided to explore inward facing cantilever snap-fit joints.

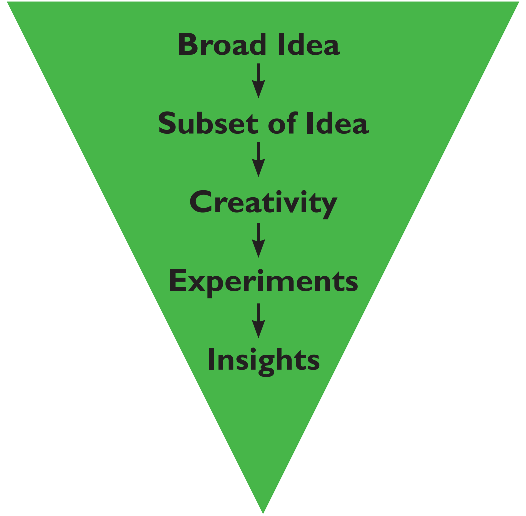
A COUPLE DISCOVERIES

My experience: Acrylic is way more brittle than Delrin as you may expect based on each material's elastic modulus and yield strength. A Delrin assembly may fit perfectly but an acrylic assembly with the exact same geometry will break.

Prototyping insight: When prototyping a compliant mechanism, use the material you intend for the final product.

Brittle

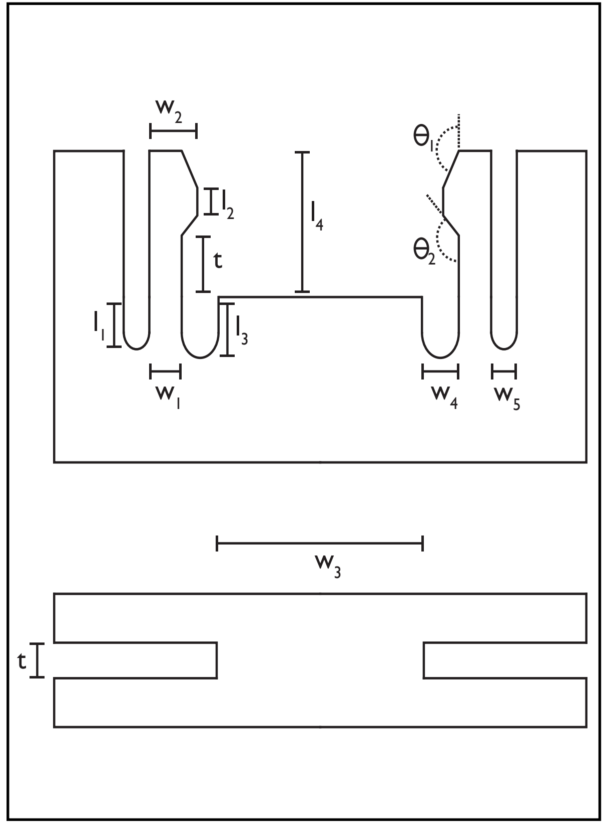
Flexible



My experience: I chose a very broad subject (snap-fit joints) and then narrowed to a sub-group (cantilever snap-fit joints). I then brainstormed a couple of geometries and tested my two favorites.

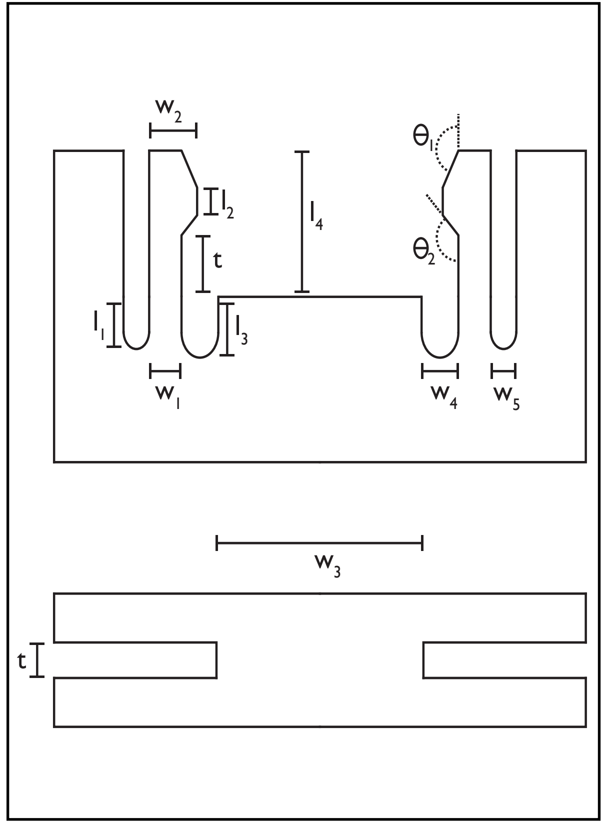
Prototyping insight: To avoid getting overwhelmed when exploring, set a scope for yourself and narrow further as you find things you think are interesting.

