

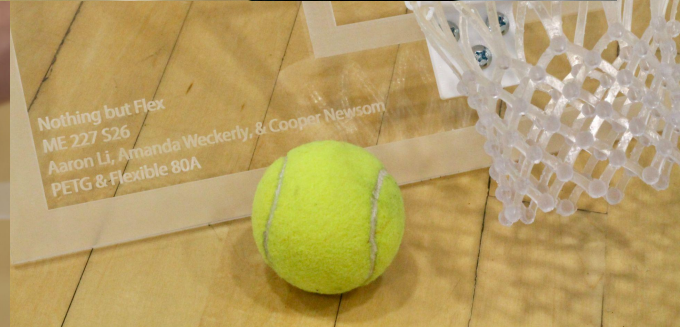
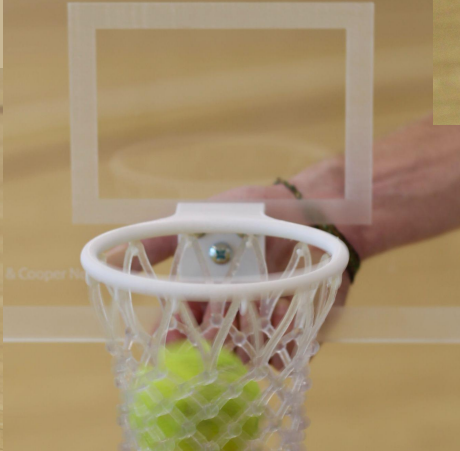
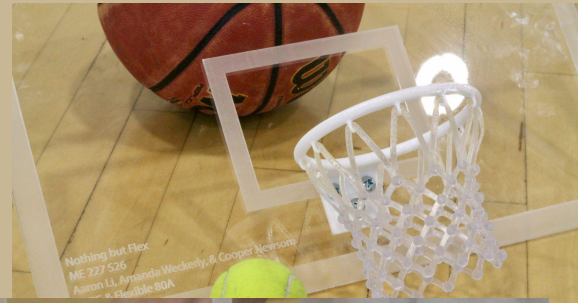
Nothing But Flex Tennis Hoop

Aaron Li, Amanda Weckerly,
and Cooper Newsom

ME 227 S26

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PETG & Flexible 80A



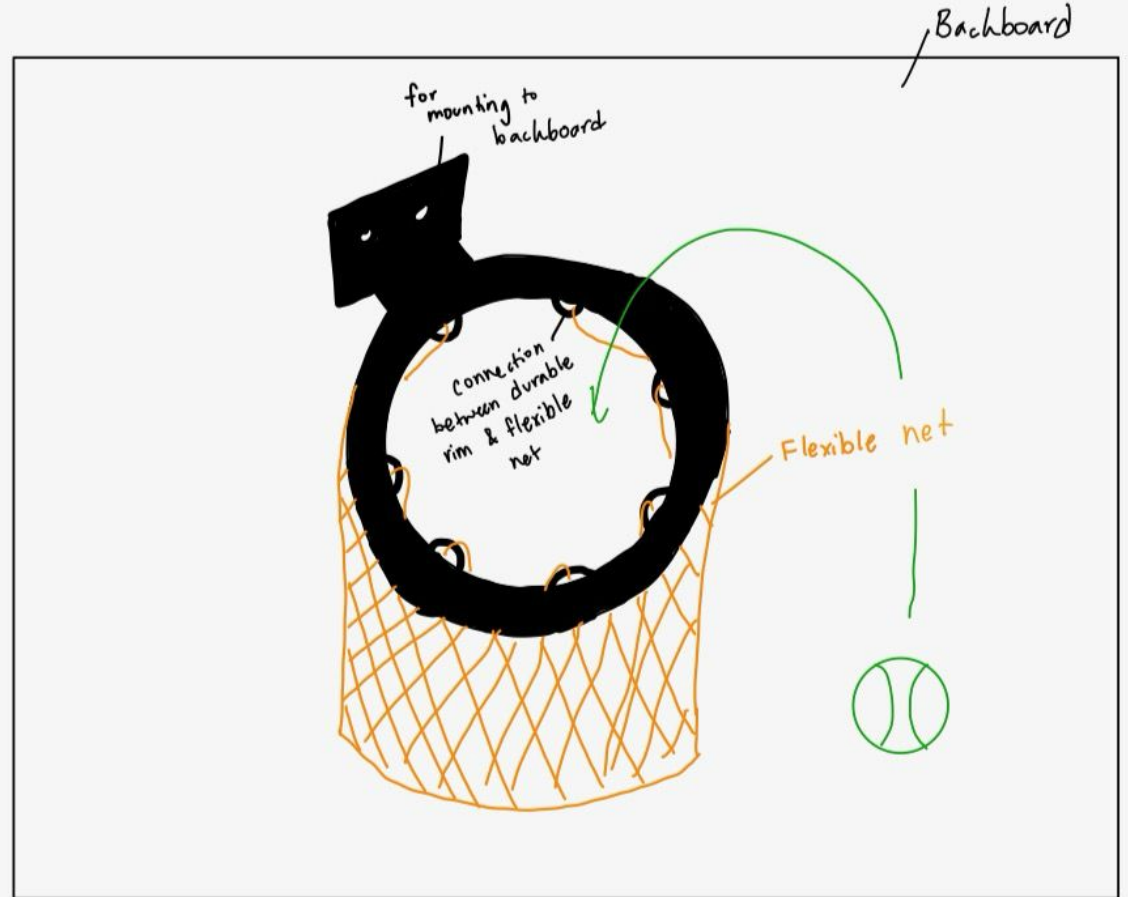


Nothing but Flex
ME 227 S26
Aaron LJ, Amanda Weckerly, & Cooper Newson
PETG & Flexible 80A

Initial Concept Sketch

Project Definition: Develop a mountable tennis ball hoop that does not break apart or permanently deform when tennis balls are tossed at it at low to medium speeds (< 10 mph; not designed for high speed throwing practice)

User: Recreational players wanting throwing practice



Design Specifications

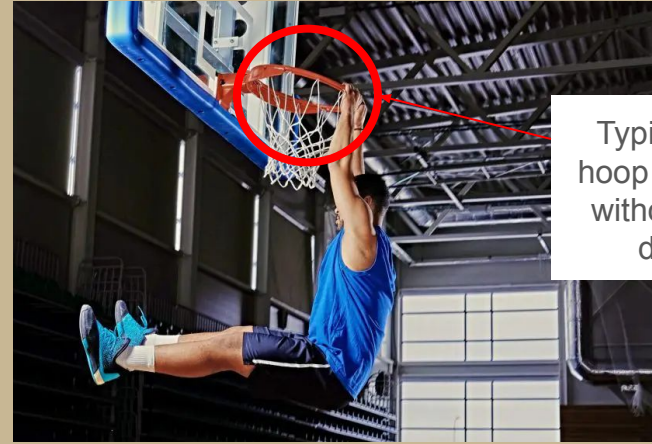
- **Breakaway Rim**

Rim that can repeatedly flex and snap back without fracturing. We aim to do this through smart design and inherent material properties – avoiding traditional spring & hinge mechanisms. A flexible rim avoids stress on the backboard.

- **Flexible Net**

- Adds a satisfying “swish” to confirm a successful shot.
- Printed as one part to avoid the complicated knotwork of traditional braided cord designs.
- Centers ball below hoop after successful shot

- Full-size hoops are too large for AMPS printers, so we scaled down to **tennis ball size** and intend our product to be used **indoors**



Typical basketball hoop are able to flex without permanent deformation

Design Constraint	Expected Resulting Force (N)
10 mph impact with rim edge (x-dir)	42.3 N
10 mph impact with rim edge (y-dir)	43.3 N
5 ft free fall onto rim (z-dir)	52.0 N

Material Comparison – Rim

Material	PLA	PETG	PP	ASA	Nylon
Strength	++	+	+	+	++
Flexibility	--	+	++	+	++
Impact Resistance	--	++	++	+	++
Fatigue Resistance	-	++	++	+	++
Printability	++	++	-	+	-



PETG has the ideal mechanical properties for our project.

- Its medium flexibility allowed for the “snap back” we wanted
- Its high impact and fatigue resistance allow it to withstand tennis balls being thrown at it repeatedly.
- Nylon and PP provide too much flexibility and were not durable enough under simulation for our expected loads. They’re also difficult to print.
- ASA would have been good for outdoor applications, but we would have lost a lot of our desired properties.

