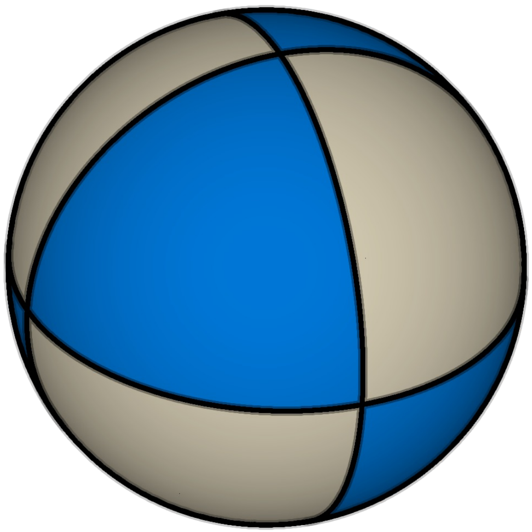
The Complete Homemade Juggling Beanbag Guide

8-Panel Spherical Octahedron Chapter



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This is part of a multi-document guide. Hyperlinks with the icon[1] open other guide documents[2], if they are saved to the same folder (**CTRL+Click** opens them in a new tab).

Visit my website to download those, and check back occasionally for revisions and corrections:

www.joshuaclifton.com/juggle

Compare the Last Edited date above on the right with the one on the web page to see if I have submitted changes.

Please contact me with your thoughts! Feedback on this project would be helpful and encouraging. You may also request custom patterns or other help with your project.

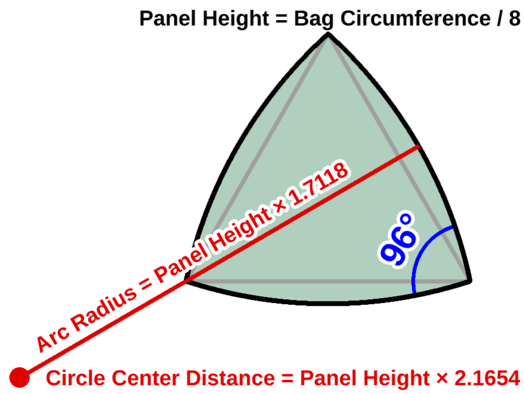
If this guide is useful to you, please **consider donating at my website** linked on the left. I am not monetizing the guide, and I am in need of income.

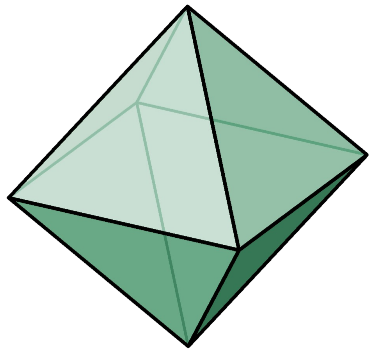
My website also provides blank **color arrangement diagrams** for experimenting with new arrangements in an image editor.

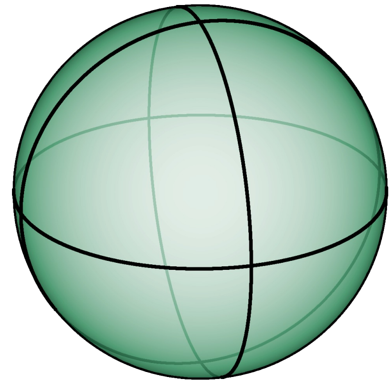
1 Icon from https://freesvg.org/vector-illustration-of-external-link-icon

2 **If the linked PDF does not open at the specified location**, keep it open, switch to the previous PDF's tab, and click the link again. **Cross-document links may not work in mobile PDF readers.** In that case you must open the document yourself and find the linked topic.

8-PANEL SPHERICAL OCTAHEDRON INSTRUCTIONS







My original denim bag, which used steeper panel curves

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Design Notes

This design is based on the regular octahedron, which is composed of eight equilateral triangular faces, but the use of curved-edge triangles transforms the otherwise sharp vertices into continuously circular seams. This design is a good balance between the uniform seam arrangement, roundness, and visual elegance of the higher panel count designs, and the ease of construction of the 4-panel orange peel ball. It also supports many color arrangements.

In October, 2022, I designed a Bézier curve for my pattern shape and included instructions for drawing it. It makes very little improvement to the ball shape, but with some fabrics, and to a perfectionist, it may be noticeable. My original, circular patterns are available at the end of the chapter.

I used the octahedron design to make 2″ diameter, pocket-sized juggling bags, which could also be used as footbags. I filled them loosely using primarily plastic pellets and increased their weight to 75g using metal BBs, which makes this small size very juggleable. To make these, use the 2″ ready-to-print pattern.

Supplies

- **For the templates**
  - Cardboard or Template Plastic, Scissors, Glue Stick or Double-Sided Adhesive Tape (to attach the pattern to the template material). **For drawing the pattern by hand:** Paper, Compass, metric Ruler, fine-point Pencil.
- **For the beanbag**
  - Fabric, Needle and durable Thread, Scissors, Fabric Marker or soft Pencil, beanbag Filler, Funnel.
- **For your information**
  - Unless you are experienced with this sort of thing, I recommend that you browse through the General Information and Techniques chapter (in the ***01 – Homemade Juggling Beanbag Guide – Index & Supplementary Chapters*** document) before starting. You may find some tips there that will improve your experience and your beanbags.

Printing and Drawing the Pattern

Later in this chapter I provide ready-to-print patterns. (When printing them, be sure to tell the Print Dialog to print only the page(s) you want so you don't print the entire document.) After those are sizing formulas, pre-calculated pattern measurements, and instructions for drawing the pattern yourself. Click the hyperlinks or look to the Chapter Index to locate those sections.

Color Arrangements

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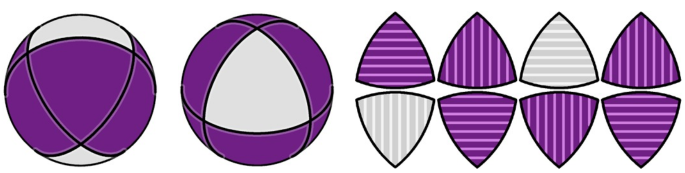
Following are all the color arrangements I could think of, including those of the 4-panel orange peel ball, grouped according to the number of colors they contain. This is a versatile design.

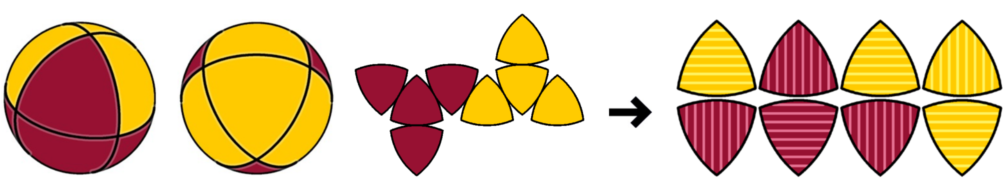
The hatching lines indicate how to orient each pattern relative to woven fabric's grain or corduroy cords. This will make the grainline conform to my recommended layout in the "Making the Panels" section, which calls for half of the panels to be oriented one way and the other half the other, and the two orientations to be alternated on the ball so that the direction of stretch and lines of the fabric are balanced.

2 colors

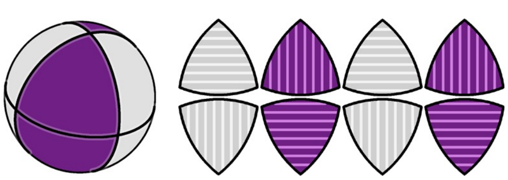
#1: Checker Ball. Checkered pattern of contrasting colors (my corduroy beanbag shown at the beginning of this chapter uses this arrangement).



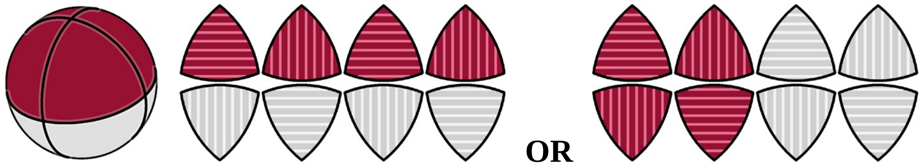
#2: Belt. A belt of 6 panels of color A around the ball between a pair of panels of color B.



#3: Twin Triforce. Each color on a triangular patch of four panels.

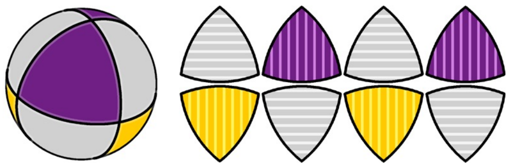


#4: Alternating Stripes. Alternating two-panel stripes of contrasting colors (orange peel ball style).

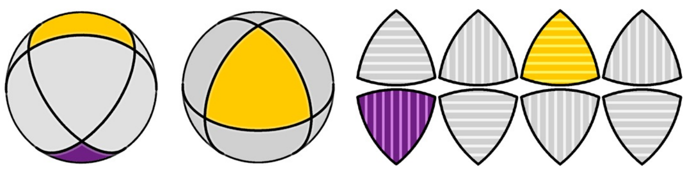


#5: Hemispheres. One hemisphere (four panels that share a corner) of each color.

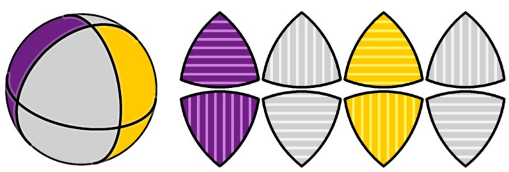
3 colors



#6: Checker Ball (3-color variation). Colors A and B alternate on one hemisphere and A and C alternate on the other with no panel having a neighbor of the same color. There will be four panels of color A, which can be thought of as a background color for B and C which are checkered throughout it. (The photo of my old denim beanbag at the beginning of this chapter depicts this arrangement.)

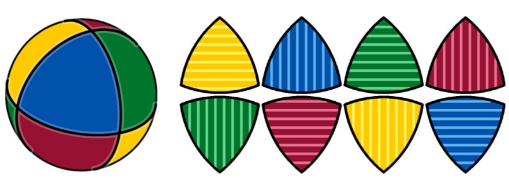


#7: Belt with Dichromatic Poles. A belt of 6 panels of color A between colors B and C which are on opposite panels.

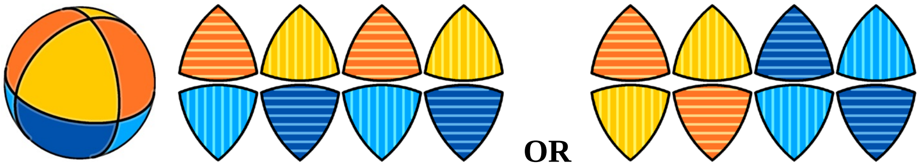


#8: Alternating Stripes (3-color variation). Color A on a pair of opposite, two-panel stripes and colors B and C on the other pair of two-panel stripes (orange peel ball style).

4 colors



#9: Patchwork Ball. Each color on pairs of opposite panels. No panel has a neighbor of the same color and all four colors are visible at any angle.



#10: Checkered Hemispheres. Two colors alternate on one hemisphere and the other two alternate on the other hemisphere. Each hemisphere (when viewed from the "pole") has a distinct color personality (fire and water in my example). Around the equator between them all four colors are visible. On the right is a footbag[3] that uses this arrangement (though it is actually a 24-panel ball).

#11: Four Stripes. Two-panel stripes of each color (orange peel ball style).

Making the Panels

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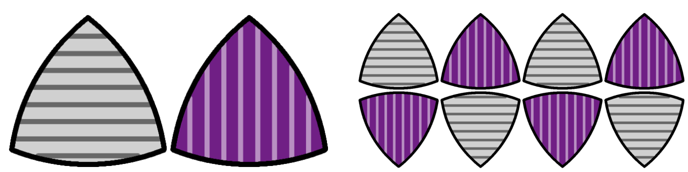
1. You will need 8 panels, and **you will be tracing the patterns onto the back of the fabric (the side that will be inside the bag)**.
2. Use the smaller, stitching template to trace the stitching pattern within each cutting pattern, being sure to center it well (centering it allows you to align the patterns more easily as you sew, but is not otherwise important).

   If you are using a woven fabric, or especially something like corduroy, I recommend orienting half of the panels horizontally to the grain or cords of the fabric and half vertically so that you can alternate the two types of panels on the bag and produce a balanced stretch and appearance.
3. Cut out the panels.

The assembly instructions begin on the next page

3 Footbag photo from http://www.jugglingstore.com/pyramid-footbag-765.html

Assembly

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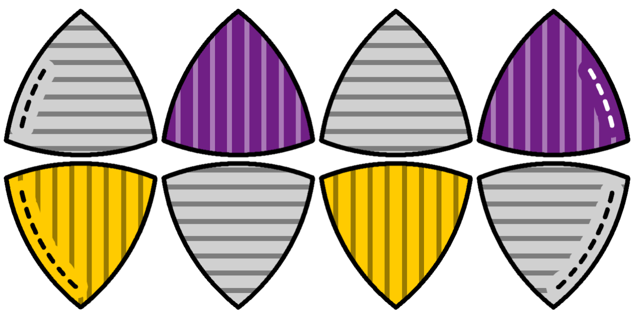
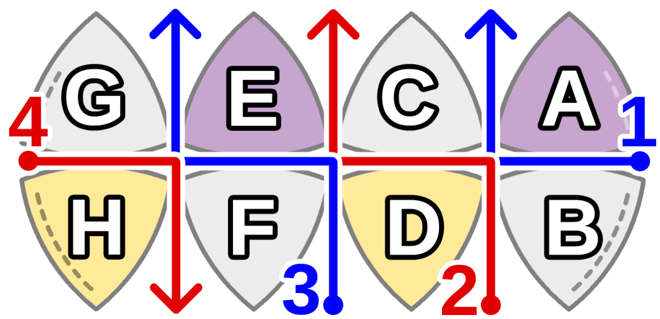
Following is my method of assembly which uses 2-5 threads. The diagrams depict the method. **The letters in the second illustration indicate the sequence in which the panels are attached**. **Each numbered path is a new thread**, though if your thread is long enough you can continue #1 into #2 (reversing 2’s direction) and even into #3. The final one or two seams, which have stitching patterns drawn on the panel fronts (indicated by the dashed lines), will be sewn from the outside.