BASIC GEOMETRY



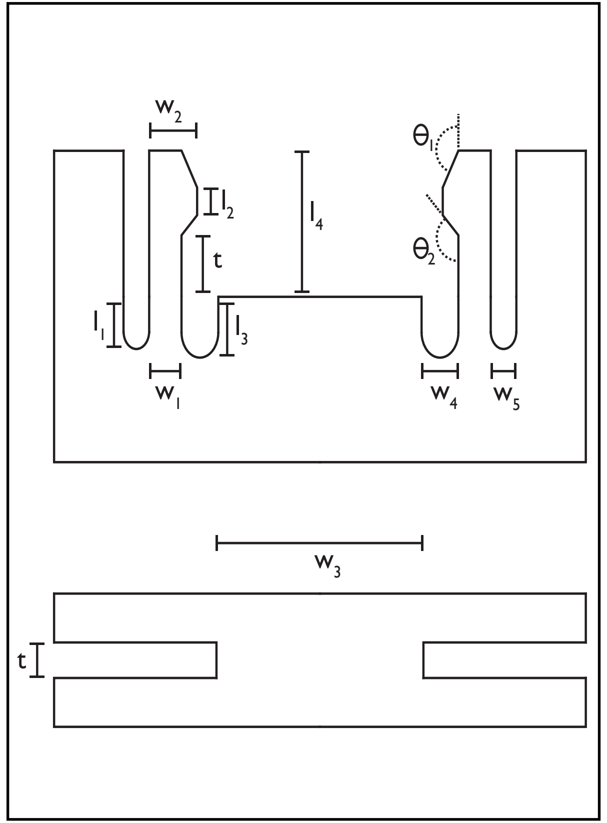
Parameter	Description	Function	Design Considerations
t	thickness of finger piece	based on the sheet material thickness	
l_1	height gutter 1	to allow for more flexibility in when pushing the finger towards the center	experiment with this length. A greater l_1 increases flexibility but reduces strength and is not as aesthetically pleasing. I would suggest you start with $l_1 = l_3$
l_2	land length	length of the nose face	the nose length is determined by the intersection of the angles and the thickness of the materail
l_3	height gutter 2	to allow for more flexibility in when pulling the finger towards the center	experiment with this length. A greater l_3 increases flexibility but reduces strength and is not as aesthetically pleasing. I would suggest you start with $l_1 = l_3$

BASIC GEOMETRY



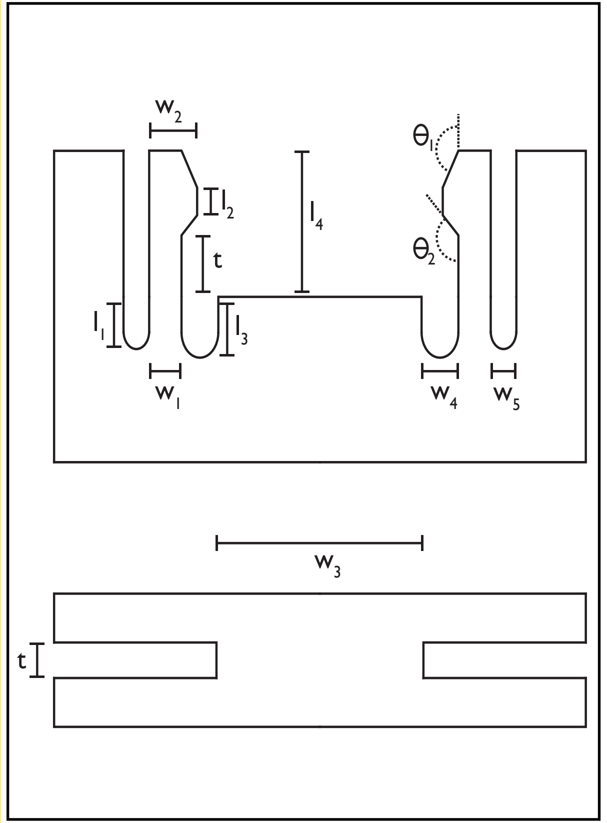
Parameter	Description	Function	Design Considerations
l_4	contact length of finger	the useable length of the finger. The finger will always be longer than the thickness of the matieral.	for a cleaner surface, this value should be quite small.
w_1	width of finger	this is the cantilever width of the snap fit that can be used to calculate forces.	$w_1 < w_2$.
w_2	overhang width	the nose is used to hold the snap-fit in place	I like to start with $w_2 = w_1 + w_4$. w_2 should not be greater than $w_1 + w_4$.
w_3	slot width	the length between the insides of the fingers	note: this applies to both the fingered and receiving parts

BASIC GEOMETRY



Parameter	Description	Function	Design Considerations
w_4	width gutter 1	width of the inside gutter	when this dimension is larger, the finger is more flexible but less aesthetically pleasing. When pushing the finger towards the center, the maximum deformation in that direction is limited to w_4
w_5	width gutter 2	width of the outside gutter	when this dimension is larger, the finger is more flexible but less aesthetically pleasing. When pushing the finger away from the center, the maximum deformation in that direction is limited to w_5

BASIC GEOMETRY



Parameter	Description	Function	Design Considerations
$theta_1$	slip angle	angle of the leading edge of the nose	the greater the angle, the easier it is initially slip the receiving part over the fingers of the fingered part
$theta_2$	return angle	angle of the under-side of the nose	the greater the angle, the more reversible the joint. However, as it becomes greater, the joints has more slop

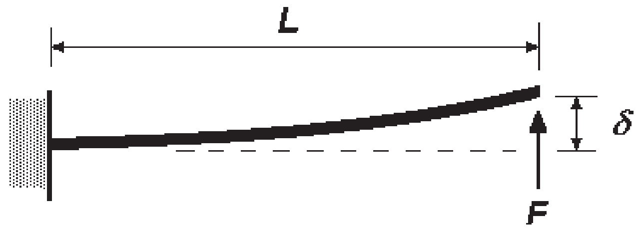
FINITE ELEMENT ANALYSIS

BACK-OF-ENVELOPE CALCULATIONS

I wanted to explore the use of back-of-the-envelope calculations and FEA when prototyping with a laser cutter. I was able to abstract some basic calculations that would help inform my FEA using basic beam bednding calculations.