Material Comparison – Net

Material	Flexible 80A	Durable	Rigid 10K	Tough 2000
Flexibility	+	–	–	–

This ended up being an easy choice, as flexible 80A was the only compliant material available. If we were working on a clean sheet design, we would compare between Flexible 80A and Elastic 50A.

Material	Flexible 80A	Elastic 50A
Flexibility/Stretch (Elongation at Break)	120%	160%
Tensile Strength (MPa)	8.9	3.4
Fatigue Resistance (cycles)	>200,000	800

If we had access to Elastic 50A, we still would have chosen Flexible 80A. While 50A is softer/stretchier and would better replicate a cord net, its far inferior strength and fatigue resistance rules it out.

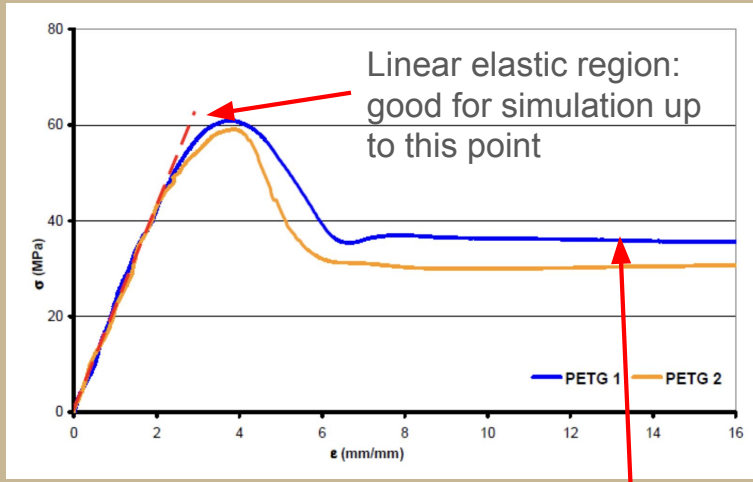
- 1): [Flexible 80A Resin TDS \(EN-US\), Formlabs](#)
- 2): [Elastic 50A Resin V2 TDS \(EN-US\), Formlabs](#)

Chosen Materials

PETG:

- High impact resistance
- High fatigue resistance
- Moderate stiffness/flexibility

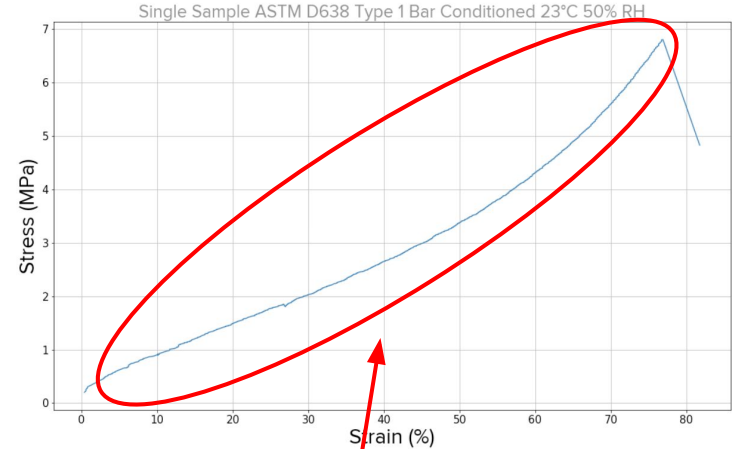
¹ PETG Stress-Strain Curve



Not brittle; will deform before breaking

² Flexible 80A Stress-Strain Curve

Formlabs Flexible 80A V1 Representative Stress-Strain Curve



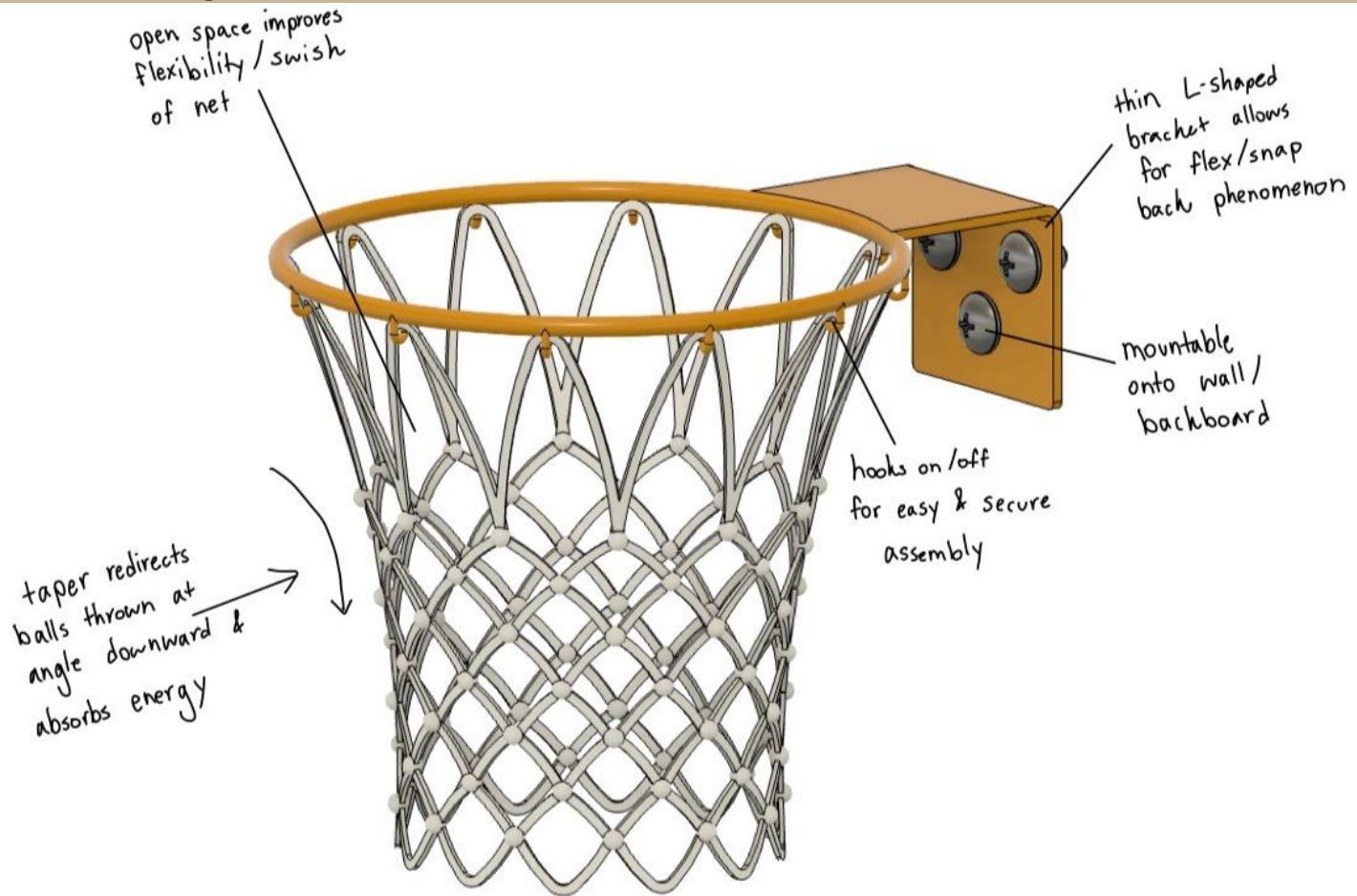
Flexible 80A:

- Flexible
- High elasticity
- High fatigue resistance

¹ "Experimental characterization of the mechanical properties of PETG and PA6 Plastics"

² Formlabs

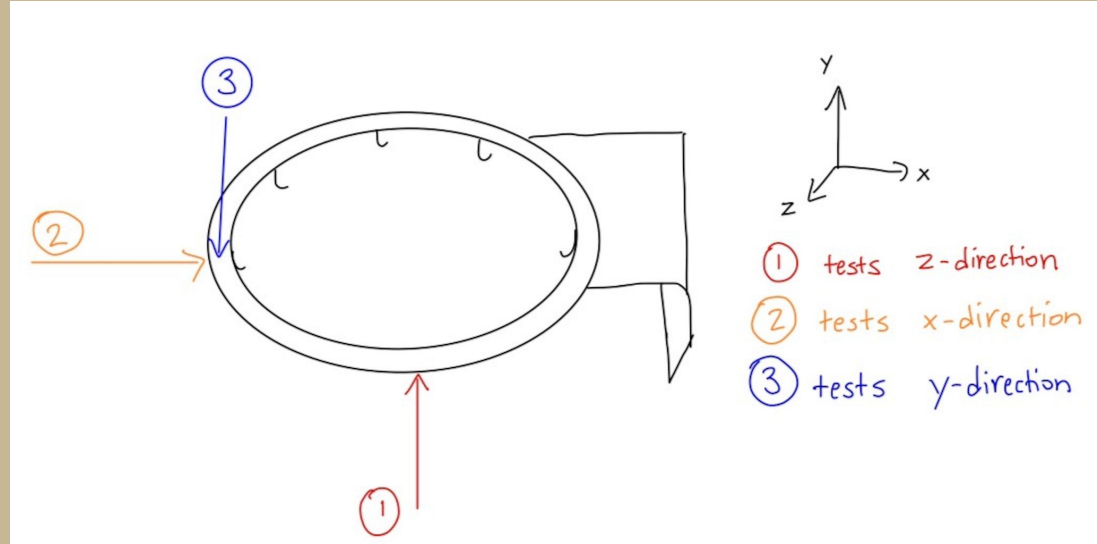
Final CAD Design



Critical Load Cases Tested with Simulation

Critical Load Cases for Simulation Test:

