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.

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.
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 critically 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
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.

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

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.

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).
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

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.

This hinge is a part of the Magical Star Machine by Jasper Nance. View it here: https://www.flickr.com/photos/nebarnix/9935376084/in/set-7215760222259663

Basic Lattice Hinge

Compression

Tension


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/

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

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 DangerAwesome:
http://www.dangerawesome.co/portfolio/mobius-strip/

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
- \( \Theta \) - total bend angle

Hinge Design

Length of Links Doubled
- Spring Stiffness: ↓
- \( \Theta_{\text{max}} \): ↑

Number of Links Doubled
- Spring Stiffness: same
- \( \Theta_{\text{max}} \): ↑

Width of Links Doubled
- Spring Stiffness: ↑
- \( \Theta_{\text{max}} \): ↓

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:

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:
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.
After looking through various industry resources, I decided to examine the snap-fit joint presence 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.

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.

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Function</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t )</td>
<td>thickness of finger piece</td>
<td>based on the sheet material thickness</td>
<td>experiment with this length.A greater ( t ) increases flexibility but reduces strength and is not as aesthetically pleasing. I would suggest you start with ( t \approx 1 ).</td>
</tr>
<tr>
<td>( l_1 )</td>
<td>height gutter 1</td>
<td>to allow for more flexibility in when pushing the finger towards the center</td>
<td></td>
</tr>
<tr>
<td>( l_2 )</td>
<td>land length</td>
<td>length of the nose face</td>
<td>the nose length is determined by the intersection of the angles and the thickness of the material</td>
</tr>
<tr>
<td>( l_3 )</td>
<td>height gutter 2</td>
<td>to allow for more flexibility in when pulling the finger towards the center</td>
<td>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_3 \approx 1 ).</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Function</td>
<td>Design Considerations</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>----------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>$l_4$</td>
<td>contact length of finger</td>
<td>the useable length of the finger. The finger will always be longer than the thickness of the material.</td>
<td>for a cleaner surface, this value should be quite small.</td>
</tr>
<tr>
<td>$w_1$</td>
<td>width of finger</td>
<td>this is the cantilever width of the snap-fit that can be used to calculate forces.</td>
<td>$w_1 &lt; w_2$</td>
</tr>
<tr>
<td>$w_2$</td>
<td>overhang width</td>
<td>the nose is used to hold the snap-fit in place</td>
<td>I like to start with $w_1 = w_2$. $w_1$ should not be greater than $w_2$.</td>
</tr>
<tr>
<td>$w_3$</td>
<td>slot width</td>
<td>the length between the insides of the fingers</td>
<td>note: this applies to both the fingered and receiving parts.</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
<tr>
<td>$w_4$</td>
<td>width gutter 1</td>
<td>width of the inside gutter</td>
<td>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 $w_4$.</td>
</tr>
<tr>
<td>$w_5$</td>
<td>width gutter 2</td>
<td>width of the outside gutter</td>
<td>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 $w_5$.</td>
</tr>
</tbody>
</table>
### BASIC GEOMETRY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$\theta_1$</td>
<td>slip angle</td>
<td>angle of the leading edge of the nose</td>
<td>the greater the angle, the easier it is initially slip the receiving part over the fingers of the fingered part</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>return angle</td>
<td>angle of the underside of the nose</td>
<td>the greater the angle, the more reversible the joint. However, as it becomes greater, the joints has more slop</td>
</tr>
</tbody>
</table>

### FINITE ELEMENT ANALYSIS

#### BACK-OFF-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 bending calculations.

\[ v = \frac{(FL^3)}{3EI} \]

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:
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.

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 face 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.
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.

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.
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.

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://lasercutlikeaboss.weebly.com/!
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.

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.
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:

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.

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 forward at a steady, reliable pace.

- 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

Testing & Characterization of Joint Geometry & Failure Modes:

- Goal / Hypothesis: Provide stress relief during deflection of compliant member (will a circular cutout at the end of the L-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 be 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 foresee.

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 then 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.

HERE IS A PEEK INTO MY PROTOTYPING PROCESS:

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 plane area.**
### Rotary Snap-Fit Joint Design

**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: \( D + g_2 + L_3 \sin \alpha_1 \geq w_2 + L_3 \sin \alpha_1 \).

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( g_1 \) | 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.

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( w_1 \) | 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.

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( L_1 \) | 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

**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 \( \sqrt{w_2^2 + t_1^2} \) to ensure smoothness of rotation.

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( t_1 \) | 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.

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( w_2 \) | Width of header pin | Increase or decrease to change overall size of joint | Generally you want to make sure \( w_2 > \alpha_2 \). However, in designs in which \( D/t_2 \) is small, make \( w_2 > D \). See notes in appendix.

**Parameter** | **Description** | **Function** | **Design Consideration**
--- | --- | --- | ---
\( L_3 \) | Length of wedge | Length which controls the greatest width of pin in conjunction with \( \alpha_1 \) | 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.

---

**Diagram:**
- **Compliant Socket**
  - \( w_2 \)
  - \( t_2 \)
  - \( h_1 \)
  - \( L_3 \)
  - \( \alpha_1 \)

**Header Pin**
- \( D \)
- \( g_2 \)
- \( g_1 \)
- \( w_1 \)
- \( L_1 \)
### JOINT DESIGN CONTD. 2

#### Parameter Description Function Design Consideration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Function</th>
<th>Design Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_1 )</td>
<td>wedge angle</td>
<td>angle which controls the greatest width of pin in conjunction with ( L_3 )</td>
<td>I used a wedge angle of 7° because it was something that my peer tried out in a previous design. It seems that increasing ( \alpha_1 ) gives a tighter snap-fit. However, it could eventually stress the compliant member of the socket enough to failure.</td>
</tr>
<tr>
<td>( h_1 )</td>
<td>height of header pin body</td>
<td>contact edge and surface between pin and socket</td>
<td>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.</td>
</tr>
<tr>
<td>( t_2 )</td>
<td>thickness of header pin based on sheet material thickness</td>
<td>based on sheet material thickness</td>
<td>Be wary of your ( D/t_2 ) ratio. See additional notes in appendix.</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>length of bearing surface</td>
<td>surface of header pin which interacts with bottom, parallel plane of socket</td>
<td>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.</td>
</tr>
</tbody>
</table>

#### Compliant Socket

![Compliant Socket Diagram](Image)

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

#### FUN WITH THE ROTARY SNAP-FIT!

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:**

- **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 successful deflection of the compliant member.

---

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

- **Smoothness of 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 successful deflection of the compliant member.
**Appendix:**

Config1: Single Header Pin  
Config2: Cross Header Pin  
JD 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/](http://lasercutlikeaboss.weebly.com/).

**Notes on D/t2 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 \( \frac{D}{t_2} \) ratio is relatively high (\( \geq 2 \)) 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 \( \sqrt{\frac{t_2}{w_2}} \).

**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 I 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
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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.