2.008 Lab Report 1

Team f/2.008: Daly, Kevin, Mandy, Max, Mostafa, Patrick

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Overview

Here included is the design for manufacturing of a yo-yo for the f/2.008 team. The yo-yo is expected to be in the shape of a camera lens with a functional, adjustable iris. We began with a concept drawing which we quickly brought to life in CAD. From the CAD, we 3D printed the yo-yo in order to further investigate mechanisms and manufacturability. We would like to thank Joe Wight and Margaret Kosten for their invaluable insight and guidance in the design process.

1 Version 1

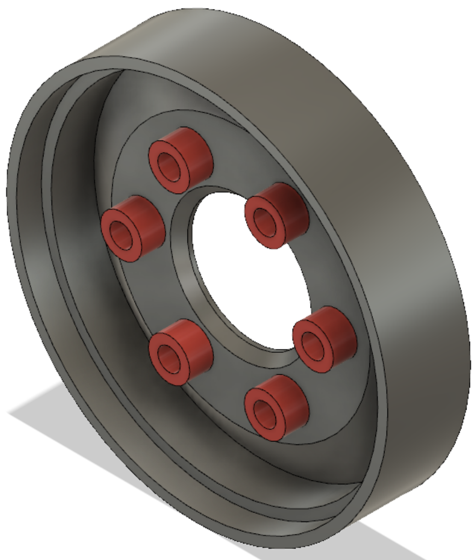


Figure 1: This is the design of the front of the yo-yo used for the first prototype. The bosses shown are used to hold the leaves in the iris mechanism. The hole in the center is where the lens bubbles out. This design would have caused difficulty in assembly, though, because the lens dome would have to be a non-circular shape to fit between the bosses; that reason also made it hard from a manufacturing standpoint.

1.1 Design Considerations

1.1.1 Making the Iris Mechanisms

We found an iris geometry calculator online at `https://iris-calculator.com/`. While we had options to choose a different number of leaves, we decided to use six in order to accurately look like a camera lens. While it may seem like we could simply scale to three leaves by only using an iris in every other peg, this was in fact a permanent decision as it affects the thickness of the iris leaves.

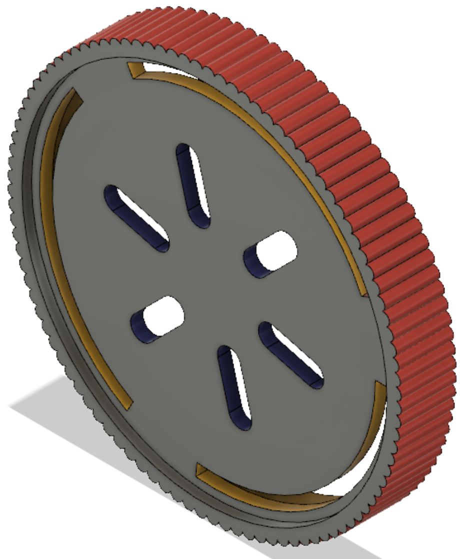


Figure 2: Here is the original design of the aperture ring. The iris pins sit in the slots of the ring. As the aperture dial is turned, the iris leaves slide along the slots, opening and closing the aperture.

The iris leaves need to be suspended by pins on either side. In Figures 1 and 2 we see that the pins were being originally held on the front of the yo-yo and the aperture dial.

As mentioned before, the location of the pegs on the front piece caused difficulties in designing a thermoformed lens.To counteract that, the next design leaves the slots on the dial, but puts the peg on the rear body. In order to regain visibility, we plan to put a hole in the center of the aperture dial. Like any part with a hold in the center, we will need to be particularly careful to avoid weld lines.

Because we have a rotating aperture ring between the front and rear body parts, it is not possible for us to have a snap fit along the entire circumference of the part. Rather, we are using small tabs that stick through the aperture ring from the rear body part to reach the front body part. For a visual, see Figure 7.

1.1.2 Snap Fit

We used the characteristics of the iris mechanism to determine the size of the snap-fit tabs. The aperture ring needs 70 degrees of rotational freedom to achieve both the maximum and minimum aperture sizes. There muse be a slot in the aperture ring large enough to allow this rotation. The tab must also be small enough to have room to rotate a full 70 degrees through the slot.