- Must withstand a ball thrown at 10 mph at the edge of the rim
- Must withstand a ball that falls onto rim from 5 ft above it
 - 5 ft was selected based on indoor constraints: with ~10 ft ceilings and the hoop mounted at ~5 ft (shoulder height)
 - This leaves a maximum ball drop height of ~5 ft



Critical Load Cases Force Derivation

$$F \Delta t = \Delta p$$

$$p_i = mv \quad p_f = -mev$$

$e \approx 0.6$ for ball-rigid surface

$$\Delta p = mv - (-mev) = mv(1+e)$$

$$F = \frac{mv(1+e)}{\Delta t}$$

$\Delta t \approx 0.01 \text{ s}$ ← assumption, worst-case

$$m_{\text{Tennis Ball}} = 0.0594 \text{ kg}$$

$$5 \text{ ft} = 1.524 \text{ m}$$

$$10 \text{ mph} = 4.47 \text{ m/s}$$

Load Case 1: Ball thrown 10 mph at rim in z-direction

Load Case 2: Ball thrown 10 mph at rim in x-direction

Load Case 3: Ball falls on rim in y-direction after dropped 5 ft

$$V_1 = V_2 = 10 \text{ mph} = 4.47 \text{ m/s}$$

$$V_3 = \sqrt{2(9.81)(1.524 \text{ m})} = 5.47 \text{ m/s}$$

free fall

$$F_1 = F_2 = \frac{(0.0594)(1.6)(4.47)}{0.01} = F_1 = F_2 = 42.3 \text{ N}$$

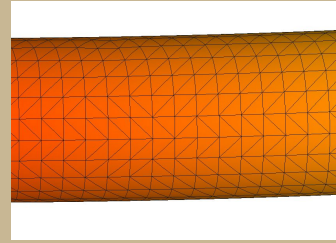
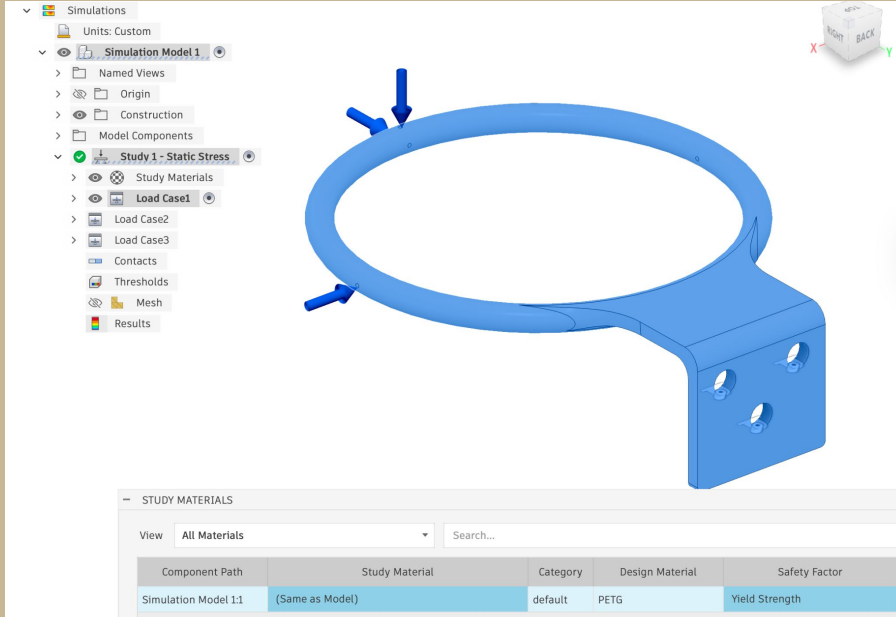
$$F_3 = \frac{(0.0594)(1.6)(5.47)}{0.01} = 51.96 \text{ N}$$

$$F_3 = 52.0 \text{ N}$$

↑
Used in
simulation

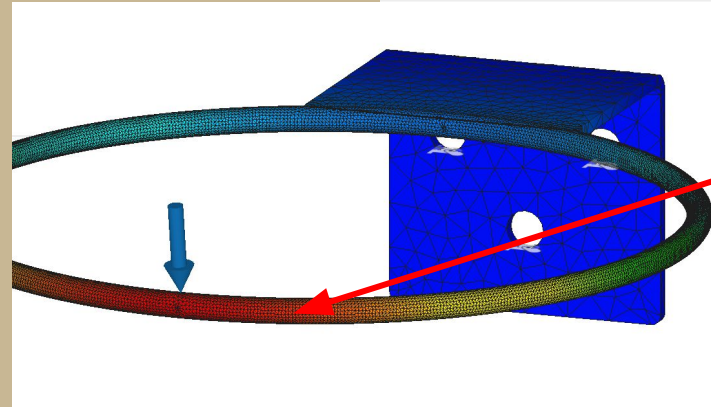
Simulation Setup

- Added material PETG with custom material properties found on Xometry
- Applied pin hole constraints and removed hook geometry to simplify model
- Applied load cases in desired areas by splitting faces at those points



MATERIAL PROPERTIES	
Material	PETG
Density	1.270E-06 kg / mm^3
Young's Modulus	1.70 GPa
Poisson's Ratio	0.38
Yield Strength	30.00 MPa
Ultimate Tensile Strength	32.00 MPa
Thermal Conductivity	2.000E-04 W / (mm C)
Thermal Expansion Coef...	8.570E-05 / C
Specific Heat	1500.00 J / (kg C)

Close



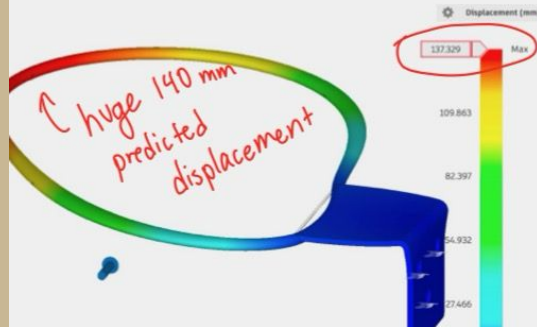
Decreased
mesh size
for better
resolution

Rim Simulation 1 Results

Load Case 1:

thrown 10 mph in Z-Dir

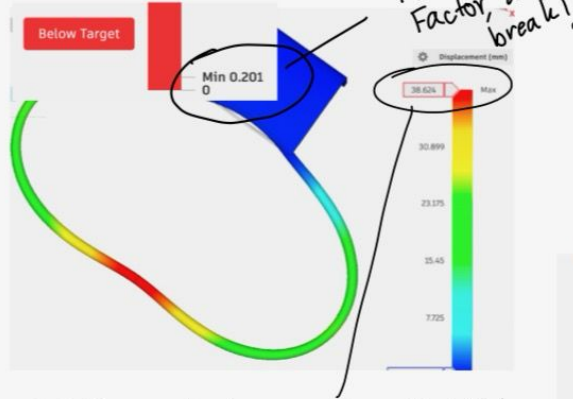
$$F = 42.3 \text{ N}$$



Load Case 2:

thrown 10 mph in X-Dir

$$F = 42.3 \text{ N}$$



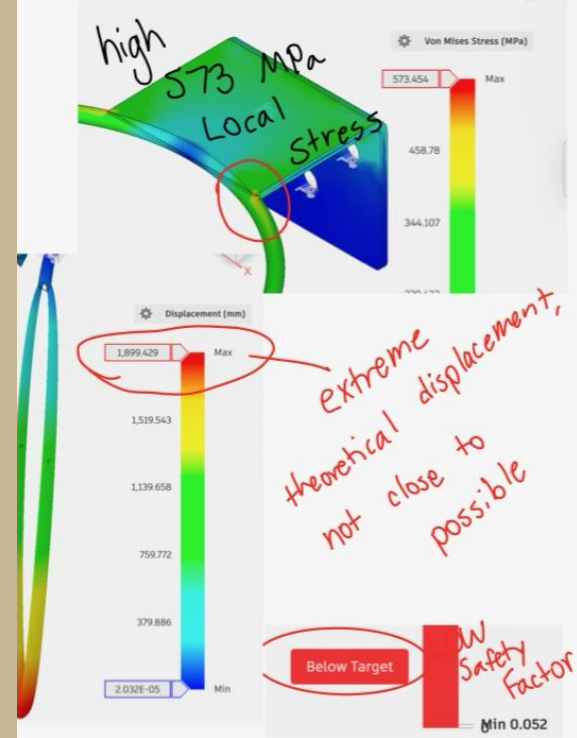
38.7 mm displacement → HUGE!