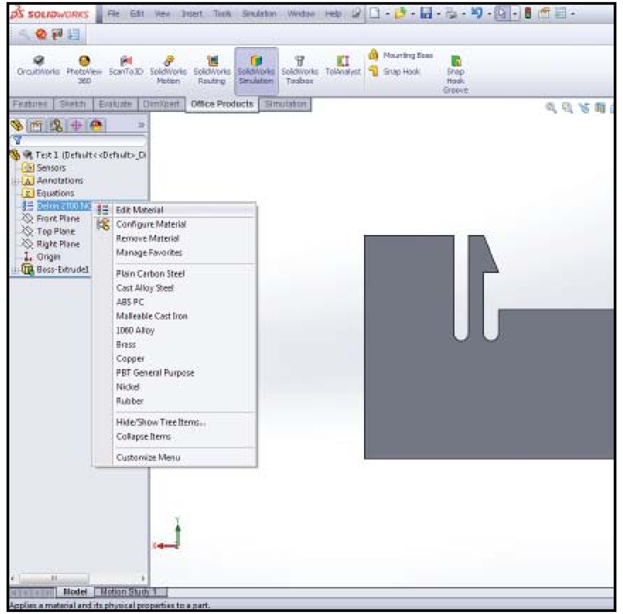
$v = (FL^3)/3EI$ where:

v: deflection
F: load
L: length of the beam
E: elastic modulus
I: are moment of inertia

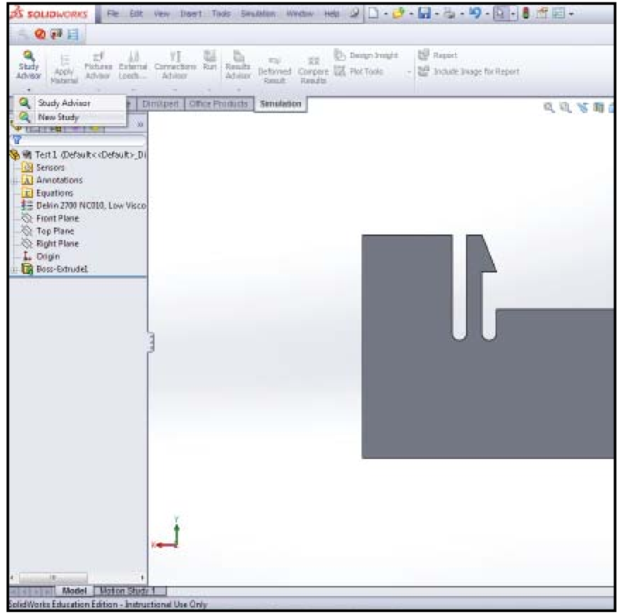


Use the space below as scratch paper:

HOW TO SET UP A FEA FOR THIS JOINT

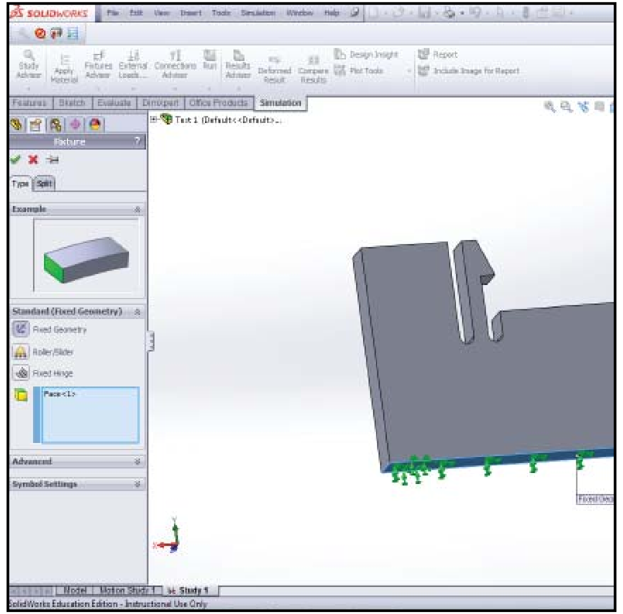


1. Set the material of your laser cut part by right-clicking on the material property of your part. Click "Edit Material" for the full list of materials with their properties. Activate the SolidWorks Simulation package in the Office Products tab.