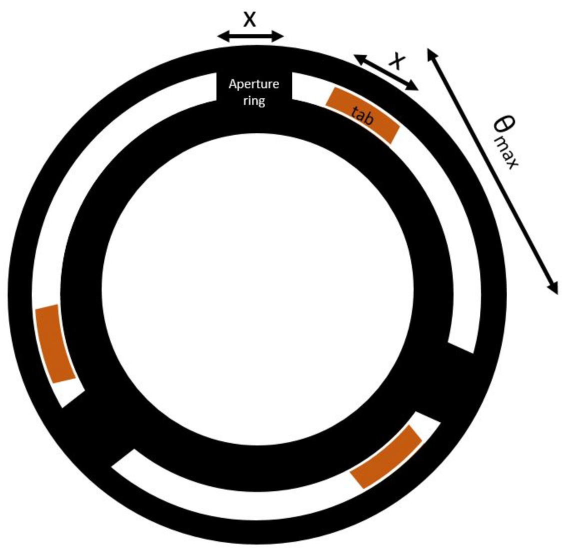


Figure 3: The angle theta that the aperture dial rotates controls how far the aperture leaves are able to close.

$$n * (\theta_{max} + x) < 360 - nx \tag{1}$$

where: n = number of tabs
θ_{max} = required angle of rotation
x = arc length of tabs
This yields that x < 25° to allow sufficient rotation, so we created the tabs with a 25° arc length to maximize strength given the constraints.

1.1.3 3D Printing versus Injection Molding Iris Leaves

There was some discussion about whether to 3D print or injection mold the iris leaves. We were concerned that it would be difficult to injection mold the thin iris leaves. However, 3D printing the leaves would take too long.

We calculated the pressure required to injection mold a thin iris leaf to confirm its feasibility:

$$\Delta P = \frac{12\mu Q L_0}{wh^3} = \frac{12\mu(V/t)60}{wh^3} \tag{2}$$

where: V = volume of iris leaf = 60 mm * 19 mm * 0.5 mm
μ = viscosity for injection molding = 10^3 Pa·s
t = (assumed) time to inject plastic = 10 s
L = max distance of flow = 60 mm
w = part width = 19 mm
h = part thickness = 0.5 mm

This yields a value of 0.17 MPa to inject a single leaf. Injection molding pressures can reach tens of pascals, so we are confident that the injection molding pressure will not be an issue for making the iris leaves.

1.2 Testing using 3D printed prototype

Figure 4: Left: The first complet 3D printed assembly. The parts had a very tight fit at first and we had to sand them down to achieve a smooth rotation.

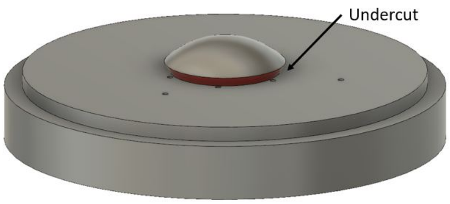
Once we decided on the camera lens with working iris, it was necessary to make a fast prototype to ensure that the moving components would work as expected. In the early drawing phase, we had a four injected molded body pieces with six additional irises. When creating this prototype, we were able to reduce the four body pieces to three. 3D printing these pieces on a Stratys printer confirmed that the moving pieces would be functional, assuming appropriate tolerances on the manufactured pieces.

Using this 3D printed piece we were able to find flaws in our designs with regards to structural stability as well as manufacturability. One of the largest problems with this design was that thermoform piece did not have a place to sit without resting on the fragile irises. In addition, spokes for the iris pegs seen in the CAD of Figure 1 would prevent the thermoformed piece from being the size of the yo-yo meaning that as the design was, there would be nothing to hold the lens stationary.

1.3 Design uncertainties

1.3.1 Constraining Lens Dome

By adding the bosses at the front of the yo-yo, we no longer have a way to constrain the lens dome. We had the idea to use a thermoformed lens with a slight undercut at its base so that the part could ”snap” into the hole at the front of the body. We made a thermoforming die to test this idea, shown in Figure 5.