Load Case 3:

Free Fall from 5ft onto Rim

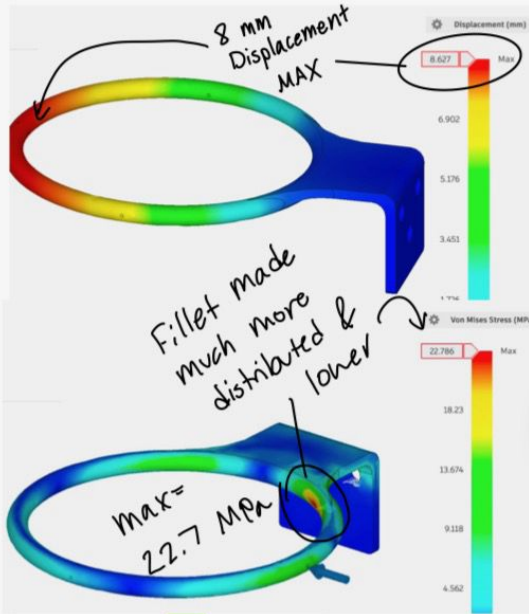
$$F = 52.0 \text{ N}$$



Final Rim Design Simulation Results

Load Case 1:

thrown 10 mph in Z-Dir
 $F = 42.3 \text{ N}$



In Range

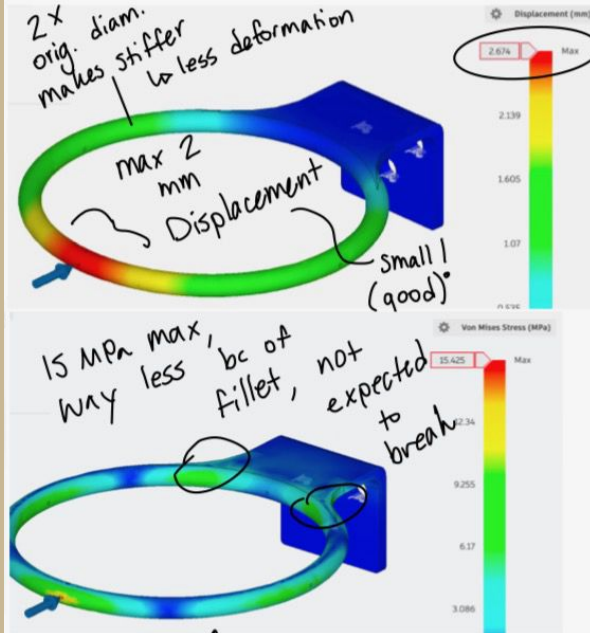
Min 1.945

1.511

1.9 Safety Factor!

Load Case 2:

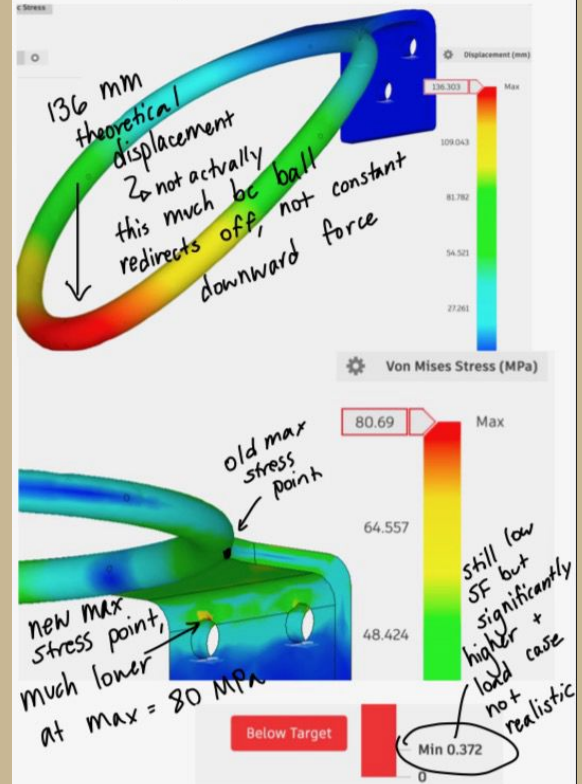
thrown 10 mph in X-Dir
 $F = 42.3 \text{ N}$



1.3 Safety Factor

Load Case 3:

Free Fall from 5ft onto R,
 $F = 52.0 \text{ N}$



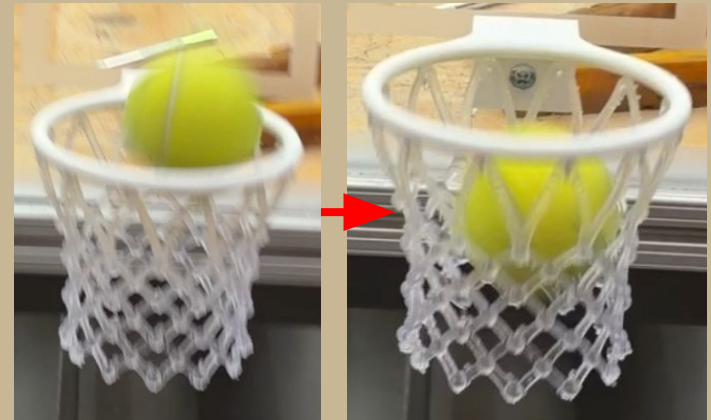
Simulation Comparison & Analysis

These are **over predictions** because:

- Model applies static load, but ball impact is short (it quickly rolls off), so the rim is not loaded long enough to reach these large displacements / stresses
- PETG has large nonlinear region on stress-strain curve

- Load Case 1
 - Theoretical max stress: 298 MPa -> 23 MPa
 - Theoretical max displacement: 140 mm -> 8 mm
 - Safety Factor increased: 0.1 -> 1.9
- Load Case 2
 - Theoretical max stress: 150 MPa -> 15 MPa
 - Theoretical max displacement: 39 mm -> 2 mm
 - Safety Factor: 0.2 -> 1.3
- Load Case 3
 - Theoretical max stress: 573 MPa -> 80 MPa
 - Theoretical max displacement: 1900 mm -> 136 mm
 - Safety Factor: 0.05 -> 0.32

Does not apply continuous,
static load on one point

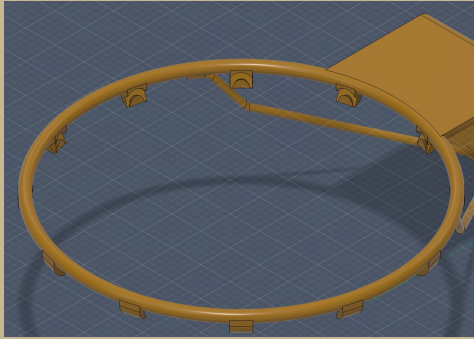


Physical Testing vs. Simulation

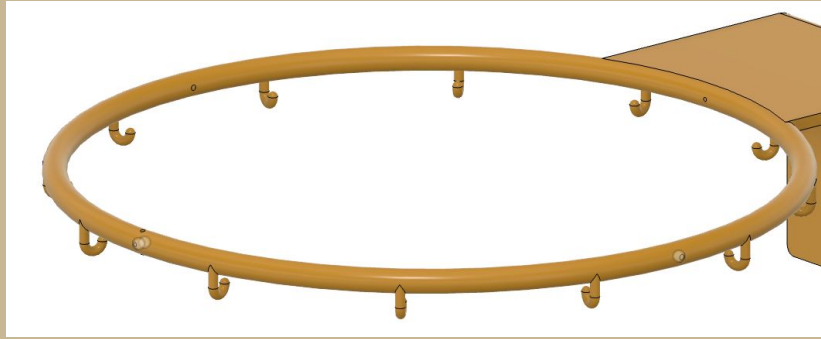
- Physical testing confirms the rim does not reach simulated failure levels under real use and can withstand the 3 load cases
 - Simulation did correctly identify its weak points and failure modes
- Rim Version 1 broke where simulation predicted when put through Load Case 3