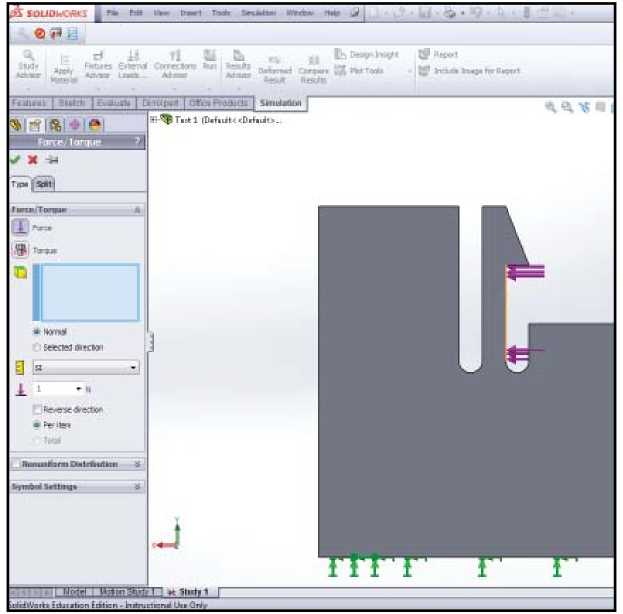


2. Make a new study within the Simulation package.

HOW TO SET UP A FEA FOR THIS JOINT

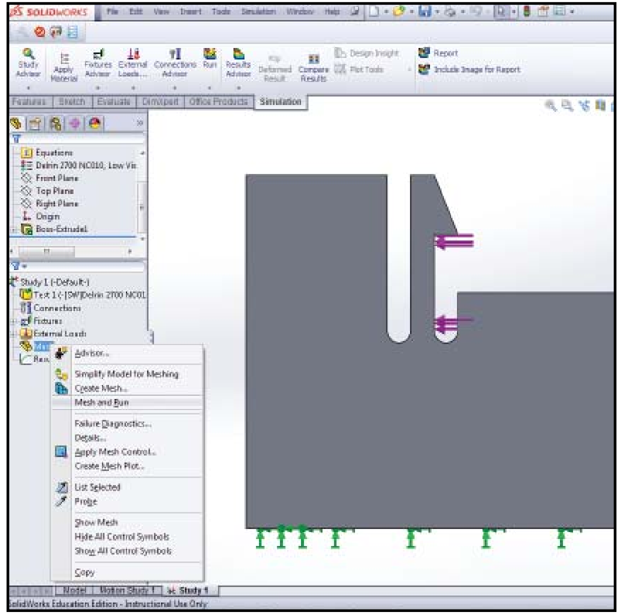


3. Click on "Fixtures" in the tab to the left. This will open the dialogue shown above. Let's assume that the bottom face has a fixed geometry. Select "Fixed Geometry" and click on bottom face. Then click the green check mark.

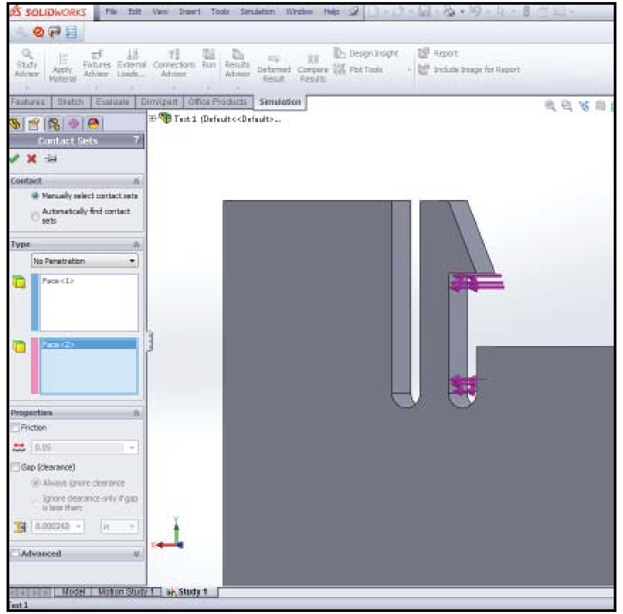


4. Click on "Force/Torque" in the tab to the left. This will open the dialogue shown above. Select an inside faces of the finger as shown above. Set the force to that calculated with the rough calculations you did before. Then click the green check mark.

HOW TO SET UP A FEA FOR THIS JOINT

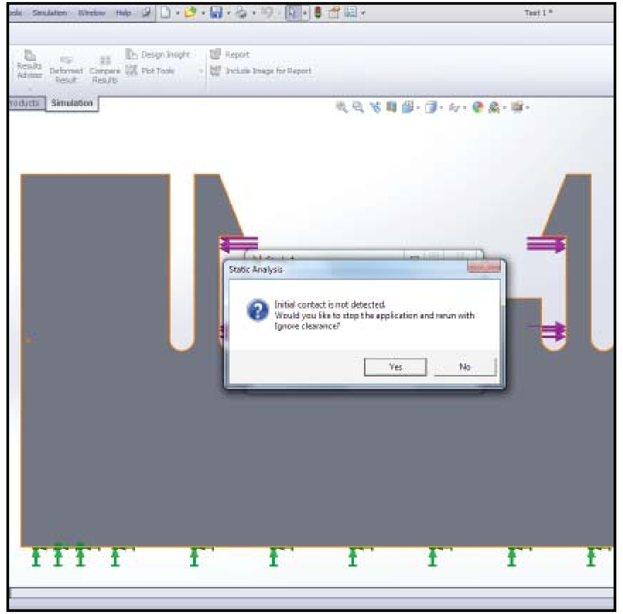


5. Click on Mesh in the Study Tree and choose mesh and run. Because these FEAs are more for a sanity check and deal with relatively small forces, you don't need to worry about mesh quality too much.

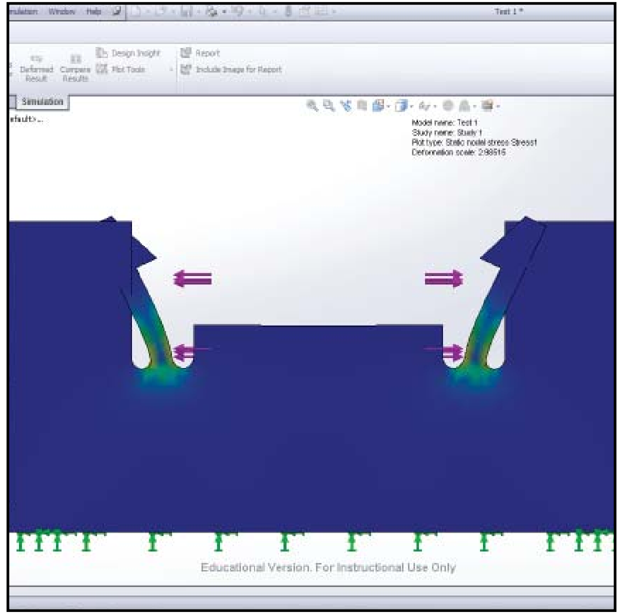


6. Click on the part to set up a contact set. A contact set dictates that planes of a part cannot self-intersect. Ensure that 'No Penetration' is selected. Click on two faces that you do not want to intersect. Note that you will need to set up two contact sets: one for each finger.