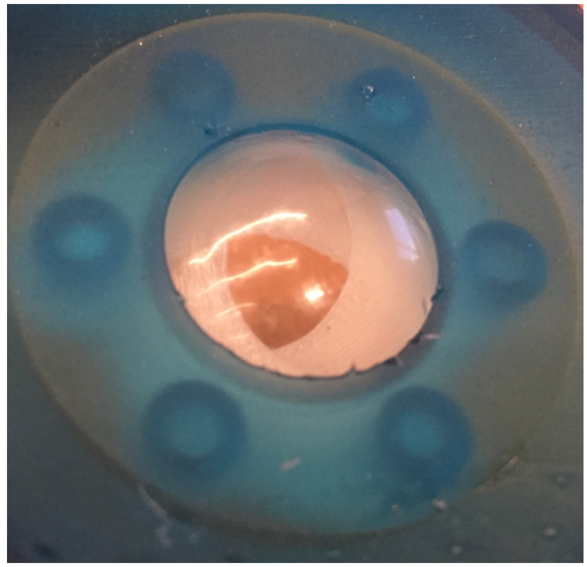


Figure 5: Left: The undercut here has small holes surrounding it in an attempt to create enough suction to cause a lasting undercut on the thermoformed piece. Right: Thermoformed lens on 3D-printed prototype.

We found through testing the thermoformed die that it was difficult to form the undercut. Although the plastic pulled into the mold, the undercut deformed back out when the part was ejected from the mold. We attempted press-fitting the lens into the 3D printed piece, but it was easy to push out with a small force. We decided to use a more traditional constraining approach in our second iteration.

1.3.2 Stability and Breakage

The 3D printed yo-yo snapped apart when dropped on the ground. We need to improve the snap fit between the front and rear for the second version to ensure a robust design. Additionally, one of the snap-fit tabs broke off, so we need to thicken that part in the second version.

1.3.3 Alignment of Rotating Pieces

We determined that the alignment of the front body relative to the rear body is important to ensure that the aperture ring can rotate a 70 degrees to achieve the full aperture motion. In the version 1 design, there was no constraint on the snap fit that positioned the front body correctly relative to the rear body.

Our first prototype was very useful for us to understand the mechanism. We were pleasantly surprised at how well the 3D printed pieces fit together, In developing the design further, we also needed to consider how warping of the injection molded parts due to shrinking will affect the fits.

2 Version 2

The major themes we addressed in designing the second version of the yo-yo were as follows:

- Extrude bosses from the rear body rather than the front body of yo-yo. This allows more room in the front body to hold the thermoformed piece.
- We shortened the entire yo-yo. The first version of the yo-yo half was 1” wide, which we realized would be too big when we added the other half. We wanted the new version to be less than 0.9” wide.
- Increasing the clearance of the rotating aperture ring. The first version had a close fit, which we expected would cause problems when making an injection molded part with shrinkage.

2.1 Components and Design for Manufacturing

In Figure 6, we see the general image of what the cross section of the yo-yo looks like. The front body and rear body pieces are snapped together, the light purple is the aperture dial which is placed free to rotate in between the two body pieces. The lightest pink is the thermoformed lens which is between the snapfit.