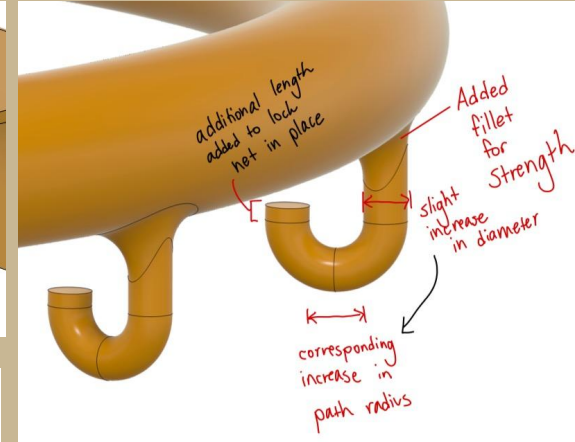
Hook Design and Simulations



Initial hook design had features far too small to print properly; ruled out even before simulation

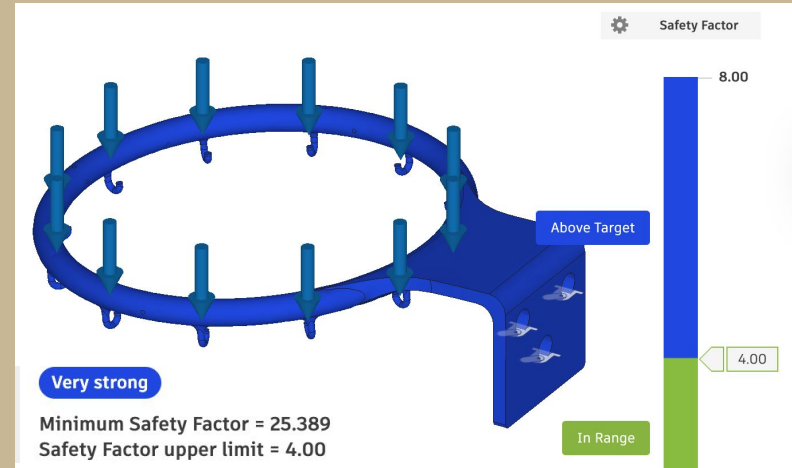


2nd hook design still was flimsy when printed so increased hook diameter and length



Final Hook Design Robustness:

- Simulation showed 1 hook can support 5 N with Safety Factor of 1.3
 - This is 10X tennis ball weight
- Simulation of net weight + $0.5 * (\text{tennis ball weight})$ on 2 adjacent hooks had safety factor = 25



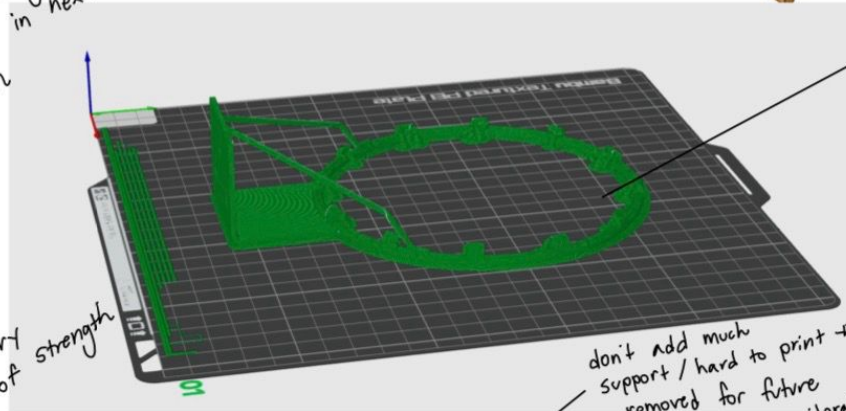
PETG Rim Initial Design

CAD:



hook shape not ideal for net or printing → redesigned in next iteration

Sliced File:



thin bracket/hoop diameter made very flexible at expense of strength
→ increased thickness next for more strength

don't add much support / hard to print → removed for future iterations

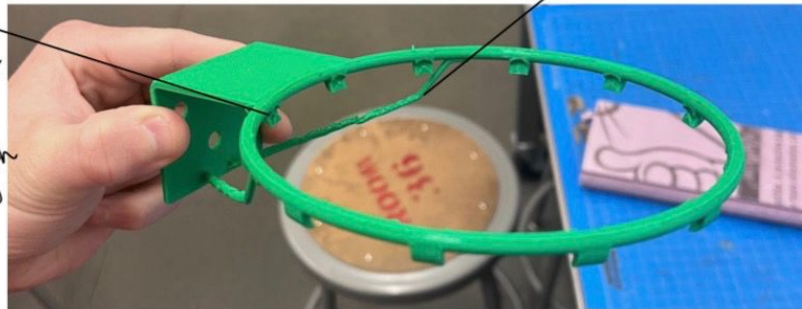
printed flat to maximize SA on build plate

print lines made hooks weak / easily breakable

Orientation later switched to



PETG Print:



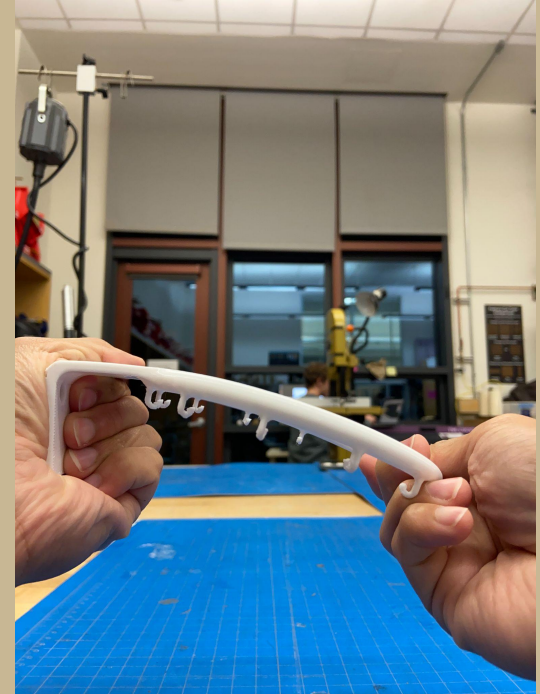
Rim Flexibility Iterations



Initial rim design was very flexible, which was desired, but also weaker as seen from our simulations

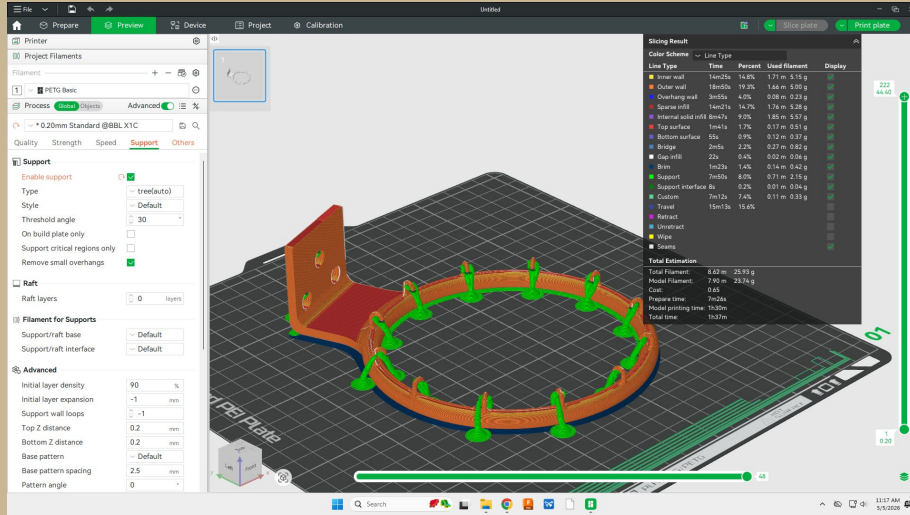


Our design changes to increase the strength of the rim caused a decrease in the flexibility, leading to a rim that was too stiff