I am right-handed and so the diagram is oriented for stitching toward the left. In case you are left-handed or prefer the opposite orientation, I included a **left-handed stitching diagram below the instructions**.





1. **Lay the panels out as shown above** (I prefer to place them front face up) and **arrange them according to your color pattern**. The **hatching lines in the first illustration serve as a guide** if you are using a woven fabric, or something like corduroy or a striped fabric and want to **orient the lengthwise/straight grain of the fabric** as I prefer to, both **for aesthetics and for a balanced fabric stretch**. Half of the panels are oriented horizontally to the grain (the grays) and half vertically (the purples and yellows), and I alternate them in the layout.

2. Use the stitching template to **draw stitching lines on the *fronts*** of the four panel edges shown with dashed lines in the diagram. My stitching pathway leaves these four edges partially unsewn so the bag can be turned out between them. They will then be **sewn from the outside following the front stitching lines**. (If you use a thin or flexible fabric and don’t need such a large opening, just skip marking the upper two panels.) Be sure to align the template as well as possible with the stitching patterns on the backs.

   If you want to **hide the stitching lines within the seam**, sketch them a millimeter or two away from the template (nearer to the panel edges) and stitch slightly inside them (toward the middle of the panels).

   I have found it helpful to **add marks along the front stitching lines for each stitch** so that I can more easily keep the exterior stitches even with each other and not get a skewed seam. I space the stitch marks $\frac{1}{8}$″ (3mm) apart. If you **make these marks on your template first**, you can more easily transfer them onto these and future panels.

3. **Place panels A and B front faces together and sew them together** toward C and D, then add C and sew it to A.

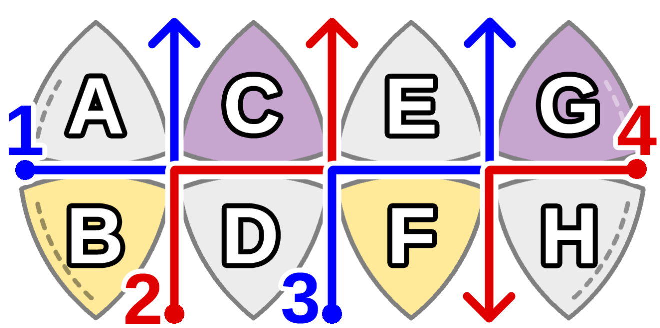
4. **Continue adding panels in alphabetical order** as in the previous step and sewing them according to the pathways depicted above. Keep in mind that you can sew the first three paths with one very long thread by reversing the direction of path #2. **Sew the panels front faces**

together so the bag will be inside out. At the end you should have a mostly completed bag with one or two adjacent, parallel seams open, and these should have stitching lines on the fronts.

When you add the fourth corner to each intersection, I recommend using the second method in the "Closing seam intersections tightly" topic of the **General Information and Techniques** chapter's "Stitching Techniques" section. **4-way and above intersections take a little extra care if you want them tightly closed and elegant-looking**. In short, **stitch each panel tip to the one diagonally opposite it (the thread will form an X across the intersection) and cinch them together**.

5. **Sew a few starter stitches at one end of the final seams** to make it easier to continue from the outside. If you don't need the entire opening to turn the bag out, continue to sew as much as you don't need. To **reduce the number of stitches you need to make from the outside**, you can make extra stitches and then loosen them to allow the panels to spread enough to turn the bag out. Then you can pull them tight again from the outside. If you want to do this, or if you want to be able to loosen the last several stitches enough to push a funnel between them, **your final thread will need several inches of extra length**.
6. At this point, **consider ironing the seam allowances flat**; see the **General Information and Techniques** chapter under "Better Seams by Ironing".
7. **Turn the bag right side out through the opening**. A good method for this is to use the back end of a pen or other slender tool to push the fabric through the opening from the opposite side and then either invert the bag around the tool, or remove the tool and work the bag through with your fingers. **Be gentle so as not to pop any stitches**.
8. **Pull out the last stitch so that the thread is on the outside** where you can get to it. Continue sewing the opening closed following the front stitching lines. For help, see the "Stitching Techniques" section of the **General Information and Techniques** chapter under "Backstitch from the exterior Approaches". Fill the bag at some point during this final sewing with a funnel. I find it helpful to **put some filler in first to prevent the bag from collapsing** while I sew, and to hold the seam allowances in place and give me something to push the needle against.

   You can sew the entire opening closed before fully filling the bag, which prevents the filler from spilling back out while you sew. Just loosen the last several stitches enough to push the funnel between them, or at least to push some filler in with your fingers. Then re-tighten the stitches (see "Tips on finishing the bag").



Left-handed stitching pathways

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Ready-to-Print Patterns

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The pattern pages are 8.27″×11″ (210mm×279mm) to fit both "Letter" and "A4" sizes. ***Make sure the print is not being scaled to fit the printer margins*** *(select Default/None scaling/Actual size/Ignore printer margins). To verify correct sizing,* ***compare the centimeter grid to a ruler*** *and adjust the next print if necessary. (Note that PDF viewers and printers can both contribute to slight size inaccuracy.)*

On the following pages are patterns for beanbag diameters from 2″ – 3″ in ¼″ increments, and a 7″ pattern for scaling to larger sizes. **These are my new Bézier curve patterns** (the cutting patterns are still circular, though). My original circular patterns are at the end of the chapter in case you want to use them instead, or compare the two. The patterns are reduced by 5% from the mathematical calculation to account for the inflation in size I observed in my corduroy bag. **If you use a completely non-stretch fabric, I recommend enlarging the pattern to about 101% to get the intended ball size.**

To make the templates, I recommend cutting out the portions of the paper with the patterns you want and using glue or double-sided tape to attach them to your template material, and then cutting along the patterns.

The cutting patterns have 4mm, 6mm, and 8mm allowances so you can choose the amount that works best for your fabric and preference (the lighter, 6mm cutting pattern is a hair under ¼″). Remember that the cutting patterns have slightly different curve radius to panel size proportions from the stitching patterns (they are parallel, not proportional), so **you should not use them as stitching patterns**.

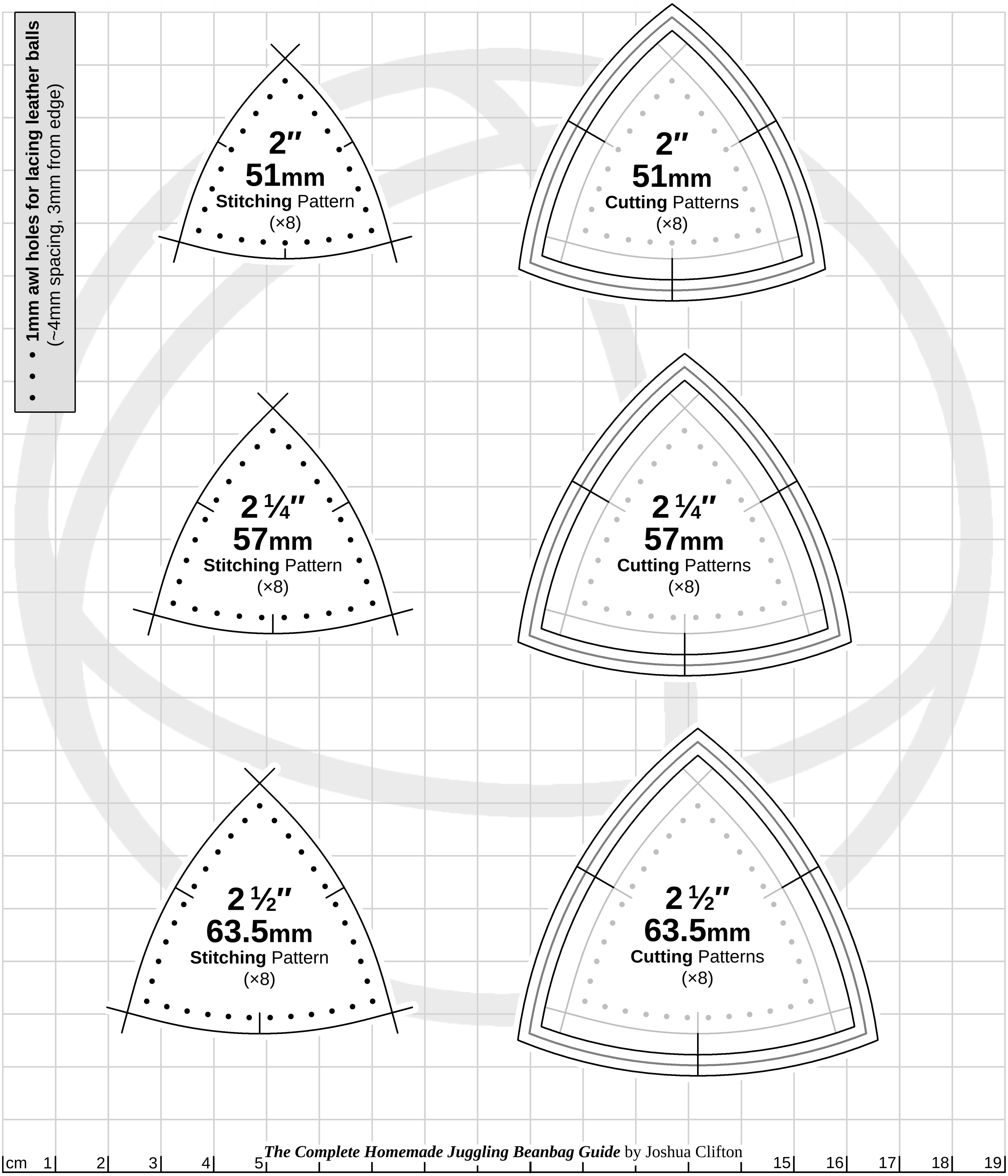
To produce other pattern sizes or correct an incorrectly sized beanbag, adjust the size scaling in the print dialog. For example, to reduce my 2.5″ pattern to the 2.3″ size recommended by the Juggling Store for small hands and numbers juggling, divide 2.3 by 2.5, multiply the result by 100, and that is your scale (92% in this case). If your beanbag ends up not being the expected size, see the **General Information and Techniques** chapter under "Adjusting/Scaling a Pattern to Produce an Accurate Ball Size" for help with correcting it.

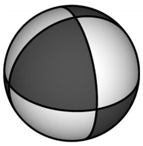
The table below provides the scaling for the ⅛″ increments between my ¼″ sizes. The centimeter grid can be used to verify correct scaling.

Target Diameter	Print this pattern size	At this scale
1¾″ (44.5mm)	2″	87.5%
1⅞″ (47.6mm)	2″	93.8%
2⅛″ (54.0mm)	2¼″	94.4%
2⅜″ (60.3mm)	2½″	95%
2⅝″ (66.7mm)	2¾″	95.4%
2⅞″ (73.0mm)	3″	95.8%

Octahedron (8 Panels)

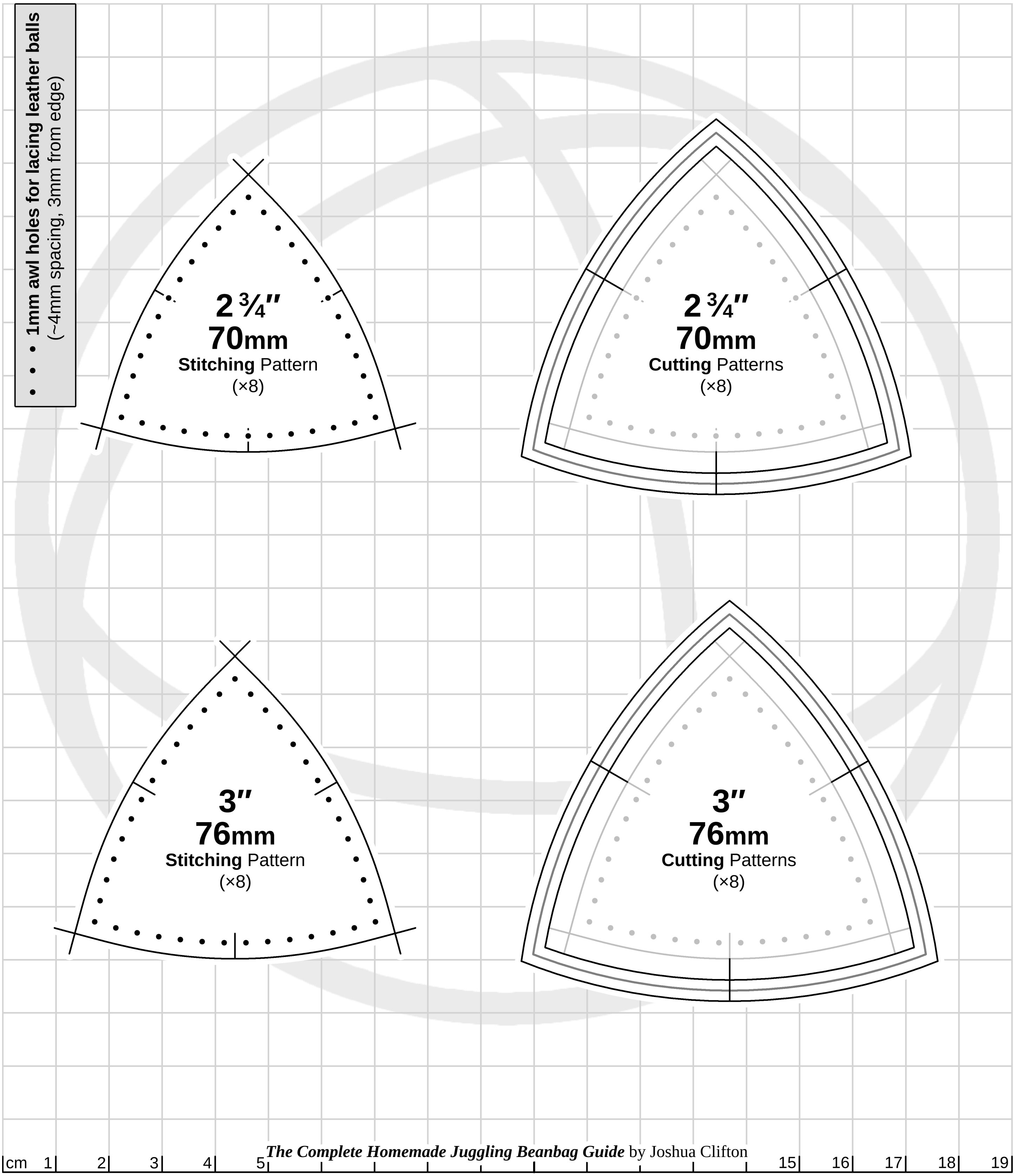
(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
The Stitching patterns use Bézier curves, the Cutting patterns are circular.)