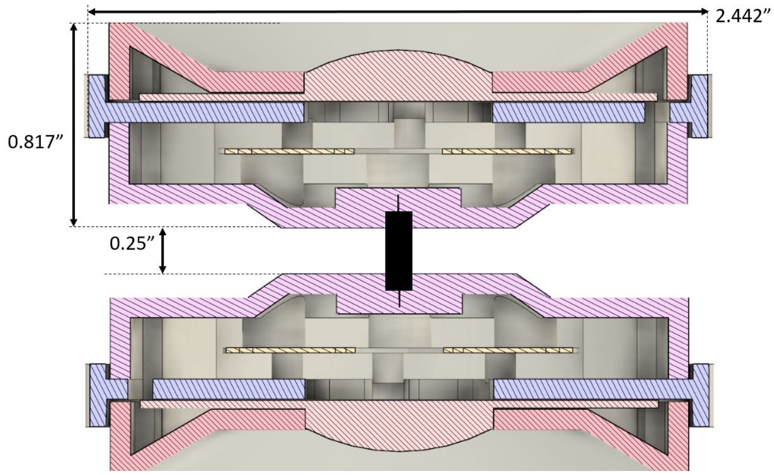


Figure 6: Cross-section side view of yo-yo with thermoformed dome

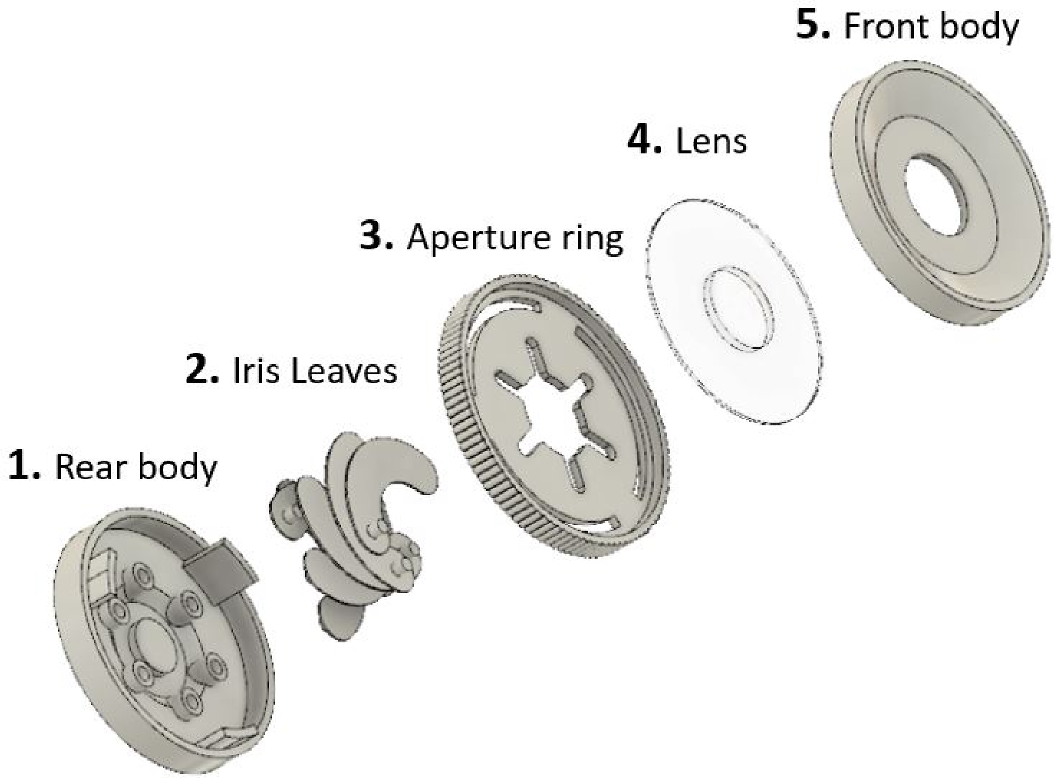


Figure 7: This is the new design for the assembly of the yo-yo. Here you can see the rear piece with pegs to connect to the iris leaves. The slots around the circumference allow the aperture ring to rotate around the front and rear bodies, which are snap fitter together. The iris pegs sit in the radial slots on the aperture ring and as the ring is rotated while the rear body is stationary the iris leaves rotate closed. The hole in the aperture ring and the clear lens allow the mechanism to be visible.

1. **Rear Body** The rear body includes a draft angle on the core side to to allow for easy ejection.
2. **Iris leaves**

   The leaves are 0.02" thick. Ejector pins will be located on the pins to prevent bending of the thin leaves
3. **Aperture ring**

   We wanted to create a fine texture on the aperture, so we are using the smallest endmill size available to create the mold (1/16"). The parting line will be on the far edge of the textured ring to make sure that the texture is consistent across the entire face. The inside of the textured ring is drafted to allow for removal from the mold. We made the outer slots in the ring slightly larger than we expect to need them to allow for shrinkage of the part and ensure a good clearance for the snap-fit tabs.
4. **Lens**

   The lens "glass" is made of thermoformed plastic. It is formed to fit between aperture ring and the front body. The lens will slide against the rotating aperture ring. We qualitatively determined that this is acceptable because the thermoforming plastic has low friction against other plastic.
5. **Front Body**

   The front body includes a draft angle on the core side to to allow for easy removal with the ejector pins. The "sharp" points on the front will be slighly rounded when machined in the cavity mold using a 1/16" endmill.

2.2 Snap fit

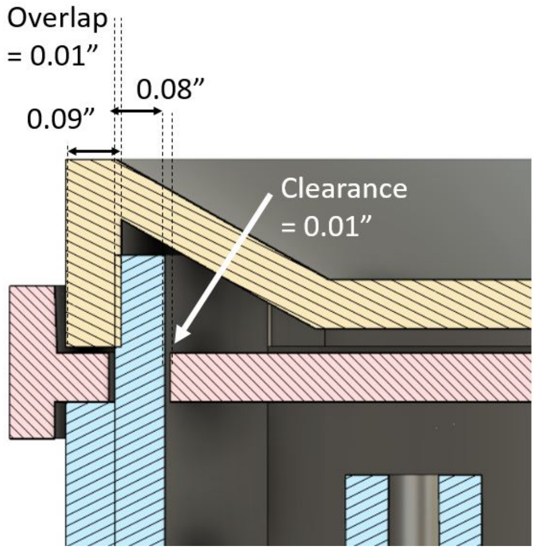


Figure 8: The rear body (blue) reaches through the aperture ring (pink) to form a snap fit with the front body (yellow).