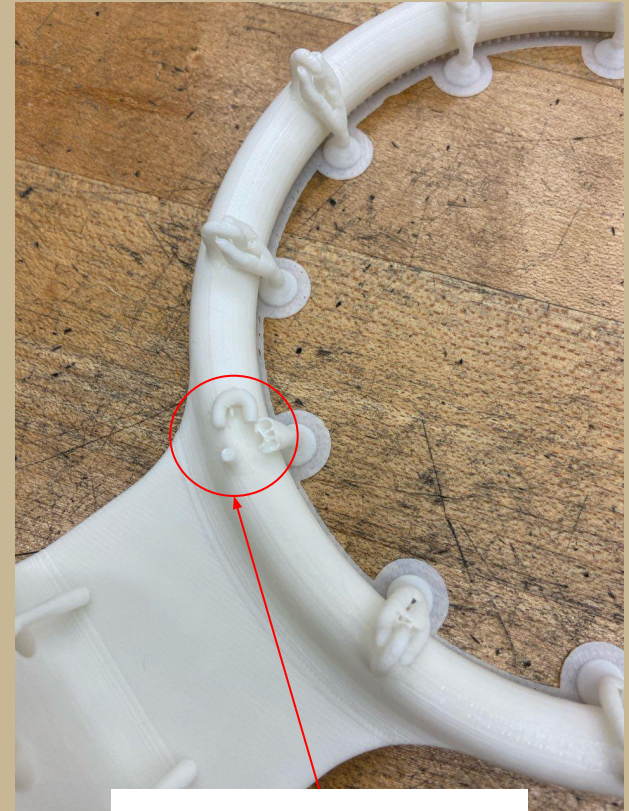


The final version was a good mix between strength and flexibility, allowing for a rim with a high safety factor and springback

Rim Printing Orientation

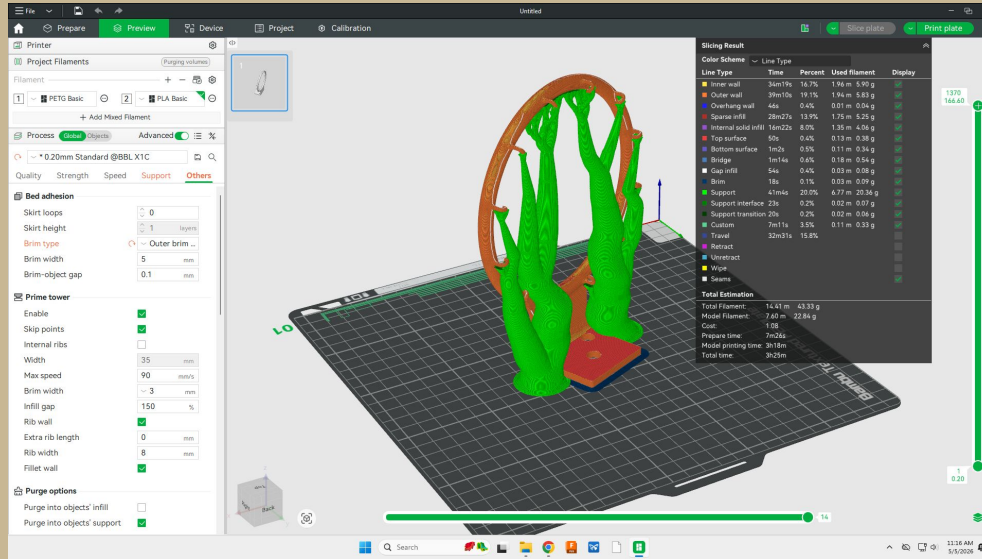


- Rim was initially printed flat with hoop hole parallel to build plate to reduce supports and material usage, but this created issues:
 - Filament layers caused our new hooks to break easily, even when a fillet was added
 - Screw holes became ovalish due to vertical sagging

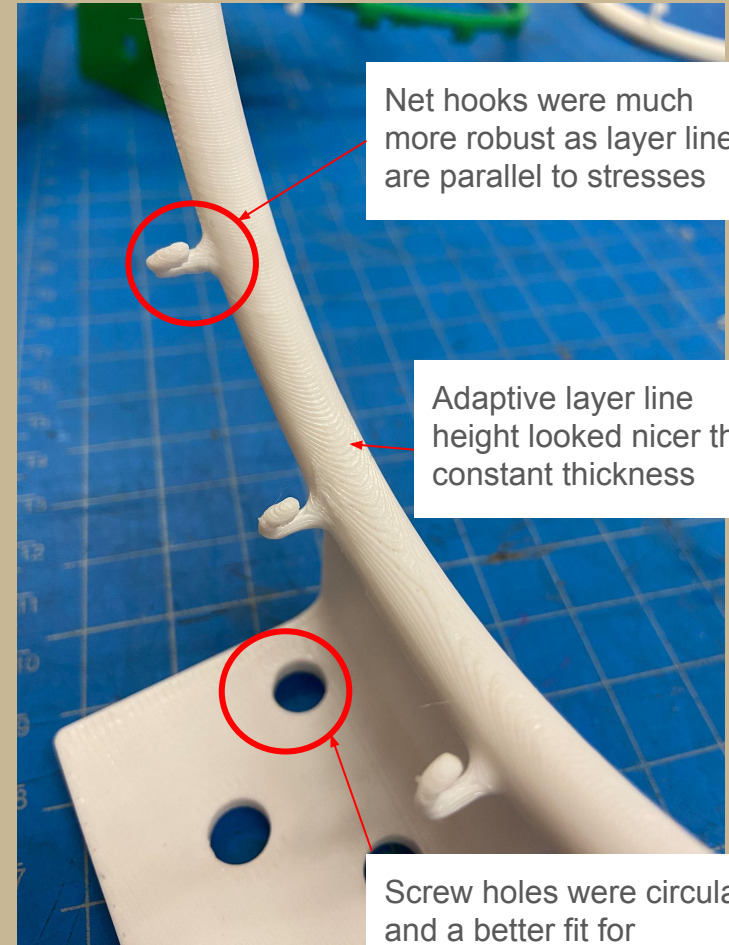


Net hooks already failed before supports were even removed

Rim Printing Orientation



- Print orientation was changed to have the hoop hole plane perpendicular to the build plate
- Screw holes were printed as circles, allowing for easy attachment to the backboard
- Net hooks possessed greater strength
- Cost only went up by ~\$0.50



Rim Iteration Sequence

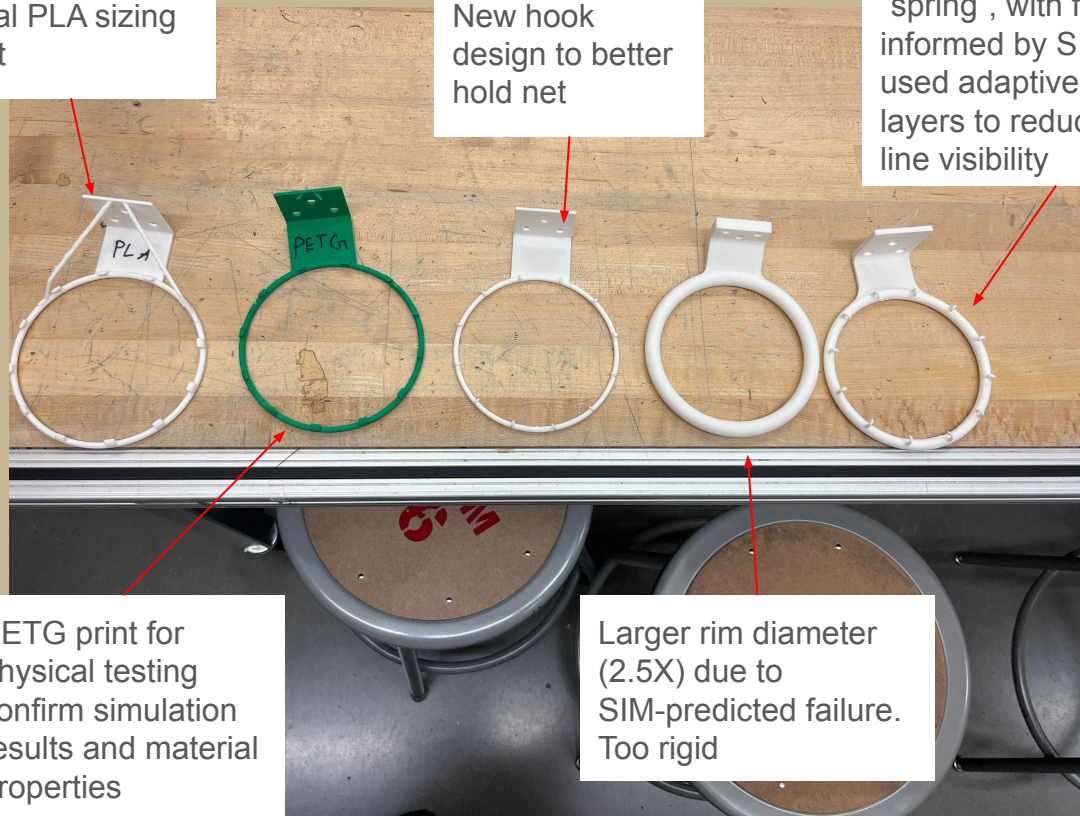
Initial PLA sizing print

New hook design to better hold net

Final design, good balance of strength and “spring”, with final hooks informed by SIM results; used adaptive, smooth layers to reduce layer line visibility