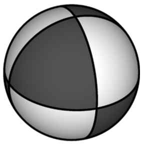




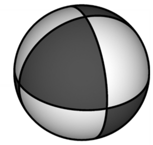
Octahedron (8 Panels)

(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
The Stitching patterns use Bézier curves, the Cutting patterns are circular.)



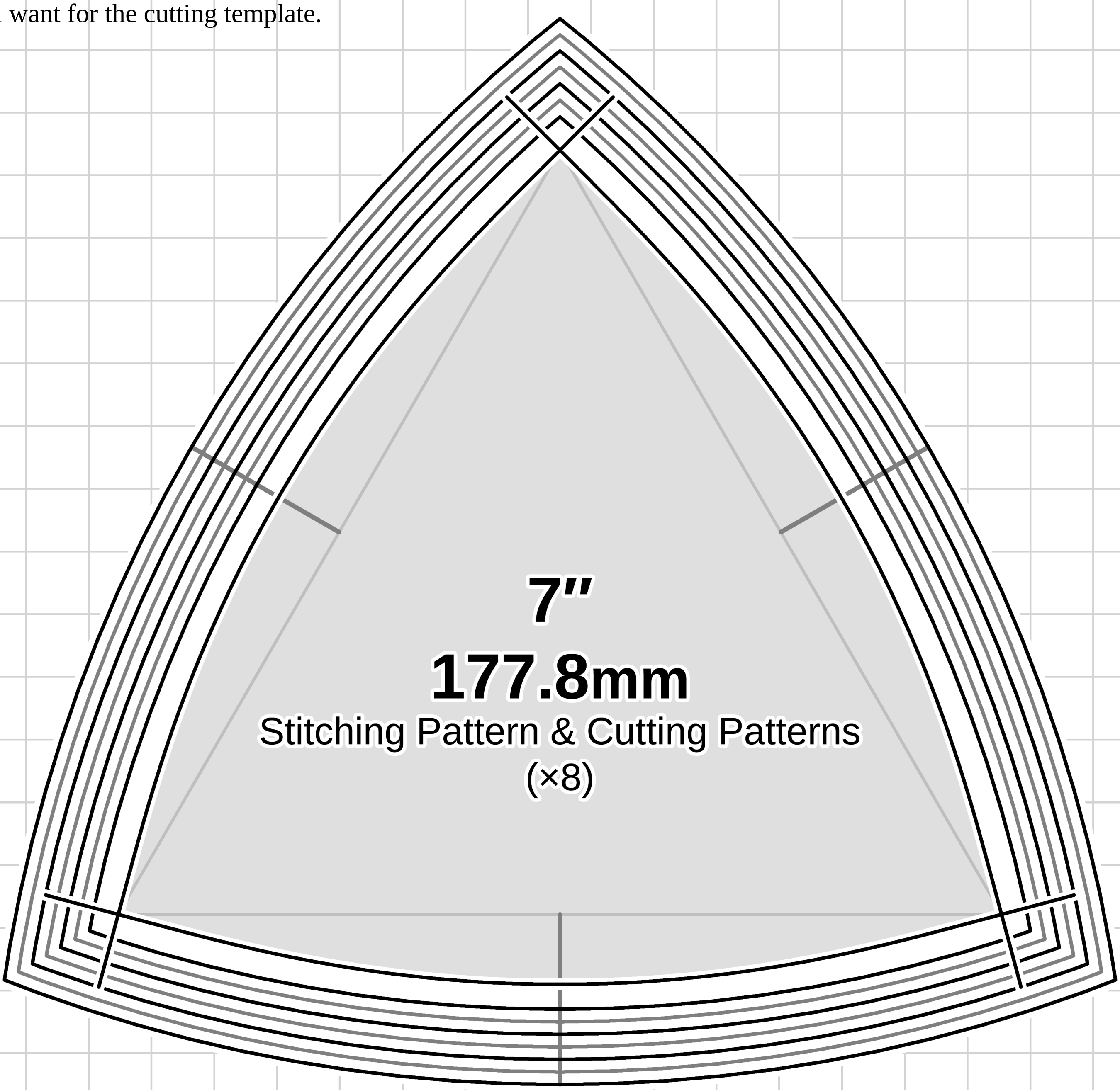


Octahedron (8 Panels)



(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
The Stitching patterns use Bézier curves, the Cutting patterns are circular.)

Extra large and versatile pattern for scaling to larger sizes in the Print Dialog. Print twice if you want both a stitching template and a cutting template. The inner pattern (filled with gray) is the Bézier curve stitching pattern. Each dark pattern outside of that marks a 4mm seam allowance interval (at 100% scaling). Those patterns are circular. Use those or the lighter, half-intervals between them to cut out the amount of allowance you want for the cutting template.



Sizing Formulas for Drawing the Pattern

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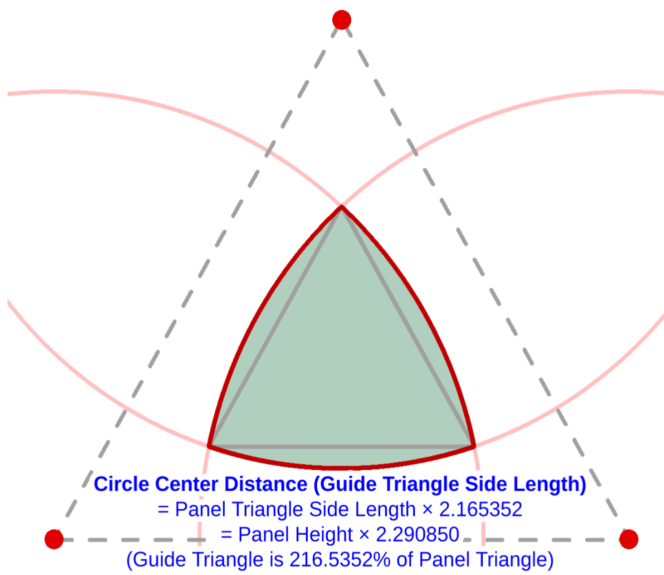
The next section has a table of pre-calculated pattern measurements for all ⅛″ diameter increments from 1¾″ – 3″. Following that are the drawing instructions. If you do not need to create a custom size, skip to that. I provide printable measuring tapes at the end of the **General Information and Techniques** chapter in case you care to measure your beanbags. The “Mathematics” section has explanations of all the formulas and ratios, and expresses their values in higher precision.

Design summary

The panel shape is formed by creating the three corners of an equilateral guide triangle to use as compass points and then drawing arcs/circles centered at those corners. The resulting circular triangle is smaller than the guide triangle. The circumference of the bag (measured between the seams) is 4 × *panel height*. I use the panel height to calculate the other parameters of the panel design.



Adjusting for the influence of fabric types on beanbag size

The bag I made with thick corduroy was **3.8 – 6.3%** larger than the mathematical prediction depending on whether I filled it loosely or over-filled it. I target halfway between the min and max inflations when sizing my patterns, which is **5%**. This makes my adjustment factor **1.05**. The bag I made with a fairly thin, stiff, tightly-woven, non-stretch fabric was 1.8 – 5.3% larger, but that was just for analyzing the shape characteristics of the bag. My denim bag from years ago measured 6 – 8.5% larger, but that used my old design. I will use the corduroy inflation to be consistent with my other newly designed bags.

I use the adjustment factor to adjust the pattern size to produce a more accurate finished size when using my fabric and stitching techniques. If you gather the seams, use a different fabric, or do anything else that changes the size of the bag, you may need to figure out your own adjustment factor. For help, see the **General Information and Techniques** chapter under “Adjusting/Scaling a Pattern to Produce an Accurate Ball Size”.

Sizing formulas

Below are the formulas to calculate the pattern construction elements (*Diameter* and *Circumference* refer to your target ball size, π = 3.1416). The value in orange is the adjustment factor. **Don’t forget to multiply the final result by 25.4 if you need to convert inches to millimeters.**

- **Panel Height = *Diameter* × *π* ÷ 4 ÷ 1.05 (≈ *Diameter* × 0.7854 ÷ 1.05)**
  = *Circumference* ÷ 4 ÷ 1.05
- **Guide Triangle Side Length = *Panel Height* × 2.2909**

- **Guide Triangle Circumradius = *Panel Height* × 1.3226**
- **Arc Radius = *Panel Height* × 1.7118**

Forming the panel shape given an equilateral starting triangle

If you want to convert an equilateral triangle into the panel shape by adding curved sides to it, here are the calculations (s = starting triangle Side length, r_t = starting triangle Circumradius):

- **Guide Triangle is 216.54% the size of the Panel Triangle**
- **Distance between Panel Triangle Side and opposite Circle Center = 1.5388s = 2.6654r_t**
- **Arc Radius = 1.6180s = 2.8025r_t**
- **Guide Triangle Side Length = 2.1654s**
- **Guide Triangle Circumradius = 2.1654r_t**

Arc (edge) length for spacing awl holes or stitch marks

To calculate the length of the curved edges, use the following formula, plugging in the Arc Radius you calculated above. (18° is the angle between the arcs, or rather tangents thereof, and the edge of the triangle they span.) If you are working with Radians, omit the $\pi/180$.

$$(Arc\ Radius)(2)(18)\left(\frac{\pi}{180}\right) \approx \textit{Arc Radius} \times 0.6283$$

Table of Pre-Calculated Pattern Measurements

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The table below has stitching pattern measurements for each ⅛″ diameter increment from 1¾″ to 3″. The values in the **Adjusted** columns account for my 1.05 adjustment factor. The adjusted values decrease the **Base** pattern size so that you will get a more accurate finished size when using a thick fabric like denim or corduroy.

To draw the cutting pattern, use the same Guide Triangle, but increase the Arc Radius by the desired seam allowance (I use 8mm). The cutting pattern will be larger than, but parallel to, the stitching pattern.

Finished Diameter	**Guide Triangle Side Length** (mm)		**Guide Triangle Circumradius** (mm)		**Arc Radius** (mm)		**Panel Height** (mm) (for double-checking)	
	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**
1¾″ (44.5mm)	79.976	**76.167**	46.174	**43.975**	59.761	**56.915**	34.911	**33.249**
1⅞″ (47.6mm)	85.688	**81.608**	49.472	**47.116**	64.030	**60.981**	37.405	**35.623**
2″ (50.8mm)	91.401	**87.048**	52.770	**50.257**	68.298	**65.046**	39.898	**37.998**
2⅛″ (54.0mm)	97.113	**92.489**	56.068	**53.399**	72.567	**69.111**	42.392	**40.373**
2¼″ (57.2mm)	102.826	**97.930**	59.367	**56.540**	76.836	**73.177**	44.886	**42.748**
2⅜″ (60.3mm)	108.539	**103.370**	62.665	**59.681**	81.104	**77.242**	47.379	**45.123**

Finished Diameter	Guide Triangle Side Length (mm)		Guide Triangle Circumradius (mm)		Arc Radius (mm)		Panel Height (mm) (for double-checking)	
	Base	Adjusted	Base	Adjusted	Base	Adjusted	Base	Adjusted
2½″ (63.5mm)	114.251	**108.811**	65.963	**62.822**	85.373	**81.307**	49.873	**47.498**
2⅝″ (66.7mm)	119.964	**114.251**	69.261	**65.963**	89.641	**85.373**	52.366	**49.873**
2¾″ (69.9mm)	125.676	**119.692**	72.559	**69.104**	93.910	**89.438**	54.860	**52.248**
2⅞″ (73.0mm)	131.389	**125.132**	75.857	**72.245**	98.179	**93.504**	57.354	**54.623**
3″ (76.2mm)	137.101	**130.573**	79.155	**75.386**	102.447	**97.569**	59.847	**56.997**