HOW TO SET UP A FEA FOR THIS JOINT



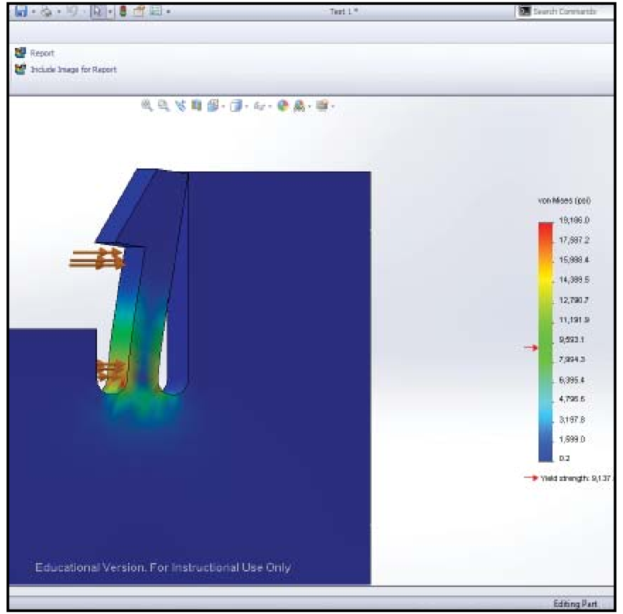
7. You may get this error message. Just click yes.



8. In my first run, my parts were self-intersecting. I was so confused because my calculations did not anticipating this. I learned that SolidWorks will automatically set a Deformation Scale. To get an accurate representation, double-click on the box above and re-set the deformation scale to 1.

FINITE ELEMENT ANALYSIS

HOW TO SET UP A FEA FOR THIS JOINT



9. You'll get your final FEA. In reality this piece was fine and did not break after multiple uses. However, there was slight plastic (i.e. it did not return to its initial state) deformation which the FEA accurately predicted.

FINAL THOUGHTS

I was satisfied with what I learned while experimenting with this joint. There are many variations of the snap-fit joint that you should certainly explore!

For the purpose of exploratory work, my prototyping method worked quite well.

To see associated files (further discussion and cut files), please visit http://lasercutlike-aboss.weebly.com/!

CITATIONS

Table 1:
http://plastics.dupont.com/plastics/pdflit/americas/delrin/230323c.pdf
http://en.wikipedia.org/wiki/Ultimate_tensile_strength
http://www.engineeringtoolbox.com/young-modulus-d_417.html
http://www.makeitfrom.com/material-data/?for=Medium-Density-Fiberboard-MDF
http://www-bsac.eecs.berkeley.edu/~mccoy/files/091018-material-properties-efunda-v02.pdf

http://blog.ponoko.com/2010/06/17/how-to-make-snug-joints-in-acrylic/
http://articles.ides.com/design/2007/0919_snapfit1.asp
http://www.freepatentsonline.com/7100252-0-large.jpg
http://www.digitalcrafting.dk/?p=555
http://fab.cba.mit.edu/classes/MIT/863.10/people/dimitris.papanikolaou/Assignment_2.html

Rotary Snap-fit

written by Annie Zeng

ROTARY SNAP-FIT

The rotary snap-fit is a compliant, dynamic joinery technique which joins two perpendicular or parallel planes and allows rotational movement between such planes. The material that I used throughout development of this joint was Delrin due to its low coefficient of friction.

INSPIRATION:

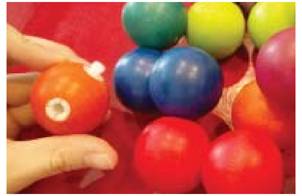


Fig 2 Inspiration for modular, rotary, snap-fit joint from non-planar connection found in "playableART Ball" by beyond123.

Fig 3 Inspiration for compliant stress relief components from "The Trebuchette" by E&M Labs.

The idea for creating a compliant, rotational joint was inspired by a modular toy we had in our lab which allowed the user to connect and disconnect colorful modules that rotated with respect to one another. A planar geometry for stress relief was inspired by a joint design by E&M labs.

DESIGN + DEVELOPMENT

HERE IS A PEEK INTO MY PROTOTYPING PROCESS:

* Formation of Design Metrics

When first deciding what type of joint to do for this issue, I generated a series of sketches of existing joints that inspired me. Then after cataloguing certain design metrics and designer goals that I wanted to fulfill with this exploration, I settled on a laser cut rotary snap-fit joint modeled after a modular toy.

Design Requirements:

- Range of motion: allows 360° rotation of two planes with respect to one another (planes can be parallel or perpendicular)
- Utilizes compliance concepts to allow snug fits in joint
- Modular & removable

Designer Values:

- Develop joint via rigorous, iterative process
- Gain experience analyzing designs using finite element analysis
- Characterize the primary modes of failure as well as the maximum axial load able to be sustained by the joint
- Elegant, simplistic design

My take on prototyping:
After developing an initial proof of concept of an idea I have in my head, I utilize prototyping to refine and improve my design. I either analyze designs in CAD or make physical artifacts, emphasizing speed. I make incremental changes to the design, altering one variable at a time so that each prototype will answer a specific question I have in mind.