PETG print for physical testing confirm simulation results and material properties

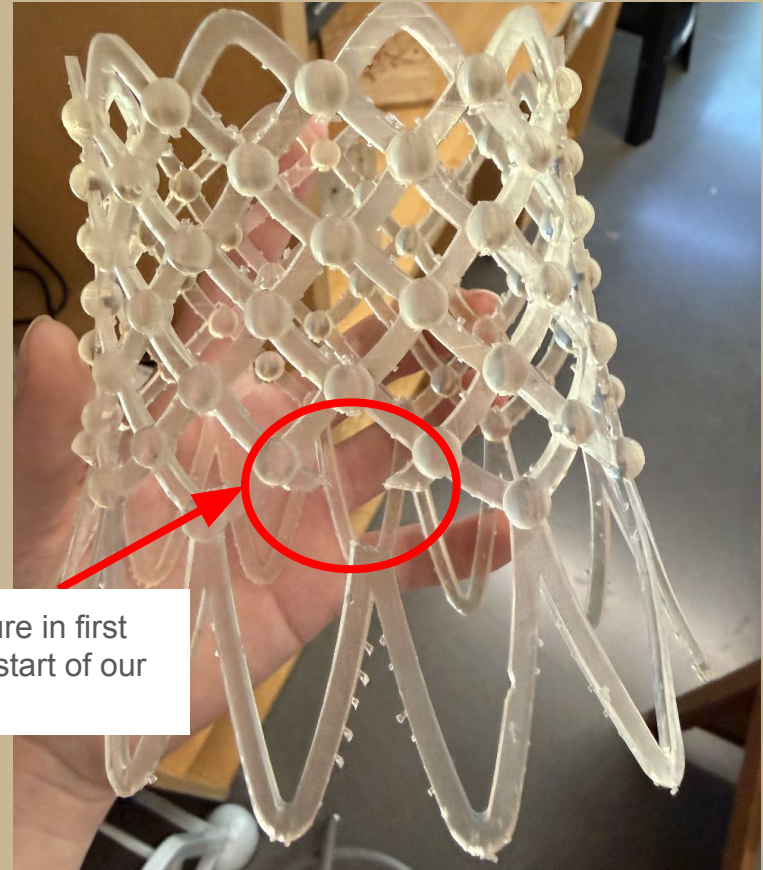
Larger rim diameter (2.5X) due to SIM-predicted failure. Too rigid



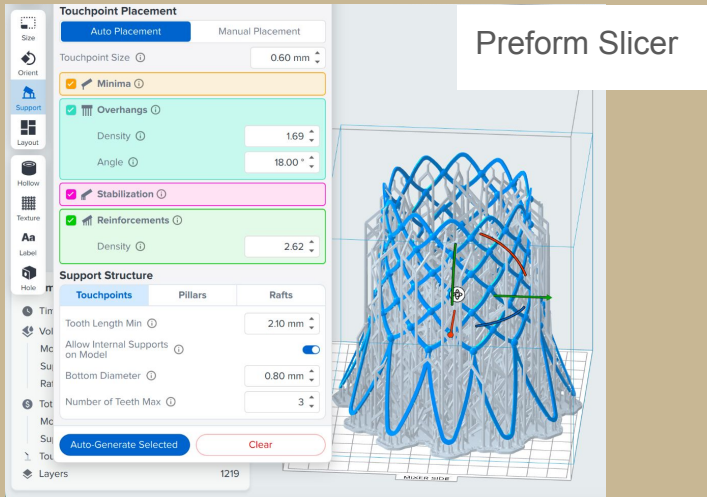
First Net Iteration and Print

First print was oriented upside down to reduce costs. It printed well except for one failure:

- Initially unsure if this was print failure or if it got damaged in wash (now believed to be a touch point failure)
- Next iteration featured fillets to all “knot” edges & increased net thickness to improve durability
- Adjusted print settings for next iteration; switched from full raft to no raft since resulting bottom layer compression won't affect net functionality and we want to reduce the material cost



Missing structure in first print (only the start of our problems...)

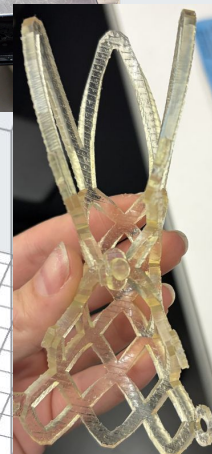
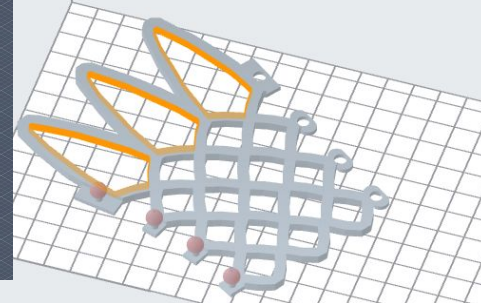
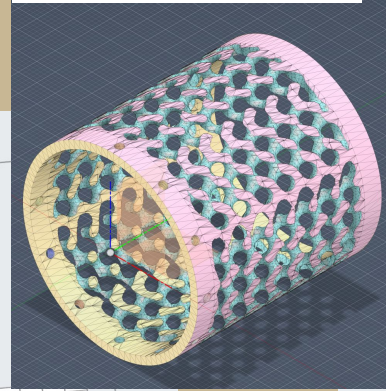
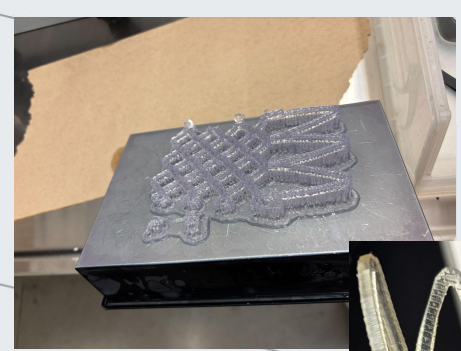


Preform Slicer

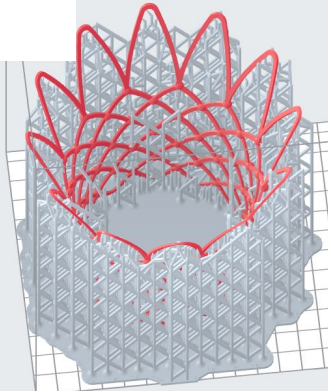
Net Design Exploration

PreForm wants A LOT of supports, which drives the total cost of the component 1200%. We tried playing with support settings to reduce this, but this only led to print failures

We also tried a self supporting lattice net, but this needed so much material that it ended up being even more expensive



Texture	
Aa	Summary ⓘ
Label	Time Estimate ⓘ ~3 h 34 m 🕒
Volume	126.74 mL ▼
Hole	Model(s) 9.38 mL
	Supports 96.86 mL
	Raft 20.50 mL
💰	Total Print Cost ⓘ 35.49 ▼
	Model Cost 2.63
	Support & Raft Cost ⓘ 32.86
📍	Touchpoints 587
🔍	Layers 1268



We experimented with printing flat segments of the net with a ball-and-socket clasp feature. This was somewhat successful, however we were told that printing flat on the build plate wasn't advised due to warpage. Angling the part added supports that wiped away any cost benefits, so we abandoned this idea. The warpage issue was probably not an insurmountable challenge, so if we had another iteration of the piece we'd like to revisit this strategy.