How to Draw the Panel Shape

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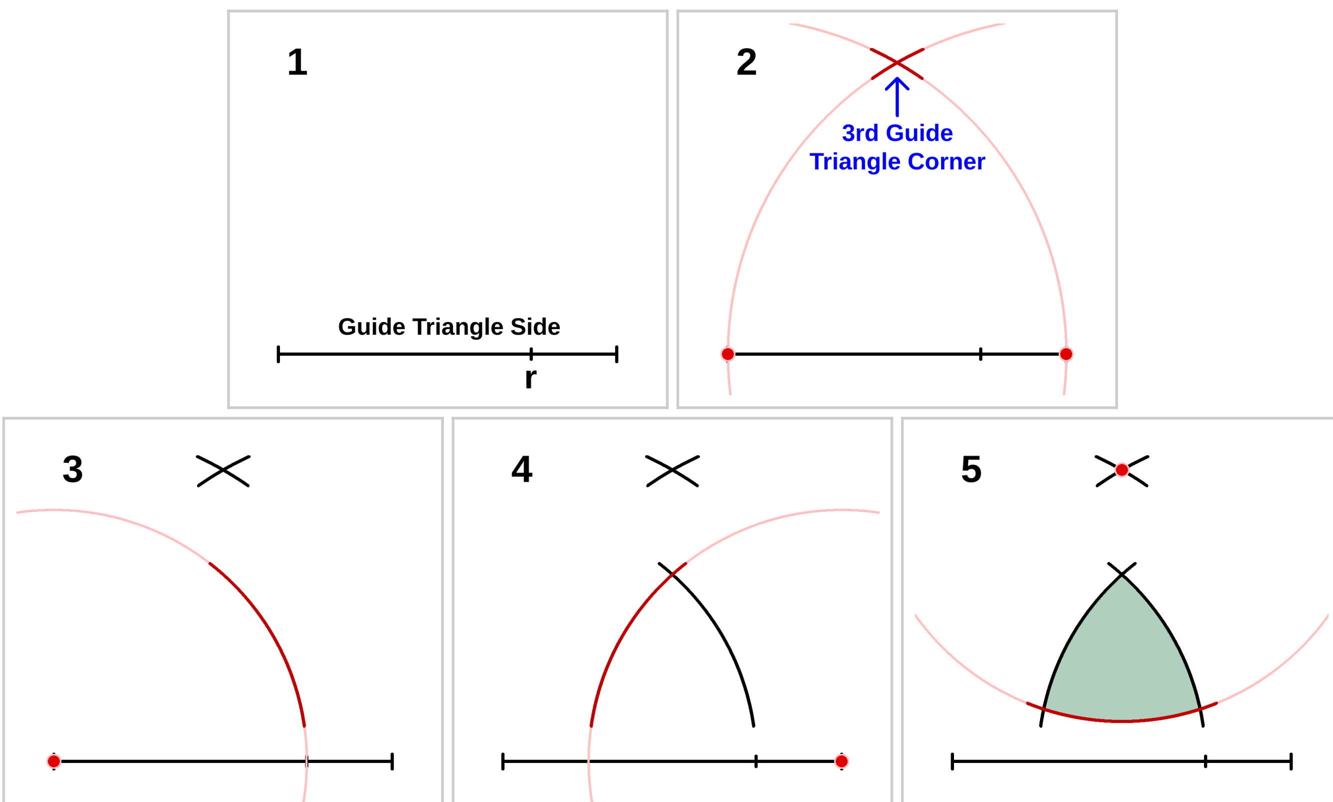
The panel shape is based on a regular (equilateral) triangle but has circular sides to produce a spherical bag. I draw this shape by constructing an equilateral guide triangle (actually just enough of it to get the three corners), setting the compass radius to 74.72% of the length of the triangle's sides, and then, using the three corners as compass points, drawing the circular triangle within the guide triangle. You may then correct the curve into a Bézier curve by following the directions in the next section, but that is not important for this design.

The illustrations below are oriented toward drawing the shape by hand and their numbers correspond to the step numbers in the manual directions. After the manual directions are SketchUp directions. To conserve your template material, I recommend that you draw the pattern on paper and then glue or tape the pattern to your template material before cutting it out.



Illustrations for the manual directions. The numbers correspond to the step numbers.

Manual directions

(The terms in bold refer to columns in the pattern measurement table above.)

1. Draw a horizontal line the length of **Guide Triangle Side Length** and mark each end of it. This is the base of an imaginary equilateral guide triangle. Mark another point (labeled *r* in Illustration 1) the distance of **Arc Radius** from one end of the line (it will lie about a quarter of the line's length from the opposite end) which will be used to extend the compass to the correct radius.
2. Before using that radius measurement, set the compass radius to the length of the line, position it at each end of the line, and draw a small arc above the center to form an X that marks the third corner of the Guide Triangle.
3. Now use the **Arc Radius** mark (the point labeled *r* in Illustration 1) to reduce the compass radius to that radius and draw an arc that extends from directly above the center of the line down to near the line as in Illustration 3.
4. Keeping the compass radius unchanged, place the compass on the other end of the line and draw another arc like the previous one.
5. Place the compass on the intersection of the first two arcs (the 3rd Guide Triangle Corner) and draw a third arc that joins the previous two arcs and completes the panel shape. The circular triangle's height (corner to middle of opposite arc) should equal the specified **Panel Height**.
6. To draw a cutting pattern, draw everything the same but increase the Arc Radius by the desired seam allowance (I use 8mm) and then draw the last three arcs from the same three points using that new radius.

SketchUp directions

(The terms in bold refer to columns in the pattern measurement table above.)

1. Use the polygon tool (in the Shapes tool drop-down, or in Draw menu -> Shapes) set to 3 sides and draw a triangle with radius = **Guide Triangle Circumradius**, which will result in a triangle with sides of length **Guide Triangle Side Length**.
2. Draw circles with the specified **Arc Radius** centered on the three corners of the guide triangle. The intersection of the circles forms the circular triangle panel shape whose height (corner to middle of opposite arc) should equal the specified **Panel Height**.
3. To draw a cutting pattern, draw the same guide triangle but increase the circle radii by the desired seam allowance (I use 8mm).

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Adjusting the Circular Curve into a Bézier Curve to Correct the Angle and Curvature at the Panel Corners

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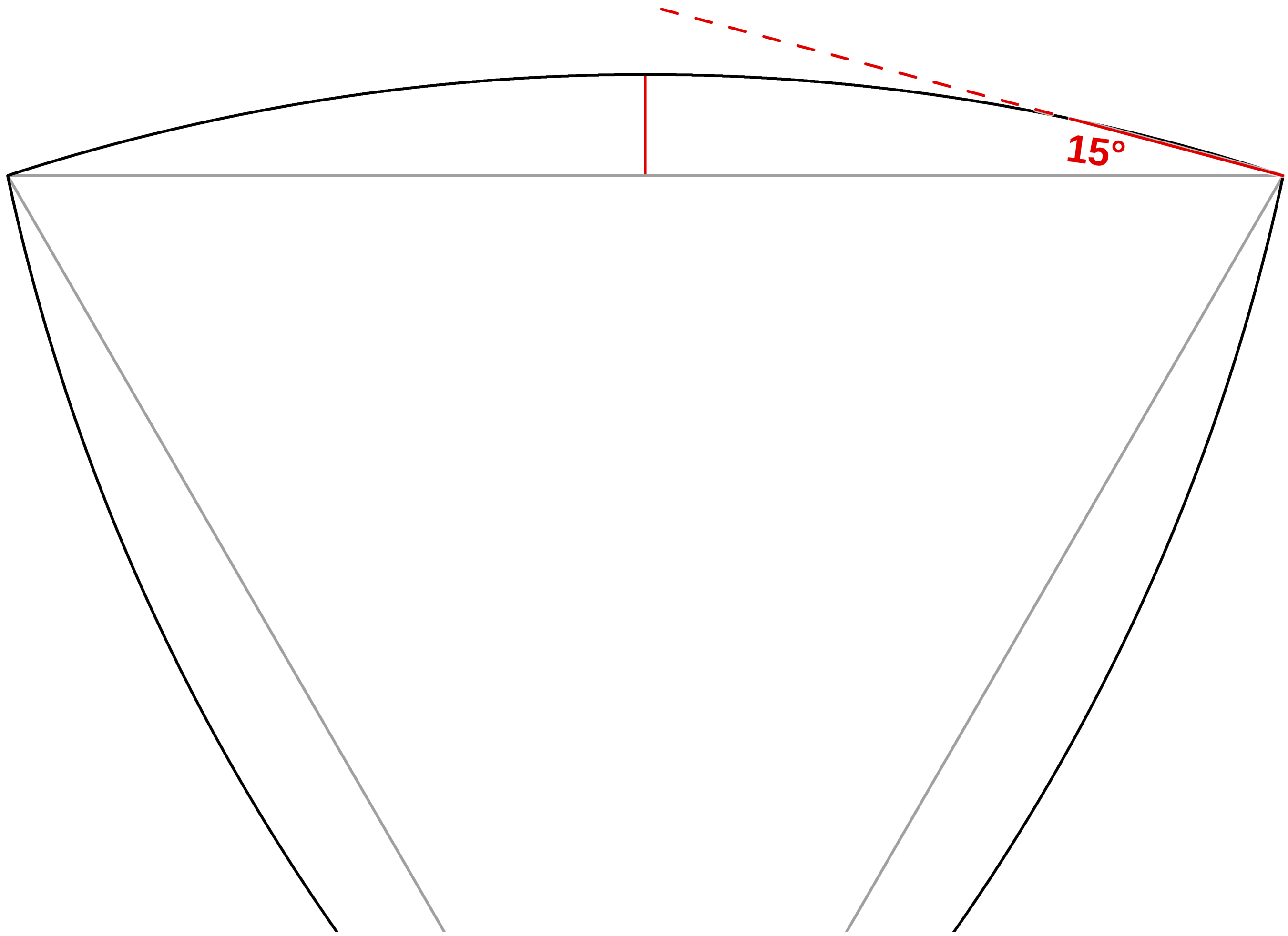
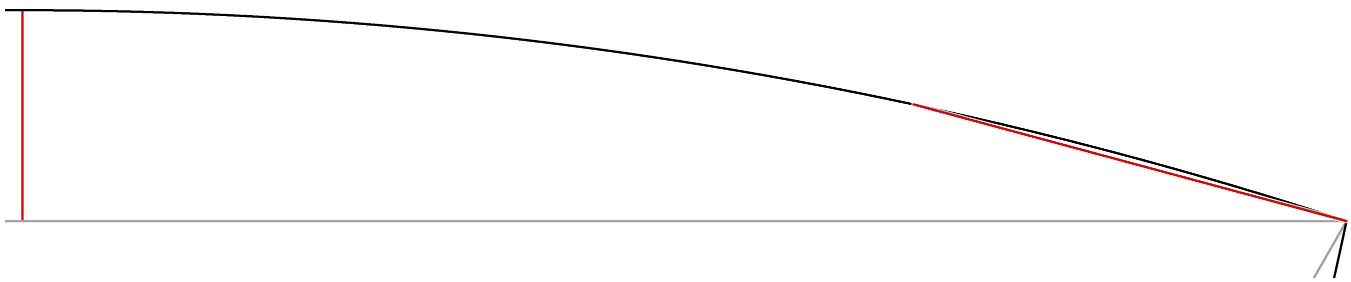
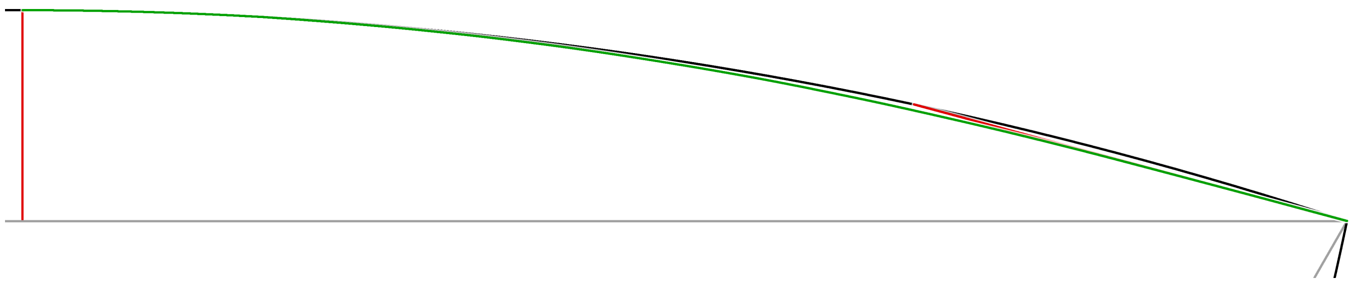
If you want to improve the shape of the panels by narrowing the 96° arc intersections down to the correct 90°, resulting in a slightly better sphere, here is the method I use. This curve adjustment is not needed, as the circular panel shape produces a very good sphere. The difference between the resulting balls is very small, and will probably not be perceptible in soft or stretchy fabrics. But with my stiff, non-stretch, design testing fabric the Bézier curve did make a noticeable improvement upon careful examination. I recommend that you draw just half of one curve as my illustrations show and then duplicate it so that the curves are symmetric and are all identical. I used the BezierSpline SketchUp plugin by Fredo6 to draw my curve.

Step 1: Draw a line at 15° to the triangle's edge as a guide for the Bézier curve at the corner, and draw a line at the center of the arc to mark the endpoint of the half curve (these are shown in red).