* Iterative Process to Develop Joint:

For the development of this joint, I focused on small and quick iterative designs which allowed me to add increasing complexity to the system. This allowed me to attribute any failures to specific changes I had made and to move foward at a steady, reliable pace.

1

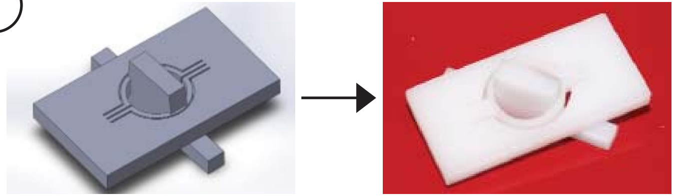


Fig 2 Prototype I was a proof of concept that explored the viability of mimicking a spherical geometry with two flat planes. The focus was on quick development, transferring and modifying known geometries for snap-fits and stress relief into the most simple design.,

2

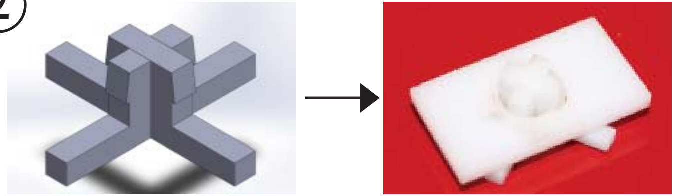


Fig 2 After discovering that smooth, full rotation of the joint was possible with a single-plane header, I then increased the complexity of the header pin by making a cross configuration. This gave the joint greater structure and rigidity.

3

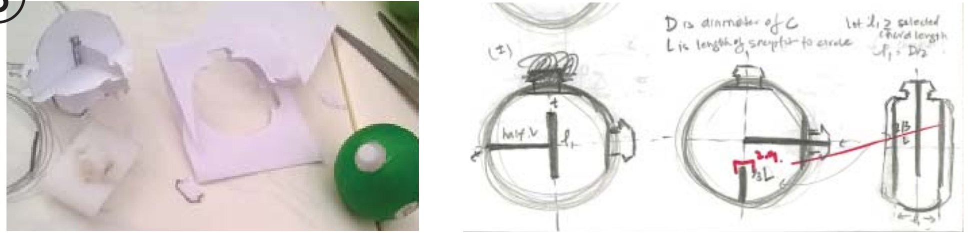
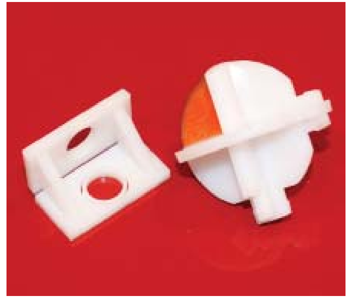


Fig 2. The final 3D module consisted of two cross header pins per module that could link with corresponding sockets. Paper prototypes of the 3D module were created initially to determine the geometry of each planar piece.



* Testing & Characterization of Joint Geometry & Failure Modes:

Fig 2 Analysis of design without circular cutout shows greater stress build-up.

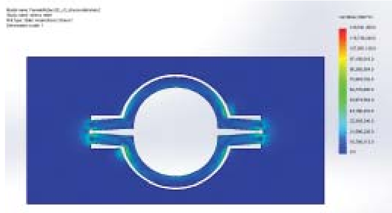


Fig 2 Analysis of design with circular cutout shows reduced stress build-up.

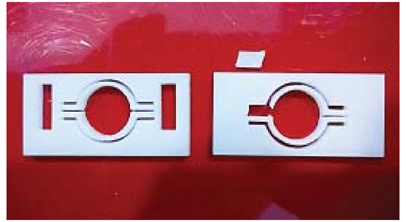
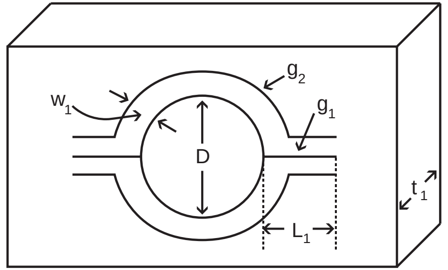


Fig 2 Failure of design in axial loading

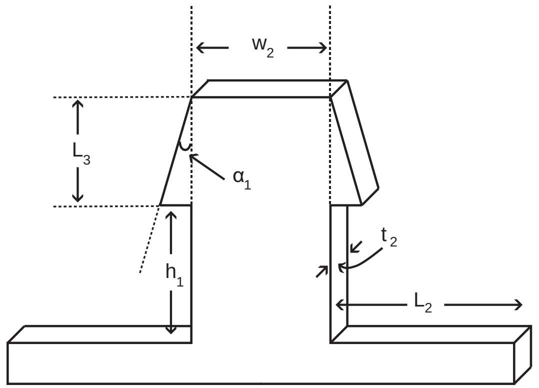
- **Goal / Hypothesis:** Provide stress relief during deflection of compliant member (will a circular cutout at the end of the L_1 gap do the trick?)
- **Experiment 1:** Analyzed geometry using SolidWorks finite element analysis (FEA) to conclude that the cutout seemed like a reasonable and beneficial addition. Saved time and material from making an actual prototype.
- **Experiment 2:** Then proceeded to make a Delrin prototype and found that the geometry was indeed successful in relieving stress along the socket face's plane. However, it significantly reduced the joint's ability to take axial loading (in the direction perpendicular to the socket face) as can seen by the failure after I inserted and removed a header pin.
- **Takeaways:** It's great to do a software analysis for quick, iterative design changes on the computer, but a physical prototype can help you recognize failures that you did not forsee.