Net Iteration Sequence

First attempt at resin printing. Almost perfect, but one ball and strut members vanished at some point in the print

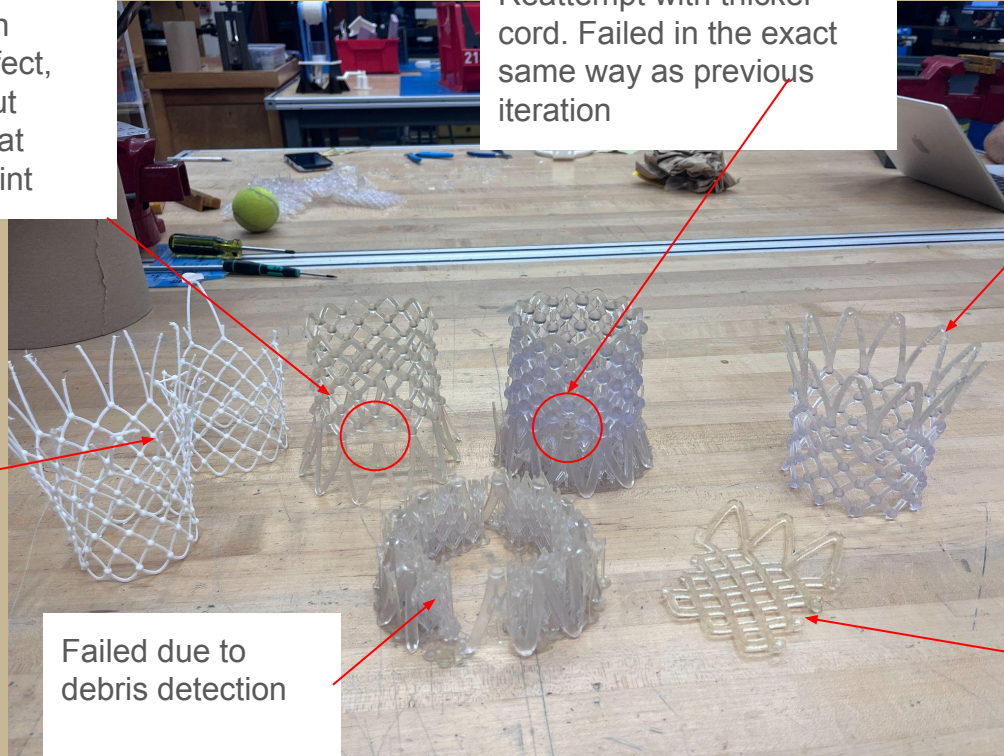
Reattempt with thicker cord. Failed in the exact same way as previous iteration

Final net. Deleted bottom swoop for better separability from build plate /raft

Initial PLA Prints to get a feel for sizing. Printed without supports as an experiment (pretty impressed!)

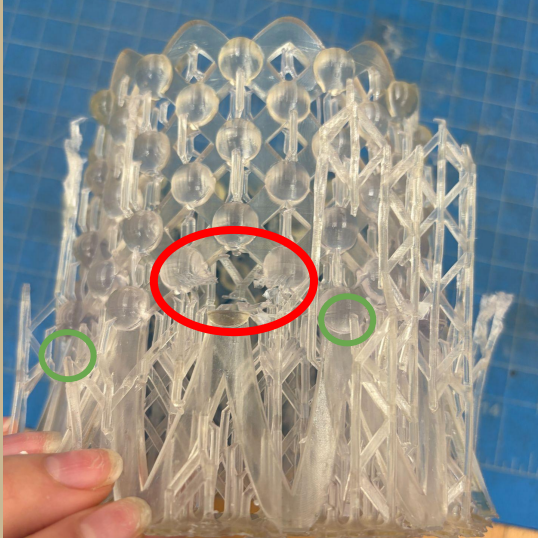
Failed due to debris detection

Flat pattern trial, not pursued as cost was more than printing the whole hoop, and printing time would be significantly longer



Failure Correction and Final Iteration

Net Iteration 2 - Thicker with Filleted "Knots"



Printing the flare upright relied on small touch tips to constrain the flare geometry. When a touch tip failed, the flare shifted, causing subsequent layers to misprint.

- Touch tip diameter was increased from 0.5 mm to 0.8 mm

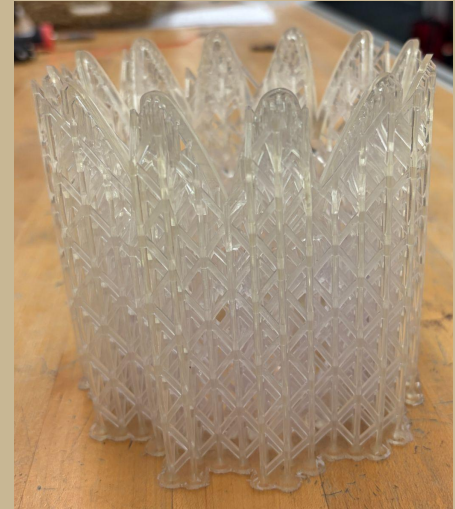
- It was reoriented upside down to reduce dependence on touch-tip support



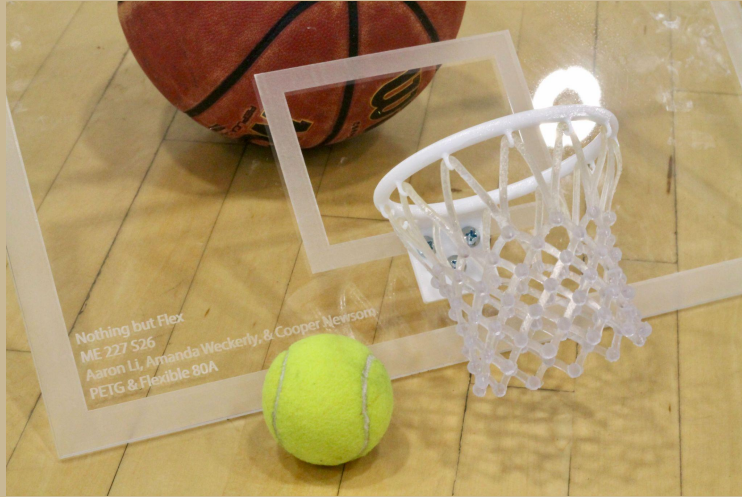
- Printed with mini rafts instead of no rafts to prevent damage

- Net thickness reduced to original size since this was not the issue

Final Iteration



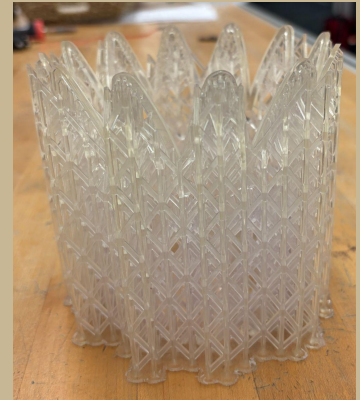
Final Result



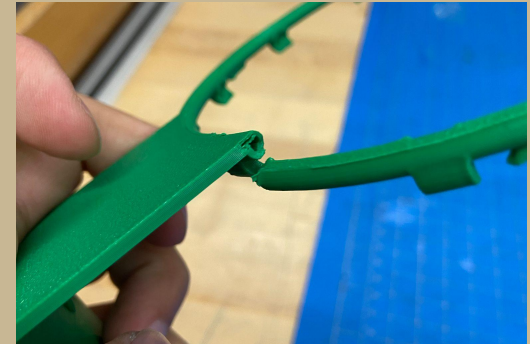
- Final assembly features an acrylic backboard with heat set inserts
- PETG rim is attached to backboard with 3 screws
- Flexible 80A net hooks onto rim
- Net is able to dampen and redirect ball falling without breaking
- Rim features flexible springback that imitates a real basketball hoop

Reflections

- Manufacturing our net included significant costs, not only monetary but also time and mental wellbeing
 - Although we explored changing the design to be split into parts, we never completely moved away from the net design and explored a different way to dampen and redirect ball movement
 - With more time, a new design, not reminiscent of a basketball net, could be explored to better fit the material properties and manufacturing method of Flexible 80A
- Simulations can spot weak points in design without real-life testing
 - We initially doubted the accuracy of our simulations, suggesting that a ball would not break our rim due to its high flexibility
 - However, real-life testing with a tennis ball confirmed that the rim would break with a great enough force
- Customizing print settings can improve print quality/cost, but optimizing too much can also introduce unforeseen failures
 - Don't reduce support settings!



This print cost >\$35, with a significant portion because of supports



Our rim broke where the simulation predicted!

Total Time & Budget

Part	Source	Unit Cost	Qty	Total
Backboard	Lab 64	\$0.00	1	\$0.00
Rim	AMPS PETG	\$1.13	1	\$1.13
Heat Set Inserts	AMPS	\$0.70	3	\$2.10
Screws	AMPS	\$0.15	3	\$0.45
Net	AMPS 80A	\$0.28	160.7	\$45.00
			Assembly Total	\$48.68
Failed / Test Nets				\$90.00
Failed / Test Rims				\$5.00
			Project Total	\$139.17



Time: ~90 hours