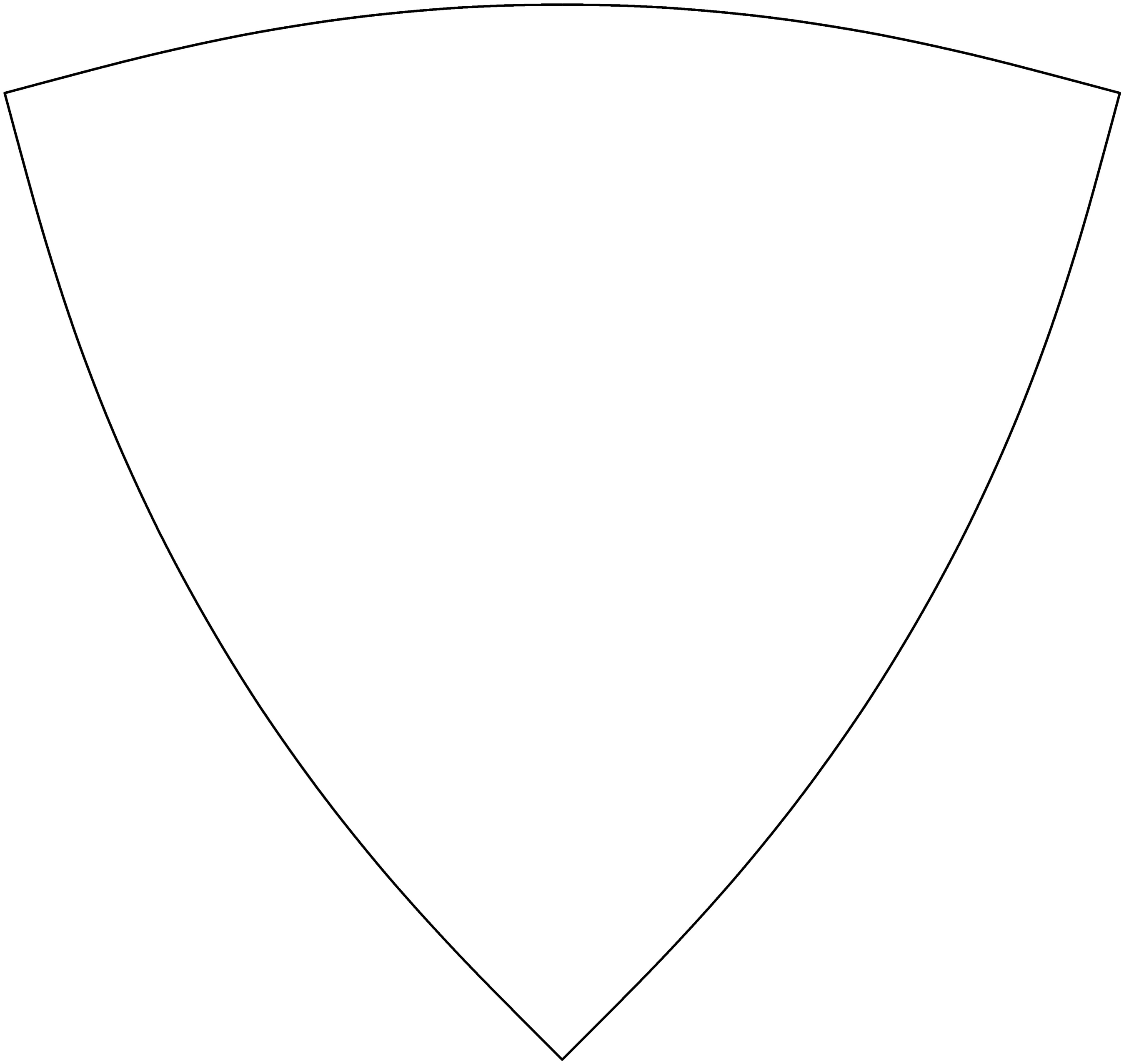






Step 2: After drawing the two guide lines, draw a curve (shown in green) that begins by following the 15° angle line and gradually curves away from it and merges into the circular curve, and forms a smooth curve without abrupt changes in curvature. I used many control points to form the curve, and I refined its shape by zooming in and out repeatedly and adjusting places where the curve changed too abruptly or had a poor shape (zooming the curve in and out helps make flaws apparent to my eyes).

The resulting shape is shown on the next page.



My final panel shape.

To see this shape compared to the circular shape, and to Marylis Ramos' pattern, see the "How I Developed This Design" section under "Designing a Bézier curve to improve the beanbag shape", and scroll down a couple pages to the comparison illustrations.

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Mathematics Behind the Relationship Between the Pattern Parameters and the Ball Size

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This section describes the math involved in drawing patterns to produce specified beanbag sizes, and creating the pattern sizing formulas. *(The numbers in tiny, right-justified typeface are my computer calculator's unrounded values which I display rounded to six places for brevity.)*

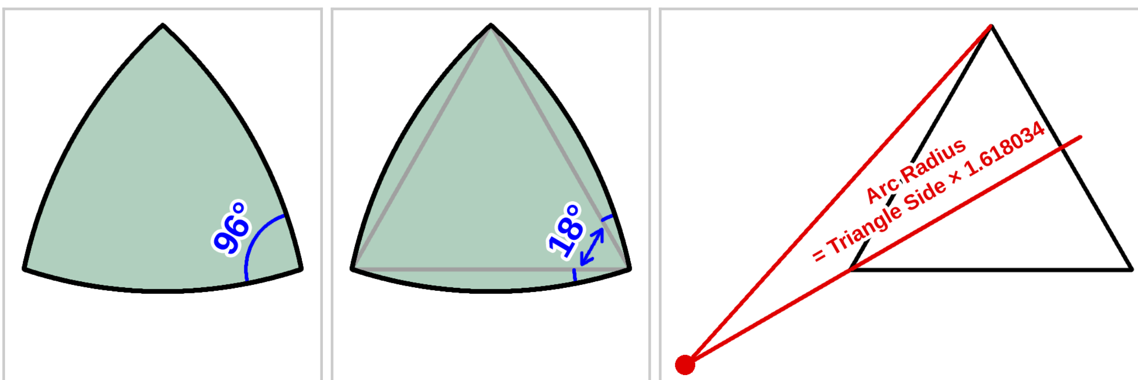
For this panel shape I chose curves that form 96° angles at the corners. I discuss in the "How I Developed This Design" section why I chose that curve of all the possible curves. In short, it makes the best sphere of the several curves I tried, and happens to be the best match for Marylis Ramos' non-circular pattern[4], which forms about as perfect a sphere as this panel structure can.

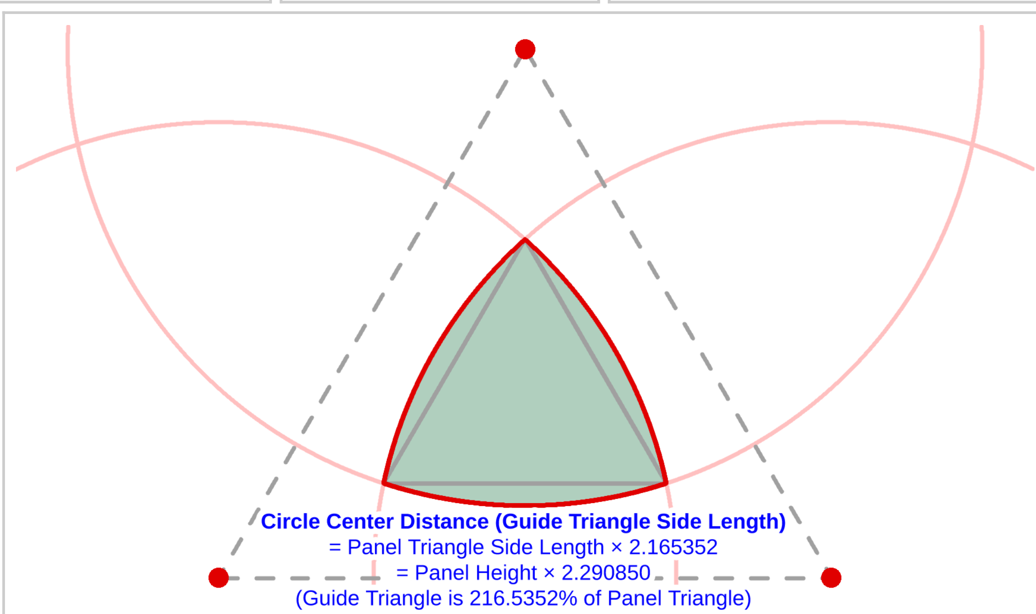
My edge arcs (their tangents, technically) intersect the edges at 18°, adding 36° to each 60° corner for a total of 96°. Using my edge arc radius formula from Chapter 5, I can calculate the radius needed to produce that arc, which is the first step toward calculating the guide triangle, whose corners are the circle centers for the arcs that form the circular triangle (s = triangle side length):

$$\textbf{Arc Radius} = \frac{0.5\,s}{\sin 18°} \approx \frac{0.5\,s}{0.309017} \approx \mathbf{1.618034}s$$

1.6180339887498948482045868343656

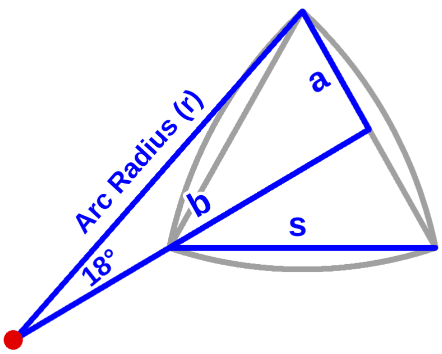
Following are diagrams of the panel shape derivation and relevant ratios and formulas.





4 Fourth page of this PDF: https://jugglingedge.com/pdf/jugglingballtemplates1.pdf

Calculating the distance between the panel triangle's center and the circle centers (the Guide Triangle's circumradius), and the distance between each circle center (the Guide Triangle's side length), involves solving a right triangle as shown below. The arc radius is the hypotenuse, side a is half of the panel triangle's side length, and I need to solve for side b, which extends from the circle center to the triangle's opposite side. After that, I can subtract the panel triangle's apothem (center to side) to get the portion of b that is the guide triangle's circumradius, and from that calculate its side length. Read the "Curved-Edge Faces" section of Chapter 5 for a full explanation of this process.



$r \approx 1.618034s$ (calculated earlier) 1.6180339887498948482045868343656

$a = 0.5s$

$b = \frac{a}{\tan 18°}$ or $\sqrt{r^2 - a^2}$ ►

$b = \frac{0.5s}{\tan 18°}$ or $\sqrt{(1.618034s)^2 - (0.5s)^2} \approx 1.538842s$ 1.5388417685876267012851452880185

Panel Triangle Apothem = $\frac{\sqrt{3}}{6}s \approx 0.288675s$ 0.28867513459481288225457439025098

Guide Triangle Circumradius ≈ 1.538842*s* – 0.288675*s* ≈ 1.250167*s* 1.2501666339928138190305708977675

Guide Triangle Side Length (Circle Center Distance) ≈ $\sqrt{3}(1.250167s)$ **≈ 2.165352*s*** 2.1653521280029182186568018053443

The height of the panel, which I use in the calculation of the other aspects of the panel design (as it is simply one quarter of the desired ball circumference) is the height of the panel triangle plus the sagitta (height of the apex of the curve above the triangle's edge). The formula for the sagitta is the following (r = arc radius, s = triangle side length, or, in this context, the chord). Note that the sagitta is simply the arc radius minus side b from above.

Panel Triangle Height = $\frac{\sqrt{3}}{2}s \approx 0.866025s$ 0.86602540378443864676372317075294

Sagitta = $r - \frac{0.5s}{\tan 18°} \approx 1.618034s - 1.538842 \approx 0.079192s$ 0.0791922201622681469194415463472

Circular Triangle Panel Height, h_p ≈ $0.866025s + 0.079192s$ **≈ 0.945218*s*** 0.94521762394670679368316471710014

Once I have the panel height expressed as a ratio of a unit equilateral triangle, I can express the arc radius and circle center distance in terms of the panel height by dividing their values by that ratio:

Arc Radius ≈ $\frac{1.618034s}{0.945218}$ **≈ 1.711811h_p** 1.7118103971782170885446531911157

Guide Triangle Side Length, s_g ≈ $\frac{2.165352s}{0.945218}h_p$ **≈ 2.290850h_p** 2.2908503535530829027260089516312

Guide Triangle Circumradius ≈ $\frac{1.250167s}{0.945218}$ **≈ 1.322623h_p** 1.3226230682970217693367192253295

Guide triangle and arc radius expressed in terms of the ball size

To be able to size the guide triangle and corresponding arc radius according to a desired ball size, I need to express them in terms of the ball's circumference, C, and diameter, D. (h_p is the height of the panel as before.)

Since $C = 4h_p$ and $h_p \approx \frac{1}{2.290850} s_g$

$$C \approx \frac{4}{2.290850} s_g$$

and so

Guide Triangle Side, $s_g \approx \frac{2.290850}{4} C \approx \mathbf{0.572713}C$ 0.5727125883882707256815022379078

$\approx \mathbf{1.799230}D$ 1.7992296602989864353898269306732

Guide Triangle Circumradius $= \frac{1}{\sqrt{3}} s_g \approx \mathbf{0.330656}C$ 0.33065576707425544233417980633237

$\approx \mathbf{1.038786}D$ 1.0387857287075787387613990569082

Since Arc Radius $\approx 1.711811 h_p$ and $h_p = \frac{C}{4}$

Arc Radius $\approx \mathbf{0.427953}C$ 0.42795259929455427213616329777893

$\approx \mathbf{1.344453}D$ 1.3444527420284282336991743502613

Cutting pattern adjustment

To make a cutting pattern, simply increase the arc radius by the desired seam allowance. The guide triangle remains the same.

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How I Developed This Design

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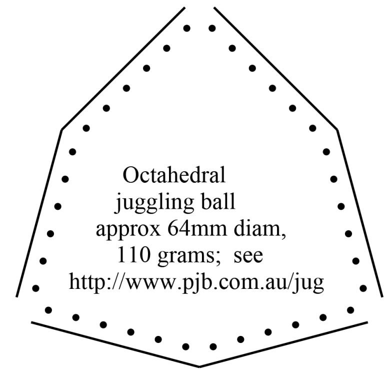
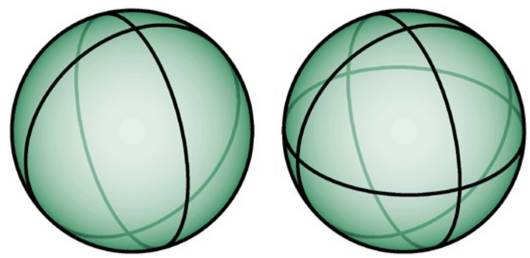
Original pattern design

I developed the original version of this design in August, 2012 while writing the first edition of this guide. I had found a web article called *How to Make Leather Juggling Balls* by Peter Billam[5] that had patterns for several polyhedral beanbag designs using bulged polygons for the panel shapes, and these included an octahedron. The website did not discuss the derivations of the shapes, however. The octahedron, along with the cube, dodecahedron, and icosahedron, actually uses angular bulges as shown on the right. I did not want to use angled bulges.



I decided that a logical way to design a curved-edge triangle was to use the circular arc from the 4-panel orange peel ball (this was when I was still using a circular curve for that design) since the two designs are closely related. As shown on the right, the octahedron could conceptually be formed by adding a seam around the equator of an orange peel ball. I made a bag according to that design and it seemed to me to have turned out well. That is the curve I used for my first edition design.



In February, 2015 I found a discussion thread on Reddit[6] in which a contributor named ds300 recommended my guide, referring to it as “an epic discourse on the subject of making beanbags”, but advised against using my 8-panel design because the triangles were “too curvy”. The fabric he used, Ultraleather, was evidently more sensitive to the panel shape than denim. He recommended instead Marylis Ramos’ pattern which is linked near the end of this tutorial: ~~http://www.twjc.co.uk/howtomakejugglingballs.html~~[7] (see her Orange Segment Series PDF, fourth page, available directly at this URL: https://jugglingedge.com/pdf/jugglingballtemplates1.pdf).

I had already been noticing a minor problem in the design of my panel. The angle was too wide for four of them to fit together when assembled from paper panels. Also, It did seem that the vertices of the finished bag were a little too flat, which (though I didn’t realize it until reading ds300’s comments) is the same as the curvature of the seams being too steep. I originally thought that the flattened vertices were a benefit. I was apparently so focused on reducing the angularity of the bag during the design process, and on my seemingly brilliant solution to the curvature problem, that I was not sensitive to the possibility of too much curve.

Discovering the vertex-angle-sum design principle

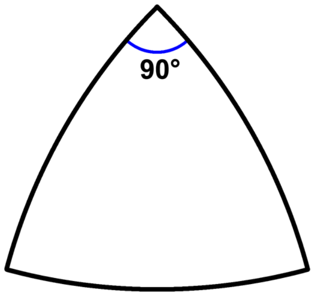
In 2013 or so I had read an article on spherical geometry[8] which explained that for polygons to form a sphere, the sum of the angles meeting at each vertex must be 360°. I later learned the mathematics to

5 http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html

6 https://www.reddit.com/r/juggling/comments/2l4pwe/making_your_own_beanbags_some_advice_and_creative/. See 2nd comment, by ds300.

7 That tutorial is no longer available as of March 16, 2023 (except via the Wayback Machine), but Ramos’ “Sewing Patterns for Jugglers” are still available: Orange Segment Series, Polyhedra Series. I also provide them on my own web server: Orange Segment Series, Polyhedra Series.

8 http://euler.slu.edu/escher/index.php/Spherical_Geometry calculate the radius of the arc that will form a specified angle to a polygon edge. (For a full explanation of this, and of the problem with strictly using math to design a fabric sphere, read the "Curved-Edge Faces" section of Chapter 5). The spherical geometry article gave me a starting point of experimentation, and the edge arc radius formula I created enabled me to design new experimental curves for my panels.



In the case of the octahedron, which has four corners at each vertex, the corners must be 90° each. It turns out that Peter Billam's panel bulges all conform to this theorem, creating angles at the corners such that the sum of angles in the solids' vertices are 360°. I guessed this and then, during the writing of the second edition guide, confirmed it by creating shapes with those angles in SketchUp and overlaying them on enlarged views of Billam's shapes. In fact, as I mentioned before, most of his patterns use angled bulges, which is the simplest way to create flat vertices, but will also create new, and non-flat, vertices in the middles of the edges.

Some time after reading that article I made an octahedron using the circular arc that forms 90° corners to see if that would produce a better bag shape. To my great disappointment, the seams angled too steeply from the vertices, creating a worse shape, but at the opposite extreme.

I understand now that an arc that forms the correct angle does not necessarily bulge outward enough to form a good bag shape. So compromises must be made. But I was so discouraged that math was apparently not going to be able to solve this problem that I lost all motivation and gave up on the project for the next five years. Trial and error and the possible need for non-circular curves were too tedious and random to consider at the time. (Arbitrary decisions and experimentation are, as a rule, against my nature, and since the only non-arbitrary option had failed me, I felt stuck. I have become somewhat less rigid in that regard since then.)

Redesigning the circular panel curvature for the Second Edition

In May, 2020, I regained my interest in correcting my designs. One commenter in that Reddit thread, peter-bone, had pointed out that because fabric stretches and distorts in complex ways to approximate a sphere, the necessary panel curvature can't be predicted by mere mathematics. He said that the best patterns he has found were derived through trial and error and had edges that were not circular arcs. I decided that I was going to take this advice and use extensive trial and error (though I still wanted to use circular curves so they can be easily defined and drawn).

The 90° arc angle almost works with the soft corduroy I first used during this new phase of the design process, but did not work so well with stiffer fabrics. I needed a steeper arc, though less steep than the orange peel arc. The orange peel arc produced an intersection angle of 106.259°.

The difference in the beanbag shape at the extremes of curve steepness is as follows. An overly shallow curve makes the bag vertices prominent enough to be felt, and makes the seams straight enough that they angle down from the vertices rather than curving circularly, forming a noticeably angular shape. Too steep of a curve causes the vertices to tend to pucker inward since a vertex sum of greater than 360° cannot fit together without distorting the fabric. It also bulges the seams out too far, resulting in the seams being more prominent than the vertices. The vertices end up looking and feeling flat while the seams look and feel like rounded corners. At enough of an extreme it can cause the octahedron to begin to look like a cube.

However, because cloth is forgiving, vertex angle sums of somewhat greater than 360° can work. As I mentioned earlier, the reason steeper arcs, forming over-wide angles, must be used is that the arc that produces the correct angle does not bulge outward enough to produce a circular seam on the bag.

A non-circular curve that forms the correct angle but also reaches the necessary bulge altitude at the apex would work the best, and seems to be what Ramos did. Her octahedron pattern has a curve that levels out slightly at the ends, unlike her tetrahedron and cube which use circular arcs. (I finally designed my own Bézier curve in late 2022, which I discuss in the next subsection.) I contacted Ramos in 2016 but got no reply to my question about how she derived her panel shapes. I made a beanbag using her pattern and a thin, non-stretch fabric that would best display the effect of the panel shape on the bag, and her design made an excellent sphere. It became the standard against which I compared my design attempts.

My first curve trial (made before the Ramos sample) put the circle centers the distance of the panel triangle's circumradius out from its corners. This resulted in a 98.213° corner, and the resulting curve was a little steeper than Ramos'. The corduroy test bag had significantly flat vertices, though I later made a second one that did not exhibit nearly as much flatness, possibly due to my not pulling the stitches quite as tightly, which I suspect altered the panel shape of the first bag slightly.

I then tried a curve that put the circle centers the distance of the panel triangle side minus the apothem (⅓ the triangle's height). This produced a 95.176° corner and appeared to be an almost exact match for Ramos' pattern, except for the fact that her curves level out slightly as they approach the corners. That produced a very good corduroy bag, but my test bags made with stiff fabrics were slightly angular.

I decided to break from my use of curves derived from non-arbitrary positions of the circle centers and increased the angle to 96°. I did not think such a small difference would be noticeable in the finished bag, but when I pay very close attention, it does make a small difference and seemed to be ideal. It also matched Ramos' curve perfectly at the apex (the 95.176° curve was just a hair below it).

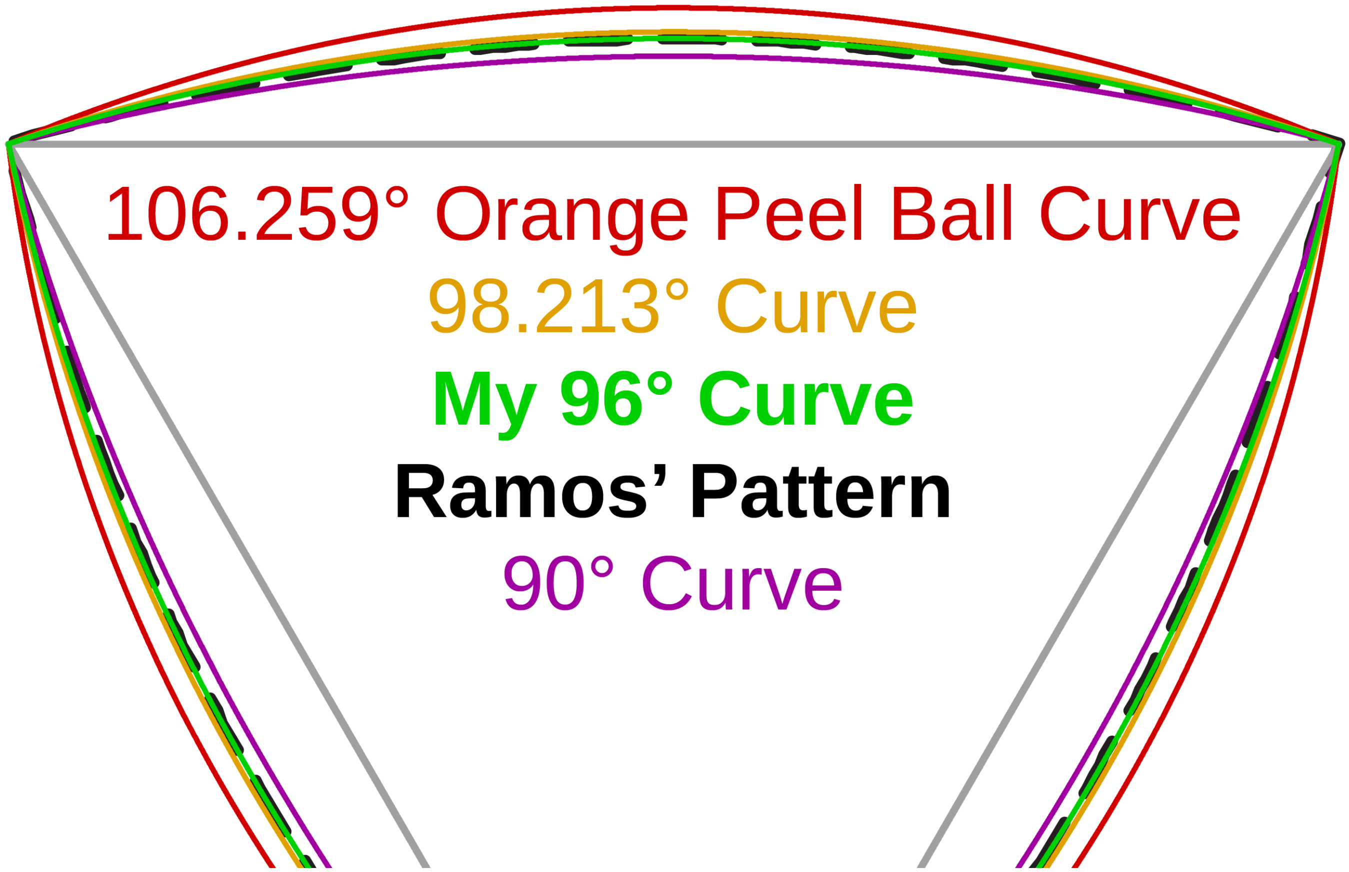
I then made four bags with a new fabric I had purchased[9] that was thin, stiff, tightly woven, and non-stretch, which would produce the most consistent and observable manifestations of panel shape changes. It is also much easier and quicker to sew than corduroy or denim. I made my Ramos sample with that fabric, as well as the three other curves I had tried.

I used many different methods of feeling and observing the bag shapes, the behavior of the vertices when compressed, and the behavior of the whole bag when squeezed. The difference between my three curves and Ramos' curve are slight when made with the thin, non-stretch fabric, but there does seem to be a consistently observable difference. It took a couple days to decide I preferred the 96° curve. I made a total of 13 test bags using 5 different fabrics to arrive at this decision.

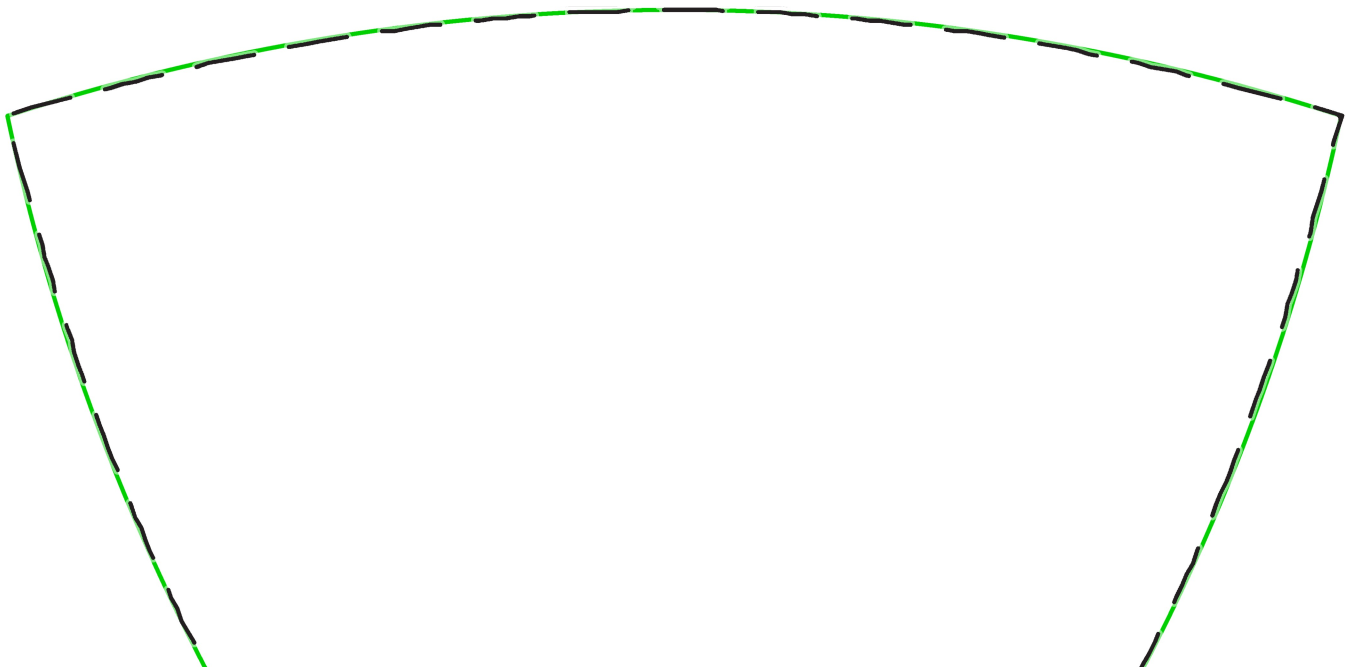
Several months after publishing my second edition guide (mid-2021), I made felt versions of my 2 – 12-panel designs just to make sure my patterns would produce a good shape even with a light, stretchy fabric. They all turned out fine. The octahedron's shape was about the same as the corduroy version, except more consistent because of the lack of a weave grain. There was no significant flatness at the vertices or over-curvature at the seams. I was satisfied with it.

9 "White Target" fabric in Jo-Ann Fabric's sportswear section (Item #16734915).

Below is a comparison of the curves I tried, overlayed on Ramos' pattern (the dashed pattern in black).



Below is just the 96° curve with Ramos' pattern overlayed on it to show the slight difference in the angles at the corners. My curve meets hers at the corners and apex, but between them, near the corners, it lies a hair above hers, meaning it is curved more steeply down into the corners. This tiny difference makes only a very small difference in the ball shape, but it can be noticeable. In the next section I discuss my own experimentation with drawing an adjusted curve that forms the correct corner angle.



Designing a Bézier curve to improve the beanbag shape

Summary: *After making two (slightly different) Bézier curve balls and two circular curve balls, my conclusion is that the Bézier curve makes only a barely discernible improvement to the ball shape. And after making two Bézier curve balls with higher apexes, matching circular curves forming 97° and 98° corners, I concluded that the 96° curve I have been using is best, though the difference is very small.*

On August 31, 2022, I finally had the motivation to design a Bézier curve for my octahedron panel. I had always before assumed that the adjusted curve that formed the correct corner angle, being so nearly the same as the circular curve, would not produce a perceptible difference in the beanbag shape, and so was not worth the effort of designing. But the matter kept nagging at me. I wanted to know for sure how much difference it would make. In my experiments with other designs, I have found that changes roughly as tiny as this can actually produce noticeable changes in the ball shape (when using a stiff, non-stretch fabric, sewing it very precisely, and ironing the seam allowances flat, and only upon obsessively close and careful examination).

Part of the deterrent to experimenting with Bézier curves previously was that, until mid-2021, I did not understand what they were. After that, I had no tool with which to draw them. The method I used for the orange peel ball pattern, drawing the curve as many straight facets, is very difficult and tedious. But in September, 2022 I found a free plugin for SketchUp Make called BezierSpline by Fredo6 that made the process much easier (looking for plugins had not until recently occurred to me).

The core reason I used circular curves, though, even after I learned of Bézier curves, was that the original purpose of this document was to provide mathematical definitions of beanbag pattern shapes so anyone can draw them at any size, or modify their design. Circular curves are easy to define and duplicate, even by hand. Bézier curves are not. But I have decided that, since the circular curves work so well for all but the orange peel ball, I can provide definitions for the circular patterns but use Bézier curve modifications of them for my own Ready-to-Print patterns, and describe how to produce close approximations of the modified curves.

I used the F-Spline tool in the BezierSpline plugin (though the Classic Bezier Curve tool would also work) to draw a curve that had the correct angle at the corner and merged into the circular curve as it approached the apex. I drew it at a large scale (1000mm from corner to corner) and scaled it down to the size of my patterns. I made two 2.75″ balls with my design testing fabric, one with the circular curve and the other with the Bézier curve.

The difference between those two balls was indeed small, and most people would probably not notice it or care. It would probably only be apparent at all with a stiff, non-stretch fabric like mine, and it became less apparent as I handled the balls more and broke in the fabric. But it was a greater difference than I had anticipated. I could quickly and definitely see which ball had the circular panels when doing a blind comparison. (The balls are identical, even in grain orientation, except that the thread I left hanging at the end is a couple inches longer on the circular ball. I can only determine which thread is longer by pulling them out straight and comparing them. So while comparing the balls I cannot tell which is which.)

The difference was that the circular curve produced vertices that were more flat and seams that were less round (producing a seam profile that had a hint of a rounded octagon shape) while the Bézier curve produced smoothly rounded vertices and seams. I could see this best by looking at the balls against a backlight so that the shape of the seam profile was clearly defined. To ensure the difference was not due to different grain orientation at each vertex, I marked a matching vertex on each ball with an arrow, and always compared the balls with the arrow at the same position and orientation on each ball.

After this experiment, it occurred to me that by using Bézier curves, I might be able to increase the apex height of the curve without producing the flattened vertices that result when using too steep of a circular curve, and this might make a better sphere. So I designed a Bézier curve based on a 98° arc and made a ball from that pattern.

As I hoped (as it would simplify everything), the ball with the higher curve apex was slightly inferior to the one with the original apex height. The extra curvature, tiny though it was, bulged out the seams enough that they were more prominent than the vertices, making the area around the vertices less circular. The difference was very small, and was not apparent at all angles, but at best the new ball was equal to the original, and at worst it had the barest hint of a rounded square shape. So my original curve apex was clearly better.

Then, just in case a 1° increase would be the best balance, I also made a ball with a 97° arc apex. It also seemed slightly inferior, though the difference was so small that I couldn't really be sure.

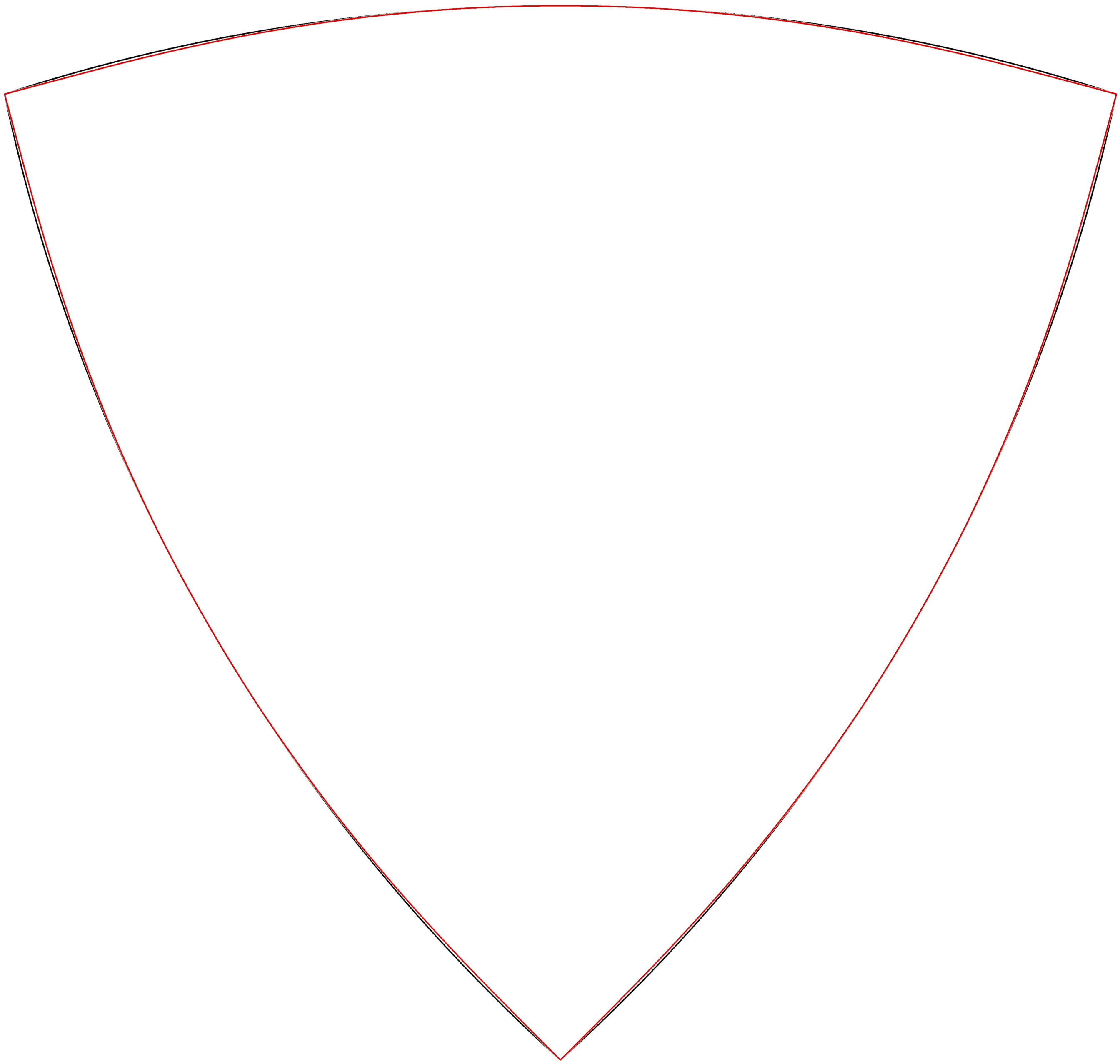
I drew a new version of my Bézier curve to be my final draft for the Ready-to-Print Patterns and tweaked it over the course of a few days to make the curvature as smooth as possible (mostly for visual aesthetics). I also adjusted it slightly from the first draft so that it hugged the circular curve a little more closely, to hopefully eliminate what I perceived as extremely minor acuteness of one or two of the vertices of my test bag.

Then, just to be sure that the characteristics of my circular ball were not a fluke, possibly due to my not ironing the seam allowances carefully enough, I made a ball with the new Bézier pattern and another with the same circular template I had used before. I ironed both their allowances the same way and very carefully. My instinct was good: the new circular ball showed much less of the characteristics that had made the first distinct. It was almost identical to both of the Bézier curve balls, only occasionally showing the barest hint of the flatness at the vertices.

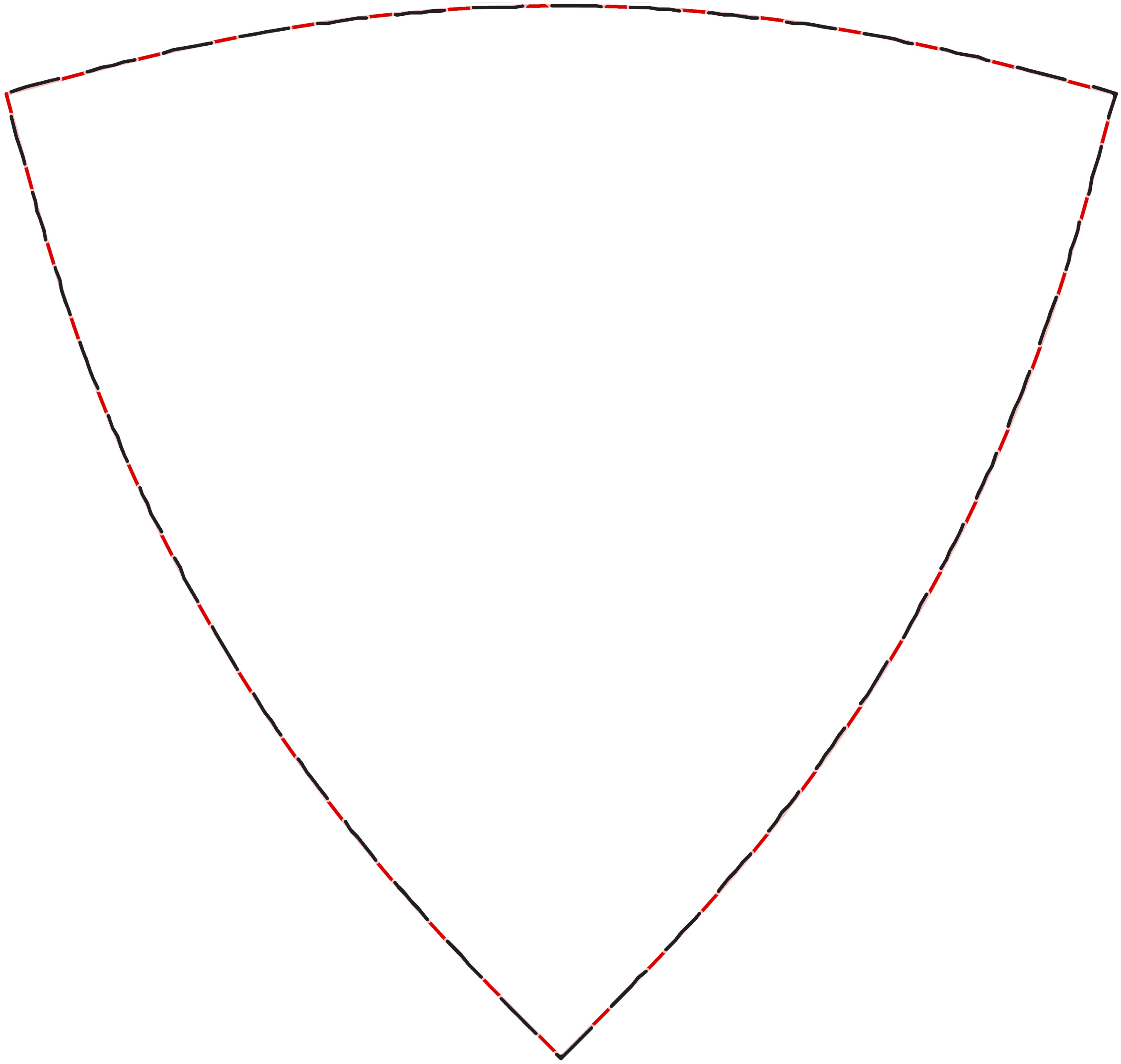
Unexpectedly, my new Bézier curve produced a ball that had the characteristics of the first circular ball, though less pronounced. I am pretty sure that my slight change to the curve could not have caused that much difference, so it was probably a manufacturing issue. But I decided to use my first curve anyway for my Ready-to-Print patterns. I had to redraw it, though, because I drew my original curve in Gimp (which has a Bézier tool), and I wanted a SketchUp model so it would be more easily and precisely scalable. I tweaked it until it matched the Gimp version, and had a perfect curvature.

So it appears that my original assumption was correct: the Bézier curve makes only an insignificant improvement. Much of the difference between the balls seems to be due to manufacturing inconsistencies. I spent four weeks and made a total of 6 beanbags to arrive at this conclusion. Since I did all this work, though, and my SketchUp curve is easy to scale to each of my pattern sizes, I will still use it in my Ready-to-Print patterns.

Below is a comparison of my Bézier curve with the circular curve, followed by a comparison to Ramos' curve. I describe how I designed and drew my curve in the section titled "Adjusting the Circular Curve into a Bézier Curve…".



The circular curve in black and the Bézier curve in red. They are nearly indistinguishable unless magnified. The widest variance between the two in a pattern sized for a 2.5″ diameter ball is 0.125mm. In this illustration, being 7″ (177.8mm) from corner to corner, the variance is 0.442mm.



My Bézier curve in red compared to Ramos' curve in black (she provides only dashed-line patterns). It was not my intention to reproduce her pattern, and I designed my curve without reference to hers. But in such a minute modification to the circular curve, there is little room for variation.

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Ready-to-Print Patterns (Original, Circular Versions)

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The pattern pages are 8.27″×11″ (210mm×279mm) to fit both "Letter" and "A4" sizes. ***Make sure the print is not being scaled to fit the printer margins*** *(select Default/None scaling/Actual size/Ignore printer margins). To verify correct sizing,* ***compare the centimeter grid to a ruler*** *and adjust the next print if necessary. (Note that PDF viewers and printers can both contribute to slight size inaccuracy.)*

On the following pages are patterns for beanbag diameters from 2″ – 3″ in ¼″ increments, and a 7″ pattern for scaling to larger sizes. **These are my original, circular curve patterns.** The patterns are sized using my inflation-corrected sizing so as hopefully to produce accurate finished sizes (they are reduced by 5% from the mathematical calculation to account for the inflation in size I observed in my corduroy bag).

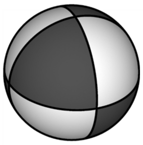
To make the templates, I recommend cutting out the portions of the paper with the patterns you want and using glue or double-sided tape to attach them to your template material, and then cutting along the patterns.

The cutting patterns have both 4mm and 8mm allowances so you can choose the amount that works better for your fabric and preference. Remember that the cutting patterns have slightly different curve radius to panel size proportions from the stitching patterns (they are parallel, not proportional), so **you should not use them as stitching patterns**.

To produce other pattern sizes or correct an incorrectly sized beanbag, adjust the size scaling in the print dialog. For example, to reduce my 2.5″ pattern to the 2.3″ size recommended by the Juggling Store for small hands and numbers juggling, divide 2.3 by 2.5, multiply the result by 100, and that is your scale (92% in this case). If your beanbag ends up not being the expected size, see the **General Information and Techniques** chapter under "Adjusting/Scaling a Pattern to Produce an Accurate Ball Size" for help with correcting it.

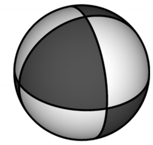
The table below provides the scaling for the ⅛″ increments between my ¼″ sizes. The centimeter grid can be used to verify correct scaling.

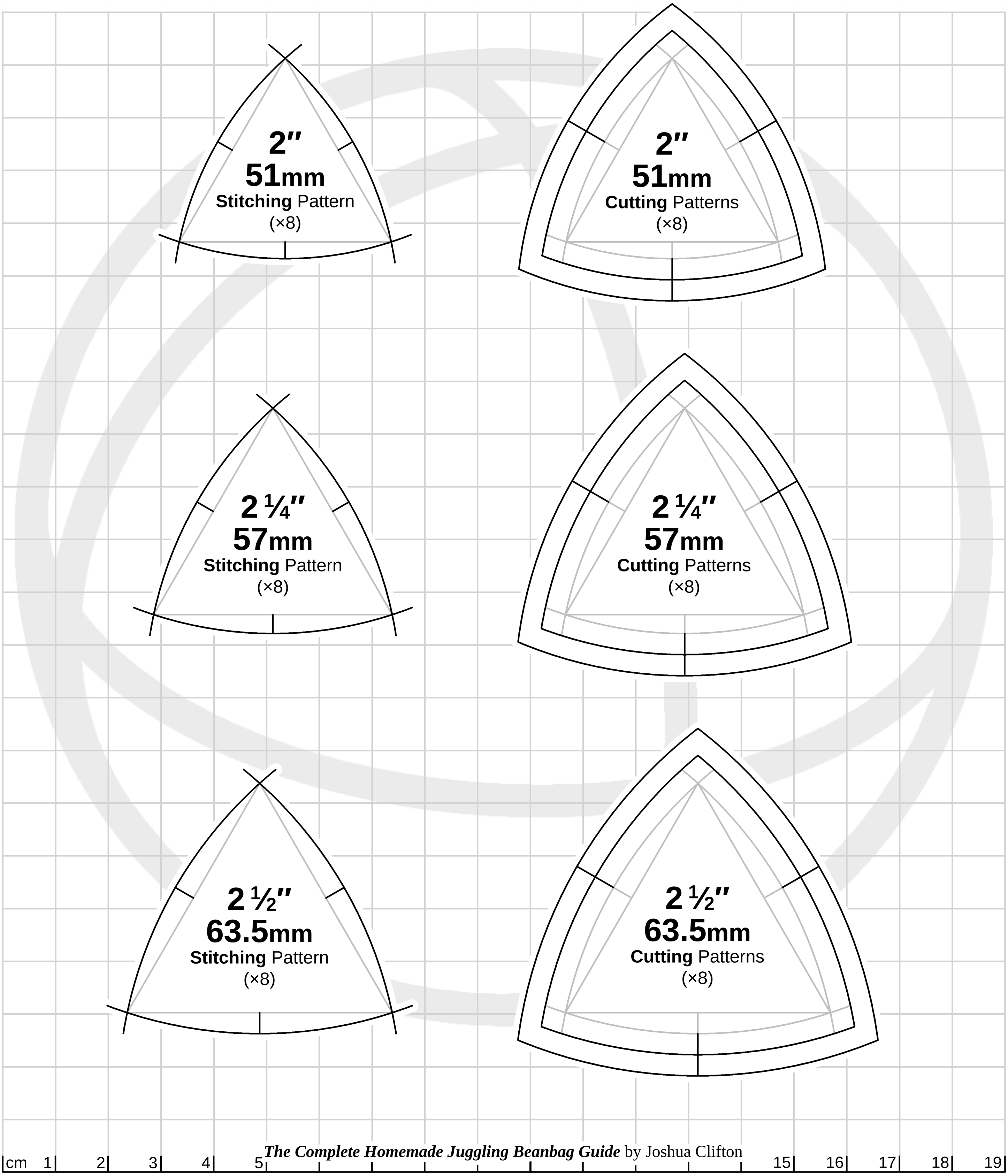
Target Diameter	Print this pattern size	At this scale
1¾″ (44.5mm)	2″	87.5%
1⅞″ (47.6mm)	2″	93.8%
2⅛″ (54.0mm)	2¼″	94.4%
2⅜″ (60.3mm)	2½″	95%
2⅝″ (66.7mm)	2¾″	95.4%
2⅞″ (73.0mm)	3″	95.8%



Octahedron (8 Panels)

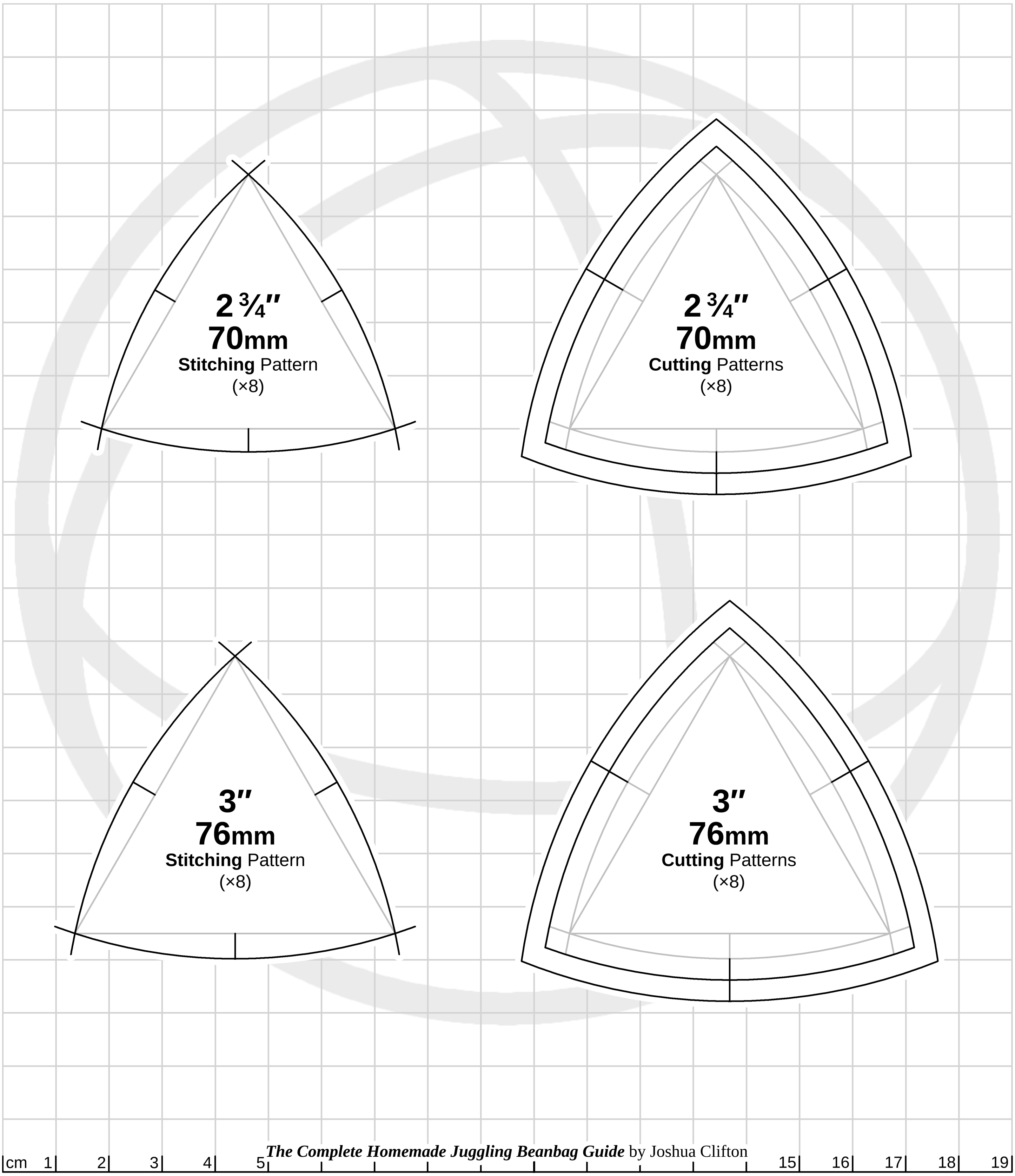
(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
These are the **Circular** patterns, for comparison to my Bézier curve patterns.)

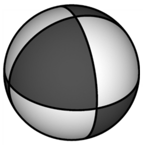




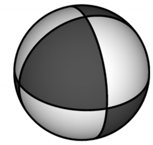
Octahedron (8 Panels)

(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
These are the **Circular** patterns, for comparison to my Bézier curve patterns.)





Octahedron (8 Panels)



(Pattern sizes are adjusted for corduroy and do not account for gathered seams.
These are the **Circular** patterns, for comparison to my Bézier curve patterns.)

Extra large and versatile pattern for scaling to larger sizes in the Print Dialog. Print twice if you want both a stitching template and a cutting template. The inner pattern (filled with gray) is the stitching pattern. Each dark pattern outside of that marks a 4mm seam allowance interval (at 100% scaling). Use those or the lighter, half-intervals between them to cut out the amount of allowance you want for the cutting template.