The only snap fit in our yo-yo is between the rear body and the front body and can be seen in Figure 8. The snap fit is between the tabs on the rear body and the slots on the front body. The tabs have a minimum thickness of 0.08.” This is a 25 percent increase in thickness from our first version, which we expect will be more robust and resistant to breakage.

The snap fit is one of the only surfaces that isn't drafted, so we can ensure a parallel fit between the two surfaces.

2.3 Yo-yo Performance Estimation

We calculated the weight of our plastic parts by getting the volume from the CAD model and multiplying that by the density of polypropylene (0.331 lb/in^3) and adding that to the weight of the the nut, spacer, and screw that we will use in the yo-yo:

weight = weight of polypropylene parts + weight of metal parts
= (3.05 in^3)*(0.0331 lbs/in^3) + 2.2 g
= 0.101 lbs + 2.2 g
= 45.8 g + 2 g
= 47.8 g

This number is a bit low from a performance standpoint; 60-70 g is a good range, while 64-68 g is ideal. We will have to take this into account for the next design iteration. We would have to add a significant amount of thickness to our parts to add additional weight, so it may be easier to add a 10g washer to each half of the yo-yo to balance the weight.

Another performance metric is the center of mass. As can be seen in Figure 9, the center of mass is in the center of the yo-yo, along the axis of the axle. This makes sense because the yo-yo is radially symmetric, and will be good for balance.

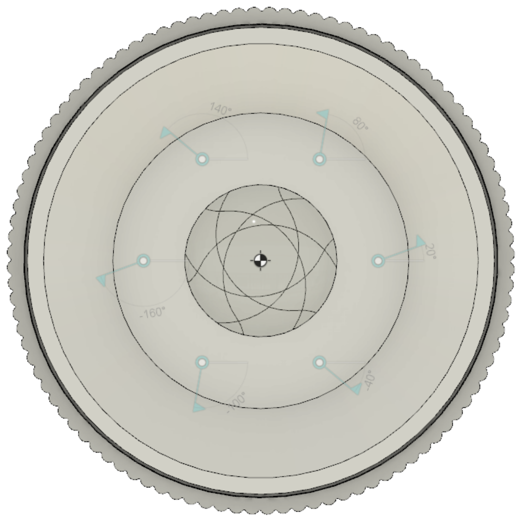


Figure 9: The center of mass of the yo-yo is located in the center.

2.4 Testing 3D printed prototype

Figure 10: The new version has the aperture ring in front of the iris leaves. The parts fit together well in the prototype.

- The rotation feels good. We aren't able to rotate with one finger – it requires at least two.
- The assembly of top and bottom portion is difficult due to the need for precise alignment. The parts jam when they are misaligned. We could consider adding tapered points to guide the tabs together more easily, or add a tapered edge to the slot for snap fitting.
- Rotating from the fully open position is stickier/more resistance than rotating from fully closed. We want to investigate further why this may be.

Figure 11: The disassembled 3D printed prototype of yo-yo version 2.

2.5 Assembly Plan

Our assembly plan is simple:

1. Lay rear body face-up
2. Insert iris leaves into body; This is the time-constraining part. It currently takes 10-20 seconds for us to insert and align all of the iris leaves. We may consider using a circular guide to align the leaves for our final assemblies.
3. Align aperture ring over iris leaves.
4. Insert thermoformed piece into front body
5. Snap front body onto rear body

That's it!

3 Next Steps

We plan to finalize our design soon and start working on the molds for injection molding. We can also begin creating the thermoformed pieces.

The complexity of the geometry makes it difficult for us to estimate shrinkage. We will need to think about this shrinkage very carefully as we design the molds for our parts. The molds will be scaled up in size by a few percent to account for shrinkage.

The iris leaves will be the first injection molded parts we make. Due to their small size and the need to make multiple parts in a single mold, we want to make sure that injection molding the part is feasible. Additionally, we can test the injection molded leaves in the 3D printed prototype to test their fit.

We also plan to add an indented feature on the lens glass and a corresponding pin on the inside of the front body to constrain the lens from rotation as the aperture lens moves behind it.