ROTARY SNAP-FIT JOINT DESIGN

Compliant Socket



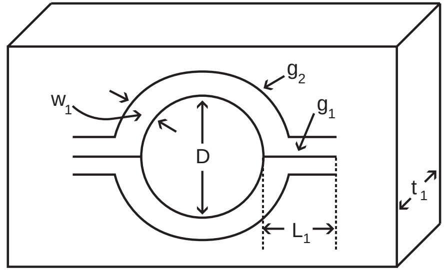
Header Pin



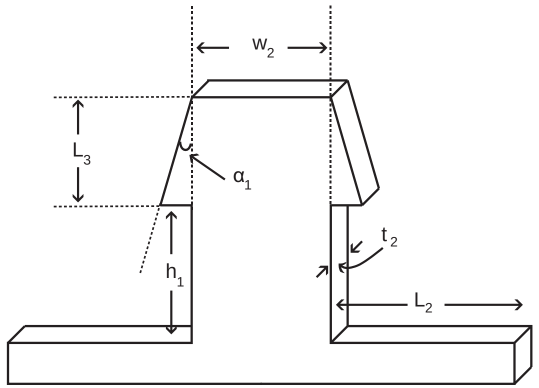
Parameter	Description	Function	Design Consideration
g_2	stress relief gap 2	provides stress relief and allows deflection of compliant part to enable insertion of header pin	Gap must be wide enough to allow full insertion of widest parts of header pin: $D+g_2 \geq w_2+L_3\sin\alpha_1$.
g_1	stress relief gap 1	similar to g_2	Increasing g_1 allows greater ease of insertion and removal of header pin. However, g_1 is the only discontinuous part of socket in which header pin rotates. A greater gap may decrease ease of rotation.
w_1	compliance width (maybe also controls amount of axial load taken, see future explorations)	controls ease of deflection of compliant member for snap-fit joint	Decreasing w_1 enables greater ease of insertion of header pin across a certain material. However, it also becomes less of a structural member and is quicker to fail.
L_1	stress relief length	provides stress relief upon deflection of compliant member	Longer L_1 is better for stress relief & increases ease of deflection of compliant member.

JOINT DESIGN CONTD. I

Compliant Socket



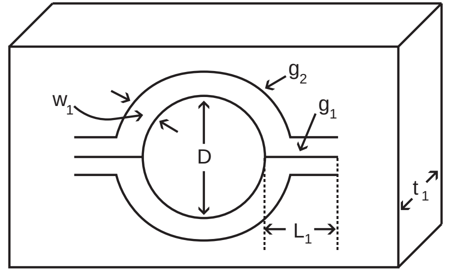
Header Pin



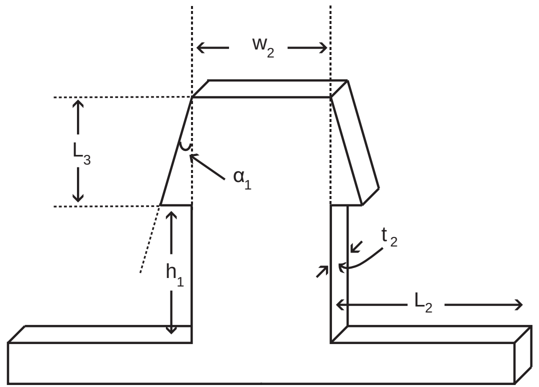
Parameter	Description	Function	Design Consideration
D	diameter of snap-fit socket	diameter marks out a circle which allows insertion and rotation of header pin	D can be taken to be the same length as w_2 until the ratio D/t_2 gets below ~2. Then increase D to a value between w_2 and $\sqrt{w_2^2+t_2^2}$ to ensure smoothness of rotation.
t_1	thickness of socket	based on sheet material thickness	Make sure $t_1=h_1$. A greater t_1 means more contact between rotational surfaces of header pin and socket. This can constrain motion more to decrease wobble from ideal planar rotation. However, it can also add more friction to rotation.
w_2	width of header pin	increase or decrease to change overall size of joint	Generally you want to make sure w_2=D. However, in designs in which D/t_2 is small, make w_2<D. See notes in appendix.
L_3	length of wedge	length which controls the greatest width of pin in conjunction with α_1	Increasing L_3 makes it harder to snap the pin into the socket, but it also ensures a tighter fit in the joint. As the greatest width of the pin ($w_2+2L_3\sin\alpha_1$) becomes increasingly greater than D, the pin becomes harder to remove.

JOINT DESIGN CONTD. 2

Compliant Socket



Header Pin



Parameter	Description	Function	Design Consideration
α_1	wedge angle	angle which controls the greatest width of pin in conjunction with L_3	I used a wedge angle of 7° because it was something that my peer tried out in a previous design. It seems that increasing α_1 gives a tighter snap-fit. However, it could eventually stress the compliant member of the socket enough to faillure.
h_1	height of header pin body	contact edge and surface between pin and socket	Make sure $h_1=t_1$. A greater h_1 means more contact between rotational surfaces of header pin and socket. This can constrain motion more to decrease wobble from ideal planar rotation. However, it can also add more friction to rotation.
t_2	thickness of header pin	based on sheet material thickness	Be wary of your D/t_2 ratio. See additional notes in appendix.
L_2	length of bearing surface	surface of header pin which interacts with bottom, parallel plane of socket	This bearing (contact) surface is a frictional interface. A greater L_2 may mean increased friction, but also may decrease unwanted wobble between the two rotational planes.

FUN WITH THE ROTARY SNAP-FIT!

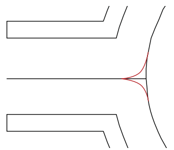
Fig 2 Header pin and socket modules which connect to mimic modular toy by beyond123. Allows 360°, planar rotation between adjacent modules.

Recall that the rotary snap-fit performs the function of a dynamic, rotational joint which allows 360° rotation between two parallel or perpendicular planes. It converts the geometry of a joint made by nonplanar methods for customizable and quick fabrication on a planar cutting tool (laser cutter). It can be made to be removable

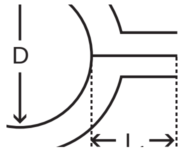
* Possible Directions for Future Work:

Things I would have liked to explore but could not budget into my time!

Maximum axial loading: Characterize how changing w_1 affects the maximum axial load that can be taken by the joint to see if it is fitting for more heavy-duty applications.



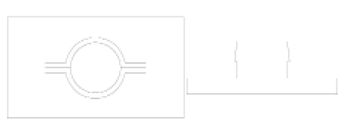
Smoothing Rotation: Right now, depending on the size of g_1 the header pin catches in the socket while completing a full rotation. Maybe altering the geometry of the corners of the socket would smooth the rotation.



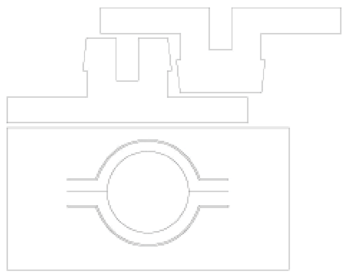
Effects of altering L_1: I wish to understand more rigorously the effects of shortening or lengthening L_1. Right now, it is just a length that I know works. I'd like to see how much I could reduce this length to reduce the overall size of the joint and still ensure sucessful deflection of the compliant member.

A P P E N D I X :

Config1: Single Header Pin



Config2: Cross Header Pin



3D Pin & Socket Modules

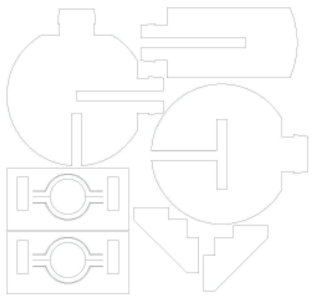
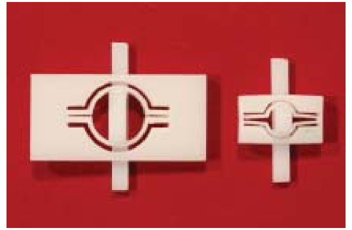
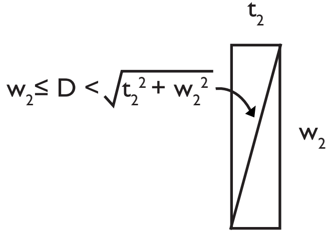


Fig 2 My cut files for each of the configurations as well as the complete module. Illustrator and SolidWorks files can be found on http://lasercutlikeaboss.weebly.com/ .

Notes on D/t_2 ratio:





The rotational smoothness of this geometry is limited by the thickness of the sheet material that is used to make the header pin. The edges of the pin will not be able to conform perfectly to the curvature of the socket due to the thickness unless additional pains are taken to make this curved geometry. This will not affect the joint too much when the D/t_2 ratio is relatively high (>~2) when D can be taken to equal w_2. However, when $D/t_2<2$, the thickness of the header pin (t_2) begins to expand the compliant gap (g_2) enough that the edges of the pin catch on the edges of the socket it comes in contact with. In these cases, make D a value between w_2 and $\sqrt{t_2^2 + w_2^2}$.

Citations:

1. playableART Ball: http://www.beyond123.com/pa/ball.html
2. E&M labs: http://www.em-labs.com/products/trebuchette

Notes & Feedback

Meet Our Team

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

Mary Morse

My prototyping process during this project was highly ineffective. My failure was in exploring too many ideas and not narrowing my focus. If I were to do this over again, I would be sure to experiment with a well-defined goal so that I don't get lost exploring lots of different ideas.

While it's not the most refined tea, I think my favorite is red rose tea. I've collected the figurines in each box since a was little.

Ingrid Hagen-Keith

My prototyping process was solid but scattered. I think that in the future, it will help me to create a set of questions before I begin exploring. While these questions may change as I learn more, I believe it will provide the scaffolding I need to make this a more pleasant process.

I've always loved jasmine tea because I would drink it a lot when I was little on a hot day. In the mornings now, I love PG Tips.

Annie Zeng

Setting design metrics and defining my own values initially as "joint enables a range of motion" or "allows me to practice incorporating FEA into my design process", respectively, allowed me to properly scope this project and remove the least necessary components when I ran short on time. Also, for each prototype, I isolated a variable that I wanted to experiment with and understand to keep things straight in my mind with increasing complexity.

I normally enjoy my black teas straight, but every once in a while I like a mix of Earl Grey , honey, and vanilla-flavored soy milk.

Contact Us

realdesignlab@gmail.com

Share your feedback on our issue with us as well as some of your own laser cutting stories. We will pick a project to feature in our next issue!

For a web-compatible version of this issue with downloadable part and cut files, visit http://lasercutlikeaboss.weebly.com/.

This issue of LCLAB was typeset in Gill Sans